book of abstracts

MANUFACTURING
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MESIC'9

GIJÓN
2021
SPAIN
june 23-24-25

book of abstracts

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PRESENTATION

We have the honour from the Organizing Committee to present you the Book of Abstracts corresponding to the 9th edition of the Manufacturing Engineering Society International Conference (MESIC), held from 23 to 25 of June, 2021.

This time, the COVID-19 pandemic has prevented the Conference from being held in person in Gijón, as originally planned, having to move to a virtual platform. We hope that the lack of face-to-face attendance has been compensated by the greater dissemination and ease of access that these new communication tools allow.

As you know, the MESIC was born under the patronage of the Manufacturing Engineering Society (SIF), to fulfil one of its founding objectives: the creation of forums for the exchange of experiences between national and international researchers and professionals in the field of Manufacturing Engineering.

This book includes the abstracts of the papers that have been finally accepted for presentation at the MESIC 2021. There are more than 170 papers, organised according to the topics of the Conference and in which researchers and professionals from 15 different countries have participated. From the Organising Committee we would like to express our sincere thanks for your personal contributions and for the opportunity to share and discuss your experiences and works in Manufacturing Engineering. We hope that both the MESIC and the contents of this publication will serve to show the current issues in this field of Engineering and will favour the opening of new work lines and collaborations.

We would also like to thank the SIF board for their constant support, dedication and experience in the organisation of this 9th edition of the MESIC, as well as the members of the Scientific Committee for their disinterested and rigorous work in the evaluation of the papers here presented.

Finally, we would like to thank the University of Oviedo and the other institutions that supported the organisation of the MESIC 2021 from the beginning and helped in its promotion and dissemination. To all of them, thank you very much.

José Carlos Rico
Chairman of the MESIC 2021

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Past, present and future of the manufacture of structural pulvimetallurgical components

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Keywords: Pulvimetallurgical, powder metallurgical components

1. Abstract

The manufacture of powder metallurgical components has evolved over the years, increasing the variety and complexity of the components and improving the properties of the materials. From the first self-lubricating bearings to complex synchronizing systems or sophisticated shapes manufactured by additive manufacturing, there is almost a century of technological development.

Powder metallurgy is an opportunistic process that bases its development on the low cost of manufacturing large series of precision parts, conquering new fields that were previously the exclusive competence of traditional processes and opening some new. Key factor for that is the continuous improvement of the efficiency of the manufacturing as well as the ability to obtain complex profiles directly from the powder shaping process (net shaping). Material waste is minimal and the energy consumption optimal.

The raw material used is metallic powder, most of the times iron-based, with alloying elements such as Ni, Mo, Cu, Cr or others. Upon exceeding the austenitizing temperature, the carbon dissolves in the iron giving a true solid phase steel fabrication. Different heat treatments and secondary operations are possible to meet the requirements of each application. Regarding the manufacturing process itself, the automation of operations and the digitization of the entire process make the manufacture of PM parts even more efficient and competitive.

As powder metallurgy has evolved, it has become more and more complex and it would be too extent to try to cover not even a general view of all of them. That is why we will focus on the structural parts, which are the ones that have had a faster development from the early 50´s, sustained mainly by the automotive industry, and what the future of this type of parts may be with the technological changes and habits of the society of the future, especially about human mobility.

The future offers threats and opportunities. Electrification will significantly reduce the number of mechanical components in the car but also the growing importance of weight and NVH opens new fields for technology. On the other hand, there are those who say that the battery electric car is a transition technology to other more efficient means of propulsion, such as the hydrogen fuel cell.

New times bring new challenges and it will be a real stress test for the innovation capability of our engineers and companies.

Towards self-aware machine tools for traceable production

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Keywords: Machine Tools, Traceability, Manufacturing instructions, Self-awareness control

1. Introduction

Five-axis machine tools technology is continuously evolving as related technologies in computing and communication, hybrid processes, artificial intelligence and sensors offer new possibilities that can enhance productivity and part quality.

Over the last decades, research has produced numerous kinematics based models and a variety of measurement schemes. Error definitions for inter- and intra-axis geometric errors have matured leading to their being included in an ISO standard. But the reality often does not care much of our models. There is stillroom for model enhancement although the emergence of data-driven models brings a shift towards such models as opposed to physics based models. Such AI based models appear easier to develop but at the expense of a loss of insight and with a much greater need for data. Physics based models generally have small and well defined numbers of parameters to be estimated, which reduces the amount of data needed but they are limited by their sophistication and ability to imitate the complexity of a machine tool. Data-driven are more flexible but require rich data sets from one machine and ideally from multiple machines of similar construction. This is where manufacturers may have a greater role to play as many are now able to collect data from multiple sites and machines. This could help answer questions about whether particular error patterns are machine design specific, which would be useful for machine maintenance and error correction.

2. Issues in self-aware machine tools

A possible long term objective is to make the machine tool aware of its current status in terms of geometry and able to anticipate changes before they affect its performance. Although some level of corrections can be done a priori, thermal errors change over minutes and hours whereas deflection due to various forces occurs almost instantaneously. Should the machine fail to compensate all error sources, it may be possible with a rich digital twin to be aware of such errors and issue a statement on the likely deviations on the resulting part, albeit with some level of uncertainty.

3. Conclusions

This keynote address mainly focuses on the contribution of the speaker’s group towards ensuring and improving the precision of a particular machine tool. A user approach is taken. Users generally do not have access to the machine construction details and CNC algorithms. Also, the machine should be busy producing parts as opposed to produce metrological data, so, the techniques proposed should be automated and brief. The presentation will cover: trends and overall research direction; error modelling, metrology and compensation of geometric errors of machines tools; thermal effects; on-machine measurement for immediate corrections or for part conformity assessment; reference artefacts for machine metrology and for non-contact part metrology.

The role of Extended Reality in Manufacturing

G.-C. Vosniakos[(1)]

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Keywords: Extended Reality, Virtual Reality, Human-Robot collaboration, Factory layout design, Manufacturing instructions.

1. Introduction

Extended Reality (XR) is an umbrella term covering Virtual, Augmented, and Mixed Reality (VR, AR and MR respectively). VR implies total user immersion in a digital world, AR adds digital elements in a live view, whilst MR requires real and digital world interaction. XR has completed 30 years of life after its birth and infancy in the nineties (Silicon Graphics stations), subsequent device-based exploration in the two-thousands, exploitation in the two-thousand-tens mainly through gaming and its current maturation and industrial use decade.

XR is continuously developing due to increasing availability of computing power and advanced interaction hardware, ranging from special devices (Head Mounted Displays, glasses, trackers and depth cameras) to non-special smart phones, yet equipped with special software. Stemming from the gaming world, open software platforms such as Unity3D allows creation of very complex virtual worlds and interaction modes.

A wealth of experience has been acquired so far by creating and testing manufacturing applications of XR trying to deal with pertinent issues and pointing to an ever more promising future.

2. Issues in deploying XR for manufacturing

In manufacturing XR is most beneficial as an approach to studying problems involving perception, cognition and strong interaction with the human user. Essentially, this is a method for capturing non-deterministic and often difficult to predict, and thus model, human behaviour. Examples pertain to the human-in-the-loop paradigm, as well as traditionally, training, prototyping and planning tasks without need to use the physical objects. XR is often compared with CAD-based simulators, but the latter cannot adequately support user experience.

An ever existing issue is the creation of the XR world by defining objects / behaviours as realistic as possible or by sacrificing realism for the benefit of cognitively equivalent additional information and cues [1].

An important issue pertains to embedding intelligence in the virtual objects (e.g. local agents) towards transfusing to them autonomous behaviour [2]. Alternatively, or additionally, scenario-based central scheduling and control of events may be designated (e.g. through Petri nets) [3].

3. Application examples

XR is an excellent tool for studying collaborative human-robot (cobot) operations. For safety reasons it is preferred to design and use virtual cobotic cells before actually implementing them [4]. However, their effectiveness, as well as acceptability by the humans involved, need to be proven [5]. Only then, can they be exploited in extensive, yet both safe and cost-effective, experiments. The aim is to try out control strategies for the cobot using metrics complying to existing safety standards [6] as well as reflecting productivity requirements [7]. The same XR models can also be used for training human operators even before the 'cobotic' cell is commissioned.

Well-known applications of XR pertain to support of assembly cells or lines. These may involve only manual labour or both humans and robots. Execution of assembly step sequences by tracking and assessing hand movements that manipulate digital objects is perfectly possible and has proven to be useful; however, force feedback is still a gap to be filled [8].

Beyond ergonomic assessment XR offers training possibilities of assemblers in the context of new product introduction by projecting assembly instructions in the virtual scene. The same approach has been extended to machine tool setup with the additional innovation of mixing digital jigs and fixtures in the real world machine scene [9].

Industrial robot programming through XR offers advantages over off-line CAD-based programming methods when alternative paradigms of 'teaching by demonstration' are desired. These involve special sensors to track human hand movement that the robot needs to imitate to acceptable accuracy, which poses a challenge [9].

Ergonomics of workplaces, task design, workflow and equipment provision is another domain fit for XR applications. An example pertains to assembly of small aircraft wings by manual labour, where everything else except the human and the riveting equipment is digital [10]. Another example pertains to experiencing the effects of expanding a manufacturing facility by adding flexible automation machinery (robots, conveyors, ASRS etc.). This can be made to collaborate with existing real machinery in a seamless way, executing prescribed scenarios stemming from concrete process plans [11].

4. Conclusions

Judging by the current progress in XR applications in manufacturing, the main advantages become conspicuous in relation to tasks where humans are involved as scene actors, i.e. in situations where numerical modelling or simulation cannot capture adequately problem dynamics. Additional factors enhancing XR usefulness are safety concerns as well as training costs relating to particular equipment or even entire systems.

In the light of Industry 4.0, an interesting challenge for the near future pertains to embedding more and more intelligence to XR. This could be data-driven, i.e. achieved though machine learning.

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Analysis of the Turning Efficiency of the Cu-Ni 70/30 ASTM B122 Alloy under Minimum Quantity of Lubricant Conditions

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Keywords: Turning; sustainability; cupronickel; Cu-Ni alloys.

1. Introduction

The use of large quantities of lubricant during machining processes represents a great environmental risk [1], in addition to the added cost of lubricants. However, dry machining is not an option in some applications and for difficult-to-machine materials, due to the high increment of the temperature that accelerates the tool wear. Besides, the control of cutting temperature is very important [2], because of its influence on residual stresses or the surface quality of the machined parts. For that reason, there is a need to evaluate new sustainable lubrication techniques for traditional machining processes such as turning. Recently, techniques as cryogenic lubrication with LN2 or laser assisted machining are becoming important in the research of manufacturing processes with material removal [3]. Nevertheless, their industrial applicability is limited due to the high cost of the specific equipment. In this research, minimum quantity of lubricant technique (MQL) is evaluated on turning of Cu-Ni 70/30 alloy. This alloy is widely used in marine and naval applications such as ship piping [4], but there is a lack of studies that analyse its machinability. The study compares MQL to dry cutting and traditional flood lubrication in terms of cutting forces and surface roughness.

2. Experimental Procedure

Cu-Ni 70/30 ASTM B122 alloy, table I, has been turned under cutting speed of 83 m/min and 0.5 mm of cutting depth for a range of feed rates from 0.1 to 0.25 mm/rev. Dry, flood and MQL have been considered as environmental conditions. MQL tests have been developed by using a mineral oil and a vegetable one.

Table I. Composition of Cu-Ni 70/30 ASTM B122 alloy.

Copper	70%
Nickel	29-30%
Iron	0.4-1%
Manganese	max 1%
Zinc	max 1%
Lead	max 0.05%

To measure the cutting forces during the turning process, a three-axes dynamometer built by the research team have been utilized and for the roughness measurements, a contact profilometer by Taylor Hobson has been used.

3. Results and Discussion

Although the research is not still completely fulfilled, the preliminary results indicate that it is possible to obtain force values similar to those obtained under traditional lubrication and lower than for the dry machining. In addition, the research points to the improvement of the surface roughness if low amount of oil is used. According to previous results under oil starvation lubrication [4], the balance of the effect of the lubrication on the cutting temperature and friction justifies the expected results.

4. Conclusions

This research evaluates the efficiency of MQL technique when turning Cu-Ni 70/30 alloy by means of cutting forces and surface integrity.

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Turning Process with Ceramic Inserts of ADI Cast Material, Surface Analysis

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Keywords: Ceramic inserts; ADI material; turning; wear mechanisms.

1. Introduction

The competitive properties provided by ductile cast iron are industrially well-known. Inside ductile cast iron, a series of foundries are distinguished commonly characterized by the graphite in spheroidal form in their matrix. This is the reason why ADI foundry is one of these castings with very particular microstructure that offers superior mechanical characteristics (high design flexibility, elevated resistance against weight, good tenacity, fatigue, and wear resistance, and additionally, cost-effective solution). A great effort has been made to standardise castings to different degrees, as reflected in ISO 1083:1997 [1,2]. The use of the use of ADI castings at an industrial level can be found in many different applications in industrial sectors as automotive or critical safety. On the contrast, many manufacturing challenges needs to be faced the low machinability compared with the rest of cast materials. Traditionally manufacturing steps are performed before performing the heat treatment, what is not feasible for complex geometries [3].

Ceramic cutting tools are presented as a possible solution to obtain a more productive process manufacturing ADI materials.

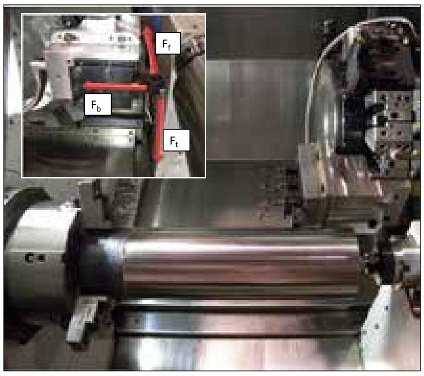

Figure 1. Caption of figure (Calibri 9p)

2. Experimental Procedure

The defined methodology includes experimental design and results. The first step consists of defining different cutting parameters in order to analyse the feasibility of using Ceramic inserts on turning ADI materials. Additionally, cutting force will be measured during the cutting process, as shown in Figure 1.

Experimental tests are performed in a turning machining centre. The material used is a Austempered Ductile Iron presented in automotive and critical safety industries. Table I shows the range of cutting parameters initially defined for the experimental set-up.

Table I. Cutting parameters definition

v_c [m/min]	f_z [mm/(r*z)]	a_p [mm]	Cutting fluids
120-280	0.1-0.3	1.5-2	Dry

3. Results and Discussion

In this paper a new research is performed for turning ADI with ceramic inserts. Tool wear mechanisms and cutting forces results will be analysed shown in Figure 2.

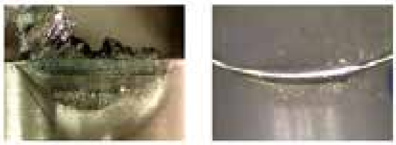

Figure 2. Caption of figure (Calibri 9p)

4. Conclusions

The main conclusions derived from this work are related to the feasibility of using ceramic inserts turning ADI materials, obtaining optimal cutting conditions aligned to mechanical properties and facing manufacturing challenges.

5. Acknowledgements

The authors would like to thank Bizialab programme of the Basque Government and the UPV/EHU for the financial aid to pre-doctoral grants PIF 19/96 and PIF 19/161.

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Comparison Between Milling Roughing Operations in Gear Full Slotting Manufacturing: Trochoidal, Plunge and Conventional Milling

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Keywords: Trochoidal milling; high efficiency milling (HEM); gear slot roughing.

1. Introduction

Manufacturing improvements in terms of manufacturing-chain costs and times reduction are becoming a real need in the industry, especially for roughing operations. In order to satisfy these industrial requirements, more efficient machining processes have been developed, such as High Efficiency Milling (HEM), which is a milling technique for roughing operations that it became popular for the last few years.

According to above mentioned direction, trochoidal milling appears as an efficient method for roughing operations of full slots, since it is a manufacturing strategy that meets the two-essential requirements of HEM. On the one hand, it must utilize higher Axial Depth of Cut (ADOC); and on the other hand, it must utilize lower radial Depth of Cut (RDOC). Trochoidal milling, apart from being a faster roughing strategy, has a number of advantages compared to the conventional milling, such as extended tool life, greater performance and cost savings.

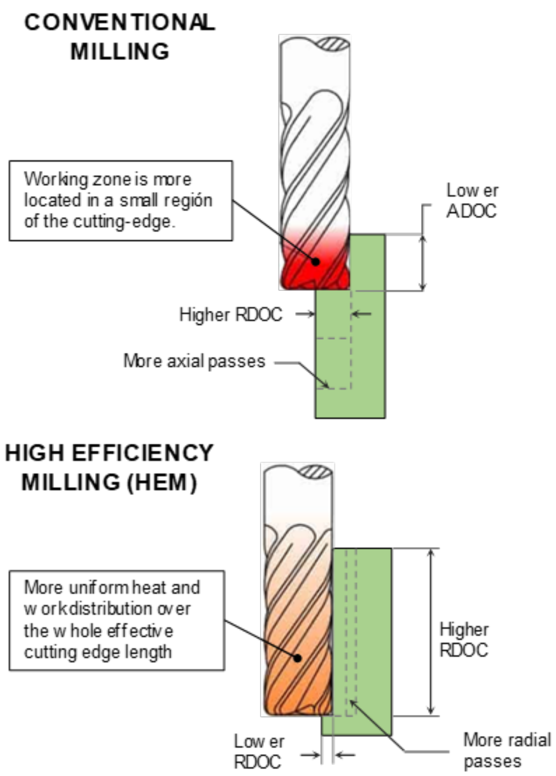

Figure 1. Conventional milling vs HEM

2. Methodology or Experimental Procedure

This work will present a comparison between three machining strategies to make a groove, that are conventional milling, plunge milling and trochoidal milling. What is intended to know is which of the three is more productive, and for this a series of simulations will be carried out varying the parameters of the groove and obtaining the total machining time of each strategy. This can be applied to the machining of gear teeth.

In addition, the time estimated time obtained by the machine's post-processor will also be checked with the real manufacturing time.

3. Results and Discussion

This work will focus on the comparison between different manufacturing processes in slotting application, in order to prove which, one is the most productive. For that, several combinations of slot parameters will be done to analyse the total machining time of each strategy in each case

4. Conclusions

Today we find it necessary to optimize the machining processes, therefore it is essential to know under which conditions which machining operation is more productive in the grooving. Therefore, it will be analysed for which widths, lengths and depths each machining operation is most suitable.

5. Acknowledgements

The authors wish to acknowledge the financial support received from the Basque Government.

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Milling Angular References and Process Parameters on Fibre Reinforced Plastics

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Keywords: Milling; delamination; fibre orientation; polymer composites.

1. Introduction

When studying the milling of composite materials with 2D fabric, it is necessary to define the angle references and parameters involved in the process, like the fiber cutting, fiber orientation and engagement angles, relationship between cutting path and fiber orientation, etc., to study the delamination defect.

The angle references have been studied in the literature [1,2], but in most cases there is no consensus among the authors on the nomenclature used, its definition and the relationship between them when explaining the effect of fiber orientation on delamination.

The relationship between the machining direction and the fiber orientation angle has led to the definition of the parameter Xd [3], as the distance of the warp yarn from the trimmed edge until the next dip below the crossing fill yarn. This parameter affects delamination.

In this article, the main directions of the fabric have been identified and angular relationships with respect to these directions have been established in the cases of edge trimming and grooves. Moreover, an in-depth study of the Xd parameter for this type of material was carried out, taking into account the delamination produced.

2. Methodology or Experimental Procedure

Firstly, the angles that allow establishing the relative angular position between the threads, which form the reinforcement fabric, and the fundamental movements of the machining process, have been defined: engagement angle (φ), fibre orientation angle (ϕ) and fibre cutting angle (χ).

Secondly, the three main directions of the fabric, which mark a variation in the orientation of delaminate, have been studied: cutting paths at 45º, 90º and 135º with the fabric weft.

Thirdly, the delamination produced by the variation of the parameter Xd in fabrics with 90º and 45º fiber orientation has been studied.

3. Results and Discussion

The ratio obtained for the angles, applicable to edge trimming (Figure 1) and grooving, is as follows:

$$\chi = \phi + \varphi \quad [1]$$

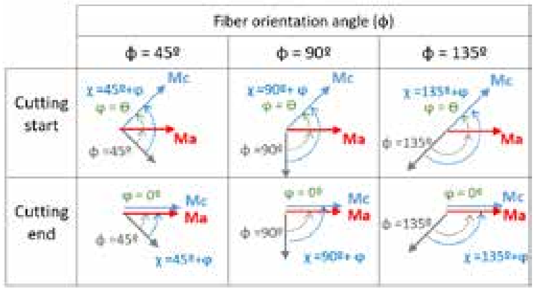

Figure 1. Angles relationship in down milling edge trimming

Figure 2 shows the variation of Xd in edge trimming with the fabric slightly inclined with respect to the cutting path and its effects on the delamination produced in the part.

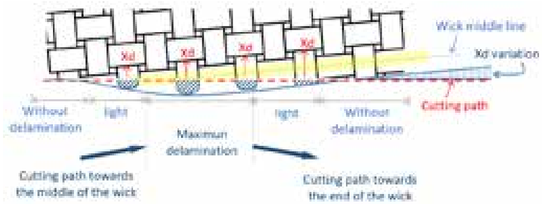

Figure 2. Variation of Xd and delamination

4. Conclusions

In this work, relations between the working angles for the milling of composite materials with fabric have been established, as well as their influence on delamination, together with Xd variation.

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Advances in Efficiency in the Groove Milling of Aluminium EN AW 2024-T3 With Zig-Zag and Trochoidal Strategies

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Keywords: Trochoidal toolpath; dynamic milling toolpath; energy saving; slot milling.

1. Introduction

Manufacturing process engineers must continually make efficient decisions. Manufacturing time, surface finish and energy consumption are aspects that must be optimized in machining. This paper deals with a study to analyze the efficiency in the roughing of grooves by milling of aluminum alloys EN AW 2024-T3 with two strategies: zig-zag and peel trochoidal. The dynamic milling strategies are conceived to maximize the removal rate and optimize the tool performance [1]. This concept is based on a discontinuous cut that favors a minimum accumulation of heat and an optimal evacuation of the swarf and minimizes the wear of the cutting edge, allowing a higher performance [2]. The influence of the lateral pass, the feed per tooth, the cutting speed and the pressure of the coolant have been analyzed. The depth of pass, a_p, has been fixed according to the manufacturer recommendation, for each strategy. The study was proposed by means of a design of experiments (DOE) established by the Taguchi method and ANOVA (analysis of variance).

2. Methodology or Experimental Procedure

The samples were machined from a 75x75x30 mm aluminium billet EN AW 2024-T3. The work was carried out in a 3-axis machining center Chevalier QP2026L. The milling tools are of Ø 10 mm, a high-performance trochoidal cutting tool (TPC) of 54° with variable helix angle and a multitask cutting tool (MTC) of 30° of integral carbide (Hoffmann Iberia, Madrid, Spain). An ap value of 10 mm for zig-zag and 30 mm for trochoidal was used.

The values of the experiments for the cutting parameters (30%, 50% and 70% of those of the tool manufacturer) used in the DOE are shown in Table I.

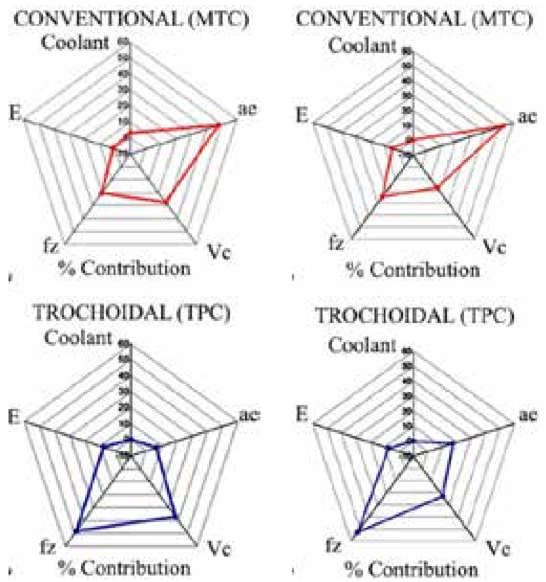
Table I. Taguchi factors and levels (DOE with 36 tests)

	Zig-zag	**Trochoidal**
Lubricant pressure (MPa)	0.1	Gravity
a_e (mm)	1.5,2.5,3.5	0.45, 0.75, 1.05
V_c (m/min)	75, 125, 175	69, 115, 161
fz (mm/tooth)	0.021, 0.035, 0.049	0.047, 0.078, 0.109

3. Results and Discussion

Figure 1 shows the response to machining time and power consumption.

Machining time and energy consumption show a strong influence of the side pass (a_e) in conventional milling, for the trochoidal one a similar level of influence appears with the feed per tooth (fz) and cutting speed (V_c). The roughness is most strongly influenced by V_c for conventional milling and by fz and ae for trochoidal milling.



(a) (b)

Figure 1. (a) Influencia para tiempo de mecanizado, influencia al consumo de energía (b)

4. Conclusions

The influence of the technological variables of the grooving process on the machining time, energy consumption and surface roughness has been evaluated for both conventional and trochoidal milling.

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Deep Hole Finishing of Inconel 718 Slmed Features by Endmilling and Reaming

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Keywords: Tool wear patterns; Inconel 718 SLMed; cutting forces.

1. Introduction

Metallic additive manufacturing has positioned itself as a strong alternative for obtaining parts for industrial use. Processes such as SLM allow complex shapes to be obtained that, in some cases, cannot be manufactured by subtractive manufacturing methods. It is of particular interest to obtain parts with complex shapes and thin walls, such as ducts for aeronautical engines, vanes, and power systems. The shapes obtained by metallic printing can be classified as Ultra near-net shape, which indicates that the machining requirements in the post-process are mainly for finishing. Usually, those parts have thin walls. It implies that the completion of these shapes through machining requires various cutting processes, among which milling operations stand out. The high cutting speeds, the low stiffness of the pieces, and the small chip section size make the machining of these pieces to be considered as highly interrupted, which makes it essential to know the cutting force and tool wear levels [1].

The objective of this study is to compare the levels of cutting force and wear of different configurations of tools for milling and reaming processes and to discuss the effect of the anisotropic nature [2] and of this family of materials on changes in the trend of wear and surface quality.

2. Methodology or Experimental Procedure

Multiple peripheral milling operations were carried out on prismatic printed parts and reaming in printed ducts of Inconel 718 SLM, wear and cutting force measurements were made under different tool configurations and the effect of each experimental condition on the surface quality of the part was analysed (Figure 1).

Figure 1. Set-up for milling and reaming

3. Results and Discussion

Analysis of the data identifies that the variable helix angle cutter configuration has the highest levels of cutting force, while wear levels are similar to those of constant helix angle cutters (Figure 2).

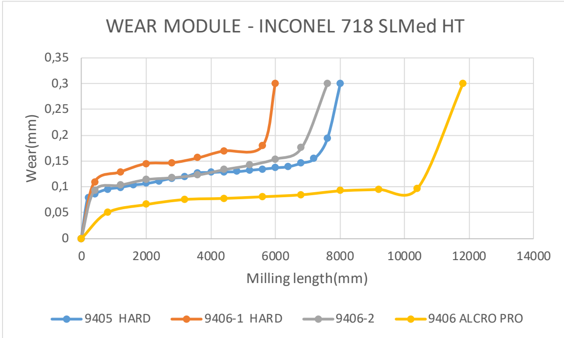

Figure 2. Wear Module-Milling Inconel 718 SLMed HT

4. Conclusions

The influence of tool wear and force levels on the surface quality of milling and reaming under different operating and manufacturing conditions is expected to be observed for the INCONEL 718 SLMed.

5. Acknowledgements

We thank the CFAA staff for all their help during the research.

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Prediction of the Dynamic Stiffness of Boring Bars

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Keywords: Chatter; stability; boring; RCSA.

1. Introduction

Boring bars are inherently slender tools which are prone to show chatter problems in boring operations due to their low dynamic stiffness and damping, being this problem their main limitation in productivity. The onset of chatter is related mainly to the dynamic stiffness of the bending mode of the boring bar when it is clamped in the toolholder. A complete dynamic model of boring bar is built in this work, which can deal with the elastic body of the boring bar by means of Timoshenko beam theory. The effect of the toolholder and the rest of the machine is considered experimentally applying Receptance Coupling Substructure Analysis (RCSA). This way, the Frequency Response Functions (FRF) of the machine can be predicted. If the frequency of the modes of the toolholder/machine has similar frequencies of the modes of the boring bar, mode coupling will occur. As a result, the shape of the modes of the boring bar are mixed with the modes originated in the machine, and the damping will be higher than the one that is not subjected to the dynamic coupling effect. Hence, the stability of stationary cutting limit will be increased.

In the present work, a dynamic model is used to calculate the optimal tool length to perform beforementioned coupling. This effect is validated with experimental frequency response functions that result in an increase in cutting stability.

2. Methodology

In order to predict the receptance or dynamic flexibility at the tool tip, the complete boring bar assembly has been divided in three parts: the machine interface, the boring bar and the boring head (Figure 1).

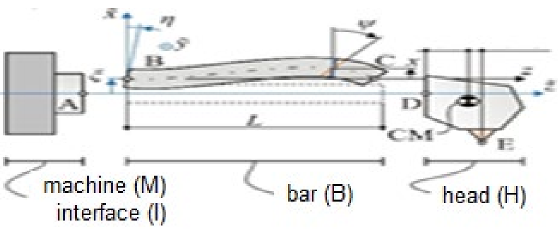

Figure 1. Boring bar assembly

The machine side has been characterized by means of inverse RCSA, which has been applied with experimental FRFs. This way the stiffness and damping of the interface between the tool and the turret has been considered. Timoshenko bean theory with fixed-boundaries has been used for the modelling of the bar, and the boring head has been modelled as a rigid element. FRFs estimations at the tool tip have been calculated with different boring bar lengths, in search of the mode coupling effect.

3. Results and Discussion

Developed model has shown that due to the mode coupling effect, the minimum of the real part of the FRF does not increase proportionally with the overhang. In fact there is a certain boring bar length for which the real part of the FRF is minimised (Figure 2).

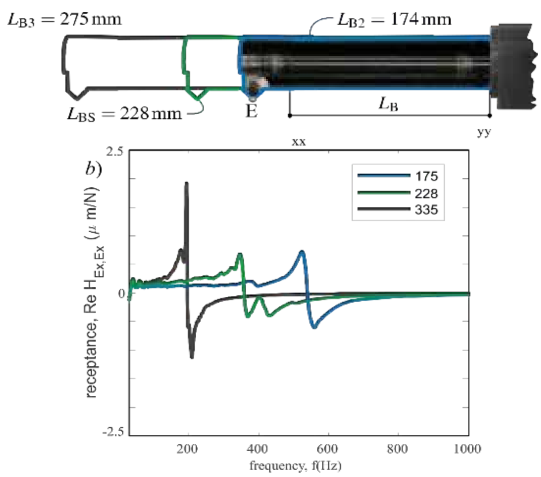

Figure 2. Estimated FRFs at the tool tip

The results have been experimentally validated by means of experimental FRFs obtention. Finally, cutting tests with boring bars with different overhangs have been carried out confirming the positive effect of the mode coupling in the final quality of the part.

4. Conclusions

The dynamic behaviour of the turret/machine side has an important role in the boring bar dynamics. It has been proven both theoretically and experimentally that mode coupling affects beneficially to the dynamic behaviour of the boring bars, enhancing their cutting capability. A model to calculate this optimal overhang has been developed and validated with experimental tests.

Design, Manufacturing and Validation of Chip Breakers in Ceramic Inserts for the Machining of Aeronautic Nickel-Based Superalloys Inconel®

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Keywords: Thermoresistant superalloys; ceramic inserts; chip breakers; laser engraving; turning, Inconel® 718.

1. Introduction

The turbomachinery components required by the aeronautical industry are subject to extreme working conditions. Therefore, these components are made with alloys that can withstand high cyclical loads at very high temperatures. However, due to their excellent mechanical properties, these kind of alloys present a challenge when manufacturing them. Thanks to their properties, the chip generated during the cutting process of turning tends to be continuous bringing with it the possibility of surface quality or tool life problems [1]. Furthermore, the chip plays a fundamental role in extracting the heat generated during the cutting process. In order to extract as much heat as possible from the cutting area, two things must be fulfilled. Firstly, the chip must be as small as possible so that no heat is transferred to the workpiece or tool. The second thing is that the extraction must be done as quickly as possible [2].

Moreover, in a world were reducing manufacturing times of components is primordial, achieve not only the cutting tool lifespan´s increase but also its capacity of machining faster is a great advance in the technique, and more in this class of materials. The nature of these kinds of alloys impedes machining from high cutting speeds. There is only one way to do it by using ceramic tools that are harder than the traditional cemented carbide tools, but much more fragile, with a shorter lifespan and too expensive. Nevertheless, in contrast with the cemented carbide tools, ceramic tools do not have chipbreakers in their geometry. In this work, it will be designed a chipbreaker to break Inconel® 718 chip. Then it will be manufactured with the laser engraving technique and, finally, it will be compared in a turning process with a ceramic tool without a chipbreaker.

2. Methodology or Experimental Procedure

For the manufacturing of the chipbreaker, a Trumpf® Trumark 5000 station will be used. Previously, a characterization of the tool material must be done to know the influence of the different parameters of the laser in the depth of the engraving.

The tests will be carried out in a CMZ TC25BTY turning center with 35 kW of spindle power and integral spindle. The material used will be Inconel® 718 aged. For the tests, two kind of tools will be used and compared: a raw ceramic tool and another one with the designed chipbreaker.

Figure 1. Tool during laser engraving process

3. Results and Discussion

The results obtained will be focused in terms of productivity, that is, the lifespan of the both tools, the one with chipbreaker and the one without it. Moreover, the extracted chip from the cutting process will also be analysed to verify if there is any difference between both tools in terms of the process temperature. Finally, the cutting forces will be recorded during the cutting process.

4. Conclusions

This research is focused on obtaining a feasible process to machine Inconel® 718 at high speed with ceramic tools and to increase the lifespan of this kind of tools during the machining of low machinability alloys.

5. Acknowledgements

The UPV/EHU itself for the financial aid for the pre-doctoral grants PIF 19/96.

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Latest Trends in Basalt Fibre Applications and Implications of Machining Processes

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Keywords: Basalt Fibre; composite; green manufacturing; machining.

1. Introduction

The basalt fibre is a material used typically in construction sector, but in the last years its use as reinforcement in organic matrix composites has had a particular attention. On this manner, applications in products intended for industry or for final consumer have been increased; components in automotive industry as an example of this [1].

The good thermal and mechanical properties of these composites in environmental typical and extremes conditions [2] have facilitated such uses.

In general, these new applications require operations on the manufacturing engineering field as the machining processes. Some works have been realised focused on milling processes, in particular in edge trimming, and studying the tool wear [3] or the delamination effect [4]. The development of cryogenic machining can contribute, as environmentally friendly process, in these materials because of their support to extremes temperatures.

Consequently, the objectives of the paper are the following: i) identify the main applications of basalt fibre reinforced composites with organic or natural matrix, and the machining operations required, ii) identify the main research groups involved in this field, and iii) analyse the role of cryogenic machining.

2. Methodology

A systematic literature review has been carried out. For this purpose, Web of Science database has been the tool used to identify the researches. The search has been realised using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology [5]. Although this methodology emerged in the medicine field, now it is recognized in other fields.

3. Results and Discussion

At first approximation, it has allowed to identify the main applications of this material, such as transport sector, in several products types (automobiles, drones, bicycles, among others). Few research groups dedicated to this field have been identified, and they focus their study especially on the field of materials properties.

Respect to machining processes, several works have been found, concentred on few researches. In all of them, the operations were executed in dry and at room temperature.

4. Conclusions

This work has allowed categorizing the main applications of composites with basalt fibre reinforced, with particular attention to organic and natural matrix; also, the relevance of machining process in the operations of manufactured products of these materials has been indicated. Finally, a new development is possible through the cryogenic machining in basalt fibre reinforced composites.

5. Acknowledgements

The authors thank the Spanish Ministry of Science, Innovation and Universities for supporting through RTI2018-102215-B-I00 project.

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Analytical Study of the Melt Pool Distortion in the Laser Powder Bed Fusion Process Caused by the Angle of Incidence of the Laser and its Effect on the Surface Finish of the Part

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Keywords: L-PBF; surface roughness; incidence angle; position dependency.

1. Introduction

LPBF (Laser Powder Bed Fusion) technology present many advantages such as the manufacturing of full dense and light metal parts by Additive Manufacturing, which can represent a major impact in sectors such as aeronautics or health. Since LPBF process productivity can be limited, a common practice to optimise the process and reduce the manufacturing time is to manufacture several parts on the same platform. However, despite the geometry and process parameters, the fact that these parts are positioned at a different position on the platform affects their surface finish.

Previous works concluded that roughness variations are due to the angle of incidence of the laser (θ) [1] [2], which could affect the roughness of the part more than other factors such as the proximity of the parts, process parameters or the metal powder. LPBF technology uses a flat field lens F-θ in the scanner to be able to work in the whole workspace. These lenses minimize the angle of incidence of the laser, but do not make the beam completely perpendicular to the platform, as shown in Figure 1. Due to this reason, there are differences in surface finish between the parts farthest from the center of the plate and those located in the center of the manufacturing platform.

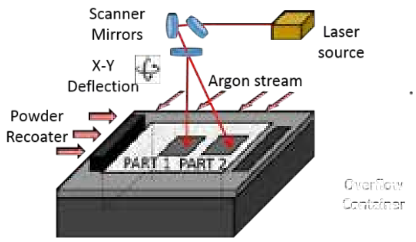

Figure 1. Diagram of the LPBF process showing the angle of incidence in the different positions of the platform.

2. Methodology or Experimental Procedure

Different tests will be carried out using a Renishaw AM400 manufacturing system. Inconel 718 powder has been used as raw material. The first tests will be performed with the aim of determining the incidence angle of the laser θ experimentally. On the one hand, it will be analysed by means of the resulting microstructure, as shown in Figure 2(a) and on the other hand by means of the shape of the laser spot on the platform (Figure 2 (b)).

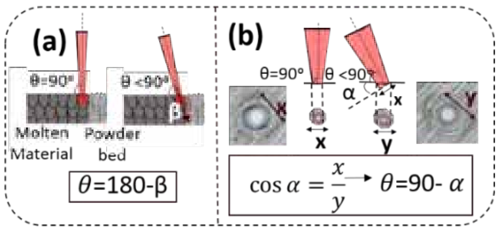

Figure 2. Experimental estimation of θ: (a) using the microstructure (b) using the laser marks on the platform.

In addition, once the incidence angle θ is determined throughout the platform, the surface roughness of the different parts distributed radially with respect to the centre will be analysed. These parts will be placed each 45º with a separation between them of 8 mm.

3. Results and Discussion

The relationship between the laser incidence angle θ and the final roughness of the parts will be determined, as well as the relevance of the influence of the position of the part at the platform.

4. Conclusions

Throughout this work, angle of incidence θ will be characterized throughout the platform and, based on the experimental results, the relationship between the surface roughness (Sa) of the part and θ incidence angle will be determined.

5. Acknowledgements

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On the Performance of Super Abrasive Machining (SAM) on Small Diameter CBN Wheel Wear

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Keywords: SAM; grinding; grain wear.

1. Introduction

Electroplated cBN wheels and SAM processes have been noted as an alternative to milling for the manufacturing of nickel superalloys used in aeroengine turbines [1]. The development of very high frequency spindles has facilitated the achievement of the cutting speeds needed in small diameter wheels. This opens the feasibility of manufacturing the aerodynamic surfaces of the blades of the IBR's by means of SAM grinding [2].

However, SAM process is not still well understood, and the effects of tool wear along the tool life are difficult to find.

In this work, the evolution of different process key parameters such as surface roughness, cutting forces and specific cutting energies are analysed. Results are related to the wheel wear.

2. Methodology or Experimental Procedure

For the realisation of this study, INCONEL 718 slabs of 250x9.5x5.5 millimetres were ground using Ø12 mm cBN cylindrical wheels with an average grain size of 76 micrometres.

Trials were executed in a five axis Hermle C52 U MT machining centre. Cutting speed was achieved with a high frequency Jäger S62-M280.07 S5 spindle, with a maximum rotating speed of 80000 rpm.

cBN wheels topography were digitalized using a confocal microscope Leica DCM 3D

Feed rates from 33 to 147 mm/min and cutting speeds from 38 to 50 m/s were tested, to cover the material removal rates considered necessary for this process being acceptable from an industrial point of view.

3. Results and Discussion

As expected, specific cutting energy increased as the sample is ground, being this increase proportionally higher during first passes and stabilising after that. This effect was bigger for lower equivalent chip thickness values.

Although the relation between normal and tangential cutting forces seemed to be almost constant during each test, the force ratio was higher as the equivalent chip thickness value decreased.

The wheel wear stage was the responsible of this behaviour being wear flat the main encountered wear type during SAM tests.

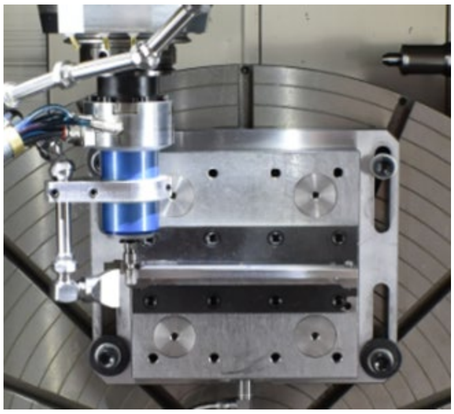

Figure 1. Machining test disposition

Regarding surface roughness analysis, numerical values are higher than expected for this grain size and materials. Through the wheel topography analysis it could be concluded that resulted high roughness was related with the number of the active cutting grit.

4. Conclusions

While specific cutting energies and cutting forces relation (F_n/F_t) were in line with the available bibliography, surface roughness is higher than expected for this tooling under the grinding conditions used.

The analysis of the cBN wheel topography showed that the active cutting edge number were lower than expected for this process and responsible for the higher roughness.

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Resin Bonded Diamond Grinding Wheels Conditioning Using Sic Rotary Dresser

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Keywords: Grinding; dressing; truing; diamond wheels; wheel surface analysis.

1. Introduction

Aerospace, automotive and energy industry are increasingly demanding advanced materials parts with high precision and complex geometry. Likewise, the superabrasive grinding wheel is a type of high-efficiency, high-precision and long-life fixed abrasive tool. Dressing of superabrasive grinding wheels is a key issue [1].

One of the characteristics of superabrasive grinding wheels is the hardness. However, once the wheel is worn the hardness and strength of this type of wheel hinder the dressing process in order to regenerate wheel profile and wheel cutting ability. [2]. Regardless the process, the dressing process of profile grinding wheels is divided in two steps: truing, to re-establish the profile, and dressing, to achieve optimum wheel surface conditions.

From the different superabrasive grinding wheels, the present work is focused on resin-bonded diamond wheels. The first work addressing this issue was carried out by Inasaki [3], stablishing the minimum time for truing and dressing and highlighting the dressing conditions. Still, research is required to find the optimum parameters and strategies for industrial application.

In this work, a methodology for efficient dressing of resin-bonded diamond wheels is presented. The methodology makes use of low-cost conventional SiC and alumina dressing tools, and can therefore be easily implemented in industry. Dressing strategies are analysed using a software tool developed to quantify the protrusion of new sharp grits. Results show efficient grinding ability and shape recovery in industrial conditions.

2. Methodology

The experimental work is carried out on a cylindrical grinding machine. Firstly, truing of resin bonded diamond wheel is done using vitrified SiC rotative dresser. In this work truing process is divided in 2 steps, firstly the worn layer is removed using more aggressive dressing parameters and after that the wheel geometry is re-established with smoother parameters. In order to determine the SiC dresser that optimize the process, different hardnesses are analysed: H, J, L. Once the geometry is obtained, the cutting ability is recovered using an Al_2O_3 rotational dresser. The wheel geometry and the wheel surface are measured during the 3 steps. While the negative of the wheel is captured on a graphite block, the wheel surface is analysed using a software tool developed in Python.

3. Results and Discussion

Results include the parameters for efficient recovery of both grinding ability and wheel shape Image analysis supported by the software tool shows the variation of grain concentration in the surface, from 31,69% for SiC (H) before dressing and 24,05% after 50pases. Grain concentration is reduced in a 7,64%. Grain exposition increases 80% regarding the initial state. Figure 1 shows wheel topography analysis using developed software.

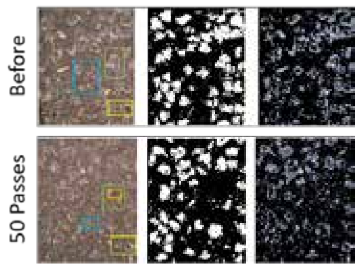

Figure 1 Comparison of surface before and after dressing.

4. Conclusions

A strategy to recover grinding ability of diamond resin-bond superabrasive wheels is presented. The strategy combines low cost alumina and SiC rotary dressers and is evaluated by wheel topography measurement. Results can be readuily transferred to industry.

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Changes in Structure and Corrosion Resistance of Cryogenically Treated WC-Co Cemented Carbides

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Keywords: WC-Co; cemented carbides; cryogenic treatment; corrosion resistance; eta phase.

1. Introduction

Cryogenic treatment of sintered carbides (SCs) is usually applied to cutting tools to increase their wear resistance [1]. However, in addition to wear resistance this method of treating SCs affects other important properties that influence the life of manufactured components, and not much attention has been paid to them. The aim of this study is to show how DCT (deep cryogenic treatment) affects the microstructure of SCs and how these changes affect their corrosion resistance. The results from the DCT samples were compared with the values for the tempered samples, and all these values were then compared with the measurements from the samples before heat treatment.

2. Experimental Procedure

Four different grades of SC, type WC-Co, were investigated, see Table I.

Table I. Characterization of the experimental material

Sample grade	Grain size (µm)	Binder volume (%)
F10	0.5-0.8	10
F15	0.5-0.8	15
C10	>6 µm	10
C15	>6 µm	15

The samples were divided into two groups with different heat treatments, see Table II.

Table II. Characterization of heat treatment procedures

Heat treatment	Temperature (^{0}C)	Holding time (min.)
DCT	-186	480
Tempering (T)	450	120

Prior to heat treatment, each sample was evaluated for corrosion resistance and microstructure. SEM metallographic analysis was one of the methods used to evaluate the structure of the samples. A potentiodynamic test was used to determine corrosion resistance.

3. Results and Discussion

Cryogenic treatment significantly reduced the corrosion rate of the samples of the F10 series, both in relation to the initial state (IC) and compared to the samples in the tempered state (T), see Fig. 1.

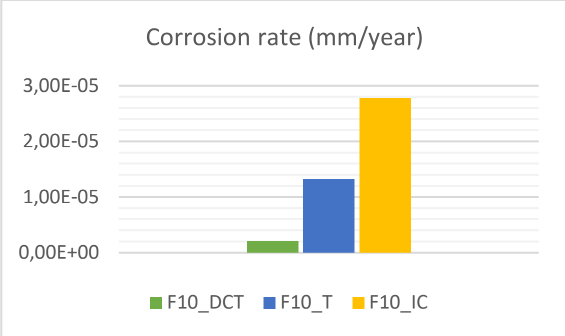

Figure 1. Comparison of corrosion rates. (IC) initial state, (T) tempered, (DCT) deep cryogenic treatment

4. Conclusions

The conclusions of this study can be summarized as follows:

- DCT caused an increase in corrosion resistance to the selected environment in all analysed varieties of SC, both in relation to the original state and tempered samples.
- The characteristic of the corrosion rate after DCT remained identical to the measurements made on the samples before this treatment, i.e. the lowest corrosion rate was shown by samples with a fine fraction of WC grains and a low proportion of Co binder.

5. Acknowledgements

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Study and Analysis of the Wiredrawing of Cuzn37 Wires via Numerical Simulations and Slab Method

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Keywords: Wiredrawing; finite element method; slab method; drawing; metal forming.

1. Introduction

The technological problem in the drawing process is conditioned by multiple factors such as drawing die geometry, wire-die tribology system, process speed and the state of the metal to be drawn, among others. Brass wire rod with Ø8 mm is obtained by continuous casting process from electrolytic materials [1]. The structural state of the wire rod is determinant, since the deformations and residual stresses accumulated in the different layers of its cross section directly affect the process and final product. Previous works demonstrated that both, the analytical and numerical simulation methods are suitable for the analysis of the wiredrawing process [2,3]. Our present work proposes a complete study of a continuous raw wiredrawing process in which an annealed wire of Ø2 mm CuZn37 is produced [4].

The main objective is the study and analysis of the sequential multi-stage wiredrawing process of brass raw wiredrawing performed in the industrial multiwire on-line wiredrawing machines.

The analytical procedure allowed us to propose a technological solution in terms of wiredrawing sequence designing and the analysis and evaluation was done by means of the implementation of FEM.

2. Methodology or Experimental Procedure

The plastic behaviour of Ø8 mm CuZn37 annealed rod wire has been determined and the coefficient of friction µ was considered in a range from 0.1 to 0.3 for the implementation of the process by the analytical method with the aim of determine the pass schedule to get the final Ø2 mm diameter wire.

The geometrical characteristics of the drawing dies can be defined with different objectives in the sense of the desired qualities of the semi-elaborated product. The Drawing die Wizard software [5] was used to determine the initial idea of appropriate geometrical parameters for the drawing dies used in the analytical calculations. The software *PullWorks* was used in the analytical definition of the pass schedule design for all the cases object of study (Figure 1). Finally, the proposed different pass schedules were simulated by FEM and the results of the simulations allowed us to understand the advantages and particularities of each one of the process proposals.

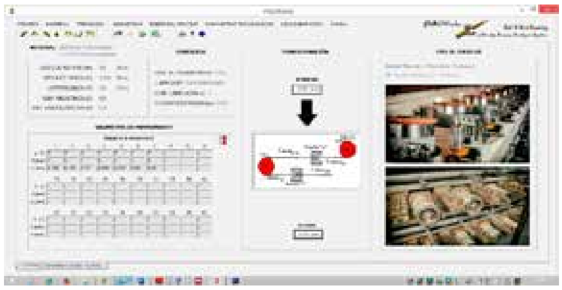

Figure 1. The process definition in PullWorks software.

3. Conclusions

The main contribution of this work will be the use of *PullWorks* software complemented with FEM simulation, allowing to understand and propose technical solutions in the multi-stage rough wiredrawing of brass. Experimental, analytical and numerical methods they complement for design and optimization of the process.

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On the Assessment of Formability and Failure af Polycarbonate Sheet Deformed by Single Point Incremental Forming

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Keywords: Polycarbonate; formability; failure; single-point incremental forming (SPIF)

1. Introduction

Nowadays, polymeric materials are used intensively in the manufacturing industry due to their excellent properties in terms of weight, strength, corrosion resistance and cost, among others.

As discussed in the recent review [1], although incremental forming of thermoplastics is relatively novel, it has drawn considerable interests and progress in recent years. To this regard, a previous work by the authors [2] a preliminary framework for the analysis of formability and failure of polymer sheet deformed by single point incremental forming (SPIF) was established.

In this context, the present investigation focuses in the evaluation of formability and failure of polymeric sheet deformed by SPIF within the material forming limits assessed following the methodologies exposed by the authors in [3].

2. Methodology or Experimental Procedure

Using the overall methodology established in [3], the conventional forming limits by necking and fracture were determined by means of Nakajima tests for polycarbonate (PC) sheet of 1 and 2 mm thickness, as depicted in Figure 1 for the former case.

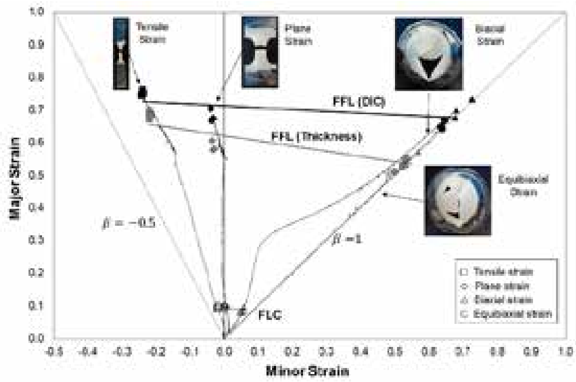

Figure 1. Formability limits by necking (FLC) and by Fracture (FFL) for 1 mm thickness PC sheets [3]

In addition, a series of SPIF tests were carried out for both material thicknesses within a range of process parameters varying tool diameter, spindle speed, feed rate and step down. The results obtained were evaluated in terms of principal strains within the formability limits obtained in the Nakajima tests.

3. Results and Discussion

Three main failure modes were assessed in the SPIF experiments: fracture, twisting and crazing. A general perspective of the influence of the process parameters in formability and the mode of failure is provided. The 3 following experimental evidences were addressed: (i) low thicknesses and higher step downs favours the appearance of twisting, (ii) most of the typical forming conditions in SPIF lead to failure by fracture in the absence of necking due to crack opening in mode I of fracture mechanics, and (iii) certain forming conditions such as higher spindle speeds are able to induce the transition from fracture towards crazing.

4. Conclusions

A general framework for the analysis of polymeric SPIF components in terms of principal strain limits is provided, including the establishment of a procedure for assessing the FLD including the forming limits by necking (FLC) and by fracture (FFL).

The application of SPIF to thermoplastics also allows achieving stable plastic deformation well above the FLC in the absence of necking, actually failing the specimen either by ductile fracture, or by the other modes of failure observed, i.e. twisting or crazing.

5. Acknowledgements

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The effect of Different Epoxidized Vegetable Oils on Injection-Moulded Starch-Based Thermoplastic Polymer Filled with Almond Shell Powder

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Keywords: Almond shell; biocomposite; injection moulding; starch-based thermoplastic; epoxidized vegetable oils.

1. Introduction

Biocomposites made of biopolymer matrix and natural waste represent an interesting sustainable solution to replace conventional polymers in a wide variety of sectors such as consumer goods, toys, automotive, building, construction and packaging. However, there are some drawbacks related to the incorporation of lignocellulosic fillers into polymers, which are mainly due to the poor interfacial adhesion between filler-matrix. This lack of interactions is responsible for a decrease in mechanical properties, mainly in ductile properties which are highly dependent on cohesion. There are several options to improve this interfacial adhesion such as physical treatments like corona or plasma treatments; chemical treatments like alkali, silane or acetylation treatments. Recently, some natural vegetable oils and epoxidized vegetable oils (EVOs) have been proposed as an environmentally-friendly compatibilizers to improve both, processability and mechanical ductile properties of biopolymer/ lignocellulosic composites [1-2].

This work reports on the effect of the variation of different epoxidized oils content on starch polymer/almond shell powder biocomposites in order to offer a 100% plant-derived formulation suitable for industrial applications.

2. Experimental Procedure

Environmentally friendly composites made of starch-based polymer Mater-Bi DI01A, filled with almond shell powder (ASP), at a constant weight content of 20 wt% and 150 µm particle size, were manufactured by extrusion-compounding. Different epoxidized vegetable oils (EVO) were added: epoxidized linseed oil (ELO), epoxidized soybean oil (ESBO) and epoxidized corn oil (ECO) to provide a plasticizing effect and to improve the low intrinsic ductile properties of TPS/AS composites. The influence of each EVO content (5, 10 and 20 phr) on the thermal, mechanical and physical properties of injection moulded specimens were studied.

3. Results and Discussion

The addition of EVO had a positive effect on the overall thermal stability of the biocomposites, increasing the onset temperature around 13-20 °C. Furthermore, the temperature of maximum mass loss rate was also higher, in comparison with the unmodified ASP biocomposite. In regard to mechanical properties, tensile and flexural modulus increased with the addition of almond shell, as expected. However, the addition of EVO produces a decrease of the stiffness of the material, more pronounced as the EVO content increases. This can be due to the enhanced almond shell-matrix compatibility produced by the EVOs, as SEM images confirm. The disintegration test showed considerable modification in the surface of the biocomposites, depending on the EVO, after 3 weeks in composting conditions, reducing their environmental impact.

4. Conclusions

New almond shell filled starch-based biocomposites were developed with improved thermal and mechanical properties by adding epoxidized vegetable oils, being a 5-10 phr ELO content more effective than ESBO or ECO.

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Ball Burnishing Effects on Hardness and Residual Stresses in UDIMET 720 Pieces

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Keywords: Burnishing; micro-hardness; nano-hardness; steel.

1. Introduction

The ball burnishing process can be used to achieve a better surface finish, as well as to improve the mechanical properties of the treated materials. This document studies the effect of this technique on the hardness pattern and residual stresses of AISI 1038 steel.

2. Methodology or Experimental Procedure

Different surfaces on a workpiece are prepared through a ball-end milling tool, obtaining periodical topologies on which the burnishing process is subsequently applied. The process is undertaken both with vibration-assistance and without. Vickers hardness measurements are made on the steel workpiece at nano and micro scales at different loads [1]. The objective is to find which micro-scale charge value helps to find the most realistic values, taking into account that this method is cheaper and easier to perform.

On the other hand, from the measurement on the nanometric scale, it is possible to find an approximation to the value of the residual stresses added by burnishing [2]. These values will be contrasted with those found from the measurements made by the x-ray technique.

Finally, indentation results will lead to decide the best burnishing parameters to modify the material surfaces. For this, all the experiments described above are conceived using a design of experiments technique. The factors of the experiments are the preload of the tool, the number of passes, the feed, the initial topology, and the burnishing strategy (Table I). This experiment design has been carried out for both conventional and vibration-assisted burnishing.

3. Results and Discussion

After this study, a relationship between micro-hardness and nano-hardness has been found on the studied steel. The values of each of the metrics have been found and correlated using statistical methods.

Using this correlation, a value for the nano-hardness has been estimated and has been correlated with the residual stresses found by x-rays.

Table I. DOE Factors for UDIMET 720

Factor	*Level*	
	1	***2***
F_p [N]	*180*	*270*
n_p	*1*	*5*
V_f [mm/min]	*600*	*900*
St	*Parallel to milling*	*Perpendicular to milling*

4. Conclusions

- A relationship between nano and micro scale hardness can be found, which facilitates the analysis of the superficial effects of steel on the steel surface.
- The burnishing force has proved to be the most relevant parameter to modify the hardness of the steel surface after ball burnishing.

5. Acknowledgements

Financial support for this study was provided by the Ministry of Science, Innovation and Universities of Spain, through grant RTI2018-101653-B-I00, which is greatly appreciated. Additionally, by the regional government of Catalonia and FEDER funds for regional development through grant IU68-016744.

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Methodology for Embedding Mineral Insulated Cables into 1.2311 Tool Steel for the Manufacture of Smart Tooling

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Keywords: Embedded sensor; laser Direct Energy Deposition; Industry 4.0; smart tooling; metal forming.

1. Introduction

In the present climate led by Industry 4.0 and digital manufacturing, the implementation of intelligent tooling in manufacturing processes has become imperative [1]. It should be highlighted, that digital manufacturing is deeply underpinned by sensor technology, which allows real-time data acquisition of key parameters [2]. In the case of metal forming processes, this requirement is translated into controlling the material flow and the temperature, especially in the tool-part contact interface [2]. Thus, controlling this contact region can be of great use in determining the physical properties of the final part. Furthermore, historical data of the temperature and pressure that the tooling is subjected to, is useful for preventive maintenance of the tooling itself. In essence, the die and mould industry could benefit greatly from the implementation of sensors in tooling, resulting in smart tooling able to acquire real-time data of the process conditions.

Traditionally, due to manufacturing limitations, sensors have been located in accessible areas of the tooling, generally far from the region of interest. However, additive manufacturing (AM) processes enable sensor integration into the tooling close to key areas, such as the tooling-workpiece interface [2]. Nonetheless, high process temperatures inherent to metal AM processes are a great challenge for successfully embedding sensors [3].

It is this context, which has motivated the present study, in which an attempt to embedding thermocouples by means of Laser Direct Energy Deposition (Laser DED) is made. Therefore, mineral insulated (MI) cables have been integrated into a 1.2311 tool steel substrate.

2. Methodology or Experimental Procedure

The experimental work has been carried out in a 5-axis laser-processing machine. As far as the materials employed, 1.2311 and 1.2344 tool steels have been used as substrate and Laser DED coating. Finally, MI cables of 3, 4.5, 6 and 8 mm diameters have been employed. The experimental work consists of initial characterisation tests and afterwards, tests under real conditions, for which two different Laser DED strategies have been evaluated. Then, the continuity of the conductors has been checked and the integrity of the deposited material assessed.

3. Results and Discussion

MI cables have been successfully embedded into the 1.2311 substrate under real conditions and, hereby, good quality 1.2344 clads have been deposited (Figure 1).

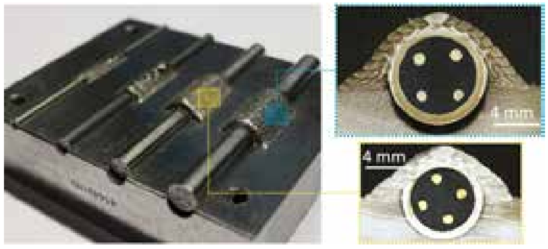

Figure 1. MI cables embedded by LMD

Satisfactory results have been obtained for larger diameter MI cables. However, the Laser DED process on smaller diameter MI cables has resulted in severe damage to the component. In fact, their lower heat dissipation capability leads to higher temperatures on the stainless steel outer casing, which combined with the lower thickness of this casing results in the perforation of the MI cable on the external cover, leading to the cable being pierced.

4. Conclusions

In this study, a suitable method for embedding MI cables for temperature measurement devices into a 1.2311 substrate has been developed. However, it is limited by the diameter of the MI cables.

5. Acknowledgements

This work is funded by the Basque Government through the SUSIE project under Grant Elkartek KK-KK-2020/00063.

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A Methodology for the Study of Friction Stir Welded Butt Joints Applied to Unweldable Aerospace Aluminium Alloys

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Keywords: FSW; Al2024-T3; butt joints; mechanical properties.

1. Introduction

Aerospace sector is continuously searching for the aircraft weight reduction, in order to obtain more sustainable products. One target in this sense is to reduce riveted joints, field in which Friction Stir Welding (FSW) is an interesting technology [1].

FSW is a solid state joining process that uses frictional heat generated by a rotating tool to join materials. The non-consumable tool rotates and traverses along the joint, heating and softening the material, without reaching melting temperatures [2].

However, the application of FSW to aeronautical alloys has not been sufficiently studied, being its application still scarce. Process parameters have a relevant influence in the joint quality, and therefore, in the in-service behaviour [3].

In this paper, a methodology for the study of FSW butt joints is presented. This procedure has been applied to one of the most used aerospace alloy, the UNS A92024-T3 (Al-Cu), and covers the design of testing bench, the tool, the process monitoring and the evaluation of the main mechanical properties of the welded joint.

2. Methodology

An experimental methodology has been applied in order to evaluate the butt joint of A92024-T3 (150 x 70 x 3 mm) samples, with the parameters shown in Table 1.

Table I. FSW parameters

Spindle speed (rev/min)	Feed-rate (mm/min)
850 / 1660	42 / 55 / 74

FSW process has been carried out in a vertical milling machine, recording forces and temperatures by using a dynamometer and an IR camera, Figure 1.

Butt joint surface quality, micro-hardness and tensile strength have been evaluated, relating them with process parameters, forces and temperatures.

3. Results and Discussion

In a general way, a decrement in process forces and temperatures are found with increment on feed-rate or decrement on spindle speed, due to the reduction of heat induced by friction.

Ultimate tensile strength (UTS) is highly reduced, fact that have been associated to the apparition of "worm holes", while elastic modulus (E) is higher than original alloy, with slight reduction with feed-rate, as is shown in Figure 1.

Figure 1. Experimental set-up

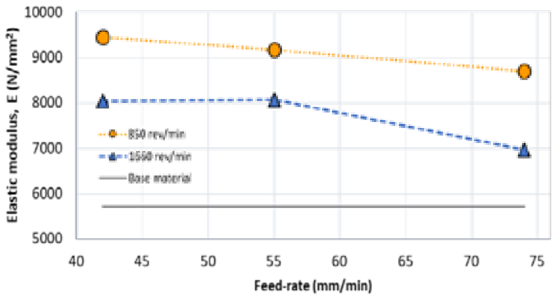

Figure 2. Elastic modulus Vs. feed-rate

4. Conclusions

In all of cases, a decrement in UTS and an increment in elastic modulus have been found, far to the industrial requirements.

The shake of the softened material is the most relevant aspect in the process, being related to process parameters and tool geometry, in order to avoid empty zones at junction. However, the developed methodology allows the study of the FSW process in a simple way, showing robust results that can be used in a wider range of parameters.

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Ontological Modelling of Welding Processes

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Keywords: Ontological modelling; interoperability; welding; standardization.

1. Introduction

In this work the need to manage the information and knowledge associated with a complex discipline such as welding is justified, and an ontological model is proposed for the welding processes.

The main objective is to show the ability of the model to effectively manage welding knowledge, especially in relation to the specification of welding processes (for instance, in the standards for welding processes qualification). A specification that must be accurate and consistent, since the adequate transmission and sharing of information and knowledge (interoperability) related to the welding processes depends largely on it.

Among existent alternatives for knowledge representation and management, ontologies stand out, that are used in various manufacturing engineering applications [1-3], although they are still very little extended in the field of welding.

2. Methodology or Experimental Procedure

The Ontology Web Language (OWL) was used to model the ontology, that has been developed and edited using the ontology editor Protégé.

3. Results and Discussion

Setting the basic entities of the ontology for the domain (Figure 1), the ontological definition of welding processes (Figure 2) and knowledge inference (Figure 3) are the most significant results of the work.

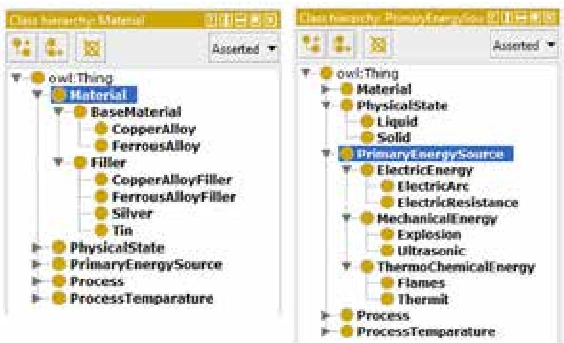

Figure 1. Basic entities of the ontology.

4. Conclusions

The ontological proposal allows: to establish consistent definitions for welding processes, which facilitate the knowledge inference in the domain; evaluate the equivalence between terms and definitions present in different standardization systems; and formalize other classification criteria, such as the one based on the degree of welding automation.

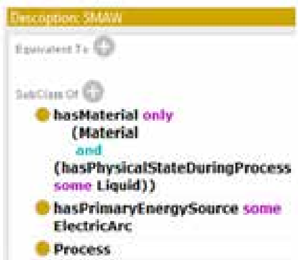

Figure 2. Ontological definition of SMAW process.

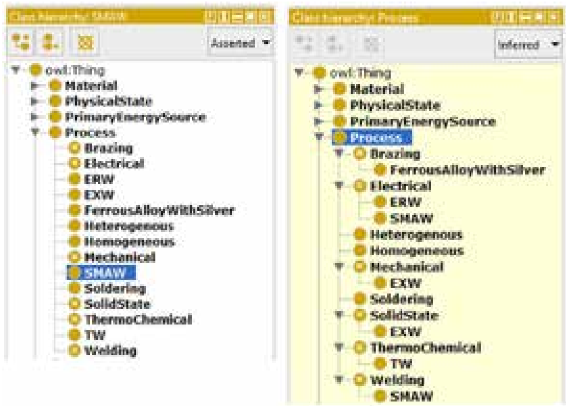

Figure 3. Class hierarchies asserted and inferred

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On Machining of Calmax Steel by EDM: an Experimental Study

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Keywords: EDM; surface roughness; SEM; Taguchi; CALMAC steel.

1. Introduction

Electrical Discharge Machining (EDM) consist of a non-conventional machining process, which is usually utilized in machining hard-to-cut materials. With EDM, any electrically conductive material can be processed, regardless of its mechanical properties, while high dimensional accuracy in complex shapes and geometries can be achieved. [1,2] EDM is commonly employed in machining of hard steel alloys, which typically require special cutting tools for their machining with conventional methods. [3, 4] The Calmax steel is a chromium - molybdenum - vanadium alloyed steel, characterized by high toughness and good wear resistance, properties that render it suitable for numerous applications. In the current study, an experimental investigation regarding the machining of Calmax steel with EDM is presented. The control parameters are the pulse-on current (Ip), the pulse-on time (Ton), and the machining Voltage. The productivity of the process is calculated based on the Material Removal Rate (MRR) and the Tool Wear Ratio (TWR). At the same time, the machined Surface Roughness is estimated in terms of Ra and Rt. Finally, for the performance mentioned above, indexes Analysis of Variance (ANOVA) was performed.

2. Methodology or Experimental Procedure

The experiments were carried out according to the Taguchi method, with control parameters the pulse-on current (I_p), the pulse-on time (T_{on}), and the applied open circuit voltage (V). By adopting a 4-level design for three factors, 16 experiments were conducted in total (L16). For the experiments, a copper electrode was utilized, and hydrocarbon oil as dielectric fluid, channelled into the working tank under constant pressure. The productivity of the process was calculated in terms of Material Removal Rate (MRR) and Tool Wear Ratio (TWR), while the machined Surface Roughness (SR) was estimated according to the Ra and Rt values. Finally, an ANOVA was performed for the aforementioned machining performance indexes. The MRR and TWR are calculated as:

$$\boldsymbol{MRR} = \frac{W_{st}-W_f}{\rho \cdot t_m} \quad [1]$$

$$\boldsymbol{TWR} = \frac{E_{st}-E_f}{W_{st}-W_f} \quad [2]$$

with the Material Removal Rate in mm^3/min, W_{st} and W_f the workpiece weight before and after the machining respectively in gr, ρ the workpiece density in gr/mm^3, t_m the machining time in min, TWR the tool wear rate in mm^3/mm^3, and E_{st}, E_{fin} the electrode weight before and after the machining respectively in gr.

In Table 1 the machining parameters are presented in detail.

Table I. Machining parameters

Experimental Parameter	Level 1	Level 2	Level 3	Level 4
Pulse-on Current (A)	5	9	13	17
Pulse-on Time (μs)	25	50	100	200
Voltage (V)	80	120	160	200

3. Results and Discussion

From the obtained data regarding the MRR, TWR, Ra and Rt, ANOVA was performed, and the above-mentioned performance indexes were correlated with the machining parameters. The surface layer was observed by SEM.

4. Conclusions

Useful and interesting conclusions were deduced concerning how the main machining parameters of EDM affect the process. By employing the results of the current study, optimization in machining planning can be attained, while they can be utilized for further research in the field of machining steel alloys with EDM as well.

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Analysis and Improvement in the Electrical Discharge Machining Process Used on the Manufacture of Moulds for Plastics Injection Moulding

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Keywords: Lean; 5S; Kanban; Continuous Improving.

1. Introduction

In most companies in the moulding industry, production departments are confronted with several adversities such as competition and competitiveness, market instability, technological development and customer specificities. Innovation therefore constitutes a priority when ensuring quality at a low cost [1]. Through Lean thinking, one can identify which activities add no value to production, and which resources are underemployed, thus allowing companies to improve their operation [2]. The main objective of this study is to improve the production processes at a company in the automotive sector by means of the application of Lean tools. As a result, one expects to minimize the manufacturing time of the moulding process in order to ensure quality at the least possible cost, ultimately contributing to customer satisfaction [3].

2. Identification of Problems

Several problems were identified in the company's production sector such as the organization of spaces, cleaning, standardization, etc. In this sector, some of the equipment also required refurbishment, ranging from highly deteriorated trestles to support tables. Furthermore, several continuous improvement tools must be implemented to eliminate errors and downtime in production, which were due to the lack of information and communication among the various departments in the company. Finally, there was also a need to address the problem of incorrect orders, which was specifically related to graphite stock.

3. Proposals for Improvement

During the first phase, one undertook the implementation of 5S methodologies (Seiri, Seiton, Seiso, Seiketsu, Shitsuke). A weekly meeting was also suggested to carry out a 5S audit, with a checklist developed for this purpose. This will ensure that all the standards are being implemented and, if necessary, establish plans for process improvement action. A framework for continuous improvement was then developed, which included all the necessary information: a Gantt diagram; relevant news and information pertaining to the company, the rates of non-conformities, accidents and complaints, etc. At the same time, a work registration form was also created. This is completed by the head of the sector and, in this way, the other workers in the sector have a work schedule. This allows for prior planning, depending on the priorities at hand. On the other hand, the existing graphite stock did not follow a pattern; consequently, one decided to set up a graphite supermarket in the erosion department, which is located in the production sector. The stock is regulated by kanban's.

4. Analysis of Results

Once the proposals for improvement were implemented, one proceeded with an analysis of the results in order to understand them, and their consequent impact on the company. In production, improvements were proposed to allow for a better organization of space, as well as improved communication between sectors and the normalization of graphite stock. Regarding the application of the 5S tool, one saw an improvement in worker safety and cleaning which, in turn, led to a reduction in the time required to look for tools. Through the implementation of 5S auditing, one was able to verify an overall improvement, from an assessment of 35% in the first audit to 85% in the subsequent audit. By implementing these tools, one observed improvements in communication between sectors, thus leading to increased productivity and production autonomy. Finally, one was also able to regulate the graphite stock by means of *Kanbans.*

5. Conclusions

Several methodologies and tools were developed to be implemented in this industry, which led to a decrease in execution times, as well as to the standardization of work and reduced stocks, culminating in lower production costs. In this regard, one was able to implement a sense of continuous improvement and, through the abovementioned results, thus motivate all the employees to continue using Lean methodology.

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Study of Particle Size and Position on Debris Evacuation During Wire EDM Operations

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Keywords: EDM; CFD; Debris evacuation.

1. Introduction

Wire Electrical Discharge Machining (WEDM) is a well known non-conventional machining process for those applications that require both good finishing and tight tolerances. One of the main problems that occur during EDM operations is wire breakage, which leads to stops in the machining process and lowers process productivity, especially in machines without automatic wire threading.

Recent findings have revealed that discharge accumulations near the same spot of the wire are the main cause for wire breakage [1]. If this discharge accumulation is not stopped the wire finally breaks. Modern WEDM machines use different control techniques to detect and interrupt discharge accumulation, but these techniques tend to decrease machining speed [1]. Some authors have used Computational Fluid Dynamics (CFD) to try to understand how the dielectric flow during the EDM process affects debris evacuation. Tanjilul [2] simulated Sinking EDM operations using a novel vacuum system and evaluated debris removal efficiency and Tomonori [3] analyzed the dielectric flow in corner cutting using WEDM in order to understand and minimize corner errors produced.

In this paper CFD (Star CCM+) is used to simulate dielectric flow and particle movement under different WEDM conditions. The objective of the performed simulations is to study the effect process variables on debris evacuation.

2. Methodology or Experimental Procedure

Simulations have been carried out using Star CCM+ software. Machining conditions with the upper and lower nozzles close to the workpiece (high pressure) and with both nozzles far from the workpiece (low pressure) have been compared. Different debris particle positions (height and angle around the wire front) and particle diameters (10, 1 and 0.1 µm) have been taken into account in order to study the effect of these variables on particle movement during machining.

3. Results and Discussion

Obtained results have shown that regarding particle size, smaller particles will leave the EDM gap more easily. Particles generated in the middle height of the workpiece have been identified as the most difficult to evacuate, remaining near the EDM zone for long periods of time, and CFD has revealed that the use of high pressure flushing conditions helps debris evacuation.

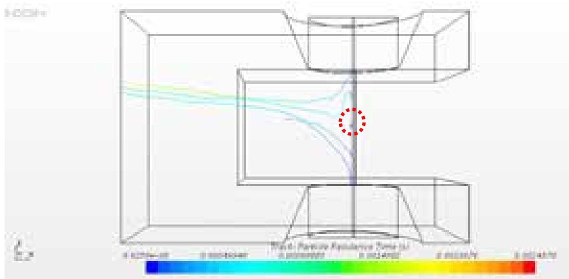

Figure 1. Particle tracks showing that some of them are not effectively evacuated

4. Conclusions

CFD simulations have been effectively used to simulate dielectric flow and particle movement. The studied variables have a clear effect on flushing, so it can be concluded that particle size and position, together with nozzle position affect process stability and wire breakage. This work can help to develop new WEDM strategies that consider the relation between mentioned variables and wire breakage.

5. Acknowledgements

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Study of the Tribological Performance of Ti6Al4V Textured with Pyramidal Dimples by Electro Discharge Machining

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Keywords: Texturing; electro-discharge; pin-on-disc; lubricant; coefficient of friction.

1. Introduction

Texturing is a well-known method for improving the tribological properties of metallic materials, by reducing friction and wear. Mainly, laser surface texturing (LST) have been applied [1], however it induces microstructural modifications and thermal stresses, modifying the surface properties of the substrate. In this line, a process barely studied for texturing is electro-discharge machining (EDM), which does not induce residual stresses and generates minimal modification at microstructural level.

The generation of dimples in a surface, following a predefined pattern, help to reduce contact area and, in some cases, to act as lubricant reservoirs. This fact improves the tribological behaviour of textured substrates, extending the lifespan of mechanical components [2].

In this line, Ti6Al4V is the most widely used Ti alloy, mainly in aerospace manufacturing for critical components. However, the deleterious innate attribute of Ti6Al4V is its incompetent tribo-behavior, reducing its field of application where there are moving contacts [3].

The objective of this work is to determine the effects of the dimple density in the wear and friction behaviour of this Ti alloy, searching an industrially scalable process capable of expanding the scope of Ti6Al4V components.

Table I. Pin-on Disc parameters

Normal load	5 N
Test radius	20 mm
Spindle speed	400 rev/min
Sliding distance	250 m

2. Experimental Procedure

Ti6Al4V samples were grinded and polished, prior to be textured with EDM processes by using graphite electrodes, in order to obtain pyramidal dimples (depth 0.25 mm) that covers 6, 11, 25 and 100% of the whole surface.

Pin-on-Disc tribological test have been carried out in dry an lubricated conditions (0,1 ml Renolin MR3 VG10), with the parameters showed in Table 1.

In addition, cross-section method has been applied to evaluate microstructural modifications, making use of metallographic procedures and SEM/EDS microscopy.

3. Results

Under dry conditions, an increment of dimple density shows a reduction on coefficient of friction (COF), but higher than the untextured surface, fact that can be associated to a local increment on contact forces when the pin passes over the dimple.

A similar behaviour is found in lubricated conditions for low and medium densities, together with a loss of lubricant due to centrifugal forces. However, with densities of 25% a relevant reduction on COF is achieved, Figure 1.

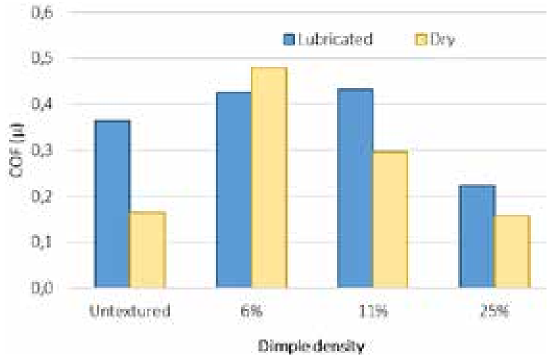

Figure 1. Coefficient of friction Vs. dimple density

4. Conclusions

Pyramidal dimples with densities of 25% of the whole contact surface may help to reduce friction coefficient in dry conditions by the reduction of the contact area. In lubricated conditions, this texture also helps to retain lubricants for a long time, reaching a reduction about 40% on COF.

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Experimental Application of a Laboratory Equipment for Micro-Electroforming Using Models Manufactured with Additive Technology

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Keywords: Micro-electroforming; micro-manufacturing; additive manufacturing; micro-structured surfaces.

1. Introduction

In this work, the progress in the combined use of two manufacturing technologies - Electroforming and additive manufacturing (DLP) - to obtain micro structured surfaces is presented. It was necessary to develop a laboratory equipment, which would allow the construction of copper shells via electrodeposition on functional models made of photosensitive resin with the capacity to reproduce details on a micrometric scale.

Both, the additive manufacturing [1] and the electroforming [2] are processes, which generated great attention in the field of micro manufacturing [3] due to their ability to reproduce details. In our case, the existence of outgoing and/or incoming geometries represented a challenge to achieve uniformity of thickness.

2. Methodology or Experimental Procedure

The first phase consisted in the production of a model with DLP LCD technology and the application of a metallizing process using sputtering to generate electric conductivity on actives surfaces.

In the second phase, this model was used in the established micro-electroforming equipment. A multi-stage process was designed. In each stages the equipment applies amperage and / or voltage values according to the needs of the pieces.

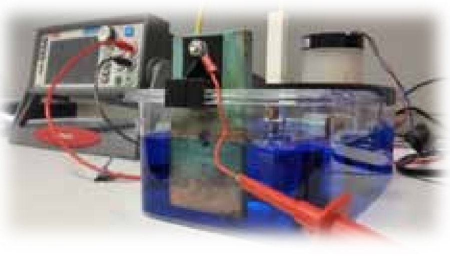

Figure 1. Micro- electroforming equipment

The operating parameters of the process are controlled by a programable power supply. This equipment has an electrolytic bath agitation system using a submerged pump. The flow of the pump can be regulated via Arduino system and is automatically adjusted according to the needs of the process. The kit also has a manifold, which evenly distributes the fluid.

3. Results and Discussion

The thickness distribution over the entire geometry was improved, even in areas of high or low exposure. The reproduction of details showed a high quality. It was possible to achieve cavities with dimensions on a micrometric scale.

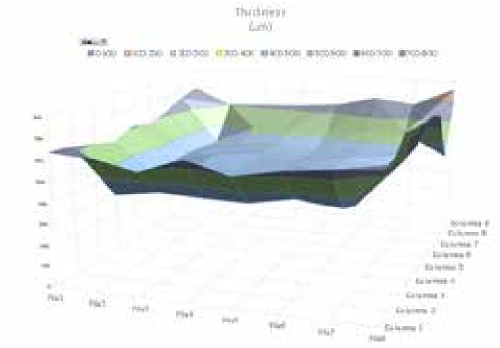

Figure 2 Thickness results

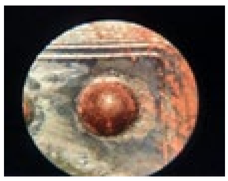

Figure 3. Microscope view

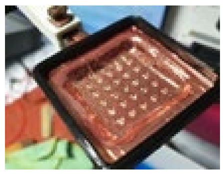

Figure 4. functional shell

4. Conclusions

Exhaustive control of the micro-electroforming parameters is essential to achieve good results in repetitions on a micrometre scale. Therefore, it is important to have an equipment, which allows a flexible modification and adaptation or the most relevant parameters of this process.

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Laser Engraving of Chip-Breaker Geometry on Alumina Ceramic Cutting Tools

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Keywords: Laser engraving; laser polishing; machining; parameter optimization.

1. Introduction

Due to the high melting temperature and pressure required for their manufacture, it is not possible to obtain ceramic inserts with chip breaker geometries from sintering [1]. Laser engraving process is an alternative to selectively remove material and reach curved surfaces [2]. This work focuses on the characterization and optimization of the laser removal parameters of ceramic material (Al_2O_3 with SiC whisker reinforcement) and the study of the influence of chip breaker geometry features in the machining of Inconel 718. Main variables of the cutting process were identified and a new two-step strategy was developed for chip breaker engraving operation. Then, the influence of chip breaker geometry has been studied comparing cutting forces and tool life in with conventional tools.

2. Methodology or Experimental Procedure

The study was divided into two phases. The first one focused on the identification of process variables and the optimization of material removal parameters. For this, a Trumark 5050 pulsed laser was used. Parameters such as power, feed rate, track overlap, pulse frequency and pulse duration, have a direct impact on energy density which in turn is directly related to the removal rate of material. Once the process parameters for the engraving and polishing operations have been set, in a second phase, a chip breaker structure has been designed in which the influence of three geometric variables, the edge lip, *t*, the entry angle, α, and the depth, *h*, (see Fig 1(b))was studied. Machining tests were carried out in Inconel 718 and results have been evaluated measuring the cutting forces, surface roughness on the machined part and tool life based on the flank wear parameter VB.

3. Results and Discussion

In laser engraving operation, the maximum material removal rate was obtained at 400 mm/s, with pulse duration of 250 ns, at maximum power and with 50% track overlap. In the subsequent polishing operation, it was seen that intermediate power levels, feed rate above 1000 mm/s and pulse durations around 320 ns provide roughness reductions of over 40%. Regarding cutting forces, the results show a significant improvement compared to tests carried out with conventional inserts. It was observed that the polishing operation has a positive effect with an improvement of about 10% compared to chip breakers engraved but no polished. The width of the cutting-edge lip, t, is the main geometric characteristic with influence on both, the cutting forces and the tool life. Thus, for *t* values of 0.1 mm average cutting forces are reduced in 25% while for values of 0.2 mm the improvement obtained is below 15%. A similar trend is also observed in the tool life values, where more favourable results are obtained when the cutting forces are lower, reaching an improvement of almost 200% in the tool life.

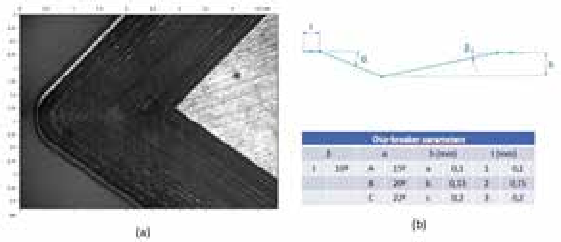

Figure 1. Tool breaker (a); Geometry parameters (b)

4. Conclusions

In the study carried out, it was found that both the geometry of the chip breaker and the surface finish of the insert on the rake face have a direct effect on the cutting forces generated as well as on the tool life. By optimizing the laser polishing parameters, roughness below 1.32 Sa and cutting force reductions above 25% in relation to ceramic inserts of conventional geometry was achieved. Thus, by optimizing the cut geometry, an increase in tool life of around 200% was also achieved. These improvements confirm the feasibility of using a nanosecond laser for engraving effective chip breaker geometries in SiC reinforced Al_2O_3 ceramic inserts for stainless steel machining applications.

5. Acknowledgements

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Effect of Laser Heat Treatments on the Hardness of Tool Steels

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Keywords: Laser; local heat treatment; hardness; mould steel.

1. Introduction

Plastic injection moulds are projected to be used for numerous million rounds of plastic products mass production [1]. These tools are subjected to strong thermo-mechanical loads which negatively affects their surface quality and strength, and consequently the productivity. To preserve the plastic products quality, damaged moulds should be repaired, thus increasing the production cost. In order to minimize the surface damage on mould steels, the application of surface treatments has been studied [2].

The application of laser-based surface treatments is widely used for the modification of metal surfaces, due to their diverse application range, high precision, and superior manufacturing efficiency [3]. Further, it allows to locally treat the surface, enabling a tailored hardness distribution.

This work presents an experimental study of different parameters, such as temperature and velocity, on the hardness of the heat-treated surfaces.

2. Experimental Procedure

In the current research two commercial steels (AISI H13 and AISI P20 mod.) were used to study the influence of laser thermal treatments. These steels are commonly used in the manufacturing of tools for injection moulds. The chemical composition of the steels used is listed in Table I.

In the experiments, a laser beam was moved in a linear path, with a transverse scanning motion. The laser head was mounted on a six-axis robot and equipped with a pyrometer and camera. The spot size was fixed in 15.2 mm and 7.2mm, and the maximum laser power was 4.5 kW, controlled in a closed loop to keep temperature constant.

Table I. Chemical composition of the mould steels (wt%)

Steels	C	Si	Mn	Cr	Mo	Ni	V
H13	0.39	1.00	0.38	5.15	1.35	-	1.0
P20 mod.	0.40	0.30	1.45	1.95	0.20	1.05	-

Experimental work used a 2x2 factorial design, focusing on temperatures targeted to 1060 ^oC and 1100 ^oC, and feed rate of 10 $mm \cdot s^{-1}$ and 15 $mm \cdot s^{-1}$.

To characterize the steels and the heated affected zone, Vickers microhardness tests were conducted on a Struers Type Duramin-1 microhardness tester. An indentation load of 2.0 kgf and a holding time of 15 s, according to the ISO 6507-1:2018 was applied. Hardness measurement profiles were obtained along multi transversal and longitudinal lines from the specimen surface and transverse sections.

3. Results and Discussion

The hardness profiles obtained showed the influence of the temperature and feed rate on the laser heat affected zones. Comparing the hardness of the base steels and the laser heat-treated steels, the hardness increases within the tempered zone.

As expected, laser heat treatments leaded to an increase in steels hardness and the heated zones presented a homogeneous hardness.

4. Conclusions

This work allowed to obtain a deeper knowledge concerning laser heat treatments characterization for plastic injection moulds application. From the results obtained, a multi parameter DOE is under development. As showed, the laser heat treatments can be assessed through the hardness evolution.

5. Acknowledgements

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Preliminary Study of Abrasive Water Jet Texturing on Low Thickness UNS A92024 Alloy Sheets

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Keywords: Surface modification; Abrasive water jet texturing; Surface Quality; Texturing

1. Introduction

Texturing and surface modification operations are a line of research of great interest nowadays. The requirement to establish a process that can generate a constant and homogeneous roughness as a previous step to joining operations, application of paint or mechanical tests is a current challenge. Technologies such as shot blasting or laser texturing have achieved great results in terms of roughness and surface activation [1,2].

Nevertheless, there is an alternative technology that is achieving great interest. Abrasive water jet texturing takes advantage of the combination of the impact of abrasive particles and water at high speed with the controlled displacement of the jet to generate a surface with a controlled roughness [3].

Thus, in comparison with other technologies, abrasive waterjet texturing can achieve higher roughness values and a constant texturing area as a function of the overlap established between the passes [4].

In this work, a preliminary study is proposed in order to establish a direct relationship between the parameters governing the technology and the roughness generated in a low thickness UNS A92024 alloy. Defectology associated to the process, as well as the combination of texturing parameters have been determined.

2. Methodology or Experimental Procedure

An abrasive water jet machining equipment (TCI Cutting, BP-C 3020, Valencia, Spain) has been used as texturing technology. The textured material was an UNS A92024 alloy with dimensions of 20mm x 50mm x 2mm. The texturing parameters used are shown in the Table I. Surface quality in terms of Ra and Rz have been obtained through a Roughness Meter (Mahr Perthometer PGK 120, Göttingen, Germany) (Figure 1).

Table I. Experimental design for abrasive water jet texturing

AMFR (g/min)	Cross Feed (mm)	SOD (mm)	TS (mm/min)
0-110	0.18-0.36	10-30-50	2000-4000-6000

Finally, the surface generated after the surface modification was evaluated by visual inspection using a metallography equipment (Nikon, SMZ 800, Tokyo, Japan). Hydraulic pressure has been set at 800 bar and all trials were carried out by a 120 mesh Indian Garnet abrasive particles.

Figure 1. Surface quality evaluation after abrasive water jet texturing process

3. Results and Discussion

A direct relationship between the main texturing parameters and the roughness generated in terms of Ra and Rt has been obtained. An increase in these parameters results in higher values of roughness due to the impact of the abrasive particles. An increase in the overlap between passes of the water jet (Cross feed) and the traverse speed generates a constant roughness area by reducing an overexposure of particles impacting the surface. In addition, a comparison of texturing with and without abrasive particles has been established which indicates that the efficiency in terms of roughness is greater by combining these particles with the water flow.

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Manufacture of an Abrasive Jet Machining (AJM) Equipment Adapted for the Treatment of Rotary Flexion Fatigue Specimens

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Keywords: Abrasive jet machining; surface integrity; light alloys; surface treatments.

1. Introduction

The surface topography influence on several physic-chemical surfaces and mechanical properties, such as the fatigue behaviour, corrosion resistance and micro-hardness, is widely accepted, even though their basic principles are unknown [1]. Machining processes results in several surface alterations, both at micro and macro-geometrical scale, being directly influenced by the cutting parameters (feed, cutting speed and cutting depth) [2]. The actual trends of light alloys machining is suppressing the use of cutting fluids in the manufacturing of structural parts of aircraft. Under these conditions, surface alterations become higher in comparison with the use of cutting fluids. In this context, a study of the cutting parameters influence on surface integrity of light alloys machined parts is being developed by the authors [3]. In order to carry out this research, different specimens of light alloys are being tested, to be used in standard test of several mechanical and geometrical properties. These results, obtained by main machining processes, have been compared to those obtained by applying an additional finishing operation, as Abrasive Jet Machining (AJM) [4]. Since there was not available, an AJM equipment has been designed, manufactured and tested.

In this work, the different steps and experimental methodology used is exposed.

2. Methodology and results

The elements that compose the AJM equipment were the following (Figure 1): gas supply system, gas filter, water separator, powder supply and mixer, hand holder, nozzle, dust exhausting unit and security chamber. For the nozzle positioning, a holder with positioning equipment and an automated rotary table have been provided to characterize the attack angle where the specimen rests.

A system with similar characteristics have a cost close to 5000 €, being necessary its adaptation (a fixture for the test specimen have to be added).

However, the AJM made *ad hoc* had a cost of 548 €, divided in: labour 180 € and materials 368 €.

a *b* *c*

Figure 1. AJM machine: a. Security chamber; b. powder supply and mixer; c. Rotatory system and nozzle.

Additionally, a setup of the equipment was carried out. The surface roughness of different specimens has been compared by using different abrasive material. Finally, the first results of the comparative analysis between specimens, with and without applying AJM, are shown.

3. Conclusions

In this work, an Abrasive Jet Machining was designed, manufactured and tested, resulting in a 85% savings in comparison with a commercial machine.

This equipment has allowed starting the research to complete the influence of surface integrity on light alloys machined parts.

4. Acknowledgements

The authors thank University of Málaga-Andalucía Tech Campus of International Excellence for its economic contribution on this paper.

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Preliminary Study of the Hardening Effect and Fatigue Behaviour Enhancement through Vibration Assisted Ball Burnishing on C45 Steel

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Keywords: Ball burnishing; hardening; fatigue; vibration assistance.

1. Introduction

Ball burnishing (BB) is a surface finishing process done by a sphere which applies a controlled force while is rolling over the surface. It improves the mechanical properties such as hardness and fatigue on cylindrical surfaces of AISI 1038 samples [1].

In addition, it is proved that vibration assisted ball burnishing (VABB) improves the fatigue life and hardness on AISI 1038 flat surfaces [2]. The aim of this paper is to analyse the influence of ball burnishing in the fatigue life and hardness of the AISI 1038 specimens. Also, a comparison between conventional ball burnishing and vibration assisted ball burnishing is done.

2. Methodology or Experimental Procedure

The experiment execution is based on a design of experiment methodology, having a total of 26 specimens with the distribution shown in Table 1. The tests were executed on a bending-fatigue rotating machine (Figure 1), following the ASTM E606/E606M–12 standard. In terms of hardness, the degree of plastic deformation on each specimen was measured with a Vickers microidentations, following the ASTM E92-82 standards for cylindrical surfaces.

Table I. Ball burnishing parameter combination

Force (N)	Nº passes	Nº samples (BB+VABB)
90	1	2+2
90	3	2+0
90	5	2+2
180	1	2+0
180	3	0+2
180	5	0+2
270	1	2+2
270	3	0+2
270	5	2+2

3. Results and Discussion

The influence of the selected parameters on the fatigue life and hardness was stablished.

The fatigue analysis is represented on S-N curves (Wöhler), in which it is compared the expected fatigue life associated to all ball burnished specimens at a maximum alternating stress.

Figure 1. Bending-fatigue rotating machine.

4. Conclusions

The following conclusions can be drawn from all tests performed on the AISI 1038 specimens:

- Vibration-assisted ball burnishing increases the expected fatigue life for this type of test.

- The burnishing forces, the number of passes and the vibration assistance are the most relevant parameters.

- There is a relation between the surface hardness and the fatigue life.

5. Acknowledgements

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Recent Advances in the Extrusion Methods for Ceramics

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Keywords: ceramics; prostheses; DIW; 3D printing

1. Introduction

In recent years, 3D printing processes have undergone an important development. They allow obtaining complex shapes, for example with porous structures, in an easy way and relatively low cost. Different plastic materials can be printed with the FFF technology. Metals such as titanium alloys are also printed with success for the manufacture of prostheses [1]. However, 3D printing of ceramics is by far less developed than printing of plastics or metals. A possible application for 3D printing of ceramics is the manufacture of prostheses, which usually have complex shapes and porous structures. Ceramic prostheses have several advantages in front of the use of other materials: they generate low debris, they are hard and they are inert and oxidation-resistant [2].

In the present work the recent advances about extrusion 3D printing of ceramic materials are presented, with a special focus on the manufacture of prostheses.

2. Methodology or Experimental Procedure

In the present work, first an overview about the different extrusion methods that allow printing ceramics is presented. Next, a specific section about the manufacture of ceramic prostheses is shown. Finally, the recent trends in the manufacture of ceramic prostheses is considered.

3. Results and Discussion

Direct Ink Writing (DIW), also known as Robocasting (RC) 3D printing technique is one of the most employed printing technologies for ceramics nowadays [3] (Figure 1).

Currently, the usual method employed to manufacture ceramic prostheses involves the sintering operation of a ceramic block and a subsequent machining process. However, due to the thermal fragility of many ceramics, machining can lead to cracks in the structure of the prosthesis.

Extrusion 3D printing of ceramics allows obtaining complex shapes and even porous structures in ceramic materials. In addition, it has the potential to print many different materials [4]. Nevertheless, there is still much work to do in order to improve the printing processes for ceramics, for example regarding dimensional accuracy and surface finish.

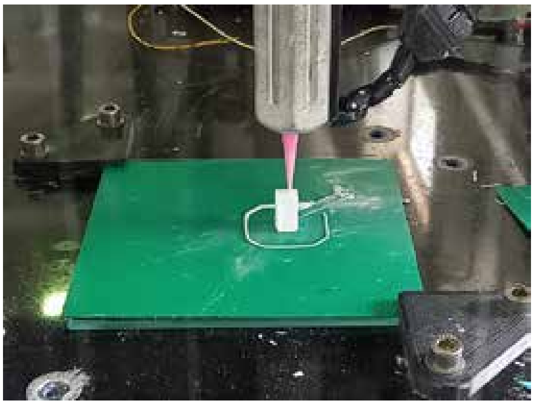

Figure 1. Example of a ceramic printed part by means of DIW

On the other hand, recent trends in 3D printing of ceramic materials include the use of ceramic filled plastic filaments with the FFF (Fused Filament Fabrication) technique.

4. Conclusions

DIW is one of the most employed techniques for printing ceramic parts, because of its easiness of use and its relatively low cost. However, in recent years ceramic filled plastic filaments have started to be printed with success by means of the FFF technology.

5. Acknowledgements

The authors thank the European Union Regional Development Fund for the financial help of project BASE3D, grant number 001-P-001646.

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Fused Filament Fabrication over Fabrics – Experiments and Applications

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Keywords: 3D printing; textile fabrics; layer thickness; structural structure; adhesion.

1. Introduction

Fused Filament Fabrication (FFF) also known under the trademarked term Fused Deposition Modeling (FDM) is a material extrusion addictive manufacturing (AM) technology used to easily print three-dimensional models by depositing melted thermoplastic material, layer by layer, without the need to use any additional molds or tools [1]. While the typical FFF process builds a part button-up on an empty building tray, the material deposition over a substrate is possible [2]. The focus on this case study is to explore FFF over fabrics and the different factors that contribute to the development of a textile structural model without any additional components, which can be applied in different contexts, by printing the Polylactic Acid (PLA) onto the surface of different types of fabric.

2. Methodology and Experimental Procedure

This study was developed using an Ultimaker 3 3D printer, with 2,85mm diameter rigid PLA filament over four different types of fabric: cotton, polyester, polyester felt and 65% polyester plus 35% cotton. Three different nozzle and build plate temperature combinations were used: 200°/60°, 220°/70° and 240°/80° with three different printing thickness: 0,25mm, 0,50mm and 0,75mm.

The experimental procedure was developed in three steps. The initial step was the design of a set of lines with different widths and thicknesses. With this geometry, the four different types of fabric were printed and used as samples of the different combinations (thickness + width + temperature + type of fabric). The resulted 12 prints were tested to establish which combination would have better adherence and structural results. On the second step, 25mm by 50mm specimens printed on the previous experiment were used. On a three point bending test with 30mm distant supports, evaluating which combination provided the highest flexural strength. The results gathered on this test were the starting point for the development of the last experiment. In this step, based on the previous results, 9 different geometries were designed and printed onto the final 2 chosen fabrics determining which fabric and geometry combination would provide the best structural result.

3. Results and Discussion

Based on the experimental tests, it was possible to gather some conclusive results. The first showed that PLA adherence to the fabric is correlated with the nozzle/building plate temperature and printing thickness. Higher temperature and thickness provide higher adherence. The weave of the textile didn´t reflect on better results but the polyester felt fabric exhibit maximum adherence with printed PLA in all sets of temperatures.

By the three-point bending test it was possible to conclude that the value of the maximum flexion force increases from the temperature set of 200º/60º to the 220º/70º although decreases to the 240º/80º. With this test was also possible to observe that 0,25mm printing thickness wasn´t sufficient to provide structural support and that the combination with the best flexion force result was the 0,75mm thickness print onto the 65% polyester plus 35% cotton fabric at the set temperature of 220º/70º with an end result of 25,0N.

On the application tests, by the study of different geometries it was possible to note that a higher PLA volume with reinforcement lines along the stress direction provided better structural results.

4. Conclusions

The development of this study aims to demonstrate with the exposed results that the fabrication of a fabric structured with a printed polymer is conceivable and can be applied in the furniture and fashion industry.

5. Acknowledgements

This work was developed within the scope of projects supported by Portuguese Foundation for Science and Technology/MCTES.

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3D Printing of Spare Parts: Experimental Study Using Non-Standardized Tests of The Maximum Supported Torque

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Keywords: Additive manufacturing; Fused Deposition Modelling; 3D printing; spare parts; torsion test.

1. Introduction

3D printing provides a way to manufacture spare parts on demand [1]: spare parts are digitized and printed only when needed. This reduces the length of the supply chain, avoids the high cost associated with full warehouses of parts and extends the life of the machine in question.

Depending on their function, these spare parts can be subjected to different states of load, simple or combined: compression, tension, shear, bending, torsion. In the literature, it is easy to find works that study the behaviour of printed specimens using tension or compression tests. However, there is hardly any information regarding torsion test [2].

In this project the goal is to know what parameters (number of perimeters, pattern, and fill density) provides increased torsional strength in a 3D printed part using fused deposition modelling (FDM) for a gas water heater selector (Figure 1). For this, 16 specimens have been printed in acrylonitrile butadiene styrene (ABS), using different numbers of perimeters, as well as different patterns and filling densities; once manufactured, they have been subjected to a non-standard destructive test.

2. Methodology

In the present work, the torsion behaviour in cylindrical pieces printed in acrylonitrile butadiene styrene (ABS) has been studied using fused deposition modelling. A total of 16 non-standard cylindrical specimens have been printed, each having hexagonal heads carved on both bases. Each specimen has been printed using different numbers of perimeters (3 or 5), different density values (60 or 80%) and different fill patterns (hexagonal or triangular). Once printed, the pieces have been tied to a workbench using a screw. Once fixed to the bench, an auditor's torque wrench has been used to find out what is the maximum torque supported by each specimen. Using the information obtained in the test, a spare part for a selector of a gas water heater has been printed (Figure 1).

3. Results and Discussion

The results obtained in the tests allow to affirm that the combination of printing parameters that provides a greater resistance to torsion is the following: 5 perimeters, triangular fill pattern and 80 % fill density. The maximum torque reached in the tests is greater than 60 Nm. Using the results obtained, a gas water heater selector has been manufactured (Figure 1).

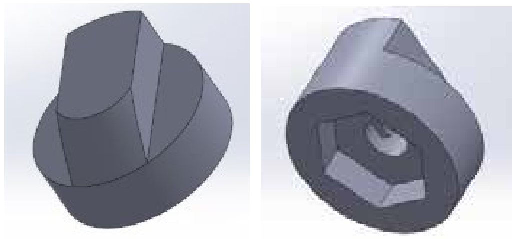

Figure 1. Design of a gas water heater selector.

4. Conclusions

Using FDM it can be printed spare parts for equipment that is discontinued or for which spare parts are not found. For certain functions, such as the selector studied, it is necessary to know the maximum torque that the part can withstand. Experimentally, this value has been determined by means of a non-standardized test. It has also been determined which number of perimeters, pattern and fill density provide the highest torsional strength.

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Tensile Properties of Elastomer Process Through FFF for Biomedical Applications

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Keywords: 3D printing; Fused Filament Fabrication; thermoplastic elastomer; tensile test.

1. Introduction

The need of study new materials used in Fused Filament Fabrication is growing as the use of this technic is increasing each year. The aim of this research is to do a mechanical characterization of two different thermoplastic elastomers processed through FFF, by studying the influence of the printing parameters on the mechanical responses obtained in tensile tests. These materials might have possible applications in the field of biomedical engineering due to their similar properties to soft tissues [1].

2. Methodology or Experimental Procedure

Three main steps are followed in order to characterize the materials as the behaviour of the samples made by additive manufacturing is anisotropic. First, a selection of the printing parameters is done. In this step, it is decided what parameters are the aim of the study which will be the variable parameters (Table I). These will be the layer height and the infill pattern, as other studies have concluded that these factors could be influent on the behaviour of the materials built through FFF [2].

Table I. Variable factors.

Factor/ Level	Low	Medium	High
Layer height	0.20	0.25	0.3
Infill pattern	25	50	75

Secondly, the design of experiments is defined to optimize the number of configurations printed, processed, and analysed, helping with the waste and time reduction. A full factorial design with four centre points has been used, so four working conditions have been tested. In order to guarantee the repeatability of the results, three samples of each configuration were printed.

The next step is to design the samples. The ASTM D638 standard has been followed. The materials studied are Flexfill TPE 96A (based on polyolefin) and Flexfill PEBA 90A (based on polyamide and polyether). The 3D model of both specimens is modelled with SolidWorks, the stl file is created with Simplify3D and the printer used was an Ender-3 Pro.

Finally, the results are processed with statistical models by applying an analysis of variance with a significance level of 95%, where all the mechanical responses as well as the influence and interaction of the parameters studied were evaluated.

3. Results and Discussion

The two thermoplastic elastomers have been characterized by analysing four mechanical parameters: Young's modulus, elastic limit, maximum stress and maximum deformation of the samples by testing them in a tensile test. The selection of the printing parameters should change depending on the material used and its final application. This is due to the fact that the statistical influence of the parameters changes according to three aspects: the material used, the printing conditions and operation context.

4. Conclusions

From this study, it is concluded that the methodology used is adequate as the results obtained demonstrate the operative setup relevant for tensile tests. Furthermore, these results allow to ensure the most suitable material for each working condition.

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Financial support for this study was provided by the CCD of the UPC, through grant A029-2020.

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Mechanical and Electrical Properties of Additively Manufactured Copper

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Keywords: Additive Manufacturing; ADAM; copper; conductivity; mechanical properties; built orientation.

1. Introduction

Additive Manufacturing (AM) technologies have been in constant development since the 1980's [1]. During this time, many AM technologies for metallic materials have been developed [2], among them the novel ADAM (Atomic Diffusion Additive Manufacturing). Few materials can be processed with this technology, highly pure copper (Cu≥ 99.8%; O and Fe ≤0.05 %) among them.

Copper is known for the great conductivity and is precious for many applications. However, manufacturing of pure copper is still challenging in AM technologies, being SLM and EBM the most developed ones [3]. However, there are two considerable main issues when cooper workpieces are built using SLM or EBM: high energy consumption due to reflectivity in SLM [4], and high thermal residual stresses due to the big thermal gradients in both SLM and EBM [4,5]. The presence of these residual stresses was found to be the cause of crack formation [3]. A thermal post process is required to remove them, increasing the cost of parts manufactured by SLM and EBM.

ADAM is free from both mentioned issues, making it the most practical technology for working with copper.

The objective of this article is to expose mechanical and electrical proprieties of copper manufactured with ADAM technology considering the influence of the built orientation. Obtained results are compared with those obtained by other AM technologies.

2. Methodology

To determine mechanical an electrical proprieties specific test samples were manufactured with Metal X machine from Markforged company. Tensile tests have been conducted, as well as hardness, conductivity, surface roughness and density measurements.

3. Results and Discussion

Table I shows obtained values of the principal parameters considered and are compared with those published in the literature. These results correspond to "as manufactured" material, without any post processing operation.

Concerning tensile strength, best values were obtained with ADAM technology, being 38% higher than that obtained with SLM [4], and 16% higher than EBM [5]. On the other hand, density is quite similar in considered three technologies. Finally, the electrical conductivity is significantly smaller than in EBM as found in literature.

Table I. Main results of additively manufactured copper

	SLM [4]	EBM [5]	ADAM
Purity of copper [%]	>99.94	>99.97	>99.8
Density [%]	99.6	99.95	99.93
Tensile Strength [Mpa]	149	177	206
Elect. Cond. [%IACS]	88	102	84

4. Conclusions

The novel ADAM technology is able to process the copper successfully obtaining good mechanical properties. Nevertheless, obtained electrical conductivity was not good enough. Besides, the influence of built orientation in the results is also discussed.

5. Acknowledgements

The authors would like to thank the Basque Government for the financial support to the Tknika 025_002 project.

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Study for the Selection of 3D Printing Parameters for the Design of TPU Products

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Keywords: Product design; additive manufacturing; TPU; elastic product; FFF.

1. Introduction

The design and development of new products represents a high investment for the industry, as it requires a long production process. In order to reduce time in the development phases, the incorporation of additive manufacturing (AM) technologies is extended to several sectors of industry [1-3]. Its main application is the generation of prototypes as it reduces the risk of overcosts and a way of optimising times during the development phase. However, in the creation of prototypes with elastic materials, such as TPU, reliable representation of the final product is important because it affects the functional properties [4-7]. Therefore, in this work we studied the appropriate manufacturing parameters for flexible material specimens, due to the complexity that this material entails.

2. Methodology or Experimental Procedure

A study of the conditions and parameters of 3D printing was carried out to improve the finishing conditions of the product printed with TPU material.

The main defects affecting the final finish of the TPU product are: lack of interlayer adhesion, lack of precision and surface finish [8, 9]. Therefore, efforts were focused on the reduction of interlayer defects and the excess or lack of filler material. In addition, extrusion temperature was studied to improve surface finish, and finishes were evaluated by tactical-visual analysis.

3. Results and Discussion

The optimal manufacturing parameters were obtained. With speeds of 20 and 30, good finishes can be obtained, but at lower speeds higher quality can be achieved. For this reason, the speed of 20 mm/s was selected, the minimum recommended. It should be noted that the temperature has been increased by 5°C with respect to the maximum recommended value obtaining better finishes.

4. Conclusions

the data obtained are considered of great value for subsequent application to elastic or flexible products. In this way, the geometry of the product can be customized with respect to its specific function and the quality of the finishes of elastic products manufactured through additive manufacturing can be improved.

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Study of the Influence of Laser Energy Density on Surface Roughness of Scalmalloy® Samples Manufactured by DMLS Technology

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Keywords: Additive manufacturing; scalmalloy; roughness; DMLS, aluminium.

1. Introduction

Direct Metal Laser Sintering (DMLS) additive manufacturing technology allows to obtain metal parts from a CAD design by selectively layer-by-layer melting of metal powder, used as raw material, using a laser beam [1]. This technology makes it possible to manufacture parts with complex geometries that can be customised and designed without imposing any limitations. It also has the advantage of reducing waste during manufacturing [2]. However, this technology has certain disadvantages, one of which is the low surface quality of the parts obtained. This problem limits its use in certain industrial sectors such as the aeronautical industry. The need to improve the surface quality requires to introduce post-processing tasks which increase the manufacturing costs the parts. Different techniques for surface improvement of parts obtained by means of DMLS have been found in the bibliography. Sand blasting, mechanical polishing, electropolishing or dry electropolishing could be mentioned among other methods [3]. There is a less studied option based on modifying the laser parameters during the DMLS process. This option would enable to obtain parts with higher surface quality and would reduce or even eliminate the post-processing tasks above mentioned.

In this work, the influence of some laser processing parameters on the surface quality of samples of the Al-Mg-Sc Scalmalloy® alloy, designed by Apworks for aeronautical applications, has been studied [4]. Thus, the influence of these parameters on the surface roughness, porosity and mechanical properties of the samples has been determined.

2. Methodology or Experimental Procedure

Scalmalloy® samples studied have been manufactured by using a DMLS EOS M290. Samples were designed to have up-skin and down-skin surfaces. The influence of laser energy density on the surface finish on each of these surfaces has been studied. Roughness of manufactured samples has been determined by using a Mahr PS10 roughness meter. On the other hand, in order to determine the presence of surface pores derived from the new manufacturing conditions, samples have been studied with a Leica DM IRM metallographic microscope. Finally, mechanical tests have been performed on those samples with the best surface finish, in order to determine the exact differences with respect to the samples manufactured with the parameters defined by Apworks.

3. Results and Discussion

The results obtained show that it is possible to decrease the roughness of the samples by increasing the energy density of the laser radiation above 10 J/mm^2 on the up-skin surface and 25 J/mm^2 on the down-skin surface. In addition, it has been found that by using an energy density of 100 J/mm^2 on both surfaces, the value of Ra is of the order of 4 μm, a value considerably lower than the 15 and 22 μm presented by the up-skin and down-skin surfaces, respectively, in samples manufactured using the default parameters. On the other hand, it has been observed, by means of metallography, that the porosity of the samples increases with the applied energy density. However, this increase in porosity does not significantly modify the studied mechanical properties.

4. Conclusions

The results obtained indicate that it is possible to improve the surface quality of Scalmalloy samples manufactured by DMLS by controlling the energy density of the laser. It has been possible to obtain samples with Ra values of the order of 4 μm by applying an energy density of 100 J/mm^2 to the up-skin and down-skin surfaces.

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Experimental Measuring of Printing Speed in FDM

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Keywords: 3D Printing, FDM; step motor speed; 3D printing speed; uncertainty.

1. Introduction

The hot-end speed or printing speed in Fused Filament Fabrication (FFF) (a well-known additive manufacturing technology) influences mechanical properties, dimensional accuracy, and process performance (actual building time).

There are differences between theoretical speed (defined in the G code) and real printing speed attained by the machine in practical applications. The use of polygonal tool-paths is the main reason why the printer cannot maintain constant reference theoretical speed.

Therefore, an accurate speed measurement is needed to obtain process time and energy consumption accurate estimations, depending on the printing speed.

This work compares the operation and the estimation error of two different measurement methods:

- Out-process solution. It is based on the estimation of the speed function of segment length and angle.
- In-process method. It is based on encoder measurements.

Several experimental tool-paths on a low-cost desktop FDM 3D printer provide the information to study and compare the above methods.

2. Methodology

The proposed measurement methods can estimate the printing speed of cartesian machines run by stepper motors.

The out-process approach is based on the procedure described in [1], which consist of two stages:

- Calibration. By moving the hot-end through reference 2D paths, we can estimate the actual average printing speed as a function of the interpolation segment length and direction change.
- Estimation. It is based on reading the G code used for printing the part and use the experimental calibration model to estimate the real speed.

The in-process method is based on holding electronic encoders on the printer stepper motors. In this work, we only mount two AS5600 encoders with a uStepper S-lite controller board on the stepper motors that run the X and Y axes (additional encoders can be used to measure the speed in the Z-axis and the extrusion speed). These devices record the number of steps per time in the motors, and computations with this information provide the actual position, speed, and acceleration through the printing process.

The measurement systems uncertainty mainly depends on the motors and encoder resolution and the time measurement uncertainty. It is a combined standard uncertainty that it is computed according to the GUM recommendation [2].

3. Results and Discussion

We test the measurement methods in three different 2D paths: lines, circles, and a sinusoidal path showed in Figure 1. All tests have been accomplished without extrusion because we are concerned with the hot-end speed.

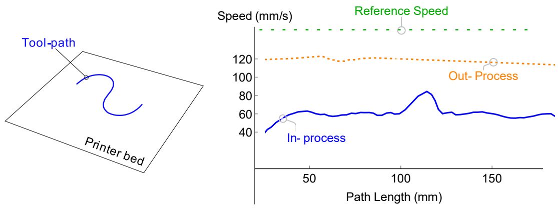

Figure 1. Examples of a measured speed profile

4. Conclusions

Besides discussing how to measure printing speed, we study the main sources of uncertainty and compare two techniques with respect to real printing time.

5. Acknowledgements

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Evaluation of Porosity in 3D Printed Trabecular Bone Structures for Prostheses

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Keywords: porosity; trabecular structure; FFF; 3D printing

1. Introduction

Hip prostheses require a smooth inner surface, which will articulate with the femoral, and a porous outer surface that will favour the fixation of the prosthesis by means of osseointegration. Such surface requires a certain degree of porosity and pore size values. Additive manufacturing (AM) allows printing porous structures in different materials in a relatively cheap way [1].

In the present work results are presented about theoretical and experimental porosity of trabecular structures manufactured in Polylactic Acid (PLA) by means of Fused Filament Fabrication (FFF). Different infill values were used, as well as different geometrical conditions.

2. Methodology or Experimental Procedure

The trabecular structures were designed with the help of the Rhinoceros software, with the Grasshopper plugin (Figure 1).

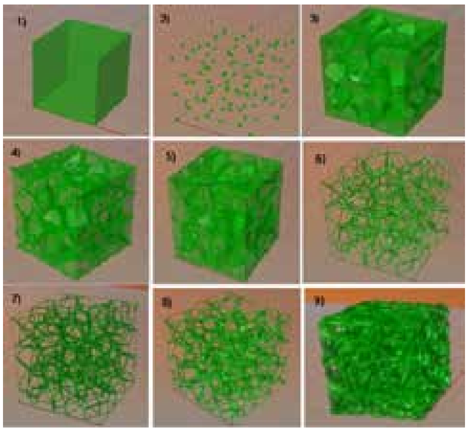

Figure 1. Design of the Voronoi porous structures

In order to print them, the geometry was exported to .stl format, and the software Cura BCN3D was employed to generate the gcode. The samples were printed in PLA (Polylactic Acid). Nozzle diameter was 0.3 mm, layer height was 0.1 mm and infill was 100 %. Different specimens were prepared having different geometrical conditions. Three variables were considered: the number of points that are used to generate struts in the structure per unit area, the area scale and the offset distance.

Porosity was calculated both experimentally, from the weight of the printed samples, and theoretically, from the drawing of the structure. Proper porosity for human bone is between 50%-90% [2].

3. Results and Discussion

As an example, the shape of one the designed structures is shown in Figure 2.

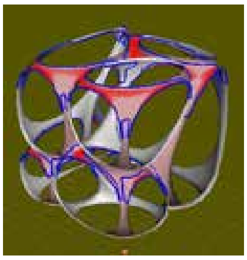

Figure 2. Designed trabecular structures

The final porosity of the scaffolds can be controlled within a defined volume of a cube, by using a different number of points joining the struts. The final porosity of the printed samples was slightly different than the theoretical one.

4. Conclusions

It is possible to print porous scaffolds with the trabecular structure, having different porosity values, using the FFF technology. However, some differences were found between the theoretical and the experimental porosity values. The present work will help to mimic tissues such as the trabecular structures of bones.

5. Acknowledgements

The authors thank Mr. Ramón Casado for his help with experimental tests as well as the European Union Regional Development Fund for financial help of project BASE3D, grant number 001-P-001646.

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Study of Corrosion Resistance in Ti-6Al-4V Additive Manufactured Parts

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Keywords: Additive manufacturing; titanium; laser direct energy deposition; corrosion; temperature control.

1. Introduction

Laser Direct Energy Deposition (DED) is an Additive Manufacturing (AM) process, which provides innovative solutions, optimization, and efficiency increase of several products and industrial applications [1]. A wide material selection can be processed by this technology, such as steel, titanium, and nickel-based alloys. Titanium is widely used in the aerospace, automobile, and medical industries due to their low density, high specific strength, corrosion resistance and biocompatibility [2]. Titanium alloys present some challenges in combination with laser additive technologies. The powders usually employed in this kind of process are highly reactive and presents a high risk of oxidation. Thus, an inert atmosphere must be ensured either by sealing the process volume and replacing the air with an inert gas or by generating a local protective atmosphere [3,4]. In the second case, inert gas is injected directly into the processing area with the use of special nozzle designs. Although, new challenges come along with this solution, as other parameters must be considered, like heat evacuation, geometry, and surface temperature. The present study evaluates the corrosion resistance of additively manufactured parts in Ti-6Al-4V, aiming to ensure its mechanical properties.

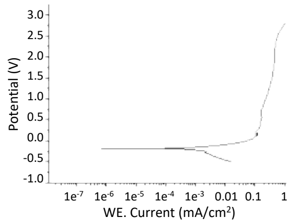
2. Methodology or Experimental Procedure

The AM experiments are carried out with a self-developed DED nozzle and a Yb:YAG fiber laser with a 1070 nm wavelength. The nozzle uses an additional protective gas flow to ensure the local inert atmosphere and to guarantee an oxidation-free titanium deposition. Both powder and substrate material are Ti-6Al-4V while argon is used as protective and drag gas. The process is monitored with a two-colour pyrometer and the laser power is closed-loop controlled to maintain a constant temperature. The Tafel curves are obtained for both, base and deposited material.

3. Results and Discussion

The results of the additive manufacturing and successive machining process are a set of cylinders with a diameter of 25 mm, Figure 1 (a). Six additive specimens are obtained from these cylinders by cutting 5 mm-thick cross-sectional layers while, a reference anode to compare with is machined from a Ti-6Al-4V billet. The specimens are tested in NaCl solution for 180 minutes until stabilize, time when the Tafel curves are obtained, Figure 1 (b). Results show that corrosion resistance of the AM parts is almost the same to the base material.

(a)



(b)

Figure 1. Ti-6Al-4V AM part (a); Tafel curve (b)

4. Conclusions

The corrosion resistance of deposited Ti-6Al-4V alloy has been analysed and compared with a reference specimen. DED tests have been carried out with a temperature-based close-loop control and an extra protective gas flow to ensure the inert atmosphere. Results show that additively manufactured titanium alloy presents a similar corrosion resistance to the reference material and no oxidation resulting from the deposition process is present.

5. Acknowledgements

This work is funded by the Basque Government through the QUALYFAM project under Grant Elkartek KK-2020/45 and the Spanish Science Ministry through the ALASURF project PID2019-109220RB-I00. The authors thank for technical and human support provided by CIDETEC.

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Presentation of a Concrete Additive Manufacturing Extruder with Online Rheology Modification Capabilities

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Keywords: AM; concrete; construction; mortar.

1. Introduction

Up to this day, the construction sector is very conservative with its innovations, even if this doesn't mean that they are not necessary. In fact, the construction jobs quality must be improved and some limitations should be overcome. This is why an Additive Manufacturing (AM) machine for cementitious materials is a disruptive innovation that will update and automate the construction industry. There is a need to develop flexibility and a quick response to the market offering customised products on a large-scale.

Also, the material has requirements of printablity that needs to be taken into consideration. The mortar must not only be self-consolidating but also stable in shape and self-sustaining because it must be pumped through the extruder system and then support its weight when being deposited layer upon layer in a short period of time, respectively. For this, not only mortar is used, also an additive is incorporated to modify rheology properties.

Both technologies, AM of mortar and Online Rheology Modification (ORM), are disruptive.

2. Experimental Procedure

To test the 3D printing machine, a workflow process has been established. It starts with the preparation of all the necessary material for the construction of the part. It is very fluid at this stage, and stable up to an hour. From the tank where it is stored, it is injected by a progressive cavity pump to the mixing chamber located just before the nozzle. At this point, the additive enters and interacts with the mortar to modify its rheology or its setting dynamic. Once the reaction has occurred, the final step is to extrude the mortar with a firm rheology that provides a faster acquisition of strength allowing it to be printable and growth in height (Figure 1).

3. Results and Discussion

Once the geometry is printed, it is possible to determine the good method of layer deposition and some printing parameters but it is also important to ensure good final properties.

To do so, the tests are compared to the lab ones. After different periods of time, several values are obtained (Figure 2).

Figure 1. 3D printed sample.

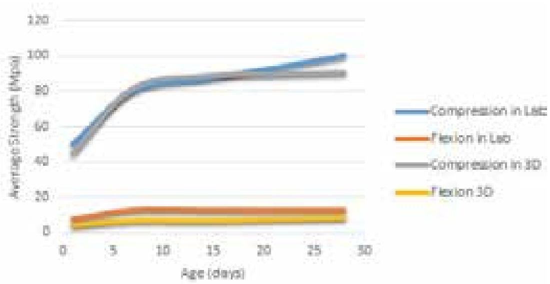

Figure 2. Lab strength VS 3D printer strength

It can be concluded that the designed 3D printing machine extrudes material with the same properties as the laboratory test.

It is worth mentioning that these values are obtained from a sample taken from the extrusion of the machine (not a complete printed part), otherwise other parameters would have influenced the results.

4. Conclusions

As it has been demonstrated, 3D printing of mortar is moving forward with advances that are not only innovative but also necessary.

5. Acknowledgements

Special thanks to Phd José Antonio Tenorio Ríos (CSIC) and Phd Hélène Lombois-Burger(Lafarge).

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Influence of Printing Conditions in Binder Jetting on the Resin Infiltration Post-Processing

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Keywords: Binder Jetting; dimensional analysis; structured light; resin infiltration; additive manufacturing.

1. Introduction

Among additive manufacturing techniques, those based on powder have undergone a great relevance in the last two decades. Nowadays, they are the techniques with the best projection. In particular, the Binder Jetting (BJ) technique is one of the most efficient in terms of cost and speed. Despite they have some limitations, some applications consider this type of process of great interest. Among them, BJ has been shown viable for manufacturing casting molds [1,2]. Nevertheless, Le Néel et al. [3] explain the necessity of more studies to optimize metal casting applications with binder jetting processes.

Parts printed by Binder Jetting and ceramic powder do not reach the mechanical properties to be used as functional parts. Therefore, among others, post infiltration processes are necessary [4].

The goal of this work is to analyse the influence of the printing process itself for the next infiltration post-process with resin. Specifically, a dimensional study is carried out to justify the choice of the position of the part on the printing bed.

2. Methodology or Experimental Procedure

Identical specimens have been printed in two different areas on the printing bed in a 3DS Project 660Pro machine. Then, two different infiltration tests were carried out, one with heat treatment and the other without it. The infiltration process was performed by immersion at atmospheric pressure, varying the infiltration time to study its effect on the quality of the infiltration, for both tests. Dimensional changes in the specimens before and after infiltration were analyzed, including the process variables.

The inspection process was performed using a Structured Blue Light scanner, Breuckmann smartSCAN3D-HE. Each specimen was scanned before infiltration and after infiltration in order to compare the 3D point clouds t using the Geomagic Control software.

3. Results and Discussion

It is confirmed that infiltration process with suitable viscosity resins do not lead to significant dimensional changes. However, the chosen printing area on the bed takes influence. In the area of lower density, dimensional differences in the Z direction (printing axis) are the most significant.

In relation to the heat treatment, when the drying time increases, the infiltration process improves, as there is a higher water evaporation that increases the internal porosity. Searching the optimal time is essential for the infiltration process.

4. Conclusions

This work demonstrates the importance of choosing the correct position of the part on the printing bed when subsequent infiltration post-processes are carried out.

Additional work with vacuum infiltrations are necessary to increase the infiltration speed by extracting the air from the interior of the parts. In addition, the application of subsequent overpressure can improve the results in terms of the mechanical properties obtained with the infiltration, but dimensional studies are necessary in this regard.

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Effect and Comparison on Mechanical Properties of Incorporating HNTs into a PLA Matrix by Injection Moulding and 3D Printing for Medical Applications

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Keywords: Polylactic acid; halloysite nanotubes (HNTs); injection-molded parts; 3D printing; mechanical properties.

1. Introduction

Currently, there is a great social awareness about the use of biopolymers capable of reducing and mitigating the environmental impact of oil use, in addition to being biodegradable and obtaining more sustainable products [1]. For this reason, in recent decades PLA has become one of the most promising biopolymers [2]. In addition, additives such as halloysite nanotubes (HNT) are aluminosilicate clays of natural origin, which have a large active surface and can also be used as containers for various functional reagents such as antioxidants or drugs [3]. This study focuses on the use of halloysite nanotubes (HNT) in PLA with a compatibilizer to analyse how their incorporation affects their mechanical properties in injected samples and 3D samples.

2. Methodology or Experimental Procedure

PLA 2003D and Halloysite nanotubes were dried at 60 °C for 48 h to remove any residual moisture. The materials were then fed into the main hopper of a co-rotating twin-screw extruder, setting the temperature profile, from the hopper to the die, as follows: 150–160–170–180 °C. The pellet was used for injection and 3D manufacturing.

Table I. Summary of compositions according to the weight content

Reference	PLA(wt. %)	HNTs(wt. %)	ESAO(phr)
A	100	0	-
B	90	10	-
C	90	10	1
D	90	10*	1

*HNTs treated with silanes

3. Results and Discussion

The incorporation of HNTs in a PLA matrix means an increase in the rigidity of the material, as opposed to a clear reduction in the ductile properties such as elongation at break or impact energy. In this case, figure 1 shows the evolution of Young's modulus values and elongation of the injected samples.

The incorporation of ESAO, and the treatment of HNTs with silanes, achieves a significant improvement in the elongation at break and ductile properties of this type of compounds. These additives allow to improve the manufacturing of specimens by means of 3D printing, thanks to the better cohesion that comes to exist between the PLA and the HNTs.

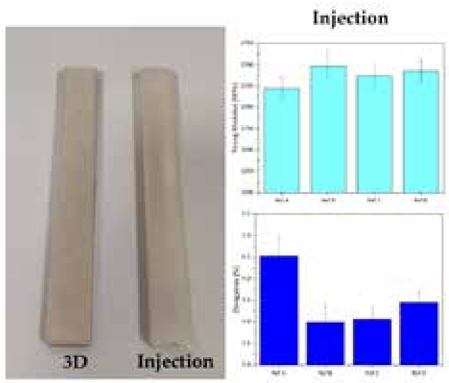

Figure 1. Summary of mechanical properties (right) and a sample of the injected specimens and 3D (Left).

4. Conclusions

The incorporation of ESAO and the treatment of HNTs with silanes allows for a direct improvement in the compatibility between PLA and HNTs. This modification has a great advantage in the manufacture of specimens by means of 3D printing, as it favors the creation of greater cohesion between PLA and HNTs, showing results that are favorable to the applicability of this type of material in different sectors

5. Acknowledgements

J. I.-M. wants to thank Universitat Politècnica de València for his FPI grant from (SP20190011) and Spanish Ministry of Science, Innovation and Universities for his FPU grant (FPU19/01759).

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Design for FDM of Flexible Tooling for Manufacturing Aeronautical Components by Incremental Sheet Forming

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Keywords: Additive manufacturing; Fused Deposition Modelling (FDM); flexible tooling; aeronautical components; incremental sheet forming.

1. Introduction

Nowadays, industrial production is required to reduce industrialization times and development costs for new products while maintaining high quality standards. In this context, the development of new flexible manufacturing technologies, such as Additive Manufacturing (AM) or Single Point Incremental Forming (SPIF), has gained relevance in the last few years.

The use of Fused Deposition Modelling (FDM) additive technique has been recently proposed in different industrial sectors for manufacturing rapid tooling (dies) to be used in conventional sheet metal stamping [1] or stretching [2] processes with a significant decrease in costs and time savings.

On the other hand, Incremental Sheet Forming (ISF) technology is characterized by an enhanced formability of the parts thus manufactured as well as the need for a small number of tooling, reducing costs compared to conventional processes such as hydroforming or stamping. The simplest variant is the single-point incremental forming (SPIF), in which once the sheet is fixed on its periphery and supported on a backing plate (tooling), a CNC numerical control guided hemispherical tool progressively deforms it, describing the geometry of the required part. Although SPIF requires a minimum number of tooling, the use of backing plates is still necessary. However, these do not require close tolerances as their only function is to collaborate in the deformation process acting as a support point. Furthermore, the strength requirements are also not a limitation since the forces involved in SPIF are very small given the local nature of the deformation [3].

Therefore, the main objective of this work is the design of a flexible tooling system, manufactured using the FDM additive technique, that allows the flexible manufacturing of different aeronautical components (wing and stabilizer ribs) by SPIF.

2. Methodology and Results

The tooling system was developed using CATIA V5®. The modularity concept involved providing the tooling with a set of interchangeable parts which, once assembled using a system of crenelated joints, will form the backing plate needed in each case for the incremental forming by SPIF of the different sheet components to manufacture.

Figure 1 shows the virtual and experimental setup of one of the possible configurations and the aeronautical rib to be manufactured before the incremental forming by SPIF.

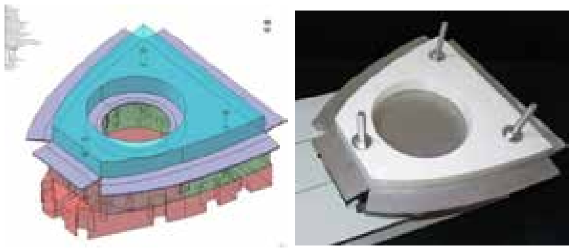

Figure 1. Virtual and experimental setup for manufacturing an aeronautical rib by SPIF

3. Conclusions

It was found that the combination of both technologies, SPIF and FDM, along with the concept of flexible tooling proposed, provided a great flexibility in the manufacturing process of a limited number of aeronautical components and allowed a clear reduction in terms of costs and time to market for a new specific prototype or product.

4. Acknowledgements

The authors wish to thank the Spanish Government for its financial support through the project PGC2018-095508-B-I00. It is also acknowledged the funding received from Cátedra Aeroespacial AIRBUS.

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Research on Desktop 3D Printing Multi-material New Concepts

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Keywords: Multi-material; additive manufacturing; 3D printing; printhead.

1. 3D Printing, Originally a Mono-Material Technology

3D printing or Additive Manufacturing (AM) was originally born as a mono-material technology. And, nowadays, most of the applications are still using only one material. A brief classification of the AM technologies, according to this subject, is given next:

- VAT Photopolimerisation, Powder Bed Fusion, Binder Jetting and Sheet Lamination have homogeneous base material on which the object made is already spread over an exposed flat surface.

- Material Jetting, Material Extrusion and Direct Energy Deposition have more room to move towards multi-materiality, but most of the present applications are limited to mono-material parts.

2. Need for Multi-Material 3D Printing

AM has a lot of potential but has not yet been fully explored, and access to the creation of multi-material products is an example of it. In the real world, most of the objects around us are multi-material, and it is thanks to this feature that they can perform their function appropriately in different industrial sectors as far away as automotive, food or health [1,2]. The most obvious progress has been made in the field of incorporating colour into the 3D printed parts, but one of the most interesting areas is the introduction of materials with different rigidities, stiffer and softer areas, with differentiated values of mechanical strength and viscoelasticity.

3. Multi-Material 3D Printing Technologies

In a deeper focus, state-of-the-art and research lines are described for Material Jetting and Direct Energy Deposition. For Material Extrusion, the most common way to perform multi-material parts is the direct use of different liquids (DIW technology) and/or filaments (FFF technology) that, under multiple strategies, ends up obtaining an object [3].

4. Material Extrusion: Research on Desktop 3D Printing New concepts

The concepts represent, in many cases, scientific problems not addressed to date, and their initial embodiment in the form of prototypes is a way of verifying the difficulties that would be encountered in the transition from research to reality.

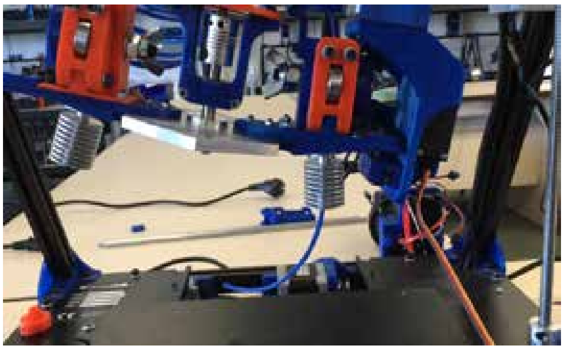

Figure 1. Revolver printhead demonstrator [3].

In brief, these concepts are: (1) revolver printhead (see Figure 1), (2) filament convergent nozzles, (3) filament mixing printhead, (4) polyurethane printhead, (5) 3D printing with UV silicone and (6) soft models by casting silicone in FFF-3D printed moulds.

5. Conclusions

The present work illustrates the under-developed path to 3D printed multi-material parts, the tiny level of application amongst the different AM technologies, and a significant research work developed in the 3D printing desktop sector.

6. Acknowledgements

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The Commissioning of a Hybrid Multi-Material 3D Printer

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Keywords: Multi-material; 3D printing; hybrid; surgical planning prototypes; health.

1. Introduction

In recent years, Additive Manufacturing (AM) has bloomed up in the medical sector. The use of AM technologies has been applied in the manufacturing of scaffolds, bioinks, surgical guides or surgical planning prototypes [1-3]. Amongst these examples, most of the 3D printed parts were manufactured using only one material.

Regarding the manufacture of scaffolds and bioinks, it is appropriate to use mono-materials printers, since usually the materials for the scaffolds are already mixed within the syringe, the same way that it is done with the bioink that has all the components mixed in it. However, for the manufacture of surgical planning prototypes it is necessary to use several materials since the wide range of anatomies.

Nowadays, although probably not being the most appropriate, the most accessible technologies and therefore used are FFF (using the moulding technique, in which a liquid is cast) or SLS. These AM technologies normally use hard materials. Also, other AM technologies such as material jetting have been employed [4]. Nevertheless, these processes require a lot of time and money, respectively.

In this context, the aim of the present study is the commissioning of a hybrid multi-material 3D printer which can combine both FFF and DIW (Direct Ink Writing) technologies for the manufacture of realistic organs.

2. Technology

The hybrid multi-material 3D printer is based on two different technologies: FFF and DIW. Regarding the materials used, FFF technique uses filament materials as PLA, ABS, Filaflex and PVA. For that, a tool changer is used to interchange 3 FFF heads. On the other hand, the DIW uses liquids materials such as silicones and hydrogels (see Figure 1).

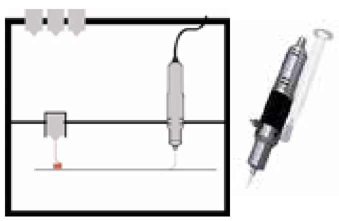

Figure 1. Tool changer scheme and the liquid head.

3. Parameters of the 3D Printer

The most important parameters that need to be considered in order to build up the 3D printer have been explored and mainly relate with the printing parameters and curing parameters.

4. Innovative Components of the Hybrid Multi-Material 3D Printer

The hybrid multi-material 3D printer has different innovative components: (1) a DIW based vipro-HEAD (1-component print head) from Viscotec, Germany, (2) a considerable printing volume (300 mm x 300 mm x 200 mm –x,y,z–), (3) a deposit for liquid based materials, around 20 oz (0,59 l), (4) an interchangeable tool and (5) UV light.

5. Conclusions

The present work demonstrates the technical feasibility of building up a hybrid multi-material 3D printer for medical contexts. This opens a window for future multi-material 3D printers in other sectors.

6. Acknowledgements

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Topic 2:
Trends in manufacturing systems

Enactive Manufacturing through Cyber-Physical Systems: A step beyond Cognitive Manufacturing.
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Influence of product variety on work allocation and server distribution of flexible manufacturing lines.
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Enactive Manufacturing through Cyber-Physical Systems: a Step Beyond Cognitive Manufacturing

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Keywords: Holonic manufacturing systems; smart manufacturing systems; cyber-physical systems; key enabling technologies.

1. Introduction

Cognitive manufacturing, as a paradigm for providing intelligence to manufacturing systems and enabling interaction with operators presents limitations. In this line, the enactive approach to cognitive science provides a paradigm for the design of new biologically inspired cognitive architectures, with an important influence on aspects of self-organization and emerging properties [1]. Likewise, the advantages of key enabling technologies (KET) reveal new opportunities for increasing industrial innovation and developing sustainable industrial environments [2]. These technologies are appropriated to overcome the limitations of cognitive manufacturing, because they can achieve the integration of physical and digital systems focused on cyber-physical systems (CPS). This allows to gather the parallelism between the new paradigm of cognitive science of enaction or embodied cognition, with the CPS concept as hybridization of the physical, technological equipment, and the virtual and intelligence in the cloud, to overcome the limitations of cognitive manufacturing. This leads to the field of enactive artificial intelligence, based on CPS formed by enactive intelligent agents with embodied, situated, distributed and constructivist intelligence [3]. This intelligence determines a form of action from the interaction mind (cloud cognition) body (technology) in the context of the manufacturing cell in the manufacturing plant, which gives rise to the term coined in this work as *enactive manufacturing*.

In this work, an architecture for the sustainable development of enactive manufacturing systems based on holonic paradigm is proposed and its main associated informational model is described.

2. Architecture proposed

Enactive manufacturing system is conceived as a learning and cognition system characterized by: (i) Knowledge is dynamically constituted through the action of the sociotechnical system (manufacturing system) interacting as a whole in the operational environment through coupling and operational dynamics (Enaction); (ii) Located in an environment with constitutive and operational coupling, self-regulated and autonomous (Technological Environment); (iii) Knowledge (explicit and tacit) is framed in technology, distributed at different levels of technological systems, in organizational modes and the biological body of operators (Embedded); (iv) An embodiment in a specific technology that promotes efficiency (Embodied); and (v) Operational mind is extended to the surrounding area, not only in the context of manufacturing system, but it is extended in the markets, suppliers and throughout the value chain (Extended). Figure 1 shows the architecture proposed.

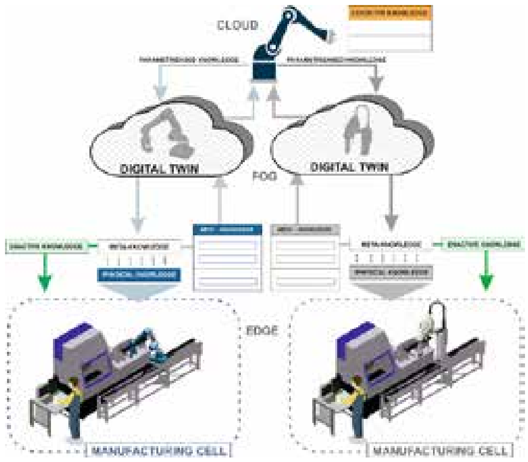

Figure 1. Architecture of enactive manufacturing holon.

3. Conclusions

The proposed architecture will allow to extend cognitive manufacturing to different modes of implementation of manufacturing systems technology, conceive of cognitive manufacturing processes parameterized according to the context of operation, and develop CPS constituted by intelligent, active agents with embodied, situated, distributed and constructivist intelligence

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Influence of Product Variety on Work Allocation and Server Distribution of Flexible Manufacturing Lines

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Keywords: Stochastic simulation; bowl phenomenon; work allocation; servers' allocation.

1. Introduction

Mass customization involves medium volume production of high variety of products. Flow assembly line properly balanced are configurations well appropriated for high volume, while flexible manufacturing systems (FMS) is a promising advanced towards keeping performance (work-in-process and throughput) under growing customization.

The work allocation problem of assigning the work content of each workstation in a manufacturing line is formulated as the design problem of capacity allocation across the line by looking for the throughput maximization and/or simultaneous work-in-process containment or minimization. A bowl phenomenon in work distribution was observed experimentally and conjectured back in the 1960's [1], but its theoretical roots have not been successfully established up today.

The increasing value of flexible capability for mass customization makes worthy the research of work allocation not only in flow lines, but also in manufacturing systems with multiple servers. They provide product flexibility through service time variability and a need of providing declutching buffers inter-stations with asynchronous (unpaced) production flow, beyond the classical model of balanced dedicated flow lines. The three problems of work-load, buffer and server allocation has been previously studied in queuing networks with metaheuristics [2], but product variety is a relevant factor of current interest not considered in former studies of dedicated flow lines.

This paper continues high variety production research and its impact on flexible systems design and operation [3]. In particular with a main objective of capacity allocation across flexible manufacturing line based on stochastic simulation and statistical analysis, and a second purpose of exploring the best-fit methodology to face its study.

2. Methodology and Experimental Procedure

Pure analytical models that tackle the problem are scarcely found in literature. The combinatorial nature of the problem induces the use of alternative methods like metaheuristics [2] or simulation. The design of the model is represented by stochastic networks and exponential time distributions, so phase-type distributions allow modelling the coefficient of variation. In this work, operations are developed through stochastic simulation in Simulink by MathWorks and processed through statistical analysis, in order to assess qualitative (operating curves) and quantitative (main parameter influence) results.

The base workstation configuration with multiple servers per workstation and product variety demand is Figure 1.

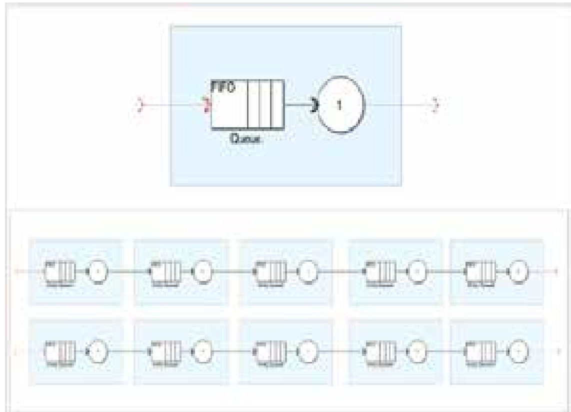

Figure 1. FMS baseline simulation flowchart

3. Results and Discussion

The influence of variety (number of portfolio products and batch sizes) is analysed regarding the buffer allocation, server's distribution and work allocation problems. The quantitative influence in the operating curves (wip and throughput) is outlined and the methodological insights are discussed for advantages and limitations.

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An Approach to Reverse Engineering Methodology for Part Reconstruction with Additive Manufacturing

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Keywords: Reverse engineering methodology; additive manufacturing; geometric reconstruction, 3D scanning; measuring techniques.

1. Introduction

In some cases, CAD models of mechanical components are not available, do not exist, or do not match the current geometry of the physical model. Issues related to the manufacturing process, such as the wear occurring during a life cycle of the part or even the unavailability of digital data (redesign of obsolete parts produced in pre-digital era, legal restriction, or trade secrecy) could explain the absence of accurate 3D data [1]. To counteract the lack of 3D data, Reverse Engineering (RE) approaches have been widely used in the last decades. Thanks to the rise of additive manufacturing technologies, complex shapes and components can be produced at low cost even in small lots, amplifying the benefits of Reverse Engineering [2].

This paper aims at developing a methodology that overcomes the manufacturing of existing components lacking technical drawings or CAD models through the use of Additive Manufacturing (AM) technologies.

2. Methodology or Experimental Procedure

The proposed methodology used in this paper has been structured in three stages. First, a review of the existing literature covering reverse engineering approaches and their application for the design recovery of mechanical components is performed. Second, a deep analysis of modern digitalization techniques, data processing activities, advanced CAD reconstruction techniques, Design for Additive Manufacturing (DfAM) approaches, and part and material-process selection methodologies is conducted to provide a structured framework for the development of the methodology. In third place, a case-study of a spare part is carried out to exemplify the benefits of implementing the proposed methodology.

3. Results and Discussion

The present paper has introduced a new framework for the analysis and evaluation of mechanical components, aiming to assess the implementation of additive manufacturing as the primary manufacturing technology and the recreation or re-design of the component's design depending on the several factors, such as acquired knowledge through component analysis, part manufacturing feasibility and customer requirements.

The introduction of AM as the primary forming manufacturing process has previously been stated as a possibility to reduce lead time, offer competitive manufacturing cost for low-volume production and enhance the design of complex components [3]. These three factors are introduced in the proposed methodology (Figure 1) as three different AM-case scenarios: *one-to-one copy*, linked to lead time reduction; *adaptation for AM*, associated with manufacturing cost reduction and *optimise*, aiming to enhance part performance. The proposed design concepts are linked to the inherent benefits of the AM and their selection relies on manufacturing considerations and established requirements.

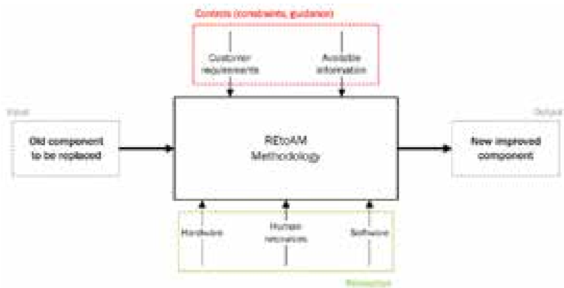

Figure 1. General overview of the reverse engineering to Additive manufacturing methodology

4. Conclusions

The present contribution along with its case-study highlights and demonstrates the benefits of implementing the methodology into a real-case project. A mechanical component of an old industrial pump model has successfully been reverse engineered and manufactured via Laser-Powder Bed Fusion (L-PBF) technology.

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Barriers to Lean and Pull System implementation: a Case Study

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Keywords: Lean Production; Pull system; implementation; barriers.

1. Introduction

Lean Production [1] is the Toyota Production System (TPS) developed in Japan that became more known after the Second World War. Pillars of TPS are Just In Time (JIT) and Jidoka or autonomation. Kim [2] stated that JIT is a system that produces or stocks "only the necessary items in necessary quantities at the necessary time". Due to that, JIT is considered a Pull system in relation to material flow system [3]. The main advantage of a Pull system is to reduce stocks between the processes involved and accordingly reduce costs from those stocks [4].

Many publications have been made about this subject and the concept of Lean Production has been spread out not only in the shop floor but also in other parts of the value stream [5]. Despite having several advantages, Lean Production remains difficult to implement and fully attain.

This paper reports part of a case study research that has been developed to understand the reasons for the barriers faced by the implementation of Pull as a production control system.

2. Methodology

The research presented in this paper draws upon the findings of a case study conducted in collaboration with a large automotive company. This case study involves several types of data collection techniques [6] namely interviews, observations, and documentary analysis.

To analyse barriers to Lean and Pull system implementation, semi-structured interviews were conducted with 17 employees representing different hierarchical levels, ranging from operational employees to mid-level and top-level managers. The research data was analysed to identify the main reasons of continuous improvement process failures, the main barriers to Pull implementation as well as the impact of the organizational structure and employees' involvement on the process.

3. Results and Discussion

The findings indicated some problems that hinder the implementation of Lean principles and the Pull system. Issues related to leadership, organization, people, technical and external factors were identified. The detailed analysis of these factors shows the importance of top management commitment on the implementation of the processes. Aspects related to departmental structure also demonstrated to be a barrier when implementing tools that involve entire value stream collaboration.

Results are considered indicative and may contribute to new knowledge by pointing out specific issues that can be considered determinant factors in similar situations.

4. Conclusions

Lean Production implementation has many advantages for manufacturing and other sectors. However, there are many challenges that companies must overtake in order to be successful on their implementation efforts. This research demonstrates some weaknesses concerning organizational culture inside the organization. Furthermore, the findings suggest that implementing Lean tools individually, one by one, and only looking at the technical point of view, may not be enough to achieve an effective implementation.

5. Acknowledgements

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Lean Safety – Assessment of the Impact of 5S and Visual Management on Safety

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Keywords: 5S; continuous improvement; Lean tools; Lean manufacturing; occupational safety; visual management.

1. Introduction

Currently, several companies have been implementing lean tools with the purpose of enhancing productivity and competitiveness. However, the effects of lean methodology in the field of workers' health and occupational safety have been addressed less frequently. *Lean Safety* consists of creating an environment of occupational safety in the workplace, which requires motivation and good management on the part of employees [1]. Accordingly, this study explores the ways in which the implementation of lean tools such as 5S and Visual Management may contribute to improvements in product quality and waste reduction, as well as to the promotion of hygiene and safety in the workplace. This was carried out by means of a case study undertaken at an industrial unit in the furniture sector, primarily focusing on its sections of joinery, finishings and assembly.

2. Methodology or Experimental Procedure

During this study, one undertook a systematic review of scientific literature dedicated to lean tools and their impact on productivity and safety. One then proceeded with the implementation of lean tools at the company for some time, during which one observed the work contexts and activities of continuous improvement. Finally, and once the lean tools had been implemented, a questionnaire was drawn up to assess the workers' perceptions of safety conditions in the workplace, thus validating the conclusions of this research.

3. Results and Discussion

The implementation of 5S and Visual Management allowed for improvements in organization due to a rearrangement of the layout and the standardization of the production process. The waste related to non-value added activities, such as motion and waiting time, was reduced by 40%. It was also possible to achieve a productivity index of 74% in the finishing section, and 87% in the joinery section. The impact of lean methodology on safety was considered during the changes carried out to the processes and operational methods, which were still not completely assimilated by workers [2]. In the context of this study, the results of the questionnaires relating to occupational safety revealed that 56,7% of the respondents confirmed there had been improvements in the workplace, and 83,3% conceded that the demarcation of areas or zones contributed to fewer work accidents. In addition, 66,7% acknowledged that the actions promoted communication amongst workers, and a total of 70% agreed that suggestions were easier to provide. Moreover, 53,3% of the respondents saw an increase in productivity, 56,7% confirmed that there was a reduction in physical exertion at the work station, and 63,3% agree that there was an improvement in the suggestions proposed by the workers and the handling of materials. A further 40% concurred that, after implementation, there was a greater motivation to carry out tasks safely. However, a relevant aspect pertains to opinions regarding physical exertion and stress at the end of the workday, which were demonstrated by higher percentages of dissent, which corresponds to 40% e 30%, respectively. These issues are primarily related to the work environment itself.

4. Conclusions

Through this study, it was possible to demonstrate that in addition to the well-known benefits, which are obtained from lean tools in terms of productivity and process improvement, lean tools are also very important to ensure a safe work and an improvement in quality of the work environment to the workers.

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Assessment of the Flexibility of Implementing Lean Tools

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Keywords: Lean Tools; Lean Production; Lean Implementation.

1. Introduction

During the 1980s, the automotive industry drew attention when it became clear that Japanese cars lasted longer than American ones, and needed less maintenance [1]. The implementation of Lean tools requires a great transformation in company culture; on the other hand, it also generates enormous benefits, which allows for great adaptability. Lean production aims to reduce costs and eliminate activities that do not add value [2]. Eight different types of waste are targeted by Lean production, eight of which are related to the production process: overproduction, waiting time, transportation, non-conformities, inadequate processing, unnecessary stocks and handling, and inefficient use of the workers' skills. In this sense, the implementation of Lean tools produces benefits for companies, since it improves the performance of the production process. This fact has already been demonstrated in several case studies undertaken in different sectors of the industry [3]. This article seeks to identify the lean tools which are most commonly used in the process industry, as well as their associated benefits. At the end of this study, one expects to: identify which lean tools make the most significant contribution and produce the greatest impact in the improvement of processes in organizations; determine which lean tools are most commonly used in different countries and activity sectors; ascertain which scientific journals or international conferences present the largest quantity of studies carried out in the field of continuous improvement through the use of Lean methodology and its tools.

2. Methodology

The collection of publications from the Web of Science platform began with the sequence of two keywords, which were inserted in the analysis: "lean tools", producing a sample of 349 publications. This set of articles was then submitted to a second phase of manual research; on this occasion, the analysis was carried out by using the set of words: "lean manufacturing". In this screening activity, one excluded the articles that did not contain this combination of words. After the second screening, the sample was reduced to a total of 121 articles.

3. Results and Discussion

Of the publications analyzed, 80% of the documents consist of articles from journals, while only 20% appeared in conferences proceedings. Of these publications and articles, 44% were cases studies, 35% consisted of research and 21% corresponded to questionnaires. With regard to distribution by country, it was found that approximately 50% of the documents published were limited to only three countries – India, Malaysia and the United States of America. As for the sector of activity, this distribution allowed one to observe that the sector of greatest reference was that of metalworking, followed by the textile and automotive areas, with a total of 24, 10 and 10 publications, respectively. This analysis allowed one to establish that the tool which was implemented most frequently in the articles was VSM (Value Stream Mapping), with a percentage of 65%. This was followed by 5S, which is also of widespread use, representing 48%, when compared to the total number of publications collected in the Web of Science.

4. Conclusions

This analysis allowed one to conclude that the most commonly used tool in publications was VSM, which indicates that the authors attribute great importance to the analysis or mapping of the value stream of industries. Furthermore, it always constitutes the first step in the identification of problems across the production line. This is followed by 5S, identified by authors as being widely implemented in shop-floor (*gemba*), which indicates that efficient production requires workstations to be organized, thus ensuring that all types of waste are reduced.

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Supply Chain Production Planning of a Manufacturing Project System 4.0: Case Study: Shipbuilding

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Keywords: Production planning; supply chain; shipbuilding; industry 4.0.

1. Introduction

Manufacturing Project System (MPS) consists of a series of phases in which there is a sequence of operations that contribute to the final objectives of the project. Projects are characterised by the high cost and difficulty of planning and administrative control [1].

It is therefore that among the MPS strategies there is an adequate management of the supply chain, as well as models to follow. Additionally, it is necessary to adapt it to Industry 4.0 in which a series of enabling technologies are established to facilitate its implementation.

This is the case of the projects that are executed in the transport sector where in many cases the product is manufactured by parts, even, in certain occasions in different geographical areas. One of the most complex products would be those associated to the naval sector, where a project involves different manufacturing centres that may or may not be located in the same shipyard, as well as different suppliers and other secondary agents. This makes that the management of all these agents has a great impact in the profitability of the project and for that reason it is necessary to establish a model of operation of the supply chain that facilitates this management [2]. Likewise, there is currently a tendency to update these manufacturing centres by progressively incorporating Industry 4.0 enabling technologies.

This article analyses and describes the main characteristics that are required by a shipbuilding supply chain from the point of view of production planning [3].

2. Methodology or Experimental Procedure

In order to carry out this study, is intend to analyse the characteristics of the shipbuilding supply chain with emphasis on the Production Planning process. Following this, MPS strategies will be addressed from the point of view of the shipbuilding supply chain.

Finally, the enabling technologies of the 4.0 industry with the greatest impact on the studied sector will be analysed.

Once we know how the MPS are applied to the naval sector and how it is currently affected by the Industry 4.0, we will be able to know the results of this combination.

3. Results and Discussion

With regard to Supply Chain Management, new models are expected for Production Planning that can recognise and model the uncertainties that arise.

It is expected to understand the benefits that digitisation can provide to supply chain production planning, to identify MPS strategies that could facilitate Supply Chain production planning, as well as the benefits that enabling technologies can contribute.

4. Conclusions

Among the results obtained are the needs of new models for production planning with respect to the management of the supply chain in a highly complex sector such as shipbuilding.

The enabling technologies of Industry 4.0 are established, which most enhance the management of the supply chain in relation to production planning.

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Metabolism in Eco-Holonic Manufacturing Systems based on the Living Systems Theory

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Keywords: Holonic Manufacturing Systems; Living Systems Theory; Metabolism; Sustainability; Industry 4.0.

1. Introduction

The industrial metabolism has been conceived on the basis of analogies about the set of biochemical reactions (anabolism and catabolism) that occur in a living being and their flows of matter, energy and substances in natural ecosystems. This conception determines forms of appropriation and consumption of substances, materials and energy, from the natural environment (natursphere) and the technical environment (technosphere) for their transformation and subsequent elimination, under the articulation of criteria of cyclicity, toxicity and efficiency. The last aim of Industrial Ecology (IE), is materialized when the variety of industrial ecosystems is eco-compatible with the variety of natural ecosystems. The naturalisation of manufacturing systems is an effort to conceive them with variety similar to natural systems in order to achieve their eco-compatibility. In addition to bionic models from natural ecosystems in the field of industrial metabolism, several attempts have been made to design technical systems using bionic models from the Living Systems Theory (LST) [1]. The formulation of manufacturing systems based on living systems (LST) can be considered as a set of dynamic systems from Bertalanffy's perspective [2]. Currently, the literature on the theory of living systems applied to sustainable manufacturing systems is limited, so it is of particular interest to study the incorporation of LST into the framework of Holonic manufacturing systems for its projection into sustainable manufacturing systems through Eco-holonic architecture.

2. Eco-holonic Architecture

Until now, the proposal for Eco-Holonic Architecture has been formulated for industry 4.0 and cyber-physical systems [3]. This work proposes a model for the design, development and improvement of production integrating bionic, fractal and holonic manufacturing in which sustainability aspects are included in a geographical host environment for the setting up of collaboration and cooperation domains.

In order to design and implement the Eco-holonic systems, several levels of analysis are established based on the bio-inspired principles of the living systems theory and oriented on the one hand from the natural ecosystems (collaborative domain), and in another way with the required variety, from the living systems theory (cooperative domain). For this purpose, the following elements are formulated: (i) Level N+1 Holarchy: defines the COLLABORATIVE DOMAIN and the holonic requirements. This analysis establishes the design domains of an Eco-Holarchy for a manufacturing ecosystem with inputs and outputs of energy, water and matter, together with its interactions with other host ecosystems; (ii) Level N Holon: acts as an adaptive interface for the variety of manufacturing systems between levels N-1 and N+1 to ensure eco-compatibility. It defines the life cycle and self-regulatory mechanisms that establish knowledge with upward and downward control strategies. At this level, sustainability indicators are established; and, (iii) N-1 level Holarchy: it defines the COOPERATION DOMAIN and the holonic competence or capacities. to establish requirements of an Eco-holonic holarchy using the theory of living systems and establishing the necessary requirements of the manufacturing system that supports that living organism. These relationships are mathematically formalised by using Ecological network analysis (ENA), which allows the quantification of the ecocompatibility of Holonic Cyberphysical Manufacturing Systems based on the LST.

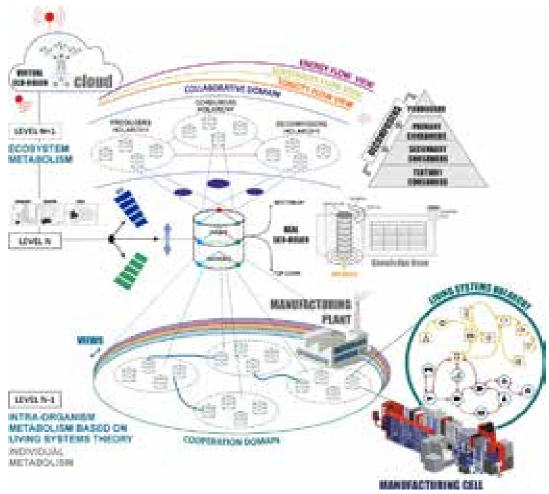

Figure 1. Metabolism in Eco-holonic Architecture based on LST.

3. Conclusions

The design of industrial metabolism models inspired by the LST and formulated through ENA, confirms that industrial ecosystems can imitate natural ecosystems in terms of structure, actors and interactions of the material, energy and substance flows within and outside the Holonic system. This analogy between both ecosystems provides a framework for the development of parks, industrial plants and eco-friendly manufacturing systems in which the environmental impact is almost zero. Moreover, the model would allow us to formulate proposals under industry 4.0 principles, for the engineering of the Eco-sustainable life cycle of products and manufacturing processes, associated to their living industrial metabolism.

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Life Cycle Assessment of Accessories of Personal Protective Equipment PPE of Easy Manufacture: Ear-Saver and Anti Contact Key

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Keywords: Design for Manufacturing; anti-contact key; ear saver; 3D printing; life cycle assessment.

1. Introduction

The new global normality requires the care and use of Personal Protective Equipment (PPE) such as N95 Masks, which protect from possible infections and diseases. Evaluation accessories for personal protective equipment from design to manufacture, such as anti-contact keys and ear savers, allows products to be developed according to the needs of both the user and the environment.

2. Experimental Procedure

The evaluation of Personal Protective Equipment (PPE) accessories (ear savers and anti-contact keys) was carried out in the design, manufacturing, use and end-of-life cycle stages, to facilitate the reengineering of the process (Table I). The experimental data were collected from commercial products designed for this aim, which were evaluated and improved.

Table I. Life cycle assessment of PPE accessories

Stage	Objective
Design	Simulate the best process
Fabrication	Select according the site to produce
Use	Adapt to infrastructure in which it is used
End of Life	Be care with the environment

The product life cycle of various PPE accessories available was evaluated and improvements were proposed to adapt them to the customer's needs.

3. Results and Discussion

Of the several manufacturing alternatives for these accessories evaluated, two of them were of most interesting: injection molding and 3D printing. For both technologies, product design engineering and mechanical simulation were carried out and parametric models were generated to meet the ergonomic criteria of the client, while new designs could be developed with new materials. Figure 1 shows the simulation mesh of the accessory that was used as the basis for the developed parametric models.

A cycle assessment, mainly of the manufacturing phase, complemented the study and defined the characteristics and requirements to adapt the product to the client's needs.

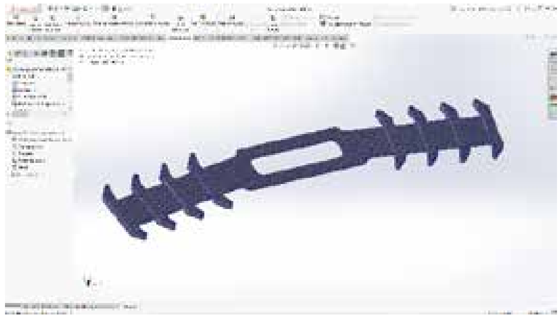

Figure 1. Ear Saver simulation

Other results of this study were: a) ergonomic elements were designed and adjusted to the conditions of use, and b) could be created by the consumer.

4. Conclusions

We consider that it is possible to make improvements to the following stages of the life cycle:

- Design: a model of the part is generated and tested with different manufacturing parameters.
- Manufacture: determine the most efficient process.
- Use: evaluation to find the optimal characteristics of the product.
- End-of-life: recommendations for final disposal or recycling.

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Topic 3:
Precision engineering and Metrology

Layer contour characterization in additive manufacturing through image binarization.
D. Blanco, A. Fernández, P. Fernández, B.J. Álvarez, F. Peña

Tribological characterization of Fused Deposition Modelling parts.
M. Batista, D. Blanco, I. del Sol, D. Piñero, J.M. Vazquez

Evaluation of mechanical properties of FDM components reinforced with fibre.
P. Rodríguez, P. Zapico, P.E. Robles, A. Soto, J. Barreiro

Experimental investigation of contact forces and temperatures in rubbing interactions of honeycomb interstate seals.
D. Soler, M. Saez de Buruaga, P.J. Arrazola

Development of a quality control system for the supply of silica refractory material from China.
D. Álvarez, M. García

Determining the required cleanliness level using synthetic test contamination.
P. Brag, V. Piotter, K. Plewa, S. Umbach, M. Herzfeldt

A comparison of fitting criteria for circle arc measurement applications.
R. Calvo, A. Arteaga, R. Domingo

Robust metrological characterization of circular profiles.
L. Greco, J. Caja, P. Maresca

Risk-based inspection planning for hydrogen technologies: review of currents standards and suggestions for modification.
F. Ustolin, D. Wan, A. Alvaro, N. Paltrinieri

Development of a Nakazima formability test methodology for high temperature applications on titanium alloys sheet metals.
J. Ayllón, V. Miguel, A. Martínez, J. Coello

Long-term stability analysis and its relationship with the steel structure of gauge blocks from several manufacturers.
A. Mínguez, J. Moreno, J. de Vicente

Effect of ambient temperature on machine tool compensation functions.
S. Aguado, P. Perez, J.A. Albajez, J. Velázquez, J. Santolaria

Defectology Characterization of FDM Drilled Parts

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Keywords: FDM; additive manufacturing; drilling; roughness.

1. Introduction

Since its emergence, the industry has made great efforts to implement additive manufacturing processes in its production systems. Increasingly, research is being carried out to improve the in-service behaviour of parts obtained by additive manufacturing [1].

In this context, the industrial use in groups and assemblies must be the next step. However, to achieve this use, the precision of the parts must also be guaranteed. In this sense, there are advances related to thermal, mechanical and chemical post-processing processes. In all of them, the quality of the parts obtained is improved [2,3]. However, it is not yet possible to achieve the characteristics required in certain industrial sectors.

Thus, for example, in the case of the aerospace industry, highly rigorous requirements are related to the assembled parts [4]. For this reason, none of the techniques developed would be able to provide the required quality. Thus, for example, an aeronautical drilling would not be possible to reproduce by additive manufacturing.

In this way, alternatives arise, such as the use of machining to obtain the same precision. This concept has been applied for some time to metal parts obtained through additive manufacturing, but not so much to polymer parts.

For this reason, given that it is expected that polymeric parts will be used in aeronautical structures, these will have to be machined to obtain the required geometric characteristics. Therefore, in this article, a parametric study of the quality of the holes made in parts obtained by FDM will be carried out.

2. Experimental Procedure

In order to achieve the objective, a series of 150 mm x 100 mm flat specimens with a thickness of 5 mm were manufactured using FDM in PETG.

Then, these specimens were drilled, using a specific system to machining polymers. The parameters proposed by the manufacturer in batches of 5 holes were used. Later, the operating parameters were modified creating a range of ±20% in cutting speed and feed and will be repeated to study the behaviour variations.

The holes obtained were subsequently characterized by means of optical and electronic microscopy. To conclude the study, the holes were analysed by a roughness measurement station. Four different generatrix per hole were analysed, as well as the side walls of the pieces and the upper surface. The parameters Ra, Rz and Rsm were selected as control roughness parameters.

3. Results and Discussion

From the experimental results, it can be seen that the drilling of parts obtained by FDM shows special characteristics compared to other monolithic polymer parts. In this sense, it is not possible to use the same strategies as in the machining of these parts mainly due to the discontinuities in the manufacturing process of FDM parts.

In this way, the use of inadequate parameters could cause softening of the thermoplastic polymer and adhesive wear of the tool. Therefore, a bad choice of parameters can damage the part.

However, the use of machining processes can significantly improve the quality of the parts and holes reaching the tolerances required in the aerospace industry.

4. Conclusions

The machinability offered by additive manufacturing parts will allow certain materials such as PETG to be used in aerospace applications.

In this way, the control of the process and its parameters can be the key to implementing this type of process industrially.

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Selecting Software Filter Settings for Evaluating Periodic and Aperiodic Surface Roughness

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Keywords: Roughness; periodic surface; aperiodic surface; software filter; statistical analysis.

1. Introduction

Measurement and evaluation of surface roughness has seen significant qualitative advances in recent years. Leading manufacturers of measuring instruments (Hommel, Carl Zeiss and others) have actively responded to new demands. This is mainly due to the fact that surface structures are often checked with dedicated measuring instruments. For this reason, the manufacturers of these machines are also the main drivers for developing standards related to high quality evaluation of machined surfaces.

This has ultimately led to improvements in the existing surface measurement and evaluation technologies, as well as in improved methods, measurement and surface evaluation systems that are still under development. [2,3] The surface structure evaluation system is defined by a set of standards that describe the marking, measurement and evaluation of surface texture, calibration of measuring instruments and other aspects. These are GPS (Geometrical Product Specification) standards. [1,4]

A lot of properties depend on the quality of the surface, such as efficiency, reliability, functional properties, external appearance, and, last but not least, the cost of the entire production process. And if there is an inaccurate assessment during evaluating the integrity of the surface, especially for assessing roughness, this can lead to fatal problems in the actual use of the inspected part in practice. In order to meet all the requirements of the evaluation of the surface structure, it is necessary to keep up with the times and always have control of new possibilities and knowledge from the fields of measuring and evaluating the integrity of the surface, and being able to implement this knowledge into real conditions of use.

In the area described in this article, the selection of software filters, this is not always the case. The main reason is low awareness and the great complexity of choosing a suitable combination of possible procedures and techniques for setting software filters.

2. Conclusion

Therefore, a comprehensive methodology for the selection of software filters for both periodic surfaces and subsequently for aperiodic surfaces was created and is described in this article. Its coherence and graphical simplicity are prerequisites for quick understanding and easy implementation of the methodology in common practice.

The methodology for the selection of the software filter has 4 steps for periodic surfaces and 5 for aperiodic surfaces, which help the user of the profilometer, whether contact or contactless, to correctly set the device. Furthermore, the methodology should ensure that two people measure the same, or at least in the order of hundredths of the same results (values), which currently is not quite the case.

3. Acknowledgements

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Influence of Different Wavelet Filtering Reconstruction Techniques Applied to Bidimensional Surface Texture Characterization

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Keywords: Surface texture; filtering; wavelets, surface finishing.

1. Introduction

The characterization of components' surface finishing based on two-dimensional information is still the most commonly used method in industry to analyse the micro geometric properties of the components' surfaces as well as their influence on such components functional behaviour.

The filtering of the measured surface profile, whose data is contained in the Z-vector where the compiled points are equispaced, is a key element in the characterization process, figure 1. Filtering makes it possible to obtain the waviness and the roughness profiles, contained in vectors (W) and (R), on which the surface finishing characteristic parameters, such as the arithmetic mean roughness (Ra) or the quadratic one (Rq), will be subsequently evaluated.

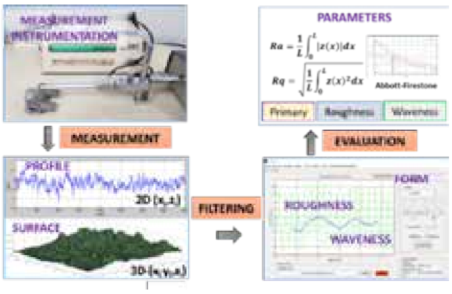

Figure 1. Surface texture characterization process

2. Methodology or Experimental Procedure

Wavelet filtering is based on applying the direct and inverse discrete wavelet transform (DWT) to the total profile (Z) in order to attain the waviness profile (W) [1]. In the filtering process, a transformation called T(z) is used, which modifies the values of the detail vector zD obtained in the decomposition stage before using it in the reconstruction phase, as shown in Figure 2. The standard ISO procedure for wavelet filtering [2] develops the scheme shown in figure 2 for various levels of decomposition/reconstruction, cancelling the detail vector zD in each reconstruction step, which is, using the function T(z) = 0 [3,4].

3. Results and Discussion

In the present work, different alternatives for the T(z) function are assessed, comparing the results obtained in each case and analysing the influence that each type of function has on the waviness and roughness profiles derived.

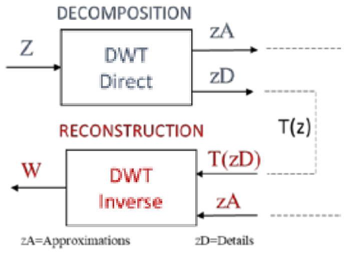

Figure 2. Discrete Wavelet Transformation of a Z vector applying a T(z) transformation before reconstruction

Likewise, a comparison of the results computed with the Gaussian filter, which is the most common filter used in the surface finishing characterization, is then established.

4. Conclusions

The main conclusions reached allow the validation of using the DWT as a powerful mathematical tool for filtering two-dimensional data in the surface finishing characterization. The importance of using different alternatives for modifying the detail vector in the wavelet filtering process must be also highlighted, determining their influence on the final results of the surface finish measurement/ characterization.

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Novel System for the Automatization of Photogrammetric Data Capture for Metrological Tasks: Application to Study of Gears

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Keywords: Metrology; gears; inspection and testing; photogrammetry; industrial quality.

1. Introduction

Photogrammetry, in combination with Structure for Motion (SfM) strategies, has been developed in recent years and it is an attractive alternative to the scanning systems [1]. In this technique, the input data are collections of single photographic images that can be acquired using a commercial camera while the outputs are dense point clouds which can be meshed to generate a metric and photorealistic 3D model of metrological interest. In the last years, the image-based modelling strategy can be integrated into different types of platforms and employed to document a wide range of scenarios and objects. Furthermore, it can consider as low-cost since the required hardware is a commercial photographic camera, lens, and commercial or free software. The 3D point clouds can be generated with submillimetre accuracy [2], provide radiometric information, and have a high spatial density.

Gear mesh faces are readily exposed to wear from improper lubrication and continued operation [3]. Therefore, it is appropriate to establish novel low-cost mechanisms to evaluate the deterioration of the gears.

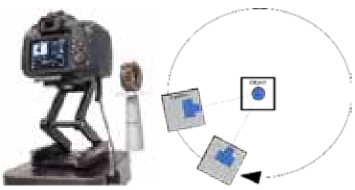

Figure 1. System configuration to generate 3D models.

2. Methodology

An autonomous and portable photogrammetric reconstruction system (Figure 1) applied to the metrological analysis of gears is designed, systematized, and calibrated to generate 3D models of gears without prior knowledge of photogrammetry. The lenses can be chosen to adapt the process as much as possible to the case study, allowing great adaptability of the system. The system is adapted and configured to automatically obtain photographs of the gears with optimal features for the application of high-accuracy photogrammetric processing (camera orientation, alignment, scaling, and densification). Thus, the data processing is applied to generate scaled and photorealistic point clouds models of gears with submillimetre accuracy.

3. Results and Discussion

The generated point cloud allows directly taking measures from the model, meshing it to obtain the solid model, observing the real texture, even exporting to CAD applications; but also allows the application of mathematical algorithms that detect the curvature, roughness, and other parameters [4] to automatically analyse areas with possible wear or the state of the profile of the gear teeth (Figure 2).

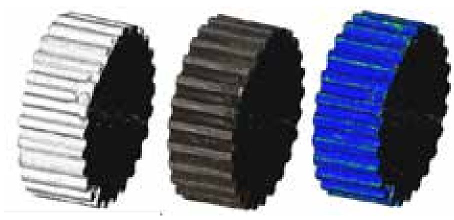

Figure 2. 3D point clouds generated: only geometry (left), geometry and texture (mid) and curvature map (right).

4. Conclusions

The designed system is suitable for 3D reconstruction of gears for metrological purposes and can serve to extract different characteristics that are difficult to measure using metrological tools or assuming higher costs in case of more complex scanning systems.

5. Acknowledgements

Research founded by PC_TCUE_2018-20_12.

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Validation of the Sandblasting Process in the Manufacturing of Precision Spheres for Non-Contact Metrology

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Keywords: Sandblasting; precision spheres; non-contact metrology.

1. Introduction

The aim of this work is to validate the blasting process as a process that modifies the surface condition of precision spheres, so that these spheres can be used for adjustment, verification and/or calibration of optical sensors and non-contact reverse engineering equipment.

The final objective of this research is to find out if a low-cost process (manual sandblasting) can be applied to stainless steel precision spheres, of very low cost, to materialize calibration spheres for its use in non-contact metrology. It is expected that the loss of precision, both in diameter and in form error of the post-blasting spheres will be low enough for this purpose. What is needed is that the form errors of the sandblasted spheres are at least one order of magnitude lower than the measurement uncertainty of the optical equipment to calibrate.

Nowadays, the costs of manufacturing and materializing precision ceramic spheres (grades G3, G5 or G10, with sphericity < 0.25 µm, Ra < 0.020 µm, according to ISO 3290/DIN 5401 [1]) are very high. On the other hand, the spheres used in this work are stainless steel precision balls commonly used in the bearing industry whose cost is lower but also featuring worse manufacturing qualities (G50 or G100 [1], with sphericity < 2.5 µm, Ra < 0.1 µm). However, for optical applications, this accuracy is enough, provided that these spheres do not exhibit excessive brightness. Precisely, the idea of the experiment is to eliminate the very shiny finish (mirror-like) of the sphere surface, in order to evaluate the variations both in diameter and in form error caused by the sandblasting operation. Another very important objective of the experiment is to quantify (if it exists) the improvement in the quality of the point clouds obtained by a laser triangulation equipment with respect to the cloud obtained on the polished, pre-sanded sphere.

2. Methodology and Experimental Procedure

Since the process chosen to carry out the modification of the surface condition is manual sandblasting, it needs statistical validation to be considered valid. For this reason, the experimentation includes a range of different spheres and a series of spheres from each range. In our case, 10 spheres of three different diameters were used (3 plates with 10 spheres, of diameters 10, 18 and 25 mm, Figure 1). In this way, average values and deviations from these sets can be used, also validating the uniformity of the sanding. The diameter and form error values of each group of spheres will be measured by contact (CMM with SP25M scanning probe) and by laser triangulation (Hexagon HP-L-10.6 sensor, also mounted on the CMM), both before and after sandblasting.

Figure 1. Contact measurement of a set of ten spheres (25 mm diameter).

3. Results and Discussion

The pre- and post-sandblasting comparison of the contact and laser measurement results provides interesting data on the modification undergone by the surfaces of the spheres, both from the point of view of diameter and the form error. In the case of the pointcloud captured without contact by the laser sensor, the influence of sanding is studied, not only in terms of the diameter and form error of best fit sphere, but also in the number of points and standard deviation of the captured point cloud. In relation to this last parameter, the influence of the filters based on this standard deviation is also studied [2].

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Uncertainty Determination of a Microvolume Characterized through Confocal Microscope Technique

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Keywords: Microvolume; confocal microscope; uncertainty; Monte Carlo Method.

1. Introduction

This work aims at describing a new procedure to measure the volume of irregular micro-holes on rough surfaces. Confocal microscopy is used to characterize the topography of small, non-regular samples. The result of each experimental measurement is a set of data that is filtered and fitted using a RANSAC algorithm [1]. This model determinates the void volume.

Developed model is validated by measuring six samples. Obtained volume values differ from 0.35 to 1.81 mm^3. Finally, the uncertainty of the measurement is estimated by using Monte Carlo method [2].

2. Methodology and Experimental Procedure

Confocal microscopy measurements of micro-holes (Figure 1) allows to obtain a matrix (X_i,Y_i,Z_i) with approximately six million points, evenly spaced on the plane XY. Based on this data, the model characterizes the volume of any micro-hole.

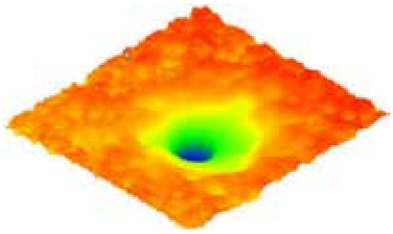

Figure 1. Coloured confocal microscopy image of an irregular micro-hole where the surface's roughness can be appreciated.

Firstly, the data are filtered reducing the size of the data matrix to the vicinity of the hole. Then, a RANSAC algorithm allows to determine the reference plane of the surface. It is fundamental to correctly select the reference plane. Moreover, the slight variations must be considered in the filtering, since these changes could lead to large deviations and therefore provoke errors in the volume estimation.

Confocal microscope is composed by a grid of equidistant dots along the X,Y axes; thus, the height (Z_i) is obtained by measuring with the grid in a certain point *i*. Volume of an element *i* (X_i,Y_i) could be calculated as Z_i times the pitch distance of the grid as $\Delta V_i = \Delta X \Delta Y Z_i$. Total volume of the void is determined as the summation of previously estimated volume of every element placed within the limits of the hole.

3. Results and Discussion

Table I shows the calculated volumes corresponding to three different samples and their standard deviations.

Table I. Calculated volume.

Sample	V [µm³]	σ_V [µm³]
1	8.2597E+08	1.6905E+07
2	1.3879E+09	3.1702E+07
3	1.6236E+09	2.7467E+07

Figure 2 shows the frequency distribution of volume elements obtained through Monte Carlo method which has been used for estimating volume uncertainty [3].

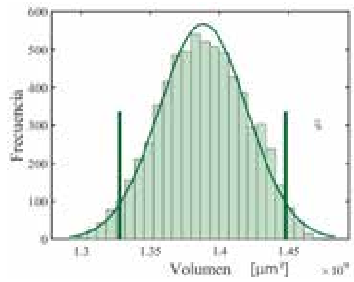

Figure 2. Probability density function of volume elements obtain from sample 2.

4. Conclusions

This work reports a novel method for measuring microvolume (in the order of one mm^3) and for estimating the uncertainty of the obtained volume.

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Environmental Conditions Compensation for a Length Measurement System Based in Laser Interferometry for Machine Tool Volumetric Verification

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Keywords: Laser interferometry; environmental compensation; machine tool; telescopic system; multilateration.

1. Introduction

Measurement systems based in laser interferometry, such as laser trackers, laser tracers or recently developed High Precision Telescopic Instruments (HPTI) where an interferometer is integrated in a telescopic system, have been usually used in industry for volumetric verification (VV) [1].

When several measurement systems (for example HPTI) are needed to measure the position of the machine tool head simultaneously during a VV [2,3], the information of the environmental control unit (ECU) has to be applied to all the measurements in order to compensate the measurement result with the ambience conditions.

This can be done connecting an ECU to each system or, as it is proposed in this work, estimating an adequate compensation model from the ECU data.

2. Methodology and Experimental Procedure

The internal compensation of the interferometer is compared with the compensation obtained from a regression using one or two environmental variables to adjust the error curve. Data acquisition is carried out in various sets using an ECU to measure the ambient conditions and, in some cases, to compensate the interferometer measurement.

The data acquired without compensate the environmental conditions is analysed to evaluate the effect of the ambience conditions. The data acquired compensating the ambient conditions is used as reference to evaluate the former, Figure 1.

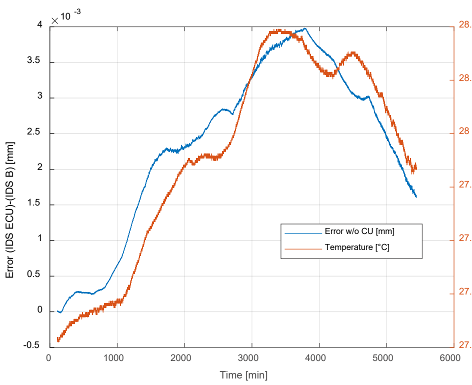

Figure 1. Difference between the interferometer measure with and without ECU (blue) and its relation with the temperature plot (orange).

3. Results and Discussion

The preliminary results show a better adjustment when using several parameters (temperature and pressure, for example) to adjust the error curve than using only the temperature, Figure 2. With all, the behaviour of the system when the temperature changes its tendency is under study.

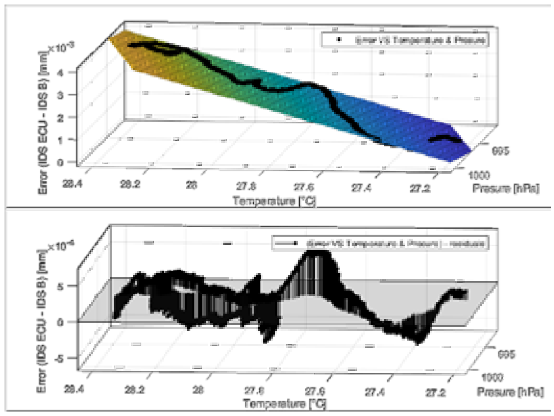

Figure 2. Linear regression model (R-square: 0.9541) and residuals plot.

4. Conclusions

A customized compensation model of the environmental conditions is proposed and evaluated comparing several options with the internal compensation of the interferometer. These results will allow the use of several HPTI with only one ECU.

5. Acknowledgements

This research was funded by the Ministerio de Economía, Industria y Competitividad with project number Reto 2017-DPI2017-90106-R.

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Influence of High Precision Telescopic Instrument Characterization on Multilateration Points Accuracy

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Keywords: Machine tool; telescopic system; interferometry; multilateration.

1. Introduction

Volumetric verification (VV) is daily increasing its relevance as a result of a strong demand for accuracy in machining and measurement process. Some measurement systems used on VV such as laser tracker provides 3D coordinates based on radial and angular information. Meanwhile others such as laser tracer or High Precision Telescopic Instrument (HPTI) use only radial information requiring multilateration technique to obtain 3D coordinates [1, 2].

This paper is focused on studying how the relationship between the three lines defined by HPTI interferometers, its measurement noise and the Machine Tool (MT) characteristics affect the accuracy of multilateration points.

2. Methodology and Experimental Procedure

Works carried out have been divided on two groups. The first group covers acquisition of real data such as vibration of the MT when HPTI is measuring, or measurement information from laser interferometers.

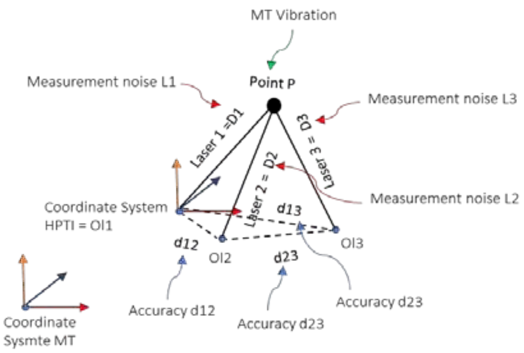

Figure 1. Influence factors to study

The second group include software development able to model HPTI measurement noise, MT vibration and calculation of multilateration points according to relative position of each laser (Figure 1).

Tests carried out are divided on analytical resolution, where values of d_{12}, d_{13} and d_{23} are fixed to solve three spheres intersection problem that define D_1, D_2, D_3, OI_1, OI_2 and OI_3 (Figure 1) and optimization resolution based on Levenberg-Marquardt Method. In this case, mulilateration points (x_p, y_p, z_p) are obtained minimizing the objective function of Eq. 1. Where $D_{i=1..3,\ calculated}$ is function of x_p, y_p, z_p and x_2, x_3, y_3. These values can be optimized joint multilateration points or independently.

$$\acute{\emptyset}_{min} = [D_1 - D_{1,calculated}, D_2 - D_{2,calculated}, D_3 - D_{3,calculated}\ ] \quad [1]$$

3. Results and Conclusions

Currently only a few preliminary results have been obtained. Table 1, presents the influence of laser location relationship when it is provided with an error of 0.1% and 1% respect original one with d_{12} = 1000 mm, d_{13} = 1166.1904 mm and d_{23} = 600 m.

Table 1. Influence of laser location relationship

Method	Initial values Accuracy	Residual Error (mm)	Mean Multilateration Points Error (mm)
Joint Optimization	99.9%	2.10^{-3}	9.10^{-4}
Joint Optimization	99%	2.10^{-3}	0.7369
Independent Optimization	99.9%	7.10^{-5}	7.10^{-5}
Independent Optimization	99%	1.10^{-4}	7.10^{-5}
Analytical	99.9%	x	4.12
Analytical	99%	x	20.02

4. Acknowledgements

This research was funded by the Ministerio de Economía, Industria y Competitividad with project number Reto 2017-DPI2017-90106-R.

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Evaluation of the Influence of Post-Processing on the Optical Inspection Accuracy of Additively Manufactured Parts

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Keywords: Accuracy; additive manufacturing (AM); optical inspection; post-processes; structured light scanner.

1. Introduction

Among other Additive Manufacturing (AM) techniques, Selective Laser Melting (SLM) stands out for its ability to create functional and complex metal parts of great interest to several sectors such as aerospace, medical or automotive among others. In these sectors the geometrical and dimensional accuracy is a critical factor. Optical measurement systems play an important role in inspecting parts obtained by AM processes, as they allow the creation of dense point clouds in very short times, characterized as rapid inspection systems.

Additively manufactured parts using SLM technology require post-processes to improve, among others, their surface finish (sandblasting) or mechanical properties (Heat Treatments (HTs)). These post-processing modify (to a greater or lesser extent) the surface finish (brightness, colour, texture, etc.) of the parts and thus their suitability to be captured by optical sensors.

In a previous study [1], the influence of different common post-processes on the geometrical and dimensional accuracy of SLM parts by a Coordinate Measuring Machine (CMM) was analysed. Now, different states of the part are measured using a 3D scanner with the aim of evaluating the optical accuracy after different post-processing, comparing the results obtained with the CMM measurements (reference). The optical measurement system used is a structured light scanner, which is one of the most suitable equipment for measuring such parts, as concluded in previous research [2].

2. Methodology

A test part consisting of 21 cubes homogenously distributed on the built-up plate was manufactured from 17-4PH stainless steel using a 3DSystems ProX 100 machine (as-built condition (AB)). After the SLM process, the part was sandblasted using a Sablex S-2 machine (post sandblasting condition (SB)). Finally, a stress relieving HT was applied, which consists in heating the part to 650 °C for 2 h followed by air cooling (post sandblasting and subsequent stress relieving HT condition (SB-HT)).

The test part was measured both by contact and optically in the different conditions (AB, SB and SB-HT). A CMM DEA global image was used for contact measurements and a structured blue-light scanner Breuckmann smartSCAN^{3D}-HE (currently AICON SmartScan) for optical measurements.

3. Results and Discussion

The flatness results show similar values in the three states. The deviations average of the geometric measurements with respect to the reference values (CMM) is about 23 µm in absolute value.

Regarding dimensional errors, there is an improvement in the cubes dimensions measurement after the sandblasting post-process (Table I). This improvement is more noticeable on the cubes lateral faces (X and Y dimension) than on the top face (Z dimension).

Table I. Cubes dimensions deviation with respect to the reference values (CMM) in absolute value.

	Deviation average (µm)			
Condition	**X**	**Y**	**Z**	**Total**
AB	49.9	40.1	33.0	41.0
SB	6.2	8.5	25.3	13.3
SB-HT	9.1	7.4	29.2	15.2

4. Conclusions

After evaluating the parts under different conditions, it is concluded the sandblasting post-process provides the parts with finishing characteristics more suitable for measurement with optical systems. This post-process smooths and removes brightness from the surface, factors that can lead to spurious points in optical measurements.

5. Acknowledgements

The authors gratefully acknowledge the financial support provided by Spanish Ministry of Science, Innovation and Universities (DPI2017-89840-R).

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Feasibility Analysis of Using Machinable Glass Ceramics to Manufacture Non-Contact Measurement Approach Metrological Artefacts

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Keywords: Machinable glass ceramics; non-contact measurement; metrological artefacts; machining conditions.

1. Introduction

In the last decades, numerous non-contact measurement methods have been developed. These methods permit to capture much more quantity of information than contact ones in less time and also with less problems of accessibility. These advantages convert them in ideal for on-machine and in-process measurement tasks. Nevertheless, it is widely and well known that the quality of the results achieved by them are highly influenced by different conditions which are usually indifferent to contact ones (optic characteristics of the surface measured, light ambient conditions, etc.). This fact, added to the important need for metrological artefacts in order to assess quality of the results and their traceability, makes that nowadays still exist the necessity to develop specific non-contact measurement focused metrological artefacts. These artefacts must be produced using materials that avoid the characteristic problems arising during digitising with non-contact sensors.

In this work, the feasibility of a commercial machinable glass ceramic to manufacture in order to manufacture metrological artefacts is analysed. Macor® machinable glass ceramic [1] of the commercial trademark Final Advanced Materials is studied, both checking the quality of the information captured over this material by a widely used non-contact laser triangulation metrological sensor, and analysing the possible problems that may arise when this material is machined with the aim to produce typical metrological geometries. The feasibility of this material is demonstrated and specific machining procedures, and also conditions, focused to obtain different types of geometries are proposed.

2. Methodology

This work can be divided in two parts. On one hand, the feasibility of using Macor® as non-contact sensor-friendly material for a laser triangulation sensor was demonstrated. For that, the quantity of points captured with this sensor and their geometrical quality were analysed using the measurements provided by a CMM Touch Probe system as reference. Moreover, these results were also compared with those obtained with the same sensor over a very used material to manufacture metrological artefacts, i.e. stainless steel.

On the other hand, several machining conditions based on Macor® manufacturer recommendations were optimized for machining the artefact geometries, and to discuss the problematic associated to these tasks. The quality of various machined surfaces was analysed by means of different methods as visual inspection, microscopy and roughness measurement.

3. Results and Discussion

The results obtained in the first part of this work demonstrates the good optical behaviour of the non-contact sensor in the digitizing of the Macor® material compared with its behaviour over the stainless steel. This demonstrates the non-contact sensor-friendly characteristics of this material.

On the other hand, different problems in the machining stage were detected related mainly to the fragility that shows this material due to its low toughness. A resin-embedded procedure was proposed, Figure 1, and different machining conditions were determined in order to both protect the integrity of the material and achieve the maximum quality of the artefact.

Figure 1. Embedded Macor® block during machining.

4. Conclusions

Macor® machinable glass ceramic is an interesting material to manufacture non-contact metrological artefacts by means of machining tasks but in specific conditions.

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CT Image Quality Influence on Different Material Edge Response Functions for Accurate Metrological Applications

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Keywords: Computed tomography; X-ray inspection; edge response function; image quality.

1. Introduction

Technological evolution is providing faster and more advanced measurement techniques and computed tomography (CT) is becoming more and more accepted in dimensional metrology during the last decades. However, results obtained from the CT are strongly influenced by a high number of parameters and thus the accuracy of CT-based measurements remains yet largely uncertain [1].

Unfortunately, the available knowledge on the main factors that affect the image quality of the radiographs collected for 3D tomographic reconstruction remains scarce. The main cause is related to the fact that each CT scan, and derived metrological performance, is influenced by individual specimen material and CT set-up magnification, focal spot size and radiation energy among others [2]. All these variables are directly related to the Edge Response Function (ERF) where dimensional measurements are performed after threshold selection.

In this research work accurate surface determinations of different materials are proposed. To do so, 4 different material samples are used. The samples are replicated in Titanium, Inconel 718, Aluminium and Copper. Further tests related to the image quality were carried out to provide a better scientific understanding of the measurement by means of CT.

2. Methodology or Experimental Procedure

A GE X-Ray machine model X-Cube Compact with 5 axes was used for the scanning purpose. The influencing material dependant variables investigated in this work have been classified in three main groups: Unsharpness, Scatter and Random Noise. Image quality analysis is conducted in dependence on CT parameters such as magnification, focal spot size and radiation energy.

3. Results and Discussion

For each material a suitable thresholding is found. General relationship between image quality and workpiece measurements is stablished. The resulting values are applied in different workpieces as shown in figure 1.

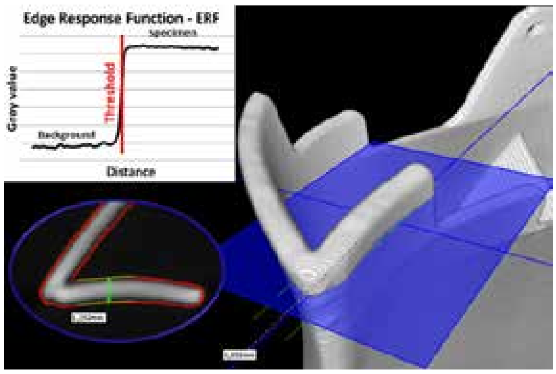

Figure 1. CT measurement after threshold determination

4. Conclusions

Results are promising and useful in metrological performances of Non-Destructive-Testing (NDT). This study contains a novel evaluation between image quality and different materials CT edge blurring, where threshold is defined.

5. Acknowledgements

Special thanks are addressed to the Department of Economic Development, Sustainability and Environment of the Basque Government by funding the KK-2020/00094 (INSPECTA) research project.

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Reference Standard for The Uncertainty Estimation of X–Ray Computed Tomography Measurements of Complex Macro- and Micro-Geometries

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Keywords: Computed tomography; reference standard; uncertainty; additive manufacturing.

1. Introduction

Nowadays, there is a wide range of metrological equipment capable of assuring traceability when measuring macro-geometries, such as Coordinate Measuring Machines (CMM). Despite of the high precision of these systems, one of their limitations is that the measuring features must be accessible. Thus, they cannot measure inner or hidden geometries. Another limitation is presented when measuring complex and non-standard geometries. As a solution, in recent years, X-ray Computed Tomography (XCT) has emerged as the only non-contact and non-destructive imaging technique that allows to inspect the geometrical dimensions of mechanical parts, including micro- and macro-geometries, and both internal and external features, without any accessibility issue [1]. For instance, one of its applications is to analyse components produced by Additive Manufacturing (AM) processes which have inner cavities that are not accessible and may be multi-material or have internal properties such as porosity, that need to be controlled [2].

In traditional uses of XCT, such as medical diagnoses or detection of flaws in industrial parts, a qualitative analysis is enough and dimensional accuracy is not required. Nevertheless, in dimensional-metrology applications, the measurements need to achieve a certain degree of accuracy. The main disadvantage of XCT is that it has many uncertainty sources which appear not only during the measuring process but also when post-processing the measured data. Additionally, there is not yet a normalized procedure for the uncertainty calculation of XCT measurements. This work presents a novel reference standard which can later be used for the uncertainty estimation of XCT measurements.

2. Methodology or Experimental Procedure

In order to estimate the uncertainty of an XCT measurement, a reference standard is required. Due to the special characteristics of XCT, these reference standards must be designed taking into account not only the geometries, but also the materials. This work, firstly, studies the state-of-the-art reference standards that are used for the calibration of XCT machines in order to analyse their limitations. Most of them consist in simple geometries that are used to calibrate exclusively one or two types of dimensions. In contrast, this work proposes a novel design that includes different types of measurable features which could allow to calibrate micro- and macro-geometries. It is worth noting that a XCT machine scans the whole artefact regardless of the quantity or type of dimensions that are being measured, and, thus, measuring more features does not increase the measuring time. The proposed reference standard is manufactured by AM, which enables to create complex multi-material parts with hidden geometries.

In addition, the proposed calibration procedure is performed by the substitution method, that is, the reference standard must be first calibrated by other traceable measuring instruments and, then, measured by XCT. Therefore, the reference standard design must be compatible with other contact metrological instruments such as CMMs or non-contact metrological instruments such as optical microscopes. For this purpose, the proposed reference standard consists in detachable parts, in order to make accessible the inner cavities. The assembly is designed to keep its repeatability when being mounted and dismounted.

3. Results and Discussion

This work proposes a reference standard for the uncertainty estimation of XCT measurements which allows to carry out accurate characterizations of complex and non-standard geometries, due to their size or shape.

4. Acknowledgements

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Analysis of the Effect of Porosity on the Mechanical Behaviour of L-PBF Inconel 718 Using XRCT

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Keywords: X-ray computed tomography; additive manufacturing; finite element analysis; porosity analysis; Inconel 718.

1. Introduction

The unexpected appearance of defects during the manufacturing process of industrial components compromises their performance. This is caused by the influence of these defects on the mechanical properties [1]. Therefore, a proper estimation of these defects allows more accurate predictions of the mechanical behaviour of the component.

In this context, X-ray computed tomography (XRCT) is increasingly being used as Non-Destructive Testing method (NDT), due to its ability to inspect internal and external structures at the same time. This advantage allows not only the qualitative analysis of defects, but also the quantitative one by dimensioning and locating each defect in the virtual reconstruction of the scanned workpiece. However, the XRCT lack of standards limits the assurance of the provided results. Hence, there is a growing trend to make it accurate and reliable [2].

Therefore, the main aim of this work is to study the influence of porosity on the mechanical behaviour of Inconel 718. As stated above, an accurate defect analysis provides accurate predictions of the mechanical properties of the workpiece. For that reason, the proposed methodology focuses on achieving accurate porosity analysis by means of XRCT. In order to estimate the mechanical properties, both experimental tests and FEM analysis are utilized. Finally, the results reveal the influence of porosity on the mechanical properties, highlighting the promising future of the proposed methodology.

2. Methodology or Experimental Procedure

The scope of this work is to assess the influence of porosity on the mechanical behaviour of Inconel 718. To this end, some test specimens were manufactured by L-PBF, according to ASTM E8/E8M. Afterwards, these specimens were scanned by means of XRCT in order to analyse the porosity of each one, as shown in Figure 1. For this purpose, the optimal scanning conditions, as well as the proper data processing techniques were investigated. Finally, the outputs generated by the previous step were used for FEM analysis. The results obtained by the analysis were correlated with the experimental results.

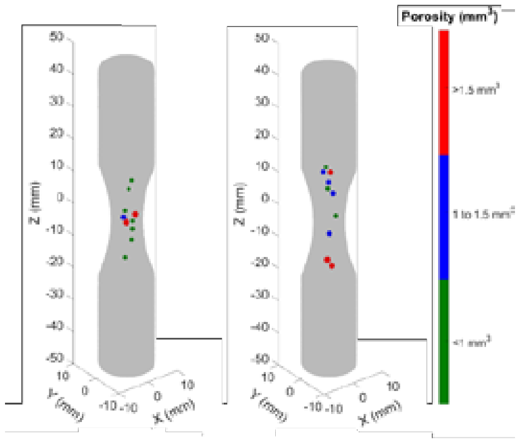

Figure 1. Porosity analysis by means of XRCT

3. Results and Discussion

The stress-strain curves obtained by the experimental tests were compared with the results estimated by FEM analysis. For further discussion, the influence of pore size, distribution and location were studied.

4. Conclusions

The mechanical behaviour of Inconel 718 workpieces manufactured by L-PBF is strongly dependent on the pores generated during the manufacturing process. The pore size, distribution and location also have their own influence on the results.

5. Acknowledgements

Special thanks are addressed to the Department of Economic Development, Sustainability and Environment of the Basque Government by funding the KK-2020/00094 (INSPECTA) research project.

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Layer Contour Characterization in Additive Manufacturing Through Image Binarization

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Keywords: Additive manufacturing; contour characterization; binarization thresholding.

1. Introduction

On-Machine Measurement (OMM) adoption will be key to dimensional and geometrical improvement of additively manufactured parts [1]. One possible approach based on OMM aims at using digital images of manufactured layers to characterize actual contour deviations with respect to their theoretical profile [2]. This strategy would also allow for in-process corrective actions. This work describes a layer-contour characterization procedure based on binarization of digital images acquired with a FlatBed Scan (FBS). This procedure has been tested off-line to evaluate the influence of median filter sizes (S_f) and threshold (T) values on the dimensional/geometrical reliability of contour characterization.

2. Methodology or Experimental Procedure

A circular contour was defined as a test-target. Once manufactured, a 2400 dpi grayscale image was obtained. Then a series of image processing stages were applied (Figure 1).

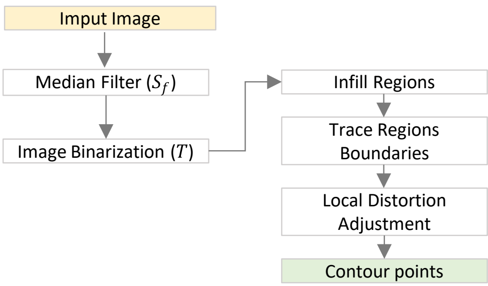

Figure 1. Image processing stages

As a result, a set of points representing the layer contour and characterized by their XY positions was obtained. These points were then clustered into 1° spaced angular sectors, so that their respective contour arcs could be characterized by the average distance of corresponding contour points to the centre of a least-squares fitted circle. These values were compared with those previously obtained with a reference method (touch-trigger coordinate measurement) to obtain radial difference values (D). Three quality indicators were the calculated: Coverage Factor (C_f), Mean Radial Difference ($\overline{D}$) and the Standard Deviation of the Radial Difference (σ_D). These calculations were repeated for different S_f and T combinations.

3. Results and Discussion

T values showed a significant influence upon contour reconstruction reliability, whereas S_f showed no significant influence. A narrow range of T values provided acceptable results ($C_f = 100\%$; $\overline{D} < 10\mu m$; $\sigma_D < 10\mu m$), whereas an optimal combination was achieved using a $S_f = 11$ and $T = 185$ test configuration ($C_f = 100\%$; $\overline{D} = 5.96\mu m$; $\sigma_D = 6.21\mu m$). It was also found that the optimal T calculated using the Otsu method [3] ($S_f = 1$ and $T = 192$) did not provide the best results, according to defined quality criteria ($C_f = 100\%$; $\overline{D} = 12.65\mu m$; $\sigma_D = 10.28\mu m$).

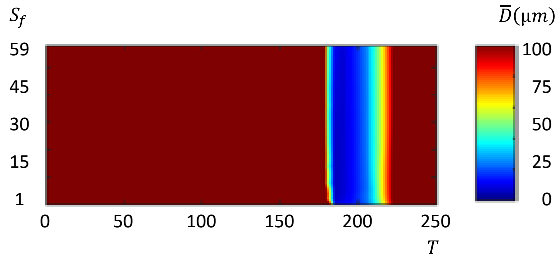

Figure 2. Distribution of $\overline{D}$ as a function of S_f and T

4. Conclusions

An appropriate selection of S_f and T for binarization allowed to characterize the proposed test-target with excellent coverage and reasonable accuracy. This conclusion seems to be true when a sharp image of layer contour is used. Further research should evaluate its trueness for images with poor contrast between contour and background.

5. Acknowledgements

This work was supported by the Spanish Ministry of Economy, Industry and Competitiveness and by FEDER (MINECO-18-DPI2017-83068-P).

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Tribological Characterization of Fused Deposition Modelling Parts

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Keywords: FDM; additive manufacturing; tribology; wear; pin-on-disc.

1. Introduction

The development of additive manufacturing processes has led to the appearance of new materials, equipment, and techniques. Associated with this development, the industry has been demanding more and more the use of these processes in different applications, which are increasingly complex.

It is common for additive manufacturing to be separated from the manufacture of prototypes, getting closer to final parts with certain functionalities. For this reason, the customisation or redesign of parts for additive manufacturing that allow them to meet design requirements is a trend that is increasingly used. In this context, numerous studies are emerging relating to the study of the mechanical properties of parts obtained by Additive Manufacturing for use in static applications [1]. However, the use of these parts in dynamic applications or where there is relative movement is not as developed [2].

There are some studies related to fatigue studies, but it is not so widespread [3]. Even less are studies related to sliding parts or parts that support contact or friction. Despite this, there are specific applications for this purpose, such as Igus [4] which also has specific filaments for this purpose.

This article proposes a characterisation of the wear that appears on parts obtained by Fused Deposition Modelling (FDM) with the aim of studying the possible application of these parts in dynamic applications.

2. Methodology or Experimental Procedure

To achieve the objective set, a series of flat square test pieces with 45 mm sides and 3 mm thickness were manufactured using FDM, with the materials and parameters described in Table 1. Straight paths were used in all cases. These parameters were selected according to the recommendations of the suppliers, the rest remained without variations.

Table I. Materials and printing parameters

Material	T (°C)	Layer thickness (mm)
PLA	200	0.25/0.35
PETG	240	0.25/0.35
ASA	260	0.25/0.35
NYLON	250	0.25

The printed samples were characterized by using optical microscopy techniques and their roughness were analysed. Also, the printed parts were subjected to Pin-on-Disc tests, where the wear mark were evaluated by image treatment techniques.

3. Results and Discussion

Analysing the data obtained, it can be seen that there is a dependence of the material on the roughness obtained, therefore, this is independent of basic parameters such as extrusion speed.

A dependence of the material on the tribological behaviour is also observed. The materials have different behaviour depending on their nature, which means that while in some materials such as PETG, the tribological behaviour is highly uniform than others as PLA or ASA, where material detachment is deposited on the pin (Figure 1).

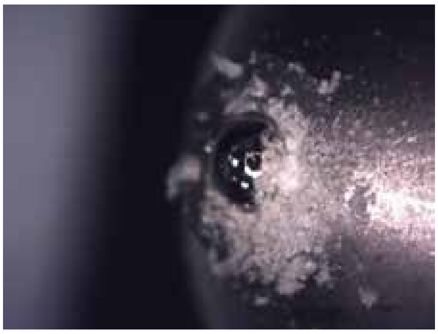

Figure 1. Wear debris of friction tests on Pin

4. Conclusions

Experimental tests confirms that some new developed materials such as PETG can be used in friction applications being competitive under specific conditions with other commonly used materials such as Nylon.

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Evaluation of Mechanical Properties of FDM Components Reinforced with Fibre

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Keywords: FDM; onyx; markforged; additive manufacturing.

1. Introduction

Fused Deposition Modelling (FDM) is the most used technique among Additive manufacturing (AM) due to his flexibility in the printing and his cost-effectiveness [1]. This flexibility in printing is the result of the wide variety of materials that can be used, including other types of materials than thermoplastics, which permits to obtain composites, improving the properties of the parts.

The most interesting composites used by FDM, is the Carbon fibre reinforced plastics (CFRPs), which increase the mechanical properties of the parts [2].

In this research, several parameters of a nylon-based composites with carbon fibre reinforcement were studied to analysis their influence in the tensile strength by a complete factorial design.

2. Methodology or Experimental Procedure

Tensile stress specimen design according to ISO 527. These specimens were manufactured by means of a Markforged One printer, using two types of matrix materials, i.e. Nylon and Onyx (a whisker carbon fibre reinforced nylon), Figure 1a and Figure 1b, respectively. Several specimens were manufactured using these materials varying specific FDM parameters as infill percentage, infill pattern type, etc. Moreover, all these specimen variety were manufactured reinforced with carbon fibre and non-reinforced, in order to analyse the importance in the tensile strength of the fibre reinforced compared with the other FDM specific parameters.

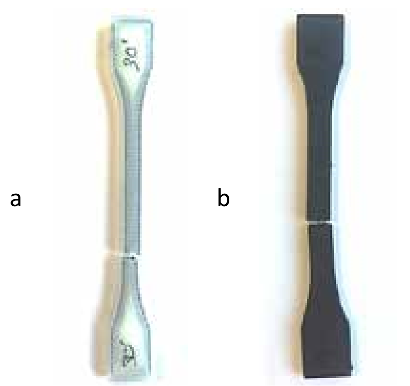

Figure 1. Example of carbon fibre reinforced tensile specimens: a) Nylon, b) Onyx.

To analyse the most influential patterns, several specimens were printed with different parameters like Fibre carbon reinforcement, material, infill percentage, infill pattern and wall thickness.

3. Results and Discussion

After the specimen were tested, the best combination of parameters is Onyx as material, with a reinforcement of carbon fibre, and a 60% of infill in a linear infill pattern.

4. Conclusions

The main conclusions of this work are:

- The most influent parameter is the fibre reinforcement.
- The Onyx material shows a better tensile performance than the Nylon.
- The infill percentage have more influence in the Onyx material than the nylon, because the whiskers of carbon fibre in the material.
- The infill pattern is the parameter with less influence in the tensile performance.
- The wall thickness has influence in the tensile performance, however this improvement can be obtained in a most efficient way with the modification of other parameters with a lower cost.

5. Acknowledgements

The authors thank the Ministerio de Economía y Competitividad of Spain for the support through the project with reference (UNLE15-EE-3258).

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Experimental Investigation of Contact Forces and Temperatures in Rubbing Interactions of Honeycomb Interstate Seals

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Keywords: Rubbing; temperature measurement; Labyrinth-Honeycomb seal; friction; abradable coating.

1. Introduction

Nowadays, aircraft engines efficiency is improved by reducing the clearance between rotating and stationary components of their engines [1]. This reduction implies the increase of non-desired contact (rubbing) between these parts that might cause subsequent wear and damage to the engine [2]. In the need to prevent the damaging effect of this rubbing, the use of labyrinth-honeycomb seals as abradable materials in the sealing system came as a solution [3]. The study of the rubbing contact is very complex because: (i) it involves multiple physical phenomena such as vibrations, friction, heat transfer or wear. (ii) Involved physical variables (forces, temperature and deformations) have nonlinear behaviour and (iii) it requires deep local studies, related to temperature and material characteristics, and global studies concerning contact velocities, vibration frequencies or resonance phenomenon. The experimental simulation of this rubbing interaction permits a deep understanding of these above-mentioned phenomena. Although there is a large number of interesting publications covering this problem, see for instance [4–6], none of them covers the interaction between the materials considered here, and only few of them contemplate thermal effects.

2. Experimental Procedure

A set-up was developed to simulate the interaction between a rotatory part, which has the shape of the fins encountered in the inter-state section of a turbine, and the labyrinth-honeycomb seal that corresponds to the static part of the turbine.

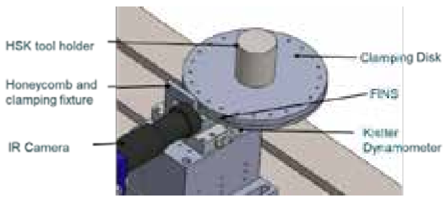

Figure 1. Schematic view of designed set-up of figure.

A high-speed infrared camera allowed the measurement of tip fin temperature after the rubbing, and the dynamic changes in forces were recorded using a 3-component dynamometer. Hastelloy-X and F110 Steel were the material used for the honeycomb structure and the fin respectively. Five rubbing conditions were tested, with sliding velocity (v_s) varying from 1 to 100 m/s and penetration velocity (v_p) from 0.05 to 10 (µm/rev). The penetration depth was kept to 2 mm. For each of these conditions six trials were performed.

3. Results and Discussion

The higher the penetration velocity, the higher the temperature, the extreme values being 375 and 260 °C. Tangential forces exhibited the same trend, while the radial forces showed a non-linear behaviour. The minimum (24 N) was observed at v_p = 0.1 µm/rev. Regarding the influence of increase sliding velocity, radial forces and temperature showed an increasing trend, while the opposite was observed for tangential forces.

4. Conclusions

Temperature, tangential and radial forces were measured in rubbing conditions and it was observed an increase of the two former along with the cutting speed, while for radial force no clear trend was observed.

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The authors would like to thank the Basque Government for the financial support to the Elkartek Project GERTURA (KK-2018/00078).

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Development of a Quality Control System for the Supply of Silica Refractory Material from China

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Keywords: Quality control; refractories; silica bricks, sampling.

1. Introduction

This document describes how to perform quality control management of refractory silica brick material purchased in China.

Silica bricks are a main actor in the lifetime of the equipment, and they are fundamental to ensure the adequate quality of the product.

The objectives of this document are:

- To define the criteria to be followed to carry out an exhaustive quality control in the manufacturing process of refractory silica bricks.

- To plan the sampling, minimising the number of samples to obtain an assessment of the quality of the consignment with the greatest precision.

- To define the criteria to be followed to reduce delivery time if a batch must be re-manufactured because of previous rejection**.**

2. Methodology or Experimental Procedure

The next steps will be followed in order to ensure the quality of the refractories.

- Quality control of the manufacturing process. It requires conducting an audit of potential suppliers to ensure that they follow a traceability in the process and have adequate technology and good manufacturing management.

- Quality control of the refractory pieces manufactured. Two standards will serve as the framework or base for this study, the ISO 5022:1979, which will be chosen for sampling and acceptance of batches of refractory pieces [1] and the DIN 1089-1, which defines the physical and chemical characteristics of refractory silica bricks [2].

- Quality control will be defined at two different levels, one to be performed by the manufacturer and the other by the customer. In the two cases both the “destructive” and “non-destructive” test to be carried out will be defined. The assessment of the quality of the consignment with the greatest precision will be obtained using the smallest number of samples.

- Criteria for acceptance of lots. The acceptance criteria of the lots are defined once the samplings and tests have been carried out and so has the procedure to follow in case of discrepancies between the manufacturer and the customer.

3. Results and Discussion

- The parts of the process that have to be controlled during manufacturing of the refractory are: selection of raw materials, grinding and screening, mixing, pressing, drying, curing and palletizing.

- Quality control will be done by dividing the order into batches to treat them as independent units for acceptance or rejection. Each piece of the batch must be identified with code, unit weight and shape.

- As for “destructive testing”, there are two possibilities to decide which type of testing shall be used: guarantee value (µg) for the mean value of the property measured or one limit (Ts or Ti) to individual values.

- Residual quartz content, apparent porosity and cold compressive strength are defined as critical parametres.

- The samples for the customer and manufacturer tests will be obtained from the same piece, dividing it and leaving a part in case of discrepancy.

4. Conclusions

The originality of this document focuses on non-standardized aspects in order to ensure better quality control of refractories.

- To avoid the loss of “see freight time” in case of rejection of any consignment, the customer's quality control must be performed at the manufacturer's facilities.

- The size of a batch should not be greater than the oven capacity. Each batch must be cured at the same time.

- Failure to comply with any of the critical parameters means rejection of the batch. If a “non-critical” parameter fails, the customer will evaluate if it permits the correct operation of the equipment.

- In case of discrepancy of the parties, an external laboratory will be used for the tests.

- The customer test must be carried out by experts who are acquainted with this kind of manufacture.

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Determining the Required Cleanliness Level Using Synthetic Test Contamination

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Keywords: Technical cleanliness, synthetic test contamination, particles, computer tomography

1. Introduction

Technical cleanliness has been an established quality feature in the automotive industry for many years. However, defining component cleanliness still causes problems for companies today due to the lack of standardized regulations. Too strict / inadequately specified cleanliness limits can be a disadvantage for both the producer and the consumer [1].

The required level of component cleanliness can be determined empirically by *fault injection testing*. For this, synthetic test particles are used. The material they are made from, as well as their shape, dimension and number can be selected according to the application concerned.

Fraunhofer IPA produced test particles for fault injection tests on journal bearings and analyzed the degree of accuracy achieved.

2. Experimental procedure

In a first step, particle characteristics typical of the contamination found on crankshafts were derived from cross-company cleanliness analyses.

42CrMoS4 was used as particle material. The test particles were produced in chip form in the lengths [500, 700, 900, 1100, 1300, 1500, 1700, 1900, 2100] µm. Width / thickness were fixed at 400 µm / 70 µm.

The particles were produced with a Kugler MicroGantry GU 2. Air was used to cool the workpiece and tool, as well as to advance the particles into a collecting device. The particles were cut from a 10 cm long half-groove path with an end mill.

The collected particles were scanned by a Bruker Skyscan 1172 microcomputer tomograph (µCT) and analyzed using VolumeGraphix StudioMax 3.0.5 [2].

Based on the analysis results, milling parameters were optimized over several cycles until the best possible degree of accuracy was achieved.

3. Results and discussion

No CAD model was available to compare target and actual dimensions. Therefore, the chips were aligned with each other using the volumetric best fit algorithm and the deviations from the nominal value in the section planes x = 200 µm and z = 150 µm were determined, see Figure 1.

The analyzed data set comprises a total of 90 test particles (10 particles of each length). The target value of $\pm$ 20 µm could not be achieved. However, a tolerance of $\pm$ 100 µm seems feasible for producing test particles in a reliable micromilling process.

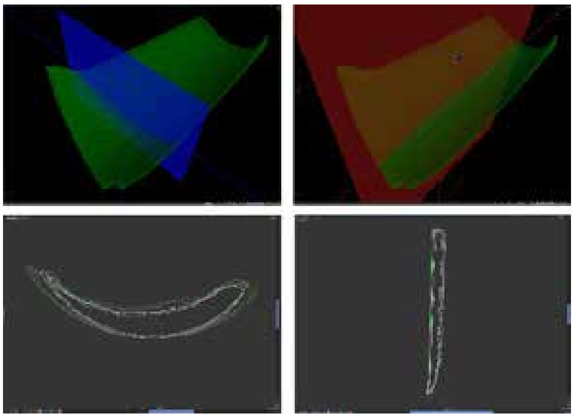

Figure 1. Section planes

4. Conclusions

In this article, µCT analyses were used to investigate the achievable degree of accuracy in producing chip-shaped test particles. Based on the results, *fault injection tests* with particles smaller than 400 µm make little sense. The uncertainty of the test results increases due to the decrease in class width for smaller pa 1.

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A Comparison of Fitting Criteria for Circle Arc Measurement Applications

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Keywords: Least-squares circle; minimum zone circle; minimum circumscribed circle; maximum inscribed circle; nose tool radius.

1. Introduction

Circle fitting from point coordinates is an important feature in dimensional metrology. The relevance of circular shapes and performance in mechanical engineering requires circle diameter as well as its shape deviation or roundness.

Four criteria of roundness are standard: least-squares (LSC), minimum zone circle (MZC) and the derived minimum circumscribed circle (MCC), maximum inscribed circle (MIC).

LSC is used in metrological calibrations, with good behaviour for outliers and minimum uncertainty on the average diameter result. Nevertheless, MZC, and the derived MCC and MIC, based on Chevichef metric, is ISO standards recommend for functional measurements. In addition to algorithm complexity, the MZC criterion is more sensible to outliers.

This work deals with a comparison of those criteria based on its accuracy for functional purposes. Former studies on circle characterization and algorithms [1-2] are in this research extended to circle arcs.

Circle arc measuring includes field and research applications in manufacturing. In particular, those in machining for the nose tool radius characterization in tool wear, thus influencing surface roughness of machined surfaces [3] and also the tool radius compensation in CNC programming.

2. Methodology and experimental procedure

The study is accomplished through a selected set of circle samples given by coordinate points, along with Monte Carlo simulation with radius probabilistic distributions and arc lengths. LSC is computed through the Levenberg-Marquardt algorithm, while MZC, MCC and MIC for arcs are fitted through new developed algorithms, based on former studies for circles [2]. The characterization of the fitted radius, root mean square error (RMSE), and the tolerance zone (TZ) over the setup of experiments allows its statistical treatment, over a range of the radius standard deviation to radius ratio (σ/R), in order to extract the influence over different arc sizes and radius spread.

3. Results and Discussion

A systematic study on selected samples allows proper characterization of the different criteria in Table 1.

Table I. Fitting of Figure 1 (σ/R=0.005)

Criteria	Radius	RMSE	TZ
LSC	1.80985	0.00830	0.02231
MZC	1.80950	0.00833	0.02053
MCC	1.81211	0.22677	0.03247
MIC	1.80907	0.02075	0.03747

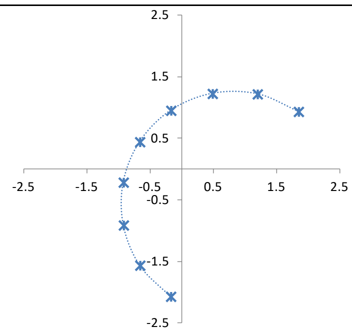

Figure 1. Arc sample dataset fitting.

4. Conclusions

Circle arcs are characterized in radius and form for the different fitting criteria, so it allows making decisions on the maximum deviation expected across criteria and its application in measurands of practical interest for manufacturing applications.

5. Acknowledgements

Developed in the framework of the project RTI2018-102215-B-100 of the Spanish State Programme of R+D+I, 2018 projects call.

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Robust Metrological Characterization of Circular Profiles

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Keywords: Circular profiles; outliers; optical profiles; trimming

1. Introduction

Outliers are likely to corrupt data acquired by optical profiles and ignoring them can badly affect the output of the analysis. Outliers are unexpected values that do not share the pattern followed by the majority of the data and may not have any pattern at all. they can be isolated or clustered. The reason is that outliers can be generated from many different sources during the data gathering process: bad behaviour of the instrument, wrong measurements by the researcher, unusual conditions (dust, for instance) that are not properly taken into account and generate altered data [1]. The presence of very few outliers can completely invalidate common analysis based on mean values and uncertainty evaluations. One ideal approach towards outliers would be to first detect them and then to remove them. Unfortunately, quite often a pre-processing of the available data aimed to identify such data inadequacies is not successful. In particular, outliers tend to mask each other and they may survive the pre-processing step. Furthermore, pre-processing should be based on appropriate statistical tools able to cope with outliers. Here, it is suggested to resort to proper robust methods that, from the one hand are designed to provide reliable estimates and uncertainties in the presence of outliers, from the other hand, work in a fashion similar to classical methods when data are not corrupted. The use of such techniques would avoid any two-steps procedure. Furthermore, another feature of robust procedures is that of providing effective tools for outlier detection stemming from the robust fit. Here, we are mainly concerned with the problem of metrological characterization of circular features using digital optical machines in the presence of noisy points.

2. Methodology

Let (x_i, y_i), i = 1, 2, ..., n be pairs of coordinates of n points belonging to a circular profile on a two dimensional plane. The problem is that of fitting a circle to the points at hand by estimating the coordinates of centre (c_x, c_y) and the radius r. Several techniques have been considered in the literature [2]. Let:

$$\begin{aligned} x_i &= \mu_x + \varepsilon_{xi} = c_x + r\cos\theta_i + \varepsilon_{xi} \\ y_i &= \mu_y + \varepsilon_{yi} = c_y + r\sin\theta_i + \varepsilon_{yi} \end{aligned} \qquad [1]$$

where $(\varepsilon_{xi}, \varepsilon_{yi})$ are error terms with a normal distribution and common uncertainty σ, without loss of generality. In order to highlight the main features of the technique, let us consider the least squares circle (LSC) problem. The estimates are obtained by minimizing the objective function: $\sum_i [d_i - r]^2$, where $d_i = \left[(x_i - c_x)^2 + (y_i - c_y)^2\right]^{1/2}$ is the algebraic distance. Under the assumption of normality of the errors, the algebraic fit is equivalent to the maximum likelihood fit. The robust technique is based on the idea of impartial trimming [3]. The optimization problem is based on a subset of the data after discarding that fraction of points with the largest distance from the fitted centre. The subset of trimmed points is not known in advance but a result of the methodology. In other words, we minimize $\sum_{(i \in I)} [d_i - r]^2$, where I is the set of indexes such that $d_i < d_j, \forall\, i \in I \wedge \forall\, j \notin I$. The size of the trimmed set can be fixed in advances or find adaptively. The method requires an iterative algorithm. The selection of initial values for the unknown parameters is a crucial point. An effective strategy is represented by subsampling. The general iteration of the algorithm can be described as follows: 1) compute distances 2) sort distances and discard those points with the largest ones 3) solve the LSC problem with the remaining points. The algorithm is assumed to reach convergence when the difference in the objective function at successive iterations is below a sufficiently small tolerance. A reweighting step may be considered further, in order to increase efficiency. In the reweighting step, we only discard those observations whose fitted distance is larger than a specified threshold value.

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Risk-based Inspection Planning for Hydrogen Technologies: Review of Currents Standards and Suggestions for Modification

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Keywords: Hydrogen containment; risk-based inspection; loss of integrity; hydrogen damage.

1. Introduction

The research addressing loss of integrity (LOI) for hydrogen containment technologies requires a multidisciplinary perspective [1]. However, lack of collaboration between materials and process safety engineers is reflected in the theory addressing the LOI phenomena. Even though mechanisms related to hydrogen-metal interaction are being extensively studied [2, 3], they are not explicitly considered by standards and recommended practices for plant inspection planning. This leads to consider generic mechanisms of material degradation while predicting LOI development and introduces additional uncertainty while planning for inspections and predictive maintenance. This contribution addresses the following research questions:

- What degradation mechanisms should be considered for hydrogen technologies?
- What is the influence of such degradation mechanisms on the potential containment breach?
- How can inspection be planned for these degradation mechanisms?

2. Methodology

A review of the available standards and recommended practices for inspection planning is conducted to identify how metal-hydrogen interactions are currently considered in terms of degradation mechanisms. Focus is given to risk-based approaches, which include the assessment of potential accident scenarios as consequence of LOI.

In particular, the association of metal-hydrogen mechanisms with damage factors influencing the predicted LOI frequency is studied to both understand their impact on risk and the inspection typology.

3. Results and Discussion

The main available standards and recommended practices for risk-based inspection planning are listed in Table I. The standards suggest inspection once the predicted risk of a piece of equipment reaches a predetermined risk value. The calculated risk can be decreased or confirmed by the inspection results. The evaluation of risk generally follows the procedure describe in Figure 1.

Table I. Risk-based inspection standards in literature

Standard	Title	Year
API 580	Risk Based Inspection	2016
API 581	Risk Based Inspection methodology	2016
DNVGL-RP-G101	Risk based inspection of offshore topsides static mechanical equipment	2017
EN16991	Risk-based inspection framework	2018

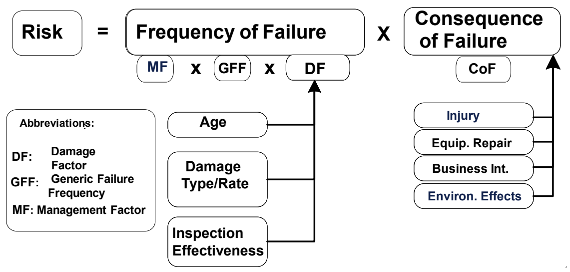

Figure 1. Risk evaluation approach

4. Conclusions

Appropriate knowledge of material degradation mechanisms for hydrogen containment is paramount as it allows not only designing the correct equipment, but also inspecting and maintaining its integrity through an effective and informed risk-based approach. A few modifications to the current standards are suggested as a result of this work.

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Development of a Nakazima Formability Test Methodology for High Temperature Applications on Titanium Alloys Sheet Metals

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Keywords: FLC; titanium; Nakazima; high temperature.

1. Introduction

The Forming Limit Curves (FLCs) are one of the main tools in the field of sheet metal forming, due to their simplicity of use and wide range of application. Its determination is usually done by means of Nakazima tests. However, traditionally it has been limited to be applied low-medium temperature conditions. The definition of FLCs in high temperature situations has been little addressed due to the technical problems it presents, resulting in the non-existence of a universal established device and methodology [1]. Moreover, titanium alloys have poor formability at moderate temperatures, what makes them be formed under high temperature conditions [2, 3]. That is why it is necessary to define the specific forming limit curves to speed up the product design stages. Obtaining the high temperature forming curves of Pure Titanium Grade 2 (Ticp2) and Ti6Al4V alloy sheets involves the design of a specific formability test device.

2. Design and Methodology

Figure 1. Experimental Nakazima test device developed.

The designed Nakazima testing equipment consists of three parts, which are coupled to a universal testing machine, as shown in Figure 1. The bottom die is fixed, and the upper blank-holder is responsible for closing the assembly and applying the clamping force to the sheet by means of two 10kN hydraulic cylinders. A hemispherical punch, attached to the upper head of the testing machine, applies the deformation on the sheet until it breaks.

A set of Joule resistances and control thermocouples housed in the bottom die and in the blank-holder allow to reach a test temperature of up to 750ºC. To avoid substantial cooling of the sheet during the contact with the punch, two additional thermocouples control the internal temperature of the punch and register the temperature of the sheet during the whole test. The use of MoS_2 lubricant on the punch-sheet contact surfaces allows to achieve the low coefficients of friction required in this type of tests at high temperatures.

3. Results and Discussion

Due to the limited plasticity of the Ti6Al4V alloy, the drawbeads on the die-blankholder contact surface must have a low-aggressive geometry to avoid premature failure in this area during the test. However, this design implies a limited holding capacity for certain specimens and materials, as it is the case of Ticp2. The high anisotropy value of this titanium alloy implies a great drawability without breakage, invalidating the formability test. Thus, the selection of specimens with specific designs for each strain state solved this problem and permitted to obtain the necessary points to compose the FLCs.

4. Conclusions

A Nakazima testing device has been developed which, together with the specific samples designed, led the authors to solve the researching problems existing in this field for the alloys proposed. The results obtained in preliminary tests have demonstrated the capability of the developed methodology to obtain the FLC of the titanium alloys in a wide range of temperature conditions.

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Long-Term Stability Analysis and its Relationship with the Steel Structure of Gauge Blocks from Several Manufacturers

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Keywords: Gauge block; dimensional stability; uncertainty; microstructure.

1. Introduction

Gauge blocks are one of the main and widespread measuring instruments across the industry and dimensional metrology laboratories [1-3]. The gauge blocks are currently manufactured under ISO 3650:1998 [1,3]. Material properties and metrological requirements for gauge blocks are defined in this standard. Among those requirements, one of the most important ones is the dimensional stability of the block, defined as the maximum permissible changes in its length per year [4]:

Table I. Dim. stability for nominal length (l_n) in mm

Grade	Max. variation in length per year
K	± (0,02 µ + 0,25 x 10^{-6} x l_n)
0	
1	± (0,05 µ + 0,5 x 10^{-6} x l_n)
2	

Due to structural transformation and residual stress, the dimensions and characteristics may change [1,5].

2. Methodology or Experimental Procedure

In this document, the authors present a method to determine statistically [6] the dimensional stability of gauge blocks, using samples sorted in three groups: length under 100 mm, 100 mm long, and longer than 100 mm, in order to cover all the typical ranges of measurement. The calibration history of gauge blocks has also been measured from the main manufacturers: FRANK, CARY, KOBA, MITUTOYO, JOHANSSON, TESA, and HELIOS. Besides, a metallurgical study has been made.

3. Results and Discussion

The analysis of the dimensional stability of the gauge blocks leads to the results shown in Figure 1.

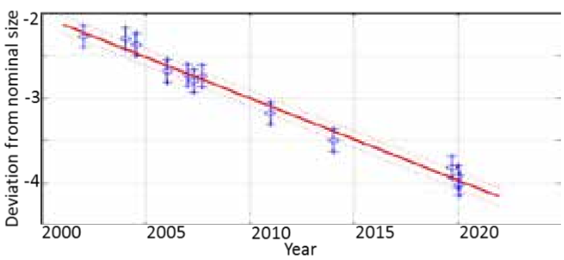

Figure 1. Deviation from nominal size over time

Figure 2 exemplifies the metallographic images that have been obtained through the metallographic attack of the gauge blocks.

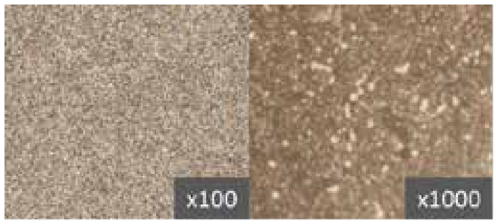

Figure 2. Martensitic microstructure of one of the samples (x100 and x1000)

4. Conclusions

Dimensional stability is highly related to the material properties. Phase changes and internal tensions affect to the measurement and could also make the gauge block go out of range, increasing the uncertainty of the measurement.

5. Acknowledgments

The authors express their gratitude to Y. Martín and R. Acevedo for their collaboration in the study.

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Effect of Ambient Temperature on Machine Tool Compensation Functions

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Keywords: Volumetric verification; calibration; environment conditions; machine tool.

1. Introduction

Nowadays machine tool accuracy is a competitive element. To improve it, machine tools (*MT*s) are verified and compensated periodically. Within all influences on machine tool volumetric verification (*VV*), thermal variations due to enviroment temperature is one of the most important.

To face it, there are different approaches, from study the influence of temperature on individual machine tool components [1], to analyse the global effect on *MT* tool center position: this is based on the *MT* kinematic model used to obtain compensation functions able to improve *MT* accuracy positioning [2]. Therefore, compensation functions are affected by thermal variation .

This paper analyses and model the effect of ambient temperature on compensation functions; assuming that all *MT* components have the same temperature. Work carried out allows to know whether compensation from verification works properly on real working conditions. Additionally, it will be able to provide compensation functions on working conditions from verification one adapting their coefficient and improving *MT* accuracy.

2. Methodology

To study the influence of environmental temperature on *MT* accuracy a synthetic data generator has been developed. It includes the kinematic model of a *MT* with XFYZ configuration with thermal variation influence [2].

It has been designed a simulation model test that aims to recreate a real *MT* volumetric verification process, where geometric errors are fixed and came from real test, all well as, optimization criteria, verification area and measurement system used.

This test is replicated at different environmental temperatures from 15 °C to 27 °C every 0.2 °C. Verification at 20 °C is the reference test. The influence of temperature is analysed for each of the 21 errors of the machine. The number of coefficients to model will be different depending on characterization function used and their degree.

The fluctuation of each coefficient at different temperatures is modeled based on optimization polynomial functions. It provides a function that models each coefficient of every geometric error at different temperatures.

3. Results and Discussion

Preliminary results show that compensation functions obtained depends strongly on temperature.

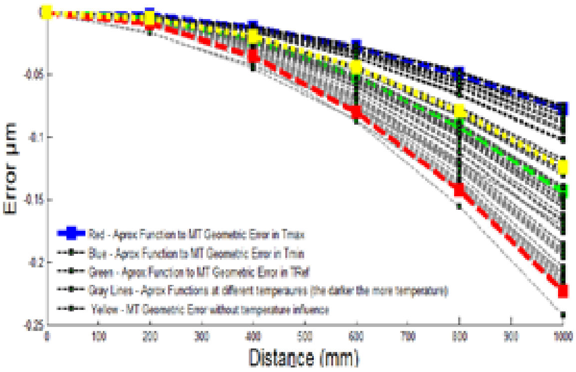

Figure 1. Compensation error of X position error at difference temperatures

Figure 1 shows compensation function of X axis position error at different temperatures. It shows a relation between error shape and temperature, but it is not the same in all cases, as can be observed when gray lines cross each other or red line is not the last one.

4. Conclusions

Because compensation functions are obtained through optimization techniques, the influence of temperature is included on geometric error compensation function. Moreover, verification conditions are different to working ones affecting to machine tool accuracy.

5. Acknowledgements

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Topic 4:
Technologies for supporting manufacturing engineering and systems

Machine-dynamics monitoring for L-DED operations.
J.I. Arrizubieta, J.E. Ruiz, M. Ostolaza, E. Ukar, A. Lamikiz

Finite element modelling and evaluation of mechanical properties of wood-PLA parts manufactured through fused filament fabrication.
J. Durlan, B. Adrover, M.D. Zandi, J. Lluma, R. Jerez, J.A. Travieso

Numerical investigation of deposition strategies on the residual stress and geometrical deviation in Laser Metal Deposition.
M. Ghasempour, D. Afonso, R. Torcato

Training program for researchers in design and manufacturing of experimental prototypes for fluids engineering using additive technologies.
L. Santamaría, M. García, A. Gharib, M. Galdo, E. Blanco, J.M. Fernández, S. Velarde

Re-design of a component of a lower-limb robotic exoskeleton for integrating sensing capacity and enhancing multi-material direct additive manufacturing.
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Product development methodology: non-quality caused in production by mistakes in product development, its measurement and improvement integration in the product development process.
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Design of a conceptual model for a maintenance object within a producer: impact on distribution network - a simulation case study.
J. Gejo, S. Gallego, M. García

Production optimization oriented to value-added: from conceptual to a simulation case study.
S. Pérez, S. Gallego, M. García

Fatigue behaviour analysis of AISI 316-L parts obtained by machining process and additive manufacturing.
C. Bermudo, F.J. Trujillo, S. Martín, M. Herrera, L. Sevilla

Analysis of residual plastic deformation of blanked sheets out of automotive aluminium alloys through hardness maps.
G. Maculotti, S. Bonù, L. Bonù, R. Cagliero, G. Genta, G. Marchiandi, M. Galetto

Methodology to estimate the modulus of elasticity of parts manufactured by FFF/FDM combining finite element simulations and experimental tests.
V. Fernández, A. García, A.M. Camacho, J. Claver, A. Rodríguez, M.A. Sebastián

Merging Complex Information in High Speed Broaching Operations in Order to Obtain a Robust Machining Process

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Keywords: Smart manufacturing; sensorization; broaching; machine data.

1. Introduction

Lean manufacturing is the new horizon that every company desires to achieve. New technological enhancements show us how the industry will evolve in the coming years, increasing their productivity and reducing their production costs. The method to do so is becoming conventional manufacturing processes into Smart processes capable of auto-correcting to ensure optimal productivity [1]. This reality is almost completed in some manufacturing areas, such as milling and turning processes. However, there are other conventional cutting procedures like broaching. Owing to be hand-operated one of the main challenges for these processes, reaching the demanding level of automation is really tough.

Broaching process presents elevated accuracy along with high surface quality for medium and large batches in the production of components with highly complex geometries [2]. It is used for many sectors such as aerospace and automotive, accomplishing their strict finishing requirements.

This study will present an initial stage of broaching machines sensorization, where different process parameters such as cutting speeds and the inclination of the cradle are analysed in-depth to evaluate their level of influence in machine data and establish a relation between them in order to make smart developments for the process optimization, using as a quality measure the wear appear in the edges of the tool. For this purpose, a test campaign will be carried out in steel F-114 to analyse the relation between these parameters.

2. Methodology or Experimental Procedure

Experimental tests will be carried out in an electromechanical broaching machine (Figure 1). The material used will be steel F-114, very used in automotive sector. During the tests several cutting speed will be analysed for different cradle inclination. In particular, 0º and 15º cradle types are going to be tested.

The experimentation will be divided in two steps. The first step consists on acquiring experimental data from the broaching machine carrying out a battery of tests with different cutting conditions. Afterwards, a second step will be carry out in which all this data will be analysed and the correlations will be established between machine data and process performance.

Figure 1. Experimental setup

3. Results and Discussion

In order to guarantee the good performance of the process, machine data must be acquired for each new material, machine or tool geometry. Then, this research is focused on obtaining a feasible method to control the broaching process taking both, technical issues and productivity ones.

4. Conclusions

In this paper, the initial stage of broaching machines sensorization work will be present in order to guarantee a robust machine process. Then, this research is focused on obtaining a feasible method to control the broaching process without extra devices, analysing the information subtracted from machine data and making finding a correlation between them and tool wear.

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The authors wish to acknowledge the financial support received from the Basque Government

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Analysis of AZ31B – Ti6Al4V Bimetallic Extrusion by Numerical Simulation and Taguchi Method

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Keywords: Extrusion; light alloys; bimetallic; FEM; Taguchi.

1. Introduction

Light alloys, and more recently, multi-material components are attracting great interest in sectors such as aerospace and transport. In this study, the direct extrusion of a bimetallic cylinder with a magnesium alloy AZ31B core and a titanium alloy Ti6Al4V sleeve has been analyzed by means of finite element (FE) simulation; special attention has been paid to the forces required and the effects associated to technological factors such as friction and geometrical conditions; the aim is to determine the most relevant parameters of the process and their influence when processing this kind of multi-material by extrusion, combining the design of experiments (DOE) technique and analysis of variance (ANOVA).

2. Methodology

A FE model with DEFORM 3D has been developed to analyse the influence of the process parameters in the extrusion process of this kind of bimetallic components. The mesh is presented in Figure 1.

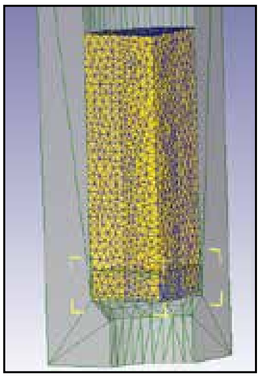

Figure 1. Initial FE mesh of bimetallic extrusion

The FE model validation has been performed comparing the simulations results for the extrusion force with the results obtained by Johnson's semi-empirical model [1,2]. Once the model is validated, the main process parameters are identified using an Ishikawa's chart and a design of experiments (DOE) methodology to quantify their influence in the required extrusion forces. Finally, Taguchi's analysis of variance (ANOVA) is applied in order to classify these parameters from the most to the less relevant in the variation of the extrusion force.

3. Results

The figure 2 shows some of the results after performing the Taguchi's ANOVA on DOE results.

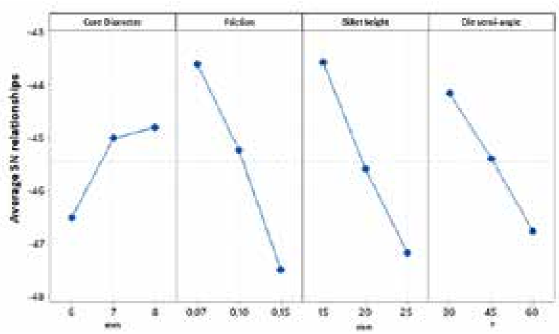

Figure 2. Main effects for SN relationships chart

4. Conclusions

A robust finite element model has been developed and validated to analyse extrusion of bimetallic components. The most influential parameter is the friction at the container/die-sleeve interface, so special attention should be paid to obtain favourable interfaces contact conditions by means of suitable lubricants, for example; followed by the geometrical dimensions of the billet, being the billet height more important than the diameter of the core.

5. Acknowledgements

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Numerical Analysis of Necking in Stretch-Bending based on Modified Maximum Force Criteria

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Keywords: Sheet metal forming; stretch-bending; necking; maximum force criterion; bending effect.

1. Introduction

In sheet metal forming processes, the stress/strain gradients through the sheet thickness induced by the forming tools have a clear stabilizing effect on the onset of necking. Thus, the use of classical failure criteria, which assume a uniform stress distribution across the thickness, is highly questionable in situations where bending is due to mild or small forming radius.

Recently, different approaches have aimed to describe the mechanism of failure and to propose a failure criterion under stretch-bending conditions that accounts for the strain/stress gradient. In a recent work [1], the authors developed a model assuming that necking should be controlled by the development of damage in a material volume located at the inner side of the sheet (concave surface). A formulation based on stresses was provided to minimise the loading-path sensitivity exhibited by the strain descriptions.

In a later work [2], the maximum force principle under stretch-bending conditions was analysed and two different approaches to predict necking were developed: a generalisation of classical maximum force criteria to stretch-bending processes (MFC-SB) and an extension of the previous work (which was called CDR, Critical-Distance Rule). The failure was successfully predicted using analytical models in different materials, such as steel, brass and aluminium. The current work presents a numerical study of both approaches.

2. Methodology

A numerical 3D model of stretch-bending tests (see schema in Figure 1) is developed in Abaqus. The simulations focus on the evolution of stress/strain gradient through the sheet thickness and the evaluation of the proposed necking criteria, MFC-SB and CDR. Both criteria are formulated in terms of the strain-hardening function $(d\sigma_Y/d\varepsilon)/\sigma_Y$ that is derived by the maximum force principle. Different configurations of blank sheet geometry and tool radius R are simulated. The major true strain ε_1 measured in the outer side of the sheet (convex surface) is evaluated for different sheet thickness to tool radius ratio (t/R). The numerical results are validated with experimental results in AA7075-O sheet of 1.6 mm thickness.

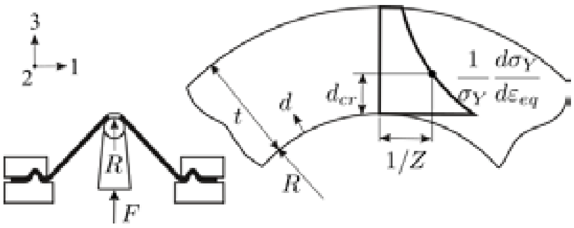

Figure 1. Gradient of the strain-hardening function through the thickness in a deformed sheet element.

3. Results and Discussion

This work is currently in progress. Preliminary results show a good agreement of simulations with experimental results for both MFC-SB and CDR. The work will include a sensitivity analysis of the time increment size in the proposed failure criteria.

4. Conclusions

The strain-hardening function $(d\sigma_Y/d\varepsilon)/\sigma_Y$ used to propose both MFC-SB and CDR criteria seems to control necking in both stretching and stretch-bending processes. However, the method used to calculate this variable in finite element simulations presents stability issues. A better implementation of the calculation procedure will be addressed in a future work.

5. Acknowledgements

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Three-dimensional Numerical Analysis of Tubular Adhesive Joints under Torsional Loads

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Keywords: Finite element method; cohesive zone models; structural adhesive; tubular joints; torsional load.

1. Introduction

Bonding using adhesives has gained a lot of presence in the design of mechanical structures in several industries, especially in the aeronautics and automotive industries. Such a method of joining has several advantages over more traditional methods such as welding or mechanical joining. These advantages include the weight reduction of the structure and the easy fabrication. In terms of manufacturing time and cost, this is a versatile method that enables the bonding of different materials, including composites, without damaging the structures to be bonded [1]. Bonded joints are also widely used to join tubular components, in vehicle frames like aeroplanes and vehicles [2]. The tubular joint design is mainly subjected either to axial or torsional loads. For the design process of these joints, analytical or numerical predictive techniques can be used.

2. Methodology or Experimental Procedure

This work compares the torsional performance of three adhesives, in aluminium tubular joints (AW6082-T651), considering the variation of the main geometric parameters: overlap length (L_O) and tube thickness (t_p). The different conditions provided a variety of numerical simulations that enabled a comparison in which regards the characteristic peak stresses that develop in adhesive joints and strengths. In order to predict the strength, the Finite Element Method (FEM) was used with the Cohesive Zone Model (CZM) [3]. The numerical analysis was divided into an elastic stress analysis of the adhesive layer, namely the analysis of shear stress (τ_{xy}), the corresponding damage, adhesive strength and energy dissipated at failure.

3. Results and Discussion

A comparison between axisymmetric two-dimensional and full three-dimensional simulations was undertaken as support. Such work as shown that the joints' geometry parameter and type of adhesive showed a major influence on joints' behaviour. The numerical study showed a major influence depending on the geometric parameter. There is a considerable increase in the maxinum load (P_{max}) as L_O increases. Joints with Araldite® 2015 have the highest strength. The lower strength and lower overall results are the adhesive joints that use the SikaForce® 7752. These results are repeated considering the variation of the thickness of the inner tube (t_{Si}) and thickness of the outer tube (t_{Se}). The Araldite® AV138, being the most brittle of the studied adhesives, presents the highest stress peaks of all, as well as favorable results for reduced t_{Si} and t_{Se} values (1 mm).

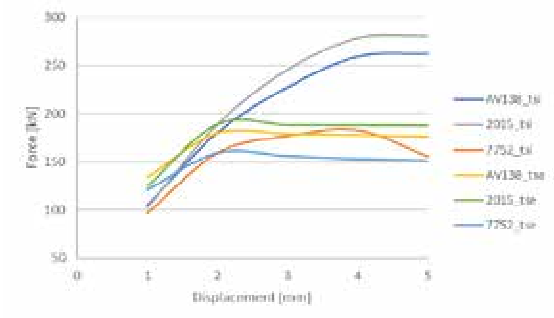

Figure 1. Strength prediction for t_{Si} variation

4. Conclusions

The joints behaviour is highly dependent on the adhesive type and L_O. For low L_O values and t_p=1 mm, the adhesive Araldite® AV138 is a viable option, in terms of joint strength. The SikaForce® 7752 despite being the most flexible adhesive, the low resistance may be a cause for the bad results. Araldite® AV138 is the one with the highest peak values of sheer stress, followed by Araldite® 2015 and finally SikaForce® 7752, which was found to be in accordance with the adhesives' behaviour observed in the literature. Araldite® 2015, the intermediate properties adhesive, presented the most favourable results in the vast majority of the cases studied.

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Modelling Adhesively-Bonded T-Joints by a Meshless Method

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Keywords: T-joints; exponent Drucker-Prager; adhesive joints; meshless methods; elastic-plastic analysis.

1. Introduction

Adhesively bonded T-joints are employed in automotive, maritime, and aerospace industries to join non-parallel panels.

Numerical analysis of adhesive joints is often performed using the Finite Element Method (FEM). However, limitations to analyse flexible materials (like adhesives) may arise due to mesh distortion. Meshless methods (MM) can be applied in such circumstances [1]. Here, the Natural Neighbour Radial Point Interpolation Method (NNRPIM) [1] was chosen. This MM only requires a nodal distribution to describe the geometry and provide accurate results even with coarse distributions [1]. This MM provides accurate results in applications like adhesive joints [2]. Also, its elastic-plastic capabilities make it suitable to analyse T-joints.

This work aims to evaluate the behaviour of the method for the elastic-plastic analysis of T-joints bonded with ductile adhesives. Aluminium substrates were considered, two different adhesive systems, and four substrate thicknesses were evaluated.

2. Methodology

Experimental strengths of these joints were previously determined by Carneiro and Campilho [3]. Such data was used as the experimental benchmark for the numerical work. Subsequently, numerical models were created using experimental dimensions. Mechanical properties of substrates and adhesives were determined from previous work [3].

The MM was programmed into MATLAB (The Mathworks INC). Then, the Exponent Drucker-Prager (EDP) yield criterion was added giving a closer representation of the adhesive behaviour. The boundary conditions and loads represented the experiments. A medium nodal density was used to analyse the joints without sacrifice in accuracy [1]. The adhesives considered were the Araldite® 2015 (A2015) and the SikaForce® 7752 (SF7752). The substrates were aluminium 6082 T651. Joint failure was considered when the equivalent strain reached the failure strain value ($\epsilon_{ef} = \epsilon_f$) for the corresponding adhesive.

3. Results and Discussion

Experimentally and numerically, the joint strength (Pmax) increased exponentially as a function of the substrate thickness. Pmax estimations from three of the four cases bonded with the A2015 were found within experimental values; the fourth was around 10% below. Conversely, the estimations from the more ductile adhesive were lower than the experimental values (in average 35%), being the thicker substrate the closer (by 15%). The difference can be attributed to the failure criteria chosen ($\epsilon_{ef} = \epsilon_f$). Despite this, the methodology is providing better estimations than those already available based on elastic analyses.

4. Conclusions

Joint strength is highly influenced by the stiffness of the upper substrate, increasing exponentially with the thickness plus an additional 100% increase if the bending is minimised. Moreover, the closeness of the results with respect to the experimental data indicate the NNRPIM with the EDP is a feasible choice to analyse adhesive joints.

5. Acknowledgements

The authors thank the Foundation for the Science and Technology of Portugal (FCT) for the funding provided through the grants: MIT-EXPL/ISF/0084/2017, POCI-01-0145-FEDER-028351, SFRH/BD/147628/2019. Also, to the Associated Laboratory for Energy, Transports, and Aeronautics (LAETA, Portugal) for the funding under the project UIDB/50022/2020.

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Investigation of Ball Burnishing Process Using Vibration and Acoustic Emissions Sensors

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Keywords: Acoustic emission; burnishing; vibration assisted burnishing.

1. Introduction

Acoustic emission is a high frequency wave (in the ultrasonic frequency band) generated when any kind of damage (crack initiation, coalescence of voids, dislocation, etc) is produced in a solid material submitted to a stress/strain state high enough [1].

During fabrication processes, like burnishing, different acoustic emission signals are usually emitted by the part that is being processed or machined and by the tool itself.

In this paper, burnishing processes under different conditions were applied on parts of C45 steel. During all these, acoustic emission was measured.

The characteristics of the acoustic emission signals were calculated from the acquired signals, and relationships with both burnishing conditions (burnishing force, feed speed, offset, vibration assistance, etc.) and surface mechanical properties obtained after burnishing were investigated.

2. Methodology

To characterize the machine–tool–part ensemble, the signals transmitted in different directions were monitored during the application of the burnishing process.

The burnishing tool was installed on a CNC Pinacho lathe, and the target workpiece was fixed in the lathe universal jaw chuck. The tool was fixed on a Kistler force-measuring table, in order to monitor it throughout the development of the experiments [2]. Acoustic emission sensors were also added to the body of the tool, as shown in Figure 1.

3. Results and Discussion

During the experiments, the acoustic emission sensor has captured a signal, whose frequencies can be correlated, on the one hand, in case of vibration-assisted burnishing, the vibration frequency of the burnishing tool (that is in the ultrasonic frequency band) is clearly noticeable. On the other hand, some other frequencies, that can be superimposed to the tool one, are related to acoustic emission events (hits) generated by different damages produced by the burnishing process in the workpiece; specifically, on the surface area undergoes plastic deformations.

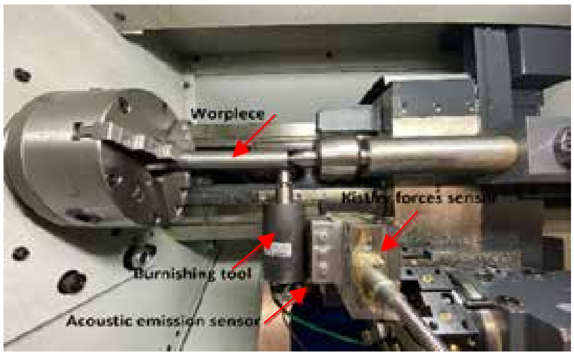

Figure 1. Experimental setup, for the analysis of acoustic emission, during the burnishing process

4. Conclusions

The main conclusion that can be reached in this research is that acoustic emission is a technique that can be used to monitor the ball burnishing process. In this way, some phenomena associated with the tool and the part are detected, which cannot be studied using another technique.

5. Acknowledgements

Financial support for this study was provided by the Ministry of Science, Innovation and Universities of Spain (grant RTI2018-101653-B-I00) and Regional Government of Catalonia and FEDER funds for regional development (grant IU68-016744).

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Investigation of Defects in Roll Contacts of Machine Elements with Acoustic Emission and Unsupervised Machine Learning

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Keywords: Acoustic emission; clustering; bearing damage.

1. Introduction

In the age of Industry 4.0 and IIoT, machines are becoming increasingly connected enabling continuous monitoring. A variety of information from machines and installed sensors is used to develop condition monitoring solutions. These systems are used to prevent premature failures and the follow-up costs due to machine downtime associated with them. Recent research in this area applies supervised machine learning, extracting features from captured signals and train classifiers. Supervised learning approaches require large amounts of labelled data, whose generation is time consuming and requires domain knowledge. For this reason, an unsupervised learning approach is being used in this work to distinguish between different defect and operation states of axial ball bearings.

2. Methodology and Experimental Procedure

Within the scope of this work, acoustic emission (AE) measurements in the ultrasonic range are recorded and evaluated. Artificial defects are seeded in the rolling contact of axial bearings. From the AE-signals a selection of state-of-the-art features is extracted. Then, the Laplacian Score [1], an unsupervised filter algorithm, is used to select the most significant features. Subsequently, the DBSCAN clustering algorithm is used to draw conclusions about the existing damage.

An axial bearing testbench was used to investigate the new approach. Four different kind of scenarios were recorded: normal condition, varying amounts of lubricant, contamination in the rolling contact, artificial pitting using an electric engraver. The measurements were captured with an acoustic emission sensor at a sampling rate of 2MHz.

3. Results

Table I. shows the feature ranking generated by the Laplacian Score for the used selection of features. Since the Laplacian Score does not remove strongly correlated, and therefore redundant features, we further reduce the features with a binary correlation comparison. Using the 3 most significant features the feature space of the different measurements can be graphed. Figure 1 shows that feature space.

All selected features are sensitive to the damage introduced.

Table I. Features selected by Laplacian Score

Rank	Score	Feature
1	1	Mean Frequency.
2	0.75	RMS
3	0.6	Formfactor
4	0.5	Kurtosis

Only in the case of artificial pittings, the change in the features compared to the normal state was small. This could be explained by the low depth of the introduced damages. All features are also very sensitive to the rolling speed. This can partially overshadow feature changes due to the various damages. If too many states are present at the same time, these overlap and the selected feature space is no longer able to achieve a suitable spatial separation.

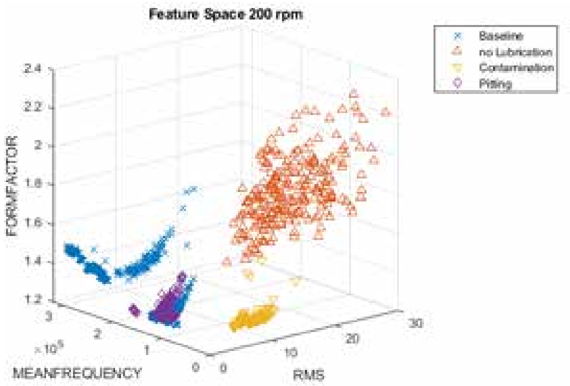

Figure 1. Generated Feature Space

4. Conclusions

As a result of this paper a comprehensive dataset of different operating conditions using an axial bearing is created. The acquired data is then processed using the DBSCAN algorithm in combination with a sliding window to differentiate different states. This technique does not require any input from the user and allows for a truly unsupervised condition monitoring.

5. Acknowledgements

This research work is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project 388141462.

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A Device to Reduce Positioning Errors Due to the Machine Tool Compliance

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Keywords: Positioning error; compliance; machine tools; mechatronics.

1. Introduction

The development of the oil&gas and renewable energies sectors has led to a strong demand of large machine tools. The design of these machines involves positioning heavy cantilever columns and rams that suffer positional errors from deflection and vibration due to the high inertial forces during the motion. The solution for these problems frequently involves having to limit the maximum acceleration and jerk during the motion planning, so the machine becomes less productive than what it could be. Here, an inertial device to compensate the positional error of the machine due to those forces is proposed. The performance of the device acting on a machine tool drive is successfully tested in Matlab, simulating real machine tools modes, machining forces and CNC motion profiles.

2. Methodology

We are going to use a simplified dynamics 2D model of the linear drive, assuming the whole column as a flexible element as shown in the scheme of Figure 1. The tip of the tool is located at point B and at another point of the column, we put a device composed of two equal discs that rotate with respect to the same geometric axis (point C) and whose centres of mass are located outside that axis of rotation. Both discs are driven by rotation actuators and can rotate with respect to the column in an independent and controlled manner. In order to model the compliant column, it is considered that it can rotate with respect to the machine carriage at point A and a spring and a damper are added to it to condense the rigidity and damping of the whole structure.

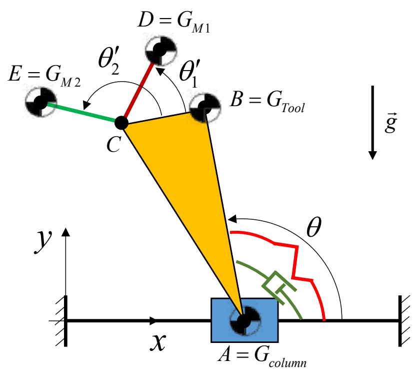

Figure 1. Scheme of the drive model with the device for minimizing positioning errors

The modelling is done in natural and mixed coordinates [1] and an additional and external CTC control [2] to the classic control loop of the drive is included. This control is in charge of receiving the estimation of the column deformation measured by means of strain gauges and deciding how the discs should rotate.

3. Results and Discussion

The proposed model has been programmed and simulated in Matlab R2019b using values of dimensions and masses of a large machine tool, from which the rigidity and damping of the whole column has been estimated through a frequency response analysis performed at the tip of the tool.

The results show that the tool positioning error is minimized to very low values even when the drive is forced to make movements with discontinuities in accelerations.

4. Conclusions

The proposed device is capable of significantly minimizing the positioning error at the tool tip. The adjustment of the control of this device is very simple since it has only one parameter and, in addition, it is very robust, producing acceptable results in a very wide range of this parameter. The development and installation of this new device requires the previous characterization of the rigidity and damping characteristics of the machine tool column and involves the installation of an additional sensor that measures the column deformation in real time, such as strain gauges.

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Design of a Machine to Rectify Ceramic Tiles for Laboratory Tests

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Keywords: Abrasive tile rectification; abrasive machining; sustainable manufacturing; energy efficiency.

1. Introduction

Machining processes with abrasives are very inefficient manufacturing processes, in which only between 15% and 30% of the electrical energy consumed is used to remove material. These processes have been widely studied in applications such as high hardness steels, tool steels, technical ceramics (alumina, zirconia, silicon carbide, ...) and glass machining. However, there are few studies that investigate their application in machining ceramic tiles, some of them in the field of polishing process for porcelain ceramic tiles [1, 2] and rectification [3].

The concept of rectification in the tile industry is different from that understood in the machinery and component manufacturing industries. In the former, the rectification process consists of machining the edges of the tile to make them straight, parallel two by two and perpendicular to the other two (squaring), in addition to controlling the size of the tile (calibrating). However, there is a lack of information in this area which hinders the improvement of the efficiency of these processes.

In this work we present the final design of a laboratory machine equipped with a single grinding wheel, which allows simulating the working conditions in a plant of a tile rectification line. Once built, grinding wheels, and working conditions tests will be analyzed to obtain information on the characterization of the process in order to apply this knowledge to improve process efficiency.

2. Methodology

The industrial process of tiles rectification is carried out by passing the tile along a line of pairs of facing wheels (i.e. 8x2) that progressively remove material from the edges until the required dimension is reached. The designed machine will only have one grinding wheel, and the tile tested must make successive passes to simulate the industrial process.

In order to carry out the design of the machine, a study of the most influential working parameters and the measurable parameters of interest (forces, powers, material removal rates, ...) will be carried out first. Next, we will define the different functional systems that the machine requires (cutting, feed movements, cooling, control, measurement, etc.), and the most appropriate constructive solution will be sought. Finally, the complete design of the machine will be carried out incorporating the previous solutions.

3. Results and Discussion

There is a great shortage of information in this area that allows improving the efficiency of these processes. For this reason, the construction of a machine to carry out laboratory studies will allow researchers to better characterize the material removal mechanisms. With this information, relationships will be established between the process parameters, energy and abrasive consumption, and material removal rates, which will lead to optimal working strategies improving the efficiency and sustainability of the process.

4. Conclusions

The equipment developed will let researchers to carry out tests about the rectification process at laboratory level and learn more about the process, which is nowadays a field where few studies may be found. This equipment can also be used to carry out tests with wheels offered by different manufacturers to characterize their performance, being a useful equipment for both abrasive wheel manufacturers and tile industries.

5. Acknowledgements

This work has been funded by the *Plan of Promotion Research 2018* from the Universitat Jaume I, Ref. UJI-A2018-17.

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Superfinishing Robotic Cell to Automate Belt Polishing Process on Critical Aeronautical Components

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Keywords: Superfinishing; robotic cell; polishing; aeronautical; advanced manufacturing.

1. Introduction

Surface quality requirements on aeronautical casting components are critical. Functional surfaces should be finished using machining process and, later on, these surfaces should be finished using polishing techniques [1]. These final processes are usually manually performed by experienced operator, mainly due to their complexity. Nowadays, new technologies provide a chance to automate these processes, but some aspects must be taken into account. On the one hand, a digital simulation of the process is necessary in order to assure a geometrical quality according to the tolerances required [2]. On the other hand, some tests should be performed to introduce new tools and abrasive materials in this kind of automated processes [3].

In this line, the driver of the proposed work is to establish a robust set-up for non-assisted polishing of casting parts using a robotic cell. Concretely, a CAD/CAM virtual environment will be developed according with the physical equipment, and a deep study will be performed in order to check for the best couple tool-material.

2. Methodology or Experimental Procedure

The methodology proposed for this work is based on the set-up and optimization of the polishing process. For this purpose, two lines will be analysed: I) virtual characterization of the robotic cell using a commercial CAD/CAM software, including the kinematics and limitations of the physical cell. II) Benchmarking and testing of different tool materials, analysing process parameters and final surface results.

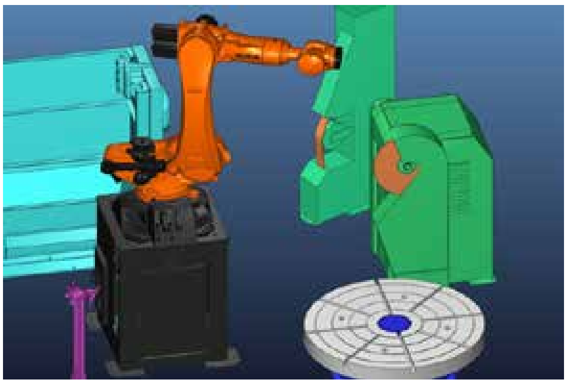

Figure 1. Virtual robotic cell for toolpath generation and control.

Working on these two main lines, a robust process will be established. Once the process is set, quality control of the final surface will be studied. Concretely, surface roughness and geometrical aspects will be presented.

3. Results and Discussion

Results will be presented in terms of productivity (material removal rate) and quality (surface integrity). Figure 2 shows an example of the behaviour of abrasive tools regarding contact time between tool and part.

Figure 2. Thermal damage on test pieces using different process conditions.

4. Conclusions

Automation of finishing processes is the key in many manufacturing sectors, mainly in aeronautical companies where components are critical. This work, present a robust set-up to achieve these purposes. Results meet with the component requirements.

5. Acknowledgements

The authors wish to acknowledge the financial support received from the Basque Government.

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Control Strategies Comparison for a Multi-stage Assembly System Using Simulation

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Keywords: Production quality; multi-stage assembly systems; stream of variation; simulation; control strategies.

1. Introduction

The goal of Zero Defect Manufacturing (ZDM) is the part scrap reduction by compensating defects and avoiding their propagation on multi-stage production systems [1]. In particular, the joint use of in-process measuring and flexible locating systems enables the application of different control strategies to proactively improve the geometrical product quality and to achieve the productivity targets. In this work, focused on the production quality paradigm in a Model-Based System Engineering (MBSE) context, two control strategies are simulated to compare their effects in a multi-stage assembly system from two points of view: productivity and geometric quality. For this, a simulation tool developed on OpenModelica [2] is used to compare alternative control actions on adjustable part locators considering the logistic flow and the quality characteristics flow based on the Stream of Variation [3].

2. Methodology or Experimental Procedure

Three scenarios have been studied:

- *Scenario_0: Non control*.
- *Scenario_1: Feed-Backward control*. Based on the measurements in the final inspection stage and their statistical treatment, corrective actions are applied to the positioners at each stage.
- *Scenario_2: Feed-Forward control*. Based on in-process measurements after the first subassembly stage, the control calculates the optimal position of the locators for the subsequent stages.

These control logics have effects on both product quality and process productivity. To study this dual effect, a comparison based on simulations has been developed, using the model proposed in [2]. The case study is based on the Problem 6.1 proposed in [3], an assembly process of car side frame.

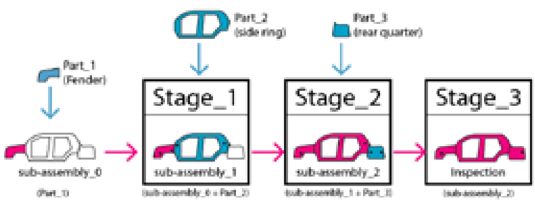

Figure 1. Assembly process for the case study

This assembly is made up of 3 sheet metal parts and it can be studied as a 2D problem. The process is composed of two assembly stages and a final inspection stage, as illustrated in Figure 1.

3. Results and Discussion

The results obtained show both control logics have notably improved the quality of the final assembly, as Figure 2 shows, even though the total number of produced units in Scenario_1 and Scenario_2 are lower than the result in Scenario_0 due to the adjustment time.

Figure 2. Maximum deviation at inspection stage

4. Conclusions

This paper has shown the potential use of MBSE in improving multi-stage assembly processes through simulation tools. The results of the case study show an important quality improvement despite a reduction of total number of produced units.

5. Acknowledgements

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Design and Construction of a Test Bench for the Manufacture and On-machine Non-contact Inspection of Parts Obtained by FFF

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Keywords: Fused filament fabrication (FFF); additive manufacturing (AM); non-contact inspection; on-machine inspection.

1. Introduction

The industrial application of additive manufacturing (AM) technologies is subjected to some limitations, such as the lack of dimensional and geometrical accuracy of manufactured parts. For this reason, many works were dedicated to improve the quality of parts manufactured by AM [1-3]. However, integrated solutions in commercial-type AM machines have not been achieved yet.

With this aim, the present work describes the development of a mechatronic test bench that incorporates a manufacturing system based on Fused Filament Fabrication (FFF) and an on-machine inspection system, both operating coordinately. As inspection systems, the feasibility of using different non-contact sensors will be tested for capturing the contour of deposited material layers for subsequent analysis and compensation of errors.

2. Test Bench Description

The test bench consists of a high rigidity aluminium structure with a workspace of 280 x 280 x 200 mm (Figure. 1). The construction table is adjusted for each deposited layer by shifting it along vertical direction (Z axis). A Bowden-type extrusion head can be displaced across the extrusion bridge (Y axis). In turn, this bridge can be moved along the structure of the machine (X axis). On the other hand, the inspection head can be moved across the inspection bridge (V-axis). This bridge is parallel to the extrusion one, sharing the same guides, although it is controlled independently (U axis). Both the extrusion and inspection heads can describe paths in the plane parallel to the construction table. All the movable elements are displaced on linear guides, driven by stepper motors, with transmissions based on pulleys and timing belts, in the case of the heads and bridges, or by means of a power screw and a nut, in the case of the table. The extrusion and inspection systems are provided with independent Arduino-based controllers that can work in a coordinated way from a machine's external PC which in turn, will also handle each of the inspection sensors to be tested.

3. Results

Once the test bench was built, a geometrical adjustment of the axes and construction table was performed, the parameters of the extrusion and inspection system controllers were adjusted, as well as the general control that coordinates the integrated operation of both systems. The test parts manufactured within the machine met a dimensional, geometrical and surface quality comparable to that of a commercial-type 3D printer. Also, the operation of the inspection head was checked on each deposited layer.

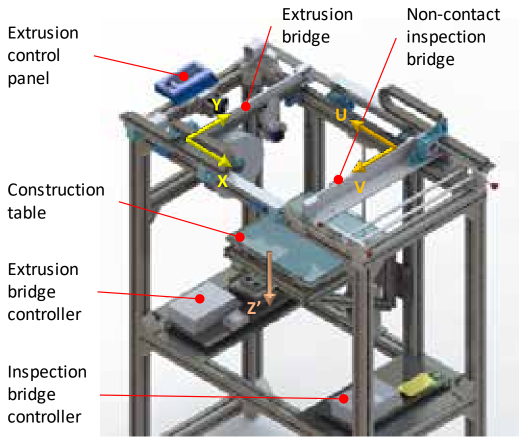

Figure 1. Test bench for FFF and non-contact inspection

4. Conclusions

The developed test bench allows for the manufacture of parts using FFF, as well as it is provided with a head to move a non-contact inspection sensor. The tests carried out show that both systems can work in an integrated way, so that it is possible to inspect each layer as soon as it is deposited during the construction of a part, as stated in the initial design specifications.

5. Acknowledgements

This work is supported by the Spanish Ministry of Economy, Industry and Competitiveness and FEDER (DPI2017-83068-P).

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Contact Image Sensor Integration in Fused Filament Fabrication Machines for Layer Inspection

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Keywords: additive manufacturing; flatbed scanner; inspection; integration.

1. Introduction

One of the main limitations of additive manufacturing (AM) is the lack of dimensional and geometrical accuracy of manufactured parts. As a solution, some authors propose the development of in-situ geometrical inspection systems and, simultaneously, the application of error compensation techniques with respect to the original CAD model [1]. For this, it would be necessary to find out a technology to measure the contour geometry of the deposited layers and suitable to be integrated into the AM machine. With this purpose, the present work analyses the feasibility to integrate a commercial-type flatbed scanner CIS sensor into an AM machine [2-4].

2. Experimental Procedure

Given the impossibility of integrating an inspection sensor into a commercial-type AM machine, a tailor-made test bench was developed specifically for this purpose. This test bench is able to produce parts by FFF (Fused Filament Fabrication) technology as well as to perform inspection tasks. The machine is provided with two mobile bridges, one for the extrusion process and the other one for digitizing the deposited layers with the CIS sensor (Figure 1a).

A reverse engineering process was carried out initially to analyse the operation and interaction of the sensor with the original scanner components and next, a procedure to integrate the CIS sensor into an external device was developed. Then, hardware and software routines were designed to control the CIS sensor installed on the test bench from a PC. An adaptor was also manufactured to attach the sensor on the inspection bridge and to enable its geometrical adjustment.

3. Results

In order to obtain high resolution images with the type of CIS sensor used, it was necessary to combine several low-resolution images and to apply digital image processing techniques. Figure 1b shows the image of a digitized layer acquired by the test bench integrated sensor. The captured images were compared to those obtained by the original scanner. The quality of the captured image shall be used later to recognise the geometrical errors of the layer contour.

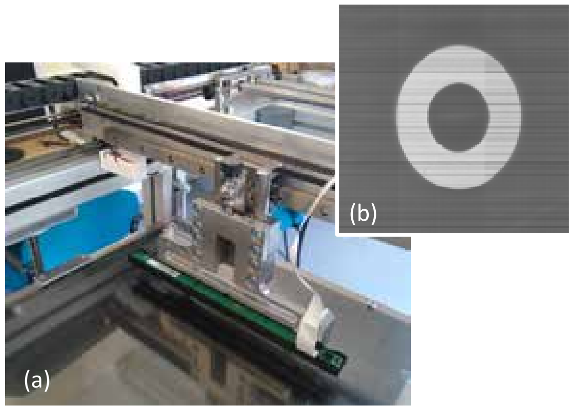

Figure 1. (a) CIS sensor on the test bench inspection bridge; (b) Sample captured image

4. Conclusions

A procedure was developed for the integration of a commercial-type flatbed scanner CIS sensor into an AM prototype machine based on FFF. The procedure can be applied to other machines different of the commercial-type scanner. In addition, results of the digitizing tests obtained demonstrate the capability of this type of sensors to analyse and improve the quality of parts manufactured using FFF technology.

5. Acknowledgements

This work is supported by the Spanish Ministry of Economy, Industry and Competitiveness and FEDER (DPI2017-83068-P).

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Topology Optimization and Additive Manufacturing Applied to a Camera Bracket for a 3U Cubesat

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Keywords: additive manufacturing; 3D printing; topology optimization; CubeSat 3U.

1. Introduction

Recent commercialization together with the growing success of the CubeSat standard have unleashed opportunities for benefiting from newcomer technologies. Space components are characterized by the uniqueness of each developed part, adapted to a specific mission. Additive Manufacturing (AM) offers superior freedom of design, allowing complex designs with virtually no cost increase. In this context, Topology Optimization (TO), a mathematical optimization technique applied to structural problems, allows achieving solutions with substantially less mass than conventional experience-driven designs.

In other words, the synergy of AM and TO involves competitive solutions for the design and manufacturing of space components.

This work describes the design and optimization of the structural support of a lightweight CubeSat camera, using TO and AM.

2. Methodology

CubeSat cameras include a very fragile optical assembly that must stay precisely aligned during all launch and ascension stages and the on-orbit operation of the satellite. The goal is to obtain a lightweight structure made in EN AW 6061-T6 that will survive, both static and dynamic, loads of the Falcon 9 launcher [1]. The analysis is performed using Altair's OptiStruct Inspire software, as follows:

1. Identify the design space, i.e. the volume that is available for the optimization after removing non-design areas that are needed to accommodate the joints. Figure 1 shows the design space and boundary conditions. Initial mass of the design space is 1.15 kg.
2. Define a mass goal: the maximum allowed mass for the camera bracket is of 0.15 kg, which represents a weight reduction of 87%.
3. Define a stiffness goal: to avoid resonance due to the launcher loads, the first eigenfrequency of the optical bracket must be above 1500 Hz.
4. Define alternative sets for the optimization parameters: three optimization alternatives are configured and compared. The one with less mass —92 g— is chosen as the final design.
5. Post-processing of the final design: The result of the optimization process is shown in Figure 2a. This geometry is smoothed with the PolyNURBS tool, with a slight mass growth up to 126 g.

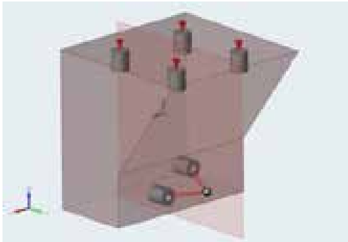

Figure 1. Design space and boundary conditions.

3. Results

Final design is shown in Figure 2b. Compliance with all design requirements [2] is verified:

– Final mass: 126 g < 150 g
– First eigenfrequency: 1572 Hz > 1500 Hz.

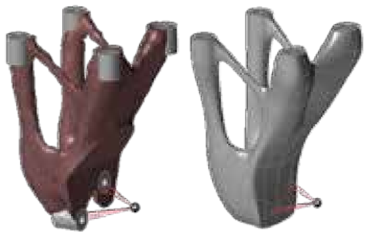

Figure 2. Optimization (a), Post-processed geometry (b).

4. Conclusions

An analysis of a CubeSat structure with Altair's OptiStruct Inspire software is presented. In this assessment, a mass reduction of over 85% is achieved, which shows the promising opportunities for design that AM together with TO enable.

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Machine-dynamics Monitoring for L-DED Operations

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Keywords: Laser; additive manufacturing; FEM; dynamics; validation.

1. Introduction

Additive Manufacturing (AM) is an emerging technology that enables to obtain near net shape parts with a minimal material waste [1]. Nevertheless, the process involves a large number of variables, which influence the final results, increasing the uncertainty of the process.

Therefore, modelling has arisen as a useful tool for AM, because it allows to anticipate the results before doing any experimental work and to correct the process parameters or trajectories accordingly [2].

One of the main challenges when developing a model is the experimental validation, since the real process conditions may differ from those theoretical. For example, the dynamics of the machine modifies process variables such as the feed rate at corners or low radii toolpaths. Consequently, a proper model should consider these variations.

In order to face this issue, a FEM model for the AM process has been entirely developed in Matlab environment. The model has the capability to adapt the mesh in every step. Therefore, the mesh is refined in the region heated by the laser in a certain step and then, the refined region moves along with the laser beam, see Figure 1.

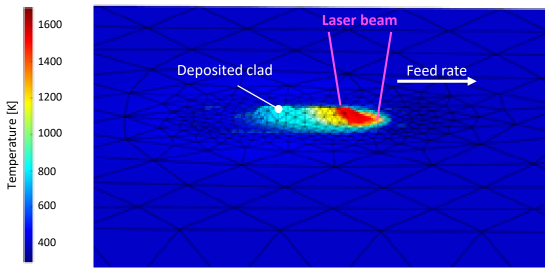

Figure 1. Simulation of the clad deposition via AM with automatic mesh refinement.

The model considers the material deposition process a distortion of the surface elements where the clad is generated. Moreover, the model includes an optimization algorithm for the mesh quality metrics, which updates the mesh every step and ensures a minimum skewness of the elements and a higher convergence of the results.

Finally, an algorithm that accounts for the dynamic behaviour of the machine is included in the model, which enables to increase the interaction time of each step proportionally to the feed rate reduction during the AM process.

2. Methodology or Experimental Procedure

A series of experimental tests that include different direction changes (0°-180°) and feed rate combinations (500-2000 mm/min) are carried out. During the tests, the real feed rate of the axes is monitored, as well as the accelerations of the machine, and their values are correlated to the theoretical feed rate of the machine.

Afterwards, a submodel which feeds the main FEM model is developed to define the real feed rate according to Eq.1, where "F" is the feed rate, "a" is the machine acceleration, and "α" the trajectory angularity:

$$F_{real} = f\left(F_{prog}, a, \alpha\right) \qquad [1]$$

In order to validate the model accuracy, the process temperatures are monitored in all tests and compared with those simulated. Besides, the clad geometry is evaluated in the straight region and in the direction change position, where a material over-accumulation is expected, and experimental results are compared with those predicted by the model.

3. Conclusions

A novel FEM model that takes into consideration the dynamic behaviour of the AM machine is obtained, which determines the real feed rate of the process and predicts the material and energy over-accumulation. In addition, the model could be adapted to any machine with a few tests, which increases its versatility and applicability.

4. Acknowledgements

This work is funded by the Basque Government through the QUALYFAM project under Grant Elkartek KK-2020/45 and the Spanish Science Ministry through the ALASURF project PID2019-109220RB-I00.

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Finite Element Modelling and Evaluation of Mechanical Properties of Wood-PLA Parts Manufactured through Fused Filament Fabrication

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Keywords: FEM; bending; wood-PLA; FFF; composite.

1. Introduction

Fused Filament Fabrication (FFF) is one of the most common additive manufacturing (AM) technologies that has arisen interesting from industry in a wide range of applications. In this paper, the mechanical properties of FFF 3D printed parts made of a wood-PLA composite are investigated both experimentally and computationally to predict the mechanical characteristics of the material processed through additive manufacturing.

There are different numerical approaches to solve this problem [1]. The novelty of the proposed model is that the manufactured parts are considered as two different ones. One of them is the one that forms the exterior walls and the other the one that forms the inner or filling. Indeed, as the material is processed through FFF, it is deposited according to a pattern where filaments and voids are combined to generate the inner volume of the part, whereas the skin must behave differently because it is deposited through a different strategy.

2. Methodology or Experimental Procedure

According to the problem statement described above, the material used to print the parts can be understood as orthotropic once it configures the volume of the part. Therefore, the same printing conditions have been repeated to print different specimens in three building orientation (0°-X, 0°-Y, and 0°-Z) and they were printed only with inside filling configuration without perimeter shell. Besides, the perimeter (skin) of the samples were printed separately with three layers in 0.4 mm height. For each printing condition, 5 specimens were manufactured and tested to guarantee the repeatability of the results [2]. These specimens were subjected to experimental tensile test. Secondly, the material's Young's modulus, Poisson's ratio and yield stress are determined and introduced in the ANSYS software. Then, a four-point bending test implementing the specimen geometry is simulated through this software. Finally, to validate the correspondence modelling, the simulation results are compared to the flexural test results which obtained previously.

3. Results and Discussion

The simulation process returns the equivalent stress that the specimen is bearing (Figure 1), the equivalent elastic strain, the total deformation and the reactive forces versus time are achieved. As it was expected, the maximum stress is distributed at the outliers of the sample between the force spans which the samples during the experimental test have experienced the similar behaviour.

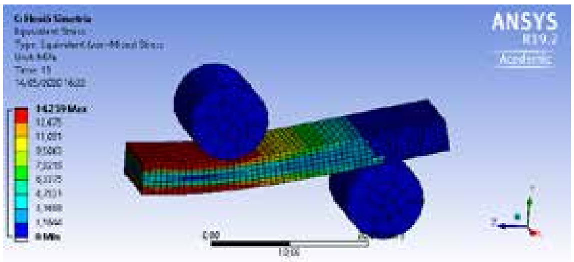

Figure 1. Results obtained by ANSYS

4. Conclusions

The deformation behaviour of the material from the experimental phase resemble to the simulation results. Therefore, the proposed model has been validated to be used to predict the behaviour of a wood-PLA composite after being processed through FFF, in contrast to its properties as raw material.

5. Acknowledgements

Financial support for this study was provided by the Generalitat de Catalonia government, through grant IU16-011591, which is greatly appreciated.

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Numerical Investigation of Deposition Strategies on the Residual Stress and Geometrical Deviation in Laser Metal Deposition

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Keywords: Numerical simulation; laser metal deposition; deposition strategy; residual stress; part deflection.

1. Introduction

Direct Energy Deposition (DED) technologies have been accentuated for the production of parts with complex geometry, repairing industries and modifying metallic parts [1]. These methods can be divided into different groups based on the process and power feed rate such as Laser Cladding and Laser Metal Deposition [2]. Laser metal deposition (LMD) is an advanced manufacturing technology that is widely used in various applications by adding material layer by layer. In this process, a 3D CAD model is created in a software then imported to a LMD machine for manufacturing parts. It is a challenging issue to control the process layer by layer in the experimental tests and to address this issue, numerical simulation can be highly beneficial to control and monitor the process. Numerous researches have been implemented in the case of simulation of the LMD to model the process thermomechanically and numerically [3].

2. Numerical simulation

A 3D model was design with a substrate base plate with 30x30x5 mm and a 20x20x8 specimen divided into 8 layers. MSC Apex software was used for meshing with 1x1x1 3D hexahedral elements. A 3D Finite Element Method was used in the Simufact Welding software. In the current research, the material considered for both substrate and powder was 316SS with 1279.85 ˚C solidus temperature, 1450 ˚C melting temperature, 0.294 Poisson ratio, 7699 kg/m^3 thermomechanical properties. To model heat conduction, a direct transient temperature model was used [4]. The laser power, feed rate and efficiency were considered 700W, 0.7 mm/s and 0.6 respectively. Cooling time of 25 seconds was assigned to the first layer and there was a 3 minutes colling time for the last layer. A set of different strategies were tested, including raster, contouring and mixed tool paths with continuous and single direction motion.

3. Results and Discussion

All studies run on and average 4370 seconds. Temperature distribution was analysed during the deposition process, reaching maximum vales over 1450^{o}C and maximum gradients over 1000^{o}C in the specimen. Residual stress reach values in the range of 400MPa to 500MPa and maximum displacement up to 0.6mm. Figure 1 shows the instant temperature distribution during the 7th layer of the two-direction continuous raster strategy as an example.

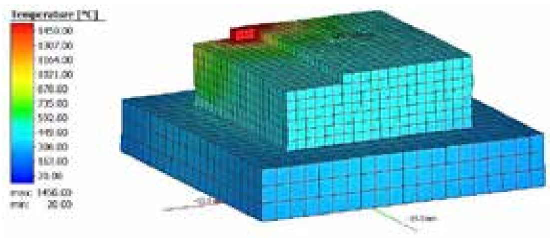

Figure 1. FE model of LMD process

4. Conclusions

In the current study, different deposition strategies have been investigated to find the values of residual stress and part deflection. Minimal maximum temperatures and gradients benefit part quality. Thus, strategies that minimize temperature distribution have the potential for better results.

5. Acknowledgements

This work was supported by Compete 2020 - Programa Operacional Competitividade e Internacionalização within LASER4AMTT project (POCI-01-0247-FEDER-039893). This work was also developed within the scope of projects supported by Portuguese Foundation for Science and Technology/MCTES.

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Training Program for Researchers in Design and Manufacturing of Experimental Prototypes for Fluids Engineering Using Additive Technologies

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Keywords: Experimental prototypes; additive manufacturing; fused deposition modelling; training techniques; DFMA.

1. Introduction

Experimental testing is one of the pillars in Fluids Engineering research. Traditionally, prototype production in this area was highly expensive and manufacturable geometries were quite limited. Nevertheless, with the arrival of Rapid Prototyping, and especially, Additive Manufacturing (AM), the scenario has changed radically. Within these technologies, Fused Deposition Modelling (FDM) has become an extraordinarily useful tool for experimental testing, allowing complex part manufacturing in light, resistant, composite materials at a very affordable cost.

With the aim of harnessing the full potential of this technology, the Fluid Mechanics Area of the University of Oviedo started in 2018 a training program for their researchers in this field.

The main objective of this work is to show the benefits and applications of incorporating AM as a resource for experimental research in Fluids Engineering, sharing the methodology used to address this task, as well as the results and experience obtained.

2. Methodology

The training of researchers was undertaken by means of two intensive courses. The first was conceived as a first approach to AM and the bases of FDM. The course included a visit to the advance manufacturing facilities of a local technological centre, and the task of assembling an FDM machine from scratch and printing basic models, as main practical activities.

The second course deepened in FDM and focused on teaching a systematic proceeding to the researchers, as well as building a solid base from which they could grow by themselves. Special emphasis was laid in Design for Manufacturing and Assembly and in appropriate selection of material, process parameter and layer orientation, considering part geometry and end-use. Finally, problem resolution was taught using cause diagnostics by part inspection.

3. Results and Discussion

After taking the courses, researchers were able to apply the new resource to their investigations. FDM was used for manufacturing experimental prototypes, as airfoils or even complete turbines, but also for a great amount of auxiliary parts (Figure 1).

The flexibility of the technology and having full control from the design to the final product, allowed the researchers to change designs almost in real time, avoiding idle times. Furthermore, quality experimental results were obtained using FDM prototypes, showing the reliability of the resource.

Figure 1. Different applications of FDM in Fluids Engineering employed by the researchers.

4. Conclusions

Integrating this technology and knowledge in this research area has granted the capability of self-manufacturing customizable, low-cost, and high-quality experimental prototypes. Additionally, the evaluation system implemented indicated that the training methods were appropriate and enabled the continuous improvement of the training program.

5. Acknowledgements

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Re-design of a Component of a Lower-Limb Robotic Exoskeleton for Integrating Sensing Capacity and Enhancing Multi-Material Direct Additive Manufacturing

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Keywords: Fused Deposition Modelling; multi-material; design; sensor; exoskeleton.

1. Introduction

Exoskeletons are high value-added products, usually manufactured in small series and often required to be adapted to the user. The user comfort is required to be maximum, whilst several sensing and actuating elements must be incorporated in the designs [1].

Multi-material additive manufacturing (AM) makes possible to produce components for such devices, as customised direct manufacturing and several technologies could be applied [2-3].

The present study addresses the redesign of an exoskeleton component, -a shank support used to attach the exoskeleton structure to the patient's lower limb-, to incorporate specific comfort and sensing functionalities (using 3 different materials: rigid, flexible and conductive) as well as improve its manufacturability by multi-material AM.

2. Methodology or Experimental Procedure

Different multi-material AM technologies are screened to list the set of requirements that define the manufacturability of a part in each possible case.

Assessing the technology constraints in coalition with the part specifications, and in a search for a compromise between technological capacity, availability and cost levels, multi-material Fused Deposition Modelling (FDM) technology is selected.

The three filament materials utilised for comparing the designs in the study are ABS (for the structural cage), TPU (for the padding) and PLA electrically conductive composite (for the internal circuitry).

The original design of the shank support (AM manufacturable, only structural part) is iterated in 3 re-design rounds, addressing the improvement of its FDM manufacturability, and the incorporation of soft padding (comfort) and sensing add-ons (function), while meeting the structural requirements set.

3. Results and Discussion

Based on the simulations, all re-designs can be manufactured via multi-material FDM with better printing conditions than in the original design. The structural requirements are met. The padding is successfully incorporated, although comfort should be assessed in live testing with end users. The solution for incorporating the circuitry is 3D printable, although its performance is not ensured, and it should be analysed in detail in further testing. Figure 1 portrays the shank support original design, the third design iteration, and its deployment in a FDM 3D printing platform.

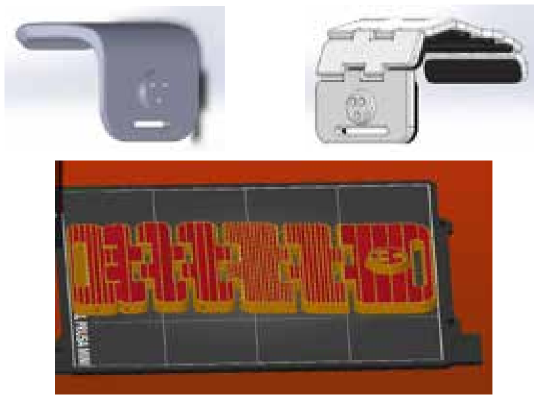

Figure 1. Original, third re-design, and FDM platform.

4. Conclusions

Three new designs are developed and analysed. The final design meets the structural requirements, includes soft padding and sensing add-ons, and proves good to be manufactured by means of multi-material AM. Still, further testing on the part performance and on the comfort level is needed.

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Product Development Methodology: Non-Quality Caused in Production by Mistakes in Product Development, its Measurement and Improvement Integration in the Product Development Process

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Keywords: Product development; defectiveness; collaborative design; tailor-made product; retail industry.

1. Introduction

The process of product development and technical documentation production required for manufacturing is a key issue in all organisations. Traditionally, the product development process has been considered responsibility of a product development area who goes alone through all the required sub-processes for turning customer specifications into a product to be put in the market and for producing the necessary documents to make it manufacturable. The time span of all these subprocesses differs widely among companies depending on the sector, the company size, or the type of product.

Additionally, product development has been considered for a long time as a very creative and technical process, in which new technologies or lean concepts were difficult to be implemented to improve quality or productivity.

In this article, we describe a new product development methodology integrated with production processes for tailor-made equipment in the retail sector, with tight product development times. This development times in this sector varies between 10 days and 3 weeks. This requires a high agility in the processes, meaning the overlap of phases, the integration of processes, cooperation, and automatization of tasks.

2. Methodology

To develop an integrated methodology for product development and technical documentation production with production processes, the current development process has been analysed in detail through different tools. First, a system to collect all the incidences related to the product design or to the technical documentation for manufacturing, was integrated in workshop stations.

Data are captured directly from the process and mined through analytical techniques to manage this real-time information and feed it back into the development process through automatic control systems integrated into the design software. Thanks to this information, the main problems in manufacturing phase have been identified.

The root cause analysis of all these incidences and its ranking have revealed the guidelines to redefine the methodology, which was implemented through an iterative process.

3. Results and Discussion

The methodology developed incorporates the principles of the product development process management through key performance indicators (KPIs), the principles of collaborative design with the manufacturing areas and the principles of standardisation of constructive solutions, in order to achieve efficiency and effectiveness. Methodology is structured in several steps, which must be fulfilled in an agile way, prior to the launch of production.

Its implementation showed an improvement over 10% in the quality of the product definition and the technical documentation produced, an increase of the productivity in both product development and manufacturing, and a boost of the internal customer satisfaction in manufacturing area with the product development work.

4. Conclusions

Methodology has been implemented in a real company with positive results. Moreover, it is scalable and applicable to other companies with significant tailor-made SKUs per day in short timing. It also allows to monitor the development process through internal and external defectiveness indicators (ppm's); generates significant learning and knowledge in product engineering areas; reduces wastes in the manufacturing phase; and creates continuous improvement in the global process.

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Design of a Conceptual Model for a Maintenance Object within a Producer: Impact on Distribution Network - a Simulation Case Study

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Keywords: Maintenance management; supply chain management; distribution network; simulation; case study.

1. Introduction

Over the last 50 years, a transition from the producers´ market to the customers´ markets has occurred [1]. Nowadays, logistics can be described as an interdisciplinary strategy to optimize the production system. Availability is, therefore, the central concern of logistics, which in turn is the link between logistics and industrial maintenance [2]. Currently there are already approaches for optimizing individual areas. In addition, in recent years, the importance of the orientation towards the added value process has increased. Maintenance should not be isolated in this regard, but rather should be "integrated" and dependent on all functional areas involved in added value [3].

Maintenance processes are closely linked to the rest of the value-added processes such as production and procurement, as well as materials management. Due to this strong interconnection of the different functional areas within the company, a comprehensive maintenance consideration is essential [3]. Therefore, this research paper pursues the analysis and design of an integrated and holistic process-oriented approach with the goal to derive the impacts and interrelationships between maintenance and distribution towards the end-customers.

2. Methodology or Experimental Procedure

The methodology used starts by reviewing the literature based on reference books and articles of supply chain management, distribution networks and maintenance management. Based on this research, a case study in a supply chain with a producer and its distribution network is designed. The producer has several production steps with their associated maintenance strategies.

With this basic framework, the case study is studied by parametrizing the maintenance strategy of a maintenance object in the production process of the producer. Goal is to observe the results of this strategy and its related maintenance characteristics in the subsequent steps of the production process and in the end-customer through the distribution network.

The analysis of the case study is performed by means of simulation. The simulation model is built using System Dynamics (SD). SD is a rigorous method for qualitative description of exploring supply chains [4]. For the research, VENSIM simulation software was selected.

3. Results and Discussion

The following results can be observed:

- Maintenance strategies play a significant role along the supply chain.
- The maintenance object and its availability have more impact in case of a high-demand scenario than in a low demand scenario.
- Maintenance personnel and reaction times are key factors for increasing availability
- Due to the level of initial stock parametrized, production breakdowns can have a low impact on end-customer specially in low demand scenarios.

4. Conclusions

The purpose of the paper is successfully achieved due to the following fact:

- Thanks to the scenarios and their results the impact of the maintenance strategy of one object could be observed. The impact depends also on other factors than only maintenance of the object, such as customer demand, stocks, supply chain steps and proximity to end-customers.

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Production Optimization Oriented to Value-Added: from Conceptual to a Simulation Case Study

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Keywords: Production optimization; lean manufacturing; theory of constraints; mining; case study.

1. Introduction

Management in companies today faces a true paradigm shift, characterized by a growing optimization of global value-added structures [1]. This need for innovation and optimization is relevant to all industries, and for the explosives manufacturing as well as reported by Karl Maslo, former EXSA regional manager [2]. To pursue this goal, lean philosophy is used as it allows applying sustainable improvements to the processes of a company, focusing on the value of the process and eliminating if possible or minimizing all those activities or tasks that when executed are not beneficial, that is, they do not add value [3]. Once all the sources of waste have been identified, it is intended to obtain the maximum productivity of the plant and identify the configuration that provides a capacity more adapted to the demand as well as achieving a reference framework of methodologies used in the improvement of processes that can be extrapolated to any other plant [4]. The research pursues to design and apply a systematic methodology to improve efficiency of a manufacturing plant increasing the value-added towards the end-customer. The objective of the work is to carry out an analysis of the manufacturing process of charged detonators to be potentially applied for other sectors.

2. Methodology or Experimental Procedure

First, a literature review is carried out with focus on the methods, tools and philosophies for the analysis and improvement of manufacturing processes as well as on the manufacturing challenges and the mining industry and explosives production. The study of the different methodologies provides an approach to the possibilities of improvement of the process under study. All this allows the generation of a model for systematic optimization by applying the tools studied. The model is applied by evaluating the production process. Then, it is possible to proceed to simulate the impact and to analyze the results obtained with the potential application of the improvement methods. The objective of this point is to assess how efficient the application of one chosen technique is on the process. Finally, recommendations of the proposed methodology are described.

3. Results and Discussion

With the application of the designed methodology the following benefits are obtained:

- With the application of the Kanban methodology, pull production system, SMED, theory of constraints, SMED or rapid response manufacturing different key indicators such as stocks, waiting times, overproduction, utilization of bottleneck resources and others can be optimized.
- Finally, based on the case study a work methodology is derived with the potential to be extrapolated to other sectors.

Based on the results, managers can decide for one or other technique depending on the improvement area they want to optimize based on their strategies.

4. Conclusions

With the development of this work, it is described how it is possible to analyze, assess and implement improvement tools in manufacturing systems with a long tradition and that to date have not needed to improve their processes significantly due to market dynamics such as manufacturing of detonators. Moreover, a work methodology for optimizing manufacturing plants based on the proposed tools can be applied to other sectors.

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Fatigue Behaviour Analysis of AISI 316-L Parts Obtained by Machining Process and Additive Manufacturing

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Keywords: Additive manufacturing; machining process; roughness; fatigue behaviour.

1. Introduction

Additive manufacturing has suffered a great boom, reaching high precision and detail in the parts generated and being implemented in different industrial sectors [1]. The incorporation of materials of different nature is feasible thanks to the enormous development of the technique, like composite and metallic materials [2].

Even though 3D printing offers the possibility to manufacture complex geometry parts or even parts impossible to elaborate by any other manufacturing process, it presents clear disadvantages compared to those obtained through the traditional manufacturing processes mentioned.

The main objective is to compare the dimensional accuracy at a micro-geometric level (surface roughness), as well as comparing the fatigue behaviour (by rotating tests) obtained in metal parts manufactured by machining and additive manufacturing processes.

2. Methodology

Two different manufacturing methods have been used, additive manufacturing by Selective Laser Manufacturing technique (STL) and dry turning process, to obtain AISI 306-L steel samples. For the additive manufacturing, two types of specimens have been considered depending on their manufacturing direction, vertical or horizontal. For the samples obtained by dry turning, the original steel bar was cut into 205 mm individual bars. Subsequently, they have been machined to the geometry shown in Figure 1, using a CNC lathe.

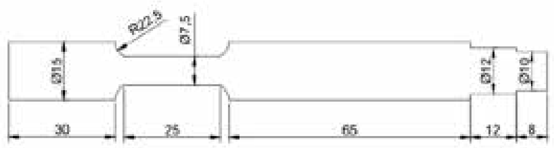

Figure 1. Tested samples geometry and

The tolerances and roughness (*Ra*) of all the specimens are analyzed. Also, for the fatigue test, an infinite life test type has been carried out. The specimen has been threaded into the part with the smallest section to be able to grab and hold the pendulum with the weight corresponding with which the test will be done (14,5 kg). Once the machinery is turned on and everything is ready, the test tube begins to rotate, thus subject to fluctuating forces.

3. Results and Discussion

An important fact when assessing fatigue behavior is the analysis of the crack growth. The best performance obtained in the mechanized specimens is mainly due to the fact that the crack growth is hindered by the orientation of the material grains, while in the 3D printed specimens, growth is favored due to the material deposition by layers. Also, the better Ra of the machined specimens compared to those of additive manufacturing delays the onset of microcracking on the surface, improving its fatigue behavior. Moreover, it can also be considered that the internal structure of the additive manufacturing specimens, in the period of solidification, trap small air pockets, helping the crack growth.

4. Conclusions

Due to the manufacturing process, the machined specimens have a better surface finish (Ra) than the ones obtained by STL. Thus, the mechanized specimens have a better fatigue behaviour than the additive manufacturing specimens. Due to the better surface finish, surface microcracks are less likely to appear and nucleate. Between both printed specimen types, the fatigue behaviour of vertical additive manufacturing samples is better than the horizontal ones, although the surface finish is better in the horizontal.

5. Acknowledgements

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Analysis of Residual Plastic Deformation of Blanked Sheets Out of Automotive Aluminium Alloys Through Hardness Maps

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Keywords: Residual plastic deformation; hardness map; blanking; aluminium; automotive.

1. Introduction

Current regulatory framework is pushing the automotive sector to an increased adoption of aluminium alloys to decrease the overall weight and enable for a fuel consumption and pollutant emission reduction. Nowadays, substitution with lighter alloys is mainly found, for vehicles in chassis and BIW, for weight reduction [1], and, in higher-end sectors, for transmission components, e.g. water pump pulleys and viscodampers, for benefits in power transmission regularity, durability and efficiency in powertrain systems, reduction of inertial masses and improved NVH performances. These applications require sheet metals to be formed in several steps (i.e. blanking, cold forming, stamping, rolling, …). Each of these work-hardens the material and contributes in reducing the residual plasticity of the component. In particular, blanking has been identified as a strategic process to reduce the scattering of mechanical properties in finished products [2] and to alter the formability especially of Al alloys in the following manufacturing steps, eventually reducing the fatigue life, which is core for power transmission components. Quick and reliable experimental procedure to assess the residual plastic deformation are scarcely available in literature and, relying mainly on destructive uniaxial tensile tests, may not be representative of the actual processing condition and of the local mechanical stress field inside the materials. This works defines a novel methodology based on hardness mapping to estimate the residual plasticity of blanked aluminium alloys sheet and to validate the mechanical stress predicted by FEM results.

2. Methodology or Experimental Procedure

Hardness measurements are known to be related to yield strength of materials and are a quick and non-destructive alternative to conventional tensile test. Falsafi et al. [3] outlined a procedure which exploits both Vickers hardness (H) and FEM to estimate the damage accumulated during the different forming steps:

$$D = 1 - \frac{H}{H_0} \quad (1)$$

Here a similar methodology is outlined. It relies solely on low load Vickers indentation tests, to reduce the computational effort, to estimate the reference hardness (H_0); it also investigates other parameters, as indentation diagonals, to cope with the approximation of monoaxial loading. Results are supported by metallographic/SEM-EDS analysis for a thorough interpretation.

3. Results and Discussion

The methodology is applied to investigate the residual plastic deformation of a blanked sheet metal out of Al 5754, in use for water pump pulleys. Fig. 1 shows that, nearer to the edge of blanking (axis origins), the material is significantly work hardened, reducing the residual plastic deformation available to the material.

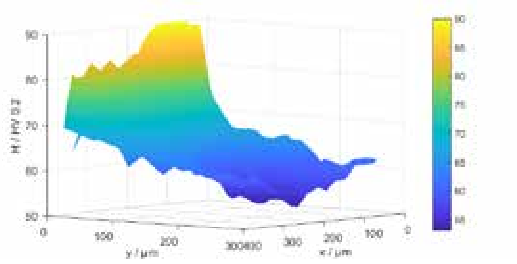

Figure 1. Hardness map of blanked sheet cross section

4. Conclusions

This work outlines a quick and fast procedure based on maps of indentations to estimate the residual plasticity of aluminium sheets, to aid process engineers in designing stamping tools and product engineers in evaluating the safety factors for automotive components.

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Methodology to Estimate the Modules of Elasticity of Parts Manufactured by FFF/FDM Combining Finite Element Simulations and Experimental Tests

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Keywords: Additive Manufacturing; FFF/FDM; material extrusion; FEM; tensile properties.

1. Introduction

Due to the manufacturing characteristics "layer by layer" of Additive Manufacturing processes (AM) such as Fused Filament Fabrication (FFF) or Fused Deposition Modelling (FDM) techniques, the manufactured parts exhibit anisotropic behaviour, and therefore it is complex to estimate their mechanical response [1]. As a consequence, finite element (FE) modelling of the performance of this kind of additive parts can be time-consuming, especially for implicit algorithms. For this reason, in this work, a proposal of simplified FEM model is presented to reduce the computation time but keeping accurate results.

2. Methodology

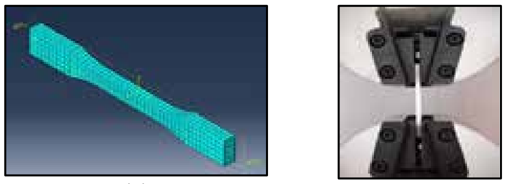
The methodology is based in a combination of experimental and numerical simulation techniques. FEM models were developed using the commercial finite element software Abaqus/Standard. At the same time, different test specimens were manufactured by a commercial equipment of FDM (model Kossel Mini) to perform tensile testing with a universal testing machine Hoytom HM-100kN. The parameters considered in this study were percentage of infill (25, 50 and 75%) and the construction orientation (XYZ). Tensile tests were performed following the guidelines specified in the standard UNE-EN ISO 17296-3 [2], and more specifically, the standard UNE-EN ISO 527-2 [3]. The last step consists of comparing the mechanical variables obtained by both experimental and simulation techniques, to adjust the simulation parameters, resulting in a simplified FE model that can be used as a prediction tool to analyse the tensile mechanical behaviour of these kind of samples.

3. Results and Discussion

Figure 1a presents the initial finite element mesh of the model developed, and Figure 1b shows one of the samples just at the beginning of the tensile test. The results show that the simplified finite element model is able to simulate the technical characteristics of components manufactured by additive manufacturing techniques, and so, to predict the mechanical behaviour of final parts.

4. Conclusions

This work shows the feasibility of the methodology proposed to reduce the computation time of finite element analysis of FFF/FDM parts under tensile loads. The FE model provide estimations about the mechanical strength of FFF parts according to the parameters considered. Finite element modelling of parts obtained by additive manufacturing is an open area for future research because it will contribute to minimize the time to market of new products based in additive manufacturing, but also the costs associated to mechanical testing of products.



(a) (b)

Figure 1. (a) Initial finite element mesh; (b) Tensile testing of one of the samples.

5. Acknowledgements

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Topic 5:
Factory of the future and Industry 4.0

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Design of a conceptual model for manufacturing companies within the 4th industrial revolution applying the Viable System model.
S. Gallego, M. García

Labour Productivity in Mixed-Model Manual Assembly 4.0

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Keywords: Assembly; productivity; mixed-model assembly; industry 4.0.

1. Introduction

The demand trends in the recent decades are the mass customisation of products or even the mass personalisation of goods [1]. The growing number of available options for both final consumers and industrial customers requires focusing on increasing the flexibility of assembly systems while maintaining high productivity levels [2] [3]. The advances in new digital technologies that could bring forward a 4th industrial revolution were conceptualised under the *tag* 'Industry 4.0' by a German strategic programme, and are namely: Big Data and Analytics, Autonomous robots, Simulation, Horizontal and vertical system integration, the industrial Internet of Things, Cybersecurity, The cloud, Additive Manufacturing and Augmented Reality [4]. Some of these technologies arrive with the promise of new opportunities for assembly systems design and operations, allowing them to fulfil the latest market requirements [5]. In particular, manual assembly lines and cells show potential for improvement when facing the complexity associated with producing a large number of products – or variants of similar products [6].

The goal of this work is finding out what technologies could be effectively applied to manual assembly systems, where/ how to implement them, and evaluating the economic and strategic return of investment of such changes.

2. Methodology or Experimental Procedure

Firstly, an analytical model is formulated in order to establish the relationships between several key factors – such as number of stations, cycle time, changeover time, batch size and quality rate, among others. A set of Key Performance Indicators are employed to jointly evaluate the effect of changes in the aforementioned factors.

Secondly, a parametric analysis provides insights into the effect that changes in the key factors as well as the combination of many of them effect on the performance indicators.

Finally, discrete events simulation – with the SIMIO software – is performed on a study case using real-case data from an international manufacturer of white goods.

3. Results and Discussion

This article aims to advance towards understanding mixed-model manual assembly cells labour productivity, and identifying their critical factors. Finally, this work intent is to detect the aspects of manual assembly that would benefit the most from the introduction of Industry 4.0 technologies.

4. Conclusions

This work aims to shed light onto the potential benefits of introducing Industry 4.0 technologies into manual assembly lines by understanding the main contributing factors to labour productivity and the role they play in preventing or enhancing mixed-model production flexibility.

5. Acknowledgements

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Insight into the Digital Innovation Hubs and their Role for the Industry 4.0 Knowledge Transfer

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Keywords: Industry 4.0; digital transformation; IoT; SME; toolbox

1. Introduction

The fourth industrial revolution means change. This transformation prompts several opportunities and challenges for the manufacturing industry; small and medium businesses are given the chance to actively participate in shaping this change. Industry 4.0 technologies like digital transformation and Internet of Things (IoT) are changing the business structures and the factories in profound ways. Large-sized enterprises have rolled up investment plans and roadmaps towards the Industry 4.0 transformation. If small and medium-sized enterprises (SME) want to prosper in the future and pursue the projects of the large-sized enterprises, they must be flexible and able to quickly adapt to new technologies, they should adopt Industry 4.0 technologies [1] [2]. The current research wants to go one step further investigating from a practical point of view the leanest way to transform SMEs. The access to the Industry 4.0 technologies must be simplified for the SMEs, especially for the microenterprises. SMEs cannot afford to lose money; they need to choose very carefully how to invest it, they need to hit the target when choosing the technologies for the transformation to the Industry 4.0 and this research has its focus on developing an interactive roadmap and a toolbox for the implementation of Industry 4.0 components in the supply chain of SMEs.

2. Methodology

In this work, we applied a research approach in three phases:

1st phase – a literature review was conducted in 2019 and 2020 to:

- identify the situation of SMEs in Europe
- benchmark the transformation towards Industry 4.0 of large enterprises
- understand Industry 4.0 concepts and technologies and estimate their costs

2nd phase – in 2020, the roadmap and toolbox for SMEs were developed using for the Front-End Development the following programming languages: HTML, CSS, Bootstrap and JavaScript [Table I].

3rd phase – the roadmap and toolbox were tested and validated in real SMEs.

Table I. Front-End Development Programming Languages

Programming language	Usage for the development of the roadmap and toolbox
HTML	Standard mark-up language for the development of a Web Page
CSS	Describes the style of the Web Page
Bootstrap	Framework for developing responsive, mobile-first websites
JavaScript	Programming language of the HTML and the Web

3. Results and Discussion

The access to the Industry 4.0 technologies must be simplified for the SMEs, especially for the microenterprises and therefore, the following roadmap, and the correspondent interactive toolbox, is proposed to simplify the decision making and the access to the Industry 4.0 technologies.

Figure 1. Roadmap for the 4th industrial revolution

4. Conclusions

This research shows that the roadmap and the toolbox help SMEs to enter the new era of the manufacturing using a simple process that is applicable in every industry and for every business case.

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Preliminary Study of Augmented Reality Based Manufacturing for Further Integration of Quality Control 4.0 Supported by Metrology

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Keywords: Augmented Reality; Industry 4.0; Metrology; Assembly; Quality 4.0

1. Introduction

In automotive and aeronautic sectors, automatic measuring systems have been widely applied when designing prototypes or assembling of relatively large volume parts. The accuracy of metrological data collected by those measuring systems is crucial to assure the high quality of product. However, the most accurate systems are usually slow due to involvement of several essential manual operations like targets placement, setting up devices, etc. In addition, the quality of measuring results can also be influenced by workers' experience [1]. In order to solve the above challenges, Augmented Reality (AR), that is one of key technologies enabling Industry 4.0 [2], is investigated and a systematic literature review is preliminary studied for further developing of an AR based quality control (QC) application working with non-contact 3D metrology.

2. Methodology

The PRISMA method was applied to answer the two main research questions:

- What is current state of AR based applications in manufacturing?
- How AR based quality control benefit to manufacturing in context of industry 4.0?

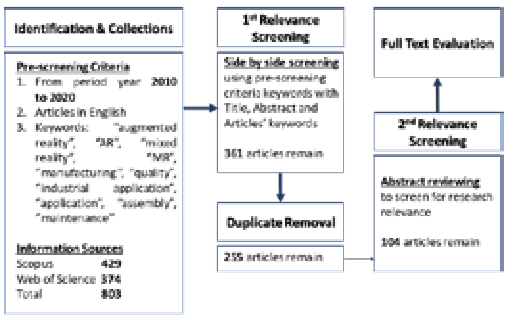

Figure 1. PRISMA flow diagram systematic review on AR application in manufacturing

The used search databases were Scopus and Web of Science. The initial search using search strings defined by specific keywords gave 803 articles. After two relevance screening processes and duplicate removal step, the remaining number of articles were 104 that would be used for full text evaluation.

3. Results and Discussion

The distribution of AR based assembly, maintenance, QC and other applications are 49%, 27%, 15% and 9% respectively. It shows that the investigation of AR applications in QC sector is still far less than in assembly and maintenance field, despite the fact that several AR based QC applications proved their benefit to manufacturing in terms of non-conformity management, quality monitoring and change management. It can be explained by the nature of these processes. Most of assembly and maintenance operations can simply get benefits from AR by replacing paper instructions with digital information overlayed in working context to reduce human errors, while AR applications in QC usually require higher accuracy in tracking and superimposing information.

In addition, the type of data used in AR based QC context are diverse depending on specific inspection task such as discrepancies check, surface quality check, etc. or different level of users like quality managers, QC workers, in-line operators, etc.

4. Conclusions

By utilizing results and methodologies of studied applications, a human-centred model combining with AR based metrology guidance application can be developed to firstly ensure the quality of measuring data. Then, to achieve quality 4.0 in long term, a ubiquitous AR based QC architecture could be built up to allow different end users fully exploit metrological data, quality data for enhancing efficiency and productivity of relevant manufacturing processes in real time.

5. Acknowledgements

This study was undertaken in the context of the DIGIMAN4.0 Project ("DIGItal MANufacturing Technologies for Zero-defect Industry 4.0 Production", http://www.digiman4-0.mek.dtu.dk) supported by the European Commission (project no. 814225).

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Path Towards Embedding Industry 4.0 Paradigm – Digital Competence Overview in HEI: the Alto Minho Region Case Study

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Keywords: Industry 4.0; digital maturity; digital readiness; alto-Minho Region; roadmap.

1. Introduction

Industry 4.0 relies on the use of interconnected drones, robots, smart security devices, autonomous vehicles, meaning that Industry 4.0 applied to business and industries rely more and more on digital technologies such as cloud computing, mobile Internet, social media, and big data. However, as stated by [1] "In Industry 4.0, people are the key players — work is getting easier, safer and more efficient — enabled through technology — but machines will continue to play the subordinate role". With such level of digital transformation [2] and digitization, and being people essential for the development of such business, Higher Education Institutions (HEI) also have an important role as they graduate the people that will have key roles in those businesses. The World Economic Forum [3] emphasizes that industry 4.0 will reshape jobs, and many of today's students will work in new job types that do not yet exist, and that will likely have an increased premium on digital skills. These students, that will be the future workforce, will need to work in an increasingly interconnected world, under more distributed and digital business models, and will be expected to collaborate with peers using digital tools to enable these new types of interactions. Thus, it is important to assess if HEI curricula's provide [4], to their graduates, the level of competences and skills that allow them to be digital readiness [5] and, therefore, be aware of this new digital transformation.

2. Methodology or Experimental Procedure

For the purpose of the presented research project, it was considered to develop and apply a survey about digital transformation amongst HEI' graduates in the Alto Minho Region, and then analyse the obtained results considering recommendations to modify HEI curricula.

3. Results and Discussion

The main objective of this work is to gain insights on graduates' awareness towards digital transformation, allowing to assess HEI curricula's, and how can this be used to redefine those same HEI curricula's in terms of main goals, skills and competencies.

4. Conclusions

The fourth industrial revolution, commonly called industry 4.0, creates an urgent necessity to update educational systems, specially the HEI curricula. Digital skills and competences of the HEI students need to be improved and enhanced, thus new learning content and new methodologies must be considered towards ensuring future professionals that will contribute for building growing and inclusive economies, especially in smaller and poor regions, like the Alto Minho region. In this sense it is important to assess HEI curricula's, in the referred region, and how can this be used to redefine those same HEI curricula's in terms of its main goals, skills and competencies towards embedding industry 4.0.

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Digital twin for the Integration of the Automatic Transport and Manufacturing Processes

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Keywords: AGV; COBOT Cyber-Physical Systems; digital twin; ROS.

1. Introduction

The digitization of manufacturing processes and machines allows us to integrate more elements that help improve productivity. An example is automated guided vehicles (AGV) and collaborative robots (COBOTS). The binomial AGV plus COBOT will allow an interaction with all the machines in the shop floor. The integration of intelligent industrial transportation with the manufacturing processes has not been implemented because its start-up interferes with the productivity.

To solve this problem, the processes must be simulated to guarantee a very precise planning that ensures the success and economic viability of the product. Digital twins [1] are ideal for these tasks since they allow us to simulate any hypothesis without any interference with the real world. The hypotheses can be very varied from a change in the process planning to the failure of an equipment or machine. Furthermore, it allows us to simulate anomalies of vehicles and other elements by changing parameters.

It is proposed a digital model of a commercial AGV with a cobot for an industrial environment. A user interface will also be developed in order to parameterize the simulations and display results in a more intuitive way. All this will be developed under an environment of cybersecurity and IoT connectivity.

2. Methodology or Experimental Procedure

The simulation environment will be run with ROS (Robotic Operating System) software [2]. It is constituted by a set of libraries and tools that allows for communication between different elements.

The creation of an external server to the ROS system allows the creation of an independent and scalable interface. This server can be provided with hyperconnectivity compatible with the requirements of the industry 4.0-cyber-physical systems.

3. Results and Discussion

As a result, a high-capacity and low-latency architecture is generated under industrial internet protocols. These characteristics make it scalable and compatible with a large number of applications. As can be seen in figure 1, cybersecurity is considered through the use of a cybersecurity router.

Figure 1. Communications architecture for industrial environments under cybersecurity requirements

The main advantage of the industrial ethernet network is its wide compatibility with various equipment, as well as being fully compatible with cyber-physical systems based on IoT.

4. Conclusions

This simulation platform allows us to predict with high reliability the hypotheses raised therein. All this leads to a reduction in costs associated with unplanned stops, maintenance prediction, among others. In any case, the result is a reduction in costs, especially unforeseen events.

In addition, the new interface facilitates the tedious work of entering parameters by modifying the code. The whole process can be visualized in 3D in order to have a more realistic perspective.

The architecture in addition to providing the advantages of the industrial internet allows scalability for future projects.

5. Acknowledgements

This research has been developed and funded by the project of the Spanish Ministry of Science and Innovation grant number PID2019-108277GB-C21.

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Development of Machine Learning Prediction Models for their Integration in a Digital Twin for a Tapered Roller Bearing Production Line

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Keywords: Industry 4.0; digital twin; machine learning.

1. Introduction

Tapered roller bearings can accommodate high radial loads as well as high axial loads. The manufacturing process consists of rings machining processes and components assembly, followed by an intense quality control. In this contribution, a digital replica -or digital twin- of the industrial process is performed. The virtual copy accurately reproduces the actual process behaviour and it is a powerful tool for efficiency and performance improvement. These replicas can also predict the real process behaviour under any potential change so determining the optimum operating conditions can be fairly facilitated.

Developing a robust and accurate digital twin requires a sufficient Internet of Things (IoT) network that efficiently and continuously records data from the process. Big Data tools are also required in order to process the information recorded by the IoT network. By using these tools, it is possible to know the state of the process as well as to achieve a deep understanding of it, what permits to propose changes and substantial improvements. Finally, by applying machine learning on the recorded data, digital twins can predict the process behaviour under possible changes and incidents.

The aim of this work is to develop a digital twin for a tapered roller bearing production line and to apply it, in order to achieve a noticeable improvement on its performance. This article is focused in the developed machine learning techniques as well as in the construction and application of the digital twin itself, which are the aspects less addressed in the state-of-the-art literature [1-4]. This article also shows how the digital twin helps us improving the performance of the production line.

2. Methodology or Experimental Procedure

This developed digital model not only reproduces the process behaviour and performance but also is able to predict operating parameters of several grinding stations based on the desired production. This prediction capability makes possible a substitution of the current manual adjustment of the grinding stations by an automatic adjustment predicted by the digital model, which is one of our main results and contributions.

3. Results and Discussion

Results from the performed simulations show that the occupancy of intermediate storage areas can be decreased from 40% down to 15%. A decrease of the cycle time in some of the critical stages of the process is also noticed. All these simulations have been performed using the automatic adjustment of the grinding stations proposed by our digital twin.

4. Conclusions

The presented work shows the methodology followed to automatize the process, to reduce the storage areas occupancy and to reduce cycle times by applying the developed digital twin. Furthermore, it can be applied to verify the consequences of any change in the process before applying it in the real production line, analyse and propose optimal production patterns, reduce the manufacturing tolerance, etc.

5. Acknowledgements

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Modular and Flexible Automation Middleware Based on Labview and OPC UA

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Keywords: Middleware; OPC UA; LabVIEW; standardization; modularization.

1. Introduction

The increasing automation level of processes in research laboratories and production systems leads to new technical challenges, especially in the implementation and maintenance of software architectures. New requirements arise considering the interface between Programmable Logic Controllers (PLC), robots, laboratory equipment, Human Machine Interfaces (HMI) and superordinate information systems (e.g. SAP). The growing demands require a flexible and standardized system to replace the heterogeneous interface landscape, which is present in many companies and institutions.

The basic idea is the implementation of a modular middleware, which connects and controls the components of individual manufacturing systems and laboratories in the context of Industry 4.0 [1].

In contrast to the software products available on the market, which usually come along with running costs and manufacturer dependencies, the created middleware is transparent, extensible and independent.

2. Methodology

Based on a market and technology research with focus on development environments, communication protocols and software architectures, the middleware and its interfaces can be defined. Due to the orientation towards industrial automation and data processing, LabVIEW is selected as the development environment. To fulfil the already mentioned requirements OPC Unified Architecture (OPC UA) is used to establish the communication layer [2]. In order to achieve significant benefits, the communication architecture must be considered in detail. A modular client-server model with well-defined interfaces and a specific handshaking for data transfer enables Plug-and-Play applications and flexibility.

3. Conclusions

The developed middleware enables higher flexibility, transparency and can be easily extended for new applications. The communication across several software layers and even hardware components on the process level create an integrated system which fulfils the increasing requirements in the context of Industry 4.0.

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An Approach for the Identification of Production Process Variables in Cross-Process Chain Production Processes like Battery Cell Production

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Keywords: Battery cell production; identification of process variables; cross-process chain production processes.

1. Introduction

Europe is currently not competitive in battery cell production [1]. To increase competitiveness, battery cell production must be made more efficient. A major factor in improving efficiency is the reduction of waste. This requires a fundamental understanding of the many dependencies between the production process variables within battery cell manufacturing. However, these dependencies are not yet fully understood [2].

Knowledge of the variables is essential for clarifying these dependencies. The challenge here is to completely determine them. For this purpose, different tools and methods are applied [3]. But, in the case of cross-process chain production processes like battery cell production, these quickly reach their limits because these tools are not suitable for the structure and properties of this processes [4]. The aim of the approach presented here is to support a complete identification of all process variables of battery cell production in the best possible way.

2. Results

The result is a digitally supported method, which is based on explicit and implicit knowledge in order to enable a complete identification of all process variables of battery cell production. The explicit knowledge is generated from documents of the workflow planning and from documents on methods and tools which are applied in the product development process. These are, for example, work and test plans or work and process instructions, as well as performance and requirement specifications. After reviewing the documents, the new knowledge gained through the explicit knowledge is combined with the implied knowledge based on the experience of the employees to fully determine the processes and the production process variables.

For this purpose, a horizontal modelling and listing of the process chain is carried out first. This is followed by a further subdivision of the process chain into individual process steps, which are further subdivided into main, secondary, sub-processes and activities. For each main process, the process variables are listed and divided into the following types: Input variables, output variables, manipulated variables, state variables and disturbance variables. If no further processes and variables can be retrieved, special questions are asked. These questions refer to the areas "completeness of process modelling" and "completeness of variables". The first area deals with questions about the subdivision of the process, while the second area concentrates on surveys on the types of variables.

A disadvantage of previous approaches to the identification of process variables in cross-process chain production processes is the absence of unique coding of variables. Frequently, variables do not only occur once, but can be found in several process steps. In this approach, the inputs for each process step are used to create a complete overview for all process variables including their assignment to the respective process steps. This is required to exclude multiple naming of the same variables under different names, to distinguish similar terms from each other due to the risk of confusion, and to add other process variables in other processes.

3. Conclusions

In the approach presented, a solution is presented which makes it possible to identify as extensively as possible the variables of cross-process chain battery cell production. This is done on the one hand by explicit knowledge based on process-relevant documents and on the other hand by implicit knowledge of the employees. The extensive identification of production process variables provides the basis for the complete clarification of dependencies in battery cell production and thus contributes to increasing efficiency.

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Project Portfolio Risk Assessment in Digital Transformation: Challenges and Opportunities

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Keywords: Project portfolio risk; digital transformation; risk assessment.

1. Introduction

Digital transformation has its own challenges and demands on organizational strategy and processes, as well as on team members capabilities [1,2]. Therefore, organizations have been engaged in a set of strategic goals and strategic initiatives aligned with digital transformation context [1]. Projects and programs grouped in project portfolios represent a fundamental element for achieving organizational strategic goals [3]. In this regard, literature recognizes that proper project portfolio management, and proper Project Portfolio Risk (PPR) management, contribute to project portfolio success, and consequently, leading to positive impacts on business strategy [3,4].

Research has been done on the impact of Industry 4.0 and digital transformation on production and supply chains, or on risk analysis regarding digital transformation adoption [5,6]. However, limited literature has been done from a PPR management perspective on how digital transformation impact on PPR assessment. Thereby, this study addresses the following research question: What are the digital transformation implications for PPR assessment?

2. Methodology

Based on a structure literature search, literature associated to risk management implications of digital transformation on different contexts, as well as literature related to demands of digital transformation on project management, were identified. Thus, based on conventional content analysis, key issues regarding digital transformation influence on risk management and project management were defined. Then, through a qualitative analysis, the key issues identified were contrasted against PPR assessment characteristics and scope, establishing a set of implications between digital transformation and PPR assessment. Finally, the implications were categorized as challenges or opportunities according to the nature of each implication identified.

3. Results

A set of concerns that PPR assessment should consider and incorporate for alignment to digital transformation demands, were identified. Dynamic portfolio risk visualization and agile incorporation of changes are part of the identified concerns. These concerns were denominated as challenges.

In addition, the analysis carried out also identified that digital transformation provides some subjects that can improve PPR assessment. Big data or virtual collaboration are two of the subjects identified. These subjects were denominated opportunities for PPR assessment.

4. Conclusions

Digital transformation and their implications on PPR assessment as unit of analysis were discussed. This research shows that digital transformation not only demands new considerations for PPR assessment, but also offers opportunities through which PPR assessment can face them, leading to improve the PPR assessment impact on project portfolio management decision-making process.

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Maintenance Management and Optimization of the Thermoforming Process for the Agri-Food Industry Using the S^2 Model

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Keywords: Thermoformer process; availability; Industry 4.0; IoT; efficiency.

1. Introduction

The agri-food industry has been greatly enhanced in recent years with the introduction of process control and the automation [1] of certain links in the production chain. The seasons of the year in which these machines must be operational and show robust and reliable operation have short durations (2 to 4 months) and are therefore greatly affected by unexpected failures that cause stops on the production lines.

This paper attempts to expose the comparative advantages that can be obtained in terms of availability and efficiency in the thermoformer process. With the introduction of Industry 4.0 [2] the S^2 model [3] and actuator control and early action, it is possible to optimize availability ratios on machines that at certain times of production require a high number of work hours and do not support unexpected failures.

2. Methodology

Analysis of two scenarios (process with or without the proposed control) provides values for overall process efficiency and availability in percentage terms and average unexpected failure repair time. To do this, all sensors, actuators, moving or static materials that can cause an unexpected stop of the machine are analyzed. Using IoT [4] for the process, it can be accessed and operated remotely by establishing secure communications.

Statistical calculation based on Weibull or Exponential distribution will be used to analyze the statistical model that best characterizes the actual process behavior.

3. Results and Discussion

The results show the improved ratios that establish a more rigorous control of efficiency, being able to schedule controlled stops with defined durations. After establishing the supply times, it possible to take the decision, i.e., those equipment's process must be repaired and/or replaced.

The comparison of proposed scenarios provides an average increase in efficiency by 7,5% and availability by 8.5%.

4. Conclusions

The benefits that are achieved in manufacturing when establishing process optimization models based on anticipation, detection, control, remote action in processes linked to large productions, represent an excellent advance in the profitability, control of information and service life of the equipment.

The benefits of this change in technology and the use of Industry 4.0 increase the transparency [5] required by current agri-food supply chain trends.

5. Acknowledgements

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Productivity Tool for Automated Guided Vehicles: OEE Indicator Perspective

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Keywords: Overall Equipment Effectiveness; OEE; performance; automated guided vehicles; AGV.

1. Introduction

Industry 4.0 is the future of global manufacturing which connect systems to things that makes dynamic management and self-organizing, improving the value chains of life cycle products [1]. The industry moves faster, the period of change or innovation are shorter, the decision must be made in less time, that is why tools should be used to help identify losses caused during a production process. The Overall Equipment Effectiveness (OEE) introduced by Nakajima (1988) [2] is a measurement tool developed from the TPM concept. Our objective consists in defining a new metric based conceptually similar to the OEE, translate to the efficiency of a logistic process in this case a system automated handling: automated guided vehicles (AGVs). The AGV is a widely used automatic guidance vehicle for the movement of raw material or finished product.

2. Methodology or Experimental Procedure

The methodology followed to achieve the main objective consisted in 3 steps. First, a literature review was conducted to understand the evolution of the indicator outside the production area. Secondly, parameters were determined, and variables were characterized for the calculation of the new performance indicator. In this step, losses related to performance, availability and quality were identified applied to the AGV function. Third, the structured metrics formulation to evaluate the new indicator and analyses the results.

3. Results and Discussion

According to our methodology we obtained a new indicator of the effectiveness of an AGV, based on the well-known OEE. In a planned route movement were calculated the three components of the OEE. The identified losses of an AGV are shown in Table 1.

Table 1. OEE breakdown losses

Category	Losses
Availability (A)	Time without work order
	Unplanned downtime
	Planned downtime
Performance (P)	Minor stoppages
	Reduced speed
Quality (Q)	Seamless runs
	Runs with incidents

The OEE it is calculated as follows Eq. 1

$$OEE = A \times P \times Q$$

$$OEE = \frac{Operating\ time}{Working\ hours} \times \frac{Ideal\ time}{Real\ time} \times \frac{Seamless\ runs}{Total\ runs} \quad [1]$$

A general outline of the new calculation of the OEE for the AGV is presents in Figure 1.

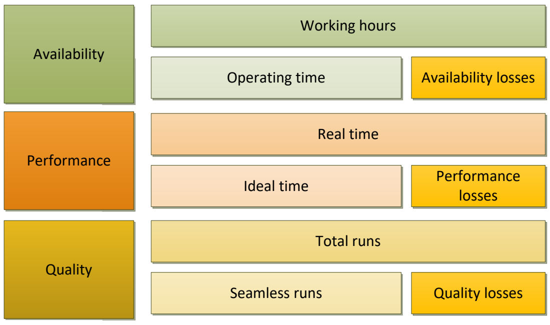

Figure 1. General outline OEE diagram

4. Conclusions

The framework stablished offers a novel way to measure the effectiveness in a logistic equipment. Through this adaptation is possible to know the effectiveness of this type of equipment in a factory, moreover, the indicator aid decision making and decrease wasting time in the AGV operation. The results of this indicator may vary in comparison to what is done for production equipment, because the AGV does not always go at its maximum speed due to turns, movement spaces, among other aspects that may affect its maximum movement capacity. It can be inferred that not always higher OEE indicates better performance.

5. Acknowledgements

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Cyber Physical Systems implementation to Develop a Smart Manufacturing

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Keywords: Industry 4.0; cyber physical systems; internet of things; Smart Manufacturing; key performance indicators.

1. Introduction

Industry 4.0 terminology is known as the recent revolution of the industrial environment. This revolution pretends to transform the traditional manufacturing process into a smart manufacturing [1]. One of the more distinguished characteristics of smart factories is their ability to increase production flexibility using real-time reconfigurable machines [2]. Although Industry 4.0 is based on several technologies, Cyber-Physical Systems (CPS) are regarded as a core technology of Industry 4.0 [3]. CPS are the integration of physical and computation processes which main functional components are their advanced connectivity, that allows real-time data acquisition, and their intelligent data management [4].

This paper aims to show how the CPS are able to transform the actual manufacturing process, for that purpose a case of study has been developed as an example of how to implement a CPS in a machine tool, specifically a 5-axis vertical milling machine of the Haas brand, in order to transform the acquisition of real-time data into worthy information for the industry.

2. Methodology or Experimental Procedure

The methodology to implement a CPS is based on its architecture. CPS architecture is formed by 5 levels (Figure 1), every level consists of guidelines to step-by-step design a CPS, from data acquisition stage to final value creation.

Figure 1. CPS architecture

3. Results and Discussion

During the implementation the variables that could be acquired has been analysed, filtered, adjusted, and finally, the most interesting variables has been selected for their real-time acquisition.

As a result, the data acquire in real time can be seen on a platform, for example time on, time off, tool changes… Moreover, this data can be downloaded and processed with Python to be transformed in more value information. In this case, these data are used to develop some real time indicators, such as OEE or the carbon footprint (see Figure 2).

Figure 2. Platform screenshot

4. Conclusions

CPS are changing the manufacturing process, making it more flexible, faster and giving more reliance to computational intelligence [5]. However, it is indispensable to know how to implement a CPS correctly and how to develop the proper tools to obtain value information from a CPS and accordingly use this value information to encourage decision-making.

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Design of a Conceptual Model for Manufacturing Companies within the 4th Industrial Revolution Applying the Viable System Model

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Keywords: Manufacturing; Industry 4.0; viable system model; technologies; organizational capabilities.

1. Introduction

The globalization and the increase of virtualisation of business relationships have significantly extended the complexity of the logistics challenge since the 1980s [1]. In addition, disasters, and pandemics such as COVID 19 (Coronavirus) affect business operations worldwide creating disruptions that compromise global economy [2]. In this context, manufacturing organizations are facing challenging moments in which organizational capabilities must evolve to remain competitive and secure long-term sustainability. To pursue this goal, the initiative created under the name "Industry 4.0" in 2011 [3] can help to strengthen the competitiveness of those manufacturing companies [4] able to adapt themselves to this fourth wave of technological advancement driven by various technological advances [5]. Most manufacturing companies have developed departments and initiated projects around the concept Industry 4.0. However, many of them lack the purpose, the organizational acceptance, and the alignment of those activities with the organization´s strategy.

2. Methodology or Experimental Procedure

The method used is the review of the literature based on reference books and articles. First, an overview of current challenges of manufacturing companies is presented. Then, the term and latest advances of "industry 4.0" are described by specifying its technologies and their current and future potential capabilities. Later, a conceptual model for improving organizational capabilities thanks to industry 4.0 is developed. For this development, the Viable System Model (VSM) was selected as methodological approach. The VSM is a cybernetic management model that was developed by Stafford Beer [6].

As a final step, based on the conceptual model the relations between technical areas, technologies and organizational strategy are determined pursuing a coordinated set of functions.

3. Results and Discussion

The results of the research are:

- Challenges of manufacturing organizations
- Industry 4.0 technologies and their current and potential capabilities
- A conceptual model for Industry 4.0 for manufacturing companies in which the relation with technical areas and company´s strategy is defined
- Implications of the conceptual model for manufacturing companies

4. Conclusions

The purpose of the paper is successfully achieved due to the following facts:

- The status of manufacturing organizations is described pointing out their current challenges
- Industry 4.0 is analysed according to the status of its technologies and their related current and future capabilities
- A conceptual model for Industry 4.0 for manufacturing companies is developed.
- Guide for future organizational structure, projects, and activities selection as well as with areas of higher potential

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Topic 6:
Manufacturing engineering in society

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3D Printed Surgical Planning Prototypes Manufactured by a Hybrid Multi-Material 3D Printer

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Keywords: Multi-material; 3D printing; hybrid; surgical planning prototypes; health.

1. Introduction

Additive Manufacturing (AM) has gone through a huge development in several fields such as aeronautics, automotive or health. In the latter one, the manufacturing of surgical planning prototypes appeared as an important application [1-4].

Most of the 3D printed surgical planning prototypes were manufactured either using the moulding technique (based on the 3D printing of the negative shape of the surgical prototype) or using high-cost technologies such as material jetting. Both approaches have been proven to be appropriate solutions. However, in terms of the moulding technique, it takes a lot of time: including the manufacture of the mold in PLA using FFF (Fused Filament Fabrication), the manufacture of inner parts, the casting of the silicone or hydrogel and the attachment of the different parts together. As this process takes a lot of time, and most hospitals require the prototypes in a 24-48 hours' period of time, it cannot be the first choice. On the other hand, most hospitals are not able to afford the cost of high-quality prototypes that material jetting technologies offer.

That is why it is necessary to develop a new cost-effective technology, which is able to achieve the tissue-mimicking effect of the soft tissues using silicones or hydrogels and to be relatively low cost. In this context, the development of a hybrid multi-material 3D printer, which combines FFF and DIW (Direct Ink Writing), appears to be an appropriate solution.

Therefore, the aim of the present study is to show the whole process of the manufacturing of a surgical planning prototype from the beginning of the process until it is delivered to the surgeons.

2. Methodology

A preliminary study is carried out for the commissioning of the hybrid multi-material machine by 3D printing a small kidney with a simple shape using three different colours (black, blue and white). The material used was PLA (Polylactic Acid).

Although no soft materials were manufactured, for the 3D printing of the silicones or hydrogels a vipro-HEAD (1-component print head) from Viscotec, Germany will be used.

3. Results and Discussion

As can be seen in Figure 1, a first kidney prototype was 3D printed. Different colours were used for each part: blue colour for the tumour; black for the kidney; and finally, white colour as support material.

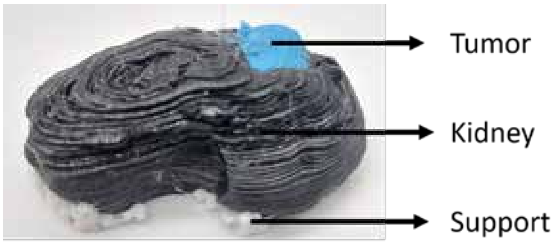

Figure 1. 3D printing of a prototype using a hybrid multi-material 3D printing which can use both hard and soft materials as well as different colours at the same time.

4. Conclusions

The present work shows an example of a surgical planning prototype that was printed in a hybrid multi-printer. Results are promising and show that this field is just starting to bloom up, but it is expected to have an important further development.

5. Acknowledgements

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Study of Additive Manufacturing Techniques to Obtain Tactile Graphics

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Keywords: Tactile graphics; additive manufacturing; rapid manufacturing; 3D printing; visual impairment.

1. Introduction

Tactile graphics (TG) are intended to facilitate communication for people with total or partial visual impairment. For this, they present elements in relief so that they can be perceived through the use of touch, also presenting graphics and flat texts so that their use is also appropriate for people without visual impairment. These graphics can be fixed or portable. As for the former, the most common are TG for urban orientation or indoors, which expose different landmarks and significant elements in relief, such as: streets, squares, buildings and Braille reading-writing code; being located in public spaces and requiring, therefore, resistance and durability. On the other hand, portable tactile graphics are flexible, small in size, single-use, and must be quite inexpensive.

Regarding the materials and methods of obtaining them, the fixed TG are manufactured in durable materials (metals and polymers) by molding and machining, as well as in ceramic materials by manual plastic forming and, very often, glazing. The particularity of their production is that they are made in very short series, mostly single series, and because of that their cost is very high. Regarding the portable TG, these are made of a paper base or by means of thermoformed polymer sheets.

In the present work, a literature review related to the application of additive manufacturing (AM) techniques to obtain tactile graphics, both directly and indirectly, is presented, showing the suitability of applying these techniques to this type of products given their specifications.

2. Methodology

The work begins with a brief description of the types of tactile graphics (fixed and portable) and the main techniques for their elaboration. Subsequently, a literature review of the state of the art related to the use of AM techniques to obtain tactile graphics is presented, differentiating between direct methods (RM: Rapid Manufacturing) and indirect methods (RT: Rapid Tooling).

The work is completed with the presentation of a new technique, currently under development, consisting of the application of the principles of AM to obtain ceramic tactile graphics by deposition of glaze to shape the relief on a ceramic tile, which leads to graphics with excellent qualities for collective use at a low cost [1].

3. Results and Discussion

The manufacture of permanent (or fixed) TG is usually carried out by conventional techniques (metal casting, thermosetting resin casting, CNC machining, handmade ceramics), and those portable by techniques based on paper (micro-encapsulation, embossed) and thermoforming of thermoplastic sheets. There are very few cases in which AM techniques are used to obtain TG, mainly using FDM and SLA techniques.

4. Conclusions

The characteristics related to the production volume (unique products or very small series) make the application of AM techniques as RM techniques very appropriate to obtain tactile graphics [2]. Furthermore, in the case of thermoformed graphics, in which a mold is required to obtain them, AM techniques are also applicable, acting in this case as RT techniques [3]. However, its current use is still very limited.

5. Acknowledgements

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Development of a Modular Kit to Improve DFA Learning

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Keywords: Design for assembly (DFA), modular kits for learning, learning by doing, conceptual understanding.

1. Introduction

During product design, the application of DFA is very important to analyse assemblability, improve the assembly process and reduce final cost. DFA was usually taught using three approaches: 1) Theoretical lessons to explain DFA fundamentals; 2) Seminar sessions to work on case studies; and 3) Laboratory sessions to disassemble and analyse products from the assembly point of view. However, the assessment activities revealed that expected objectives were not being achieved. One of the main problems was students' misunderstanding and mix-up of what a handling and an insertion operation are. Students also showed difficulties when it came to propose valid solutions to achieve real assembly improvements. In addition, only two real products could be analysed due to time restrictions and it was difficult to find real cases that combined several problems. Therefore, in this work a modular kit to be physically used by students for experimentation is proposed. The aim is to improve learning outcomes through multiple practical cases on a single product.

2. Methodology

To carry out this work, firstly a simple product made up of very few components (5 or 6) was selected. The selected product enabled to obtain a set of multiple cases showing different types of problems and solutions by means of changing some of the features that influence assemblability. In order to simplify the process, the alteration of features was accomplished by replacing portions of the same component (modular kits) rather than by using a large number of different components. In this way students were instilled the idea of modifying a component feature instead of substituting it. To realise the kit a classical DFA application problem, the simple valve example proposed by Boothroyd et al. [1], was chosen. Then, different assembly problems and solutions applicable to this product were proposed. Once the kit design was defined, it was manufactured. In previous academic years, the study of the above-mentioned valve problem had been carried out in a blackboard-based problem session. This academic year, the problem session has been replaced by a seminar session where students could physically experiment with the modular kit in small groups. The project was implemented in two courses at Jaume I University.

3. Results and Discussion

To assess the results of the project, two studies were performed. The first one involved carrying out surveys among students. The second provided a comparative study between the results obtained by the students in the assessment tests in the present academic year, and those obtained by students in previous academic years. Expected results by the implementation of this project on educational innovation were: to achieve a better understanding of the assembly processes; to improve the comprehension of the difficulties that may arise during the analysis of the assembly process; and to enhance the process of finding solutions that can be dealt with during the design process. Accordingly, an improvement of the learning outcomes and knowledge retention by students about DFA is expected. Previous studies carried out by the authors [2] show that skills acquired through practical learning result in a student's greater knowledge retention in the long term.

4. Conclusions

The use of modular kits by students makes possible physical assessment, thus enhancing the understanding of the problem and the development of solutions. The fact that the kits are made up of few components to assess assemblability of different design solutions by changing singular component features has improved learning outcomes.

5. Acknowledgements

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Responding to Rapidly Changing Product Demand through a Coordinated Additive Manufacturing Production System: a COVID-19 Case Study

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Keywords: Responsive manufacturing; additive manufacturing; agent based modelling; anarchic manufacturing; COVID-19.

1. Introduction

COVID-19's lockdown policies saw Modern Manufacturing Practice (MMP) - batch/mass/just-in-time supply chains – severed and societal demands rapidly change from products such as vehicles and clothing to Personal Protection Equipment (PPE), ventilators and equipment for remote working. The need for responsive manufacturing resulted in government/frontline services turning to society's Additive Manufacturing (AM) capability - homes, schools, universities, and industry - to provide essential products. While AM managed to respond and support government/frontline services, the highly distributed and diverse nature of AM saw major production inefficiencies and unnecessary delays.

To further enhance the responsiveness and productivity of AM, this paper develops and evaluates a series of strategies for co-ordinating AM for rapidly changing product demand. The strategies employ a host-client agent-based architecture that enables local governance of production logic thereby enabling the AM community to come together to tackle society's production needs.

To enable local governance, it is first necessary to understand how the selection and combination of production logics impact the overall performance of the production system itself. Correspondingly, the contribution of this paper is in the characterisation and quantification of the impacts of production logics and the consequences they have on AM production systems.

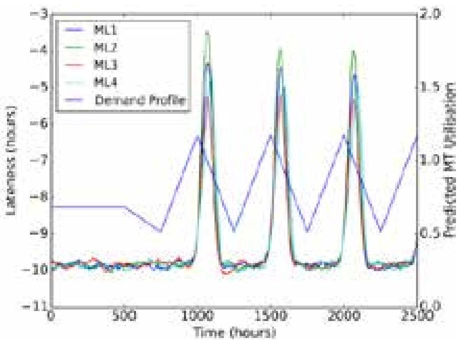

Figure 1. Performance of Machine Logics with fluctuating demand profile

2. Methodology

The simulation modelling methods followed the methodology set out in [1], where Agent Based Modelling (ABM) is used to model individual agent behaviour and simulation experiments run to observe the impact of varying experimental factors. Autonomous 3D printers selected jobs from a centralised queue in accordance to one of four production heuristics. Four product demand scenarios (Steady state (SS), Saw Tooth (ST), Step Change (SC) and Ramp (R)) were used, and the productions systems response recorded.

3. Results and Discussion

Figure 1 provides the result for the saw tooth demand scenario and the response from the four tested machine logic sets. Statistical testing on the distributions of each logic set showed significant variance in their response. Across all the scenarios, ML3 production logic was the most consistent. However, each scenario featured a different production logic set as the top performer. For SS no machine logic was shown to perform better or more consistently. For ST, SC and R ML3, ML1 and ML3/4 were shown to perform best respectively.

4. Conclusions

The study shows that the combination of production logics has a significant impact on the performance of host-client agent-based production systems and that desirable combinations exist for different production scenarios. The team are looking to further optimise production logics for host-client agent-based production systems, evaluate the scaling behaviour of these systems (e.g. 100,000+ machines) and how we may optimally transition between one set and another.

5. Acknowledgements

The work reported in this paper has been undertaken as part of the ProtoTwin project, conducted at the University of Bristol's DMF Lab (http://www.dmf-lab.co.uk) and is funded by the Engineering and Physical Sciences Research Council (EPSRC), Grant reference EP/R032696/1.

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First Approach for the Optimization and Fabrication of a Customizable Stent Prototype by 3D Printing Technologies

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Keywords: Stent; 3D print; thermoplastic; simulation; fabrication.

1. Introduction

During the recent years stents have been employed as an efficient treatment for patients with gastrointestinal diseases. Self-expandable metallic stents (SEMSs) have become a one of the most notable innovation ins therapeutic endoscopy since in 1990s were introduced [1]

Thermoplastic stents were designed to offer a solution to the main problems of metallic stents like inflammations, perforations, anastomotic strictures and peptic strictures [2].

Due to the low stiffness of the polymers, the radial force provided by this kind of stets is low. For solving this problem, many studies have been performed to optimize the geometry of them [3].

The introduction of thermoplastics offers the opportunity to introduce new manufacturing process like additive manufacturing (3D printing). With this kind of technique, personalized stents can be obtained in a short period of time [4].

2. Methodology or Experimental Procedure

The optimization of the geometry has been performed with ANSYS MECHANICAL 2020 R2 with a parametric optimization process.

The resulting geometry has been printed with a SigmaX printer (BCN3D, Barcelona, Spain). In order to obtain the best printing outcomes, different configurations for the 3D printing supports have been considered. The main material was TPU and also PVA for the supports.

3. Results and Discussion

By the utilization of the parametric optimization process, the radial force has been improved. Before its installation, the stent must be crimped, and consequently, there is a plastic deformation of the material that reduces the radial force. The modification of the geometry allows to reduce the plastic deformation and as a result increases the radial force.

The best printing conditions have been obtained after different modifications on the parameters. The main focus has been put on the supports configuration.

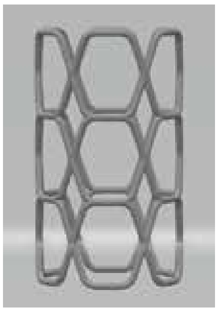

Figure 1. Resulting stent

4. Conclusions

The results obtained show a new alternative for the fabrication of biodegradable stents. Before its implantation, the security of the device should be tested by in vivo and in vitro test.

5. Acknowledgements

J. I.-M. wants to thank Universitat Politècnica de València for his FPI grant from (SP20190011) and Spanish Ministry of Science, Innovation and Universities for his FPU grant (FPU19/01759).

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A Case Study of Re-Design for 3D Printing: Proposal to Replace Metallic Fastening Elements in an Orthopedic Corset with 3D Printed PLA850 Substitutes

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Keywords: Additive manufacturing; 3D printing; Fused Deposition Modelling, FDM; orthopedic; Polylactic Acid, PLA.

1. Introduction

Orthopedic corsets are prescribed for patients suffering from scoliosis. These corsets, usually made of polypropylene, incorporate metal closures that serve to progressively correct the curvature of the back.

The closures are traditionally manufactured in sheet metal and incorporate some elements that must be welded (Figure 1). Due to this, metal closures have several handicaps: (i) increase the weight of the corset; (ii) raise its cost; (iii) are manufactured by third companies; (iv) increase delivery time to the customer.

3D printing provides an alternative way to manufacture lightweight and cheap closures, which can be produced in the orthopedic workshop themselves and which allow reducing the delivery time of the corset to the client [1].

The aim of the present work is the redesign of the closures of an orthopedic corset, so that they can be manufactured by fused deposition modelling (FDM) in polylactic acid (PLA850).

2. Methodology

To achieve the proposed objective, the original metallic design has been taken as a starting point (Figure 1). From this design, new designs that are feasible to produce through additive manufacturing have been proposed [2]. For this, the methodology proposed by Salonitis & Al Zarban [3] has been followed. The redesign process has been carried out in several stages. After each stage, the specialized technicians evaluated the proposed design and indicated the failures and improvements to be made.

The orthopedic technicians showed their concern about the mechanical resistance of a particular piece. To maximize the resistance in this piece, a design of experiments was developed to select the most suitable printing parameters.

The manufacturing cost of the printed parts was also evaluated and compared with the sales price set by the supplier for the metal parts.

3. Results and Discussion

After each redesign stage, a set of pieces has been printed, which have been used in the qualitative evaluation by specialist orthopedic technicians. In addition, a series of specimens have been printed that have been used to make non-standard bending test. With the results obtained, it can be stated that 100% filling and the cubic type pattern provide the maximum values of flexural strength.

Figure 1. Original metal closure for orthopedic corset.

4. Conclusions

Additive manufacturing is shown as an alternative to traditional manufacturing processes to produce closures for orthopedic corsets. Parts made of PLA 380 are lightweight, low cost and can be manufactured directly in the orthopedic workshop. The mechanical tests carried out have made it possible to select the most suitable printing parameters.

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An Overview of the Additive Manufacturing Capabilities in the Development of Rehabilitation Products with Customized Elastic Properties

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Keywords: Elastomers; additive manufacturing; rehabilitation products; TPU; energy absorption.

1. Introduction

At present, different types of Additive Manufacturing (AM) technologies, compatible with different types of material are appearing. In particular, the use of elastomeric polymers has increased due to their elastic properties, which have turned out to be of great interest for all types of products and industrial sectors, highlighting the healthcare sector [1].

The versatility of production control offered by AM has facilitated its integration with biomedical and rehabilitation engineering, allowing the customization of products according to the physiological and medical needs of each patient [2].

This article reviews the main developments of AM in the rehabilitation industry and its use with elastic materials showing case studies that point the important potential of this technology to innovate in the design and manufacture of products focused on the rehabilitation industry.

2. State of the Art

The advantages of AM to manufacture complex geometries and custom flexible structures (shape, density, geometry etc.) provides the possibility to use the elastic properties of different materials to design elastic products with "customized" properties in order to obtain damping profiles that could be adapted to a specific energy absorbing application.

One of the most widely used materials in the sense of the above is Thermoplastic Polyurethane (TPU).

Several compression studies of porous TPU structures [3,4] have proven its effectiveness for shock absorption and have shown that the amount of absorbed energy is influenced by the density of the structure and the type of geometry used, among other parameters. This highlights the possibility of customizing the elastic behaviour of structures and could be implemented in rehabilitation programs which usually use elastic products with highly specific levels of resistance, harder or softer, to try not to strain injured muscles under dynamic loading conditions, for example hand therapy balls.

However, a high percentage of the current research results is related to the development of support rehabilitation products under static loading conditions such as prostheses and orthotics [5].

3. Conclusions

The AM technologies have sufficient capacity to manufacture personalized products according to the physiological and medical needs of each patient. Elastic materials such as TPU can be focused towards rehabilitation therapies that need specific energy absorption profiles.

It has been detected that the use of AM technologies for the development of rehabilitation products with personalized elastic properties under dynamic loading conditions is underdeveloped and could be considered as a potentially interesting and little studied field of study.

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Classification of Leading Indicators for the Dynamic Analyses of Emerging Risks in Integrated Management Systems for Quality, Environment, and Safety

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Keywords: Dynamics risk analysis; emerging risk; management system; proactive indicators.

1. Introduction

Companies that adopt multiple management systems require integrated approaches that optimize resources and results. In the case of risk management systems of a new or emerging nature, the use of dynamics risk analysis approaches and the integration of real-time monitoring data in the risk assessment process offers an optimization opportunity [1].

Such monitoring process should be integrated into the iterative process PDCA (Plan-Do-Check-Act) used by organizations to achieve continual improvement [2], this process being the basis of the integration process of management systems [3]. This requires indicators that can be incorporated into the PDCA process from an integrative perspective. These indicators need proactive approaches, especially when risks are emerging given their dynamic characteristics.

In this way, the main objective of this work is to identify, and classify proactive indicators that facilitate the dynamic analyses of emerging risks in an integrated management system for quality, environment, and occupational risks.

2. Methodology

The theoretical framework proposed by [4], the dynamic risk analysis methods considered by [5-6] and the proactive indicators suggested by [7-9] are analysed. This analysis has been developed in the context of the integration of management systems.

3. Conclusions

A classification of proactive indicators that facilitate the dynamic analysis of emerging risks has been obtained. This classification differentiates typologies of the dynamic risk analysis methods and management systems, considering both individual and integrative perspectives.

4. Acknowledgements

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Occupational Health and Safety Start at School of Engineering

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Keywords: Occupational health and safety; manufacturing engineering; training methods.

1. Introduction

The concept of Occupational Health and Safety was born with the industrial revolution with the intention of protecting workers from the occupational risks to which they are exposed in their jobs. The manufacturing sector is one of the sectors with the highest accident rate due to different factors that range from the use of dangerous machinery, the lack of training for specific risks or the lack of preventive culture.

Following European Directives, different regulations in European countries where there should be European convergence, however not even within the countries themselves or within the same university there is such convergence. Taking into account that a governmental regulation is articulated in a different way so that the students get to do the training without having received training in occupational health and safety, it does not collaborate in a positive way to people who will later face the working world and nowadays globalized.

This is why training in Occupational Health and Safety is included in the academic plans of universities worldwide [1]. Specifically, in the subjects related to manufacturing engineering, the training has a high risk, for this reason this article investigates the current situation of training in the field of Occupational Health and Safety with regard to manufacturing engineering in order to find out the importance given to it, and therefore its effectiveness [2], and to propose options that will make it possible to reduce the accident rate in the future [3]. By analysing different universities, it will be possible to compare how they are carried out and establish what is happening in a restricted area such as Spain.

The aim of this paper is to analyse training in the area of occupational health and safety in engineering degrees and its relationship with the field of manufacturing engineering, analysing the coordination between subjects and the timing of training in Occupational Health and Safety.

2. Methodology or Experimental Procedure

In order to carry out the analysis, the aim is to study the most relevant Spanish universities in the field of manufacturing engineering, analysing the specific degrees associated with this field according to different ranking like to the Shanghai ranking or others that may be relevant, which will allow to find out about the preventive culture that exists in the different selected universities, that will enable to establish a comparison with other subjects that have nothing to do with engineering.

At the same time, it will be necessary to carry out a study of the focus given to the subject of Occupational Health and Safety in the study plans and its relation to the current legislation in this field.

3. Results and Discussion

A first analysis shows that students attend laboratories and workshops from the first courses, with specific training. After that it is expected to know if there is previous training in safety matters and its importance to this field for each university. The number of credits assigned to it and even additional training will be announced.

It is expected to find a relationship of the importance that the subject of occupational hazards has for a profession with the characteristics of Manufacturing Engineering. The possibilities that exist to implement a preventive culture from academic training will be made known. It is expected to know the methods carried out for the effectiveness of such training.

4. Conclusions

According to the results obtained, an assessment could be made that would allow us to establish improvements in the area of Occupational Health and Safety. It is hoped that it will be possible to conclude with a contribution of a type of practical methodology capable of implementing measures prior to the professional development of the Mechanical Engineer.

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Safety Efficiency Value Stream Mapping (SEVSM) - A new Tool to Support the Implementation of Lean Safety

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Keywords: Lean; health and safety at work; Lean Safety; Safety and Value Stream Mapping; TPM; standard work.

1. Introduction

It is estimated that 1000 people die every day due to accidents at work and 6500 due to occupational diseases worldwide. Besides, 2.33 million work-related deaths were recorded in 2014 and 2.78 million deaths in 2017 [1]. Lean Safety was designated to create a safe and healthy work environment, in which risk management is performed, reducing or eliminating them, and seeking to motivate employees [2]. The use of Lean Safety to improve occupational safety and health in organizations contributes to the reduction of waste, in particular in the time when employees are absent from their activities, in costs arising from payments to employee's insurance and damaged tools or equipment. However, the lack of indicators related to employee safety, the cost associated with the implementation of management systems, and the complexity of industries make it difficult to apply Lean tools, which corroborates the negative impact on the health and safety of employees.

As can be demanded, health and safety at work are of paramount importance nowadays for institutions, given the social and financial reasons that arise from it. In parallel, the institutions focus on improving processes and eliminating waste from production processes. Therefore, there is a need to develop tools capable of combining these two themes.

2. Methodology or Experimental Procedure

Thus, a tool was developed: Safety and Value Stream Mapping (SVSM), which aims to facilitate the identification of the risk level of each job, obtained through risk assessment, verification of the type of risk as to the cause of the security breach, and an indication of the most appropriate Lean tool to be applied for risk resolution. Furthermore, it is possible to obtain a diagnosis of the production flow, with the most significant production indicators for analysis.

The SVSM aims to combine tools to analyse the indicators from the productive perspective of the processes, safety and efficiency.

3. Results and Discussion

The SVSM was implemented in a metalworking company, where problems were identified in the productive and security fields. After performing the SVSM procedures to solve the problems found, the most appropriate Lean tools were applied to each process, namely Total Productive Maintenance (TPM) and Standard Work. The improvements obtained with the TPM were 38% of the risk level of the organization's job. The improvements obtained with Standard Work were 31.8% in reducing the process time and 49.3% in reducing the risk level.

Table I. Proposal of tools combinations

Proposal of tools combinations	
Value Stream Mapping	Productivity perspective, by mapping the flow of information, material and the process.
Safety Stream Mapping	Occupational safety perspective, through the risk level of each production area.
Overall Equipment Effectiveness	Efficiency perspective, through availability, performance and quality.

4. Conclusions

The applicability of SVSM was efficient and promising, given the positive impact on occupational safety and productivity of the organization. However, it is necessary to implement it in different organizations and different industrial sectors.

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Impact of the Current Production, Supply and Consumption Standards on the Sustainable Development Goals

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Keywords: Greenhouse gas; municipal solid waste; energy; transport; sustainable development goals; CO_2.

1. Introduction

The current path which the industry is following cannot continue to progress towards a complete degradation of the natural resources and the nature itself.

The aim of this paper consists in analysing and filtering the information which will be used as foundation to quantify the impact on the environment of the current manufacturing and to decide which actions are to be applied to mitigate the effects of the climate change on the ecosystems.

2. Methodology

Exhaustive review and filtering of the latest available statistics and literature focused in: analysis to provide reliable data reflecting the footprint of the human kind on the environment and the identification of the main methodologies which would boost the necessary Sustainable Development Goals (SDG) [1].

3. Results and Discussion

There will be presented three different sorts of results: the gap which exists between the impact of the human industrial activities on the nature and the Sustainable Development Goals 2030 (Figure 1); the best methodologies, such as the LCA (Life Cycle Assessment), to quantify and mitigate this impact (Table I) and the fields where an improvement of the manufacturing methods would decrease the negative consequences on the ecosystems and living beings (Table II).

Table I. 3 Phases system to decarbonize the industry [2]

Phase	Period	Actions	CO_2 Reduction
Phase 1	2020-2035	Energy efficiency improvement Electrification of industrial processes	20%
Phase 2	2035-2050	Materials replacing Implementing CO_2 capture systems	50%
Phase 3	2050-2070	Increase of the hydrogene use	80-100%

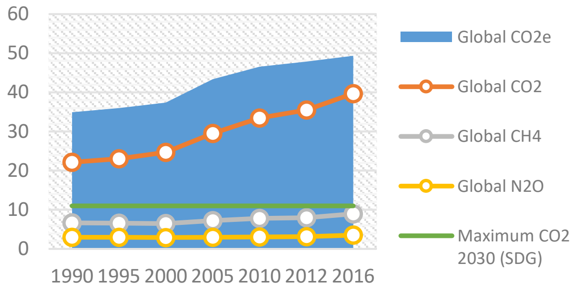

Figure 1. Evolution of the main greenhouse gas emissions (GHG) global production (Gt) [3] [4]

Table II. EU/UN Sustainable Development Goals influenced directly by the industrial activities [1]

Sustainable Development Goals		
Clean water supply	Clean and affordable energy	Sustainable industrialization
Sustainable cities and societies	Sustainable production and consumption	Climate action

4. Conclusions

The current production standards are against the SDGs. The contrasted data shows that unless a new industrial revolution occurs, the targets for the CO_2 emissions will not be achieved neither by 2030 nor by 2050. Moreover, there is a lack of comprehension concerning the real impact of a certain activity in the environment and to tackle this, the available methodologies need to be improved and spread within the industry, guaranteeing their utilization.

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Sustainable and Advanced Manufacturing Processes of Light Structural Materials of the Transport Sector

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Keywords: Hybrid components; lightweight structural materials; light alloys; sustainability; aeronautics.

1. Introduction

It is estimated that CO_2 emissions from within the European Union in 2016 are distributed as follows, 72% for road transport, 13.6% for shipping and 13.4% for civil aviation, with the remaining 1% for other activities, including railways. The commitments adopted by the Advisory Council for Aeronautics Research in Europe (ACARE) include a 75% and 90% reduction in CO_2 and NO_x emissions respectively and the design and manufacture of recyclable vehicles. Besides, there is a consensus on the benefit of reducing the mass of vehicles concerning their fuel consumption. In this context, and to meet the increasingly strict requirements, in recent years research has been carried out into new, more efficient materials and multi-materials and innovative production processes to reduce both the consumption linked to transport and the pollution caused. On the other hand, the domain of structural lightweight materials is broad, so in this paper a review of the scientific literature published on them during the last 5 years is proposed, making a selection of the most relevant articles by defining a search strategy for articles included in the database of Web of Science, published in Open Access, in English, in journals with impact factor Q1-Q2, or proceedings of prestigious conferences, during the period 01/01/2015 to 01/01/2020. The final objective of the work is to provide a global perspective of what are the latest trends in studies on light structural materials with application in the aeronautical and/or automotive fields, in studies oriented towards sustainability, and with special interest towards studies where advanced manufacturing processes and/or machining processes are applied [1,2].

2. Methodology or Experimental Procedure

The aim of the methodology applied is to establish a state of the art minimizing the risk of bias in the selection of the studies included. Initially, the key concepts representative of the knowledge area to be studied are identified, the quality, inclusion and exclusion criteria to be applied to all studies are defined to eliminate any possibility of bias in the selection, and the search criteria and Boolean equations to be used are established. As a search tool for the selection of articles, the use of the Web of Science (WoS) has been established, as it provides access to a series of multidisciplinary databases containing a large number of articles from scientific journals and conference proceedings of verified quality. The selected studies are classified by the number of citations.

3. Conclusions

There are various lines of work aimed at optimising consumption and reducing the emission of pollutants: the development of new engine technologies, the use of alternative technologies, and the reduction of the weight of vehicles, either by reducing their size or by replacing conventional heavy materials with new materials or multi-materials. Within this last line, the use of light structural materials such as light alloys of titanium, aluminium and magnesium, all of them with an excellent density/mechanical properties ratio, the use of plastic and polymer compounds, or the potential multiple combinations between them, can be highlighted.

4. Acknowledgements

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Fused Deposition Modelling Process Environmental Performance through the Carbon Footprint Evaluation

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Keywords: Fused deposition modelling; carbon footprint; environmental feasibility; additive manufacturing.

1. Introduction

In traditional plastic manufacturing processes such as injection molding, the type of plastic influences energy performance, thus impacting the environment [1]. Additive manufacturing does not escape this reality. To evaluate the main source of greenhouse gases in the FDM process, an energy performance evaluation was conducted [2] on the printing of different materials. After obtaining the equivalent CO2 emissions, they were compared with the results obtained by Tagliaferri [3] with the eco indicator 99. The aim is to show the variability of the emissions produced in manufacturing using FDM technology depending on the material used and the production batches.

2. Methodology

Five types of plastic materials were selected (Table I) and their printing was simulated using CURA software on an Ultimaker S5 printer.

Table I. Selected materials, printing difficulty and melting point

Material	Printing difficulty	Melting point (K)
PLA	Low	433
PETG	Low	513
ABS	Medium	473
TPU	High	490
PP	High	358

To obtain the energy consumption in FDM technology, the energy consumption formula was adapted from [4]. For the calculation of greenhouse gases, we rely on [5] and [2].

3. Results and Discussion

Compared to the research of Tagliaferri [3] the geometry selected for this work is standard [6] and used for other types of tests. Moreover, multiple materials selected instead of PA12. Furthermore, the comparison of the production capacity of FDM technology against those already mentioned puts it at a disadvantage for multiple production series, however, this is not the main advantage of the technology. FDM technology offers greater freedom in the selection of material for the required application.

4. Conclusions

Among the materials chosen for this study, ABS has a greater effect on CO2 equivalent emissions (990.99 kg), while PLA and PETG according to the results are the materials that produce the least CO2 equivalent 220.26 kg and 220.35 kg respectively. By comparing these results with those obtained in the study by Tagliaferri [3] we can conclude that the variability in the CO2 emissions due to the printing materials may be greater than the one due to the printing technology. When testing with different materials, it is possible to observe that depending on the need, the type of material can be modified to find one with less environmental impact, without sacrificing the desired mechanical properties.

5. Acknowledgements

The authors gratefully acknowledge the financial support provided by the Santander Foundation for the mobility of Ph.D. students.

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Evaluation of a Soft Skills *Serious Game* Educational Methodology in an Industrial Technical Training Program

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Keywords: serious games; gamification; soft skills; learning factory.

1. Introduction

The technical training of the industrial branches sometimes shows important shortcomings of new graduates in training and practice in analytical skills, high-level critical thinking, communication skills, teamwork and understanding of engineering in business practice, commonly called soft skills [1]. Other authors add that education in industrial areas has not been able to keep pace with advances in manufacturing technology, nor with the demands of the labour market [2].

Gamification, understood as the application of design elements and game principles in the context of achieving learning outcomes, acquires a remarkable dimension and relevance. The development of educational methodologies based on gamification is necessary to ensure meaningful training results. Such methodologies should help to reduce technical training gaps. It is therefore necessary to measure its results in order to evaluate its effectiveness.

In this context, this work it is focused on designing, developing, and measuring the results of a training module including gamification. This module is taught in an experimental training program aimed at a group with a heterogeneous educational levels whose all its members play the role of team leader, perfectly characterized in the Automotive Cluster of Aragon (Caar) skills and competencies model. The objective of the work is to evaluate the improvement of the training outcomes in soft skills when applying a gamification training method and its differential impact on the target group based on their profile.

2. Methodology

This work carries out a methodology and results evaluation project for soft skills-conflict resolution module, through gamification. The module is taught in the experimental training program for team leaders, developed between the Department of Education of the Government of Aragon, and Caar. This work is framed in the context of the doctoral thesis that Caar develops in close collaboration with the School of Engineering and Architecture of the University of Zaragoza, (EINA), about the impact of gamification, characterized in the concept of a learning factory. The module is taught for a sixteen student group, who develop a similar professional profile in their companies. However, they have different academic and experiential levels, which allows to draw relevant conclusions related to these profiles. For this evaluation, a discussion is carried out on the evaluation methods of gamified training, its advantages and disadvantages, and the more effective evaluation model is chosen in this context.

3. Results and Discussion

The work allows to obtain significant results on the methodology used in relation to the heterogeneity of the group. In addition, it is expected to expand the study in a second phase to other groups of students of different profiles, engineering students and working professionals, contrasting gamification with traditional methods. The final objective is to carry out the study in a significant sample to be able to generalize the results.

4. Conclusions

The study draws conclusions about the design of the methodology, the validity and efficacy of the educational method, the evaluation model and the relationship between training, experience, and educational results. Likewise, this work is essential to be able to extend the study to other reference groups, student profiles, and other types of methodologies to be able to contrast their different effectiveness. The results of the work will also serve for the design of future educational programs linked to gamification, especially in the context of the learning factory.

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Digital Skills Mentoring for Online Teaching and Evaluation in the Industrial Engineering Faculty of the University of Malaga

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Keywords: Mentoring; online; industrial engineering; digital skills; Covid-19.

1. Introduction

The current situation caused by the Covid-19 has led a change in the teaching way of the University of Malaga. This change has been oriented to online teaching and evaluation procedures.

The technological development has allowed the use of synchronous and asynchronous online communication tools, which facilitate the distance teaching processes [1]. These tools are usually integrated into virtual training systems which facilitate the students learning process [2].

However, the use of this educational technology is sometimes novel or of low use by teachers, due to the most usual in person teaching process. Therefore, the teaching staff training and information about the use of virtual spaces is required [3].

In this work, different actuation of digital skills mentoring, focused to teaching staffs of the Industrial Engineering Faculty in the University of Malaga, have been exposed.

2. Methodology

In order to focus the actions required in the mentoring process, an initial assessment of teacher´s needs has been carried out. To this end, a questionnaire has been proposed to participants in the mentoring process.

Different videos were performed to explain the use of Moodle tools for evaluation activities. These videos were available throughout the mentoring process. Furthermore, additional videos about videoconferences tools were also carried out.

To facilitate the use of these tools, two online seminaries were developed, the first one about Moodle evaluation tools and the second one about Google Meet and Microsoft Teams videoconference tools.

Finally, all the participants doubts were resolved through emails or videoconference.

3. Results and Discussion

The digital skills mentoring process were carried out between June and September of 2020. Twenty-one participants and two mentors were part of this actuation.

Regarding the initial questionnaire, the first actions has been related to the evaluation tools, due to the exam period coincidences. Eighteen videos have been performed to explain different Moodle tools for the evaluation activities. The objective of these videos was to create an objective evaluation test (using options such as selecting the correct answer, related terms or short answer, among others), as well as activities to evaluate problems related to the content taught.

Two seminars on online assessment techniques and the use of the Google Meet and Microsoft Teams platforms have also been held, lasting two hours each one.

In addition to the doubts raised during the seminars, a total of 11 questions related to the use of online evaluation tools have been resolved.

4. Conclusions

The digital skills mentoring has facilitated the teaching staff labour using synchronous and asynchronous online communication tools available in Moodle. The Seminars and videos performed have allow creating new evaluations methodologies in the Industrial Engineering Faculty of the University of Malaga. In addition, it can be considered that these actions have improved the teaching staff capacity.

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Design Learning: a Methodology for the Autonomous Design and Manufacture Customized Toys Based on Machine Learning

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Keywords: Product design; customization; augmented reality AR; mix reality MR.

1. Introduction

The current international pandemic situation has caused collateral damage in many sectors of the economy, including the industrial and commercial sectors [1], as well as altering the lifestyle of families. One segment of the population that has experienced this global problem most closely has been children, who have seen limited opportunities for personal development and learning [2]. This article seeks to find an innovative alternative for the manufacture and marketing of toys aimed especially at the youngest children and also those with special physical and psychological needs, and in this way mitigate some of the negative effects of quarantine. In this way, and through augmented reality (AR) [3], mixed reality (MR), deep learning techniques and additive manufacturing [4], a methodology is created that is capable of capturing the needs and tastes of children and creating virtual images that children will use to validate design concepts. In this way, the design properties of shape, colour and material will be combined to define the ideal toy for a child or group of children in a personalised way, creating the digital files necessary for its manufacture in an autonomous way by additive manufacturing [5] or other manufacturing processes, to be sent to the child's home. This new methodology called Design Learning is presented in this paper through a case study.

2. Methodology or Experimental Procedure

This methodology has three types of techniques to reach the final product: pre-designed toys, personalized toys and toys for special needs. Following the first of the routes, this methodology is explained through a case study. In this way, three types of toys are created, which in turn are divided into two sub-levels of decision with two options in each sub-level. In this way, 21 toy proposals are created in which two children of 4 and 6 years of age use AR technology to choose and validate the proposals.

3. Results and Discussion

The results of the case study show a great interest on the part of the children in participating in the decision process, so the 21 proposals were tested in a very short time. Despite the need to explore the full potential of this methodology through deep learning techniques or to design an experimental test with children with special needs, it provides industry and commerce with a low-cost proposal that favours learning and development of the youngest in time of pandemic.

4. Conclusions

It proposes an innovative design methodology based on AR, deep learning and new production technologies that, after a case study, promises to bring benefits to both the industrial and commercial sectors, as well as to improve the development and learning opportunities for children.

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Creation of a Virtual Museum as a Learning Tool in the Teaching of the Manufacturing Engineering Subject

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Keywords: Manufacturing engineering; learning process; virtual museum.

1. Introduction

The subject Manufacturing Engineering is taught at the second course of the Industrial Engineering Degrees and students in this course probably have never known about its contents. Consequently, teaching of this kind of subjects must be especially designed to complete successfully the educational process [1]. Every lecturer must be sensitive with the problem of finding the best possible method of organizing information and its effective teaching to the students. In this context, the generation of a virtual museum related to the manufacturing scope is part of the set of activities that constitutes the teaching structure of this subject at the Industrial Engineering School of Malaga University. This activity not only encourages the knowledge and personal work of the student, but it is also supposed to promote the collaborative work among students. Each project is materialized by a poster, following a format similar to that required for a contribution to Conferences. In this way, students can also develop other skills, such as the capacity to synthesize and organize information in a small space and to show the information in an attractive way to the reader. Eventually, by applying of different control elements it is possible to evaluate the impact of this activity on the students learning performance. As a result, the best posters will be part of the collection, being accessible to students in subsequent years [2].

2. Methodology

The methodology is developed through four stages. Each stage presents its own characteristics and needs support actions to get successfully their objectives. The starting point is to state the structure and design requirements that resources must satisfy. In second stage it will be performed a description of the activities to be carried out by the students. Next step will involve the characterization of the development and monitoring processes. Eventually, at the last stage, outcomes will be evaluated.

3. Results and Discussion

Once lecturers implicated have designed the general structure of the projects and the workgroups have been formed (up to 4 students per group) each group is given the necessary documentary resources and customize its project according a particular topic (object, process or biography), setting the description of fields for each type [3]. Following the template designed and taking into account the compulsory fields, posters will be filled out. The whole process implies five in-class sessions. In the first one, the professor describes the goal and the main lines of the project. In the two next ones the workgroups are tutored in order to identify the progress of their studies. Finally, in last sessions projects are presented to the audience. The evaluation of the projects is based on three relevant items: level of participation, project quality and suitable presentation. Students' outcomes will allow us to determine the impact of this type of activity in their learning comprehension and retention and consequently, its influence in their final punctuation. Additionally, by means of anonymous questionnaires, students are encouraged to show their level of satisfaction with this activity and therefore tutors will be able to identify and address students' needs and expectations.

4. Conclusions

Once this innovative experience has been carried out, an analysis is proposed from different study variables: 1) participation level; 2) relation between the average grade of the whole subject and the project grade, for each degree and group 3) detailed evaluation per specific groups; 4) satisfaction level will be quantified.

5. Acknowledgements

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The Teaching-Learning Process in Specific Engineering Subjects through Different Technology-Based Teaching Methodologies Applied During the State of Alarm

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Keywords: Teaching methodology; synchronous; asynchronous; state of alarm; Covid-19.

1. Introduction

The safety measures contemplated in *Real Decreto 463/2020*, of March 14, which declares the State of Alarm for the management of the health crisis situation caused by COVID-19, determine the temporary suspension of the face-to-face educational activities and establish that these will have to be developed through distance and online modalities.

This fact, which conditions traditional face-to-face teaching, forced us to look for new alternatives to meet the teaching objectives.

This article presents the results and qualifications obtained by the students in the application of three different teaching methodologies in the teaching of the subject Manufacturing Processes II, of the University Center of Mérida in the Degree in Engineering in Industrial Design and Product Development (GIDIDP).

The main objective has been to evaluate the influence of the different methodologies on the qualification of the students and the skills acquired.

2. Methodology

The methodologies developed are: Face-to-face (traditional methodology), Synchronous (online teaching in real time) [1-2], Asynchronous (online teaching on demand) [3]

The data have been analyzed through the academic qualifications obtained by the students in the final evaluation, final exam (theoretical and practical), practices, partial controls, and student satisfaction survey.

Table I. Distribution of the subjects of the subject

Teaching	Subjects
Face to face	1,2,3,4
Synchronous	5,6
Asynchronous	7,8,9,10

3. Results and Discussion

The results obtained show in general terms similar qualifications in the application of the different methodologies, with slight differences.

4. Conclusions

The results obtained show a rapid adaptation of the engineering students to the different methodologies applied, having acquired the competencies in a satisfactory way, regardless of the teaching methodology used.

5. Acknowledgements

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Integrating BIM in Industrial Engineering Programs. A New Strategy Model

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Keywords: BIM; higher education; industrial engineering; BIM roles and competences; effective integration strategy.

1. Introduction

The BIM methodology (Building Information Modelling) is a response to the need for modernization and digitalization of the Architecture, Engineering and Construction (AEC) sector. It is a collaborative work methodology based on the existence of a single digital model in construction projects, buildings or infrastructures, which is shared by the different participating agents, for their management, throughout the entire life cycle. This remarkable transformation of the sector implies, among other consequences, that higher education must be aligned with the new professional demands that will appear in the market. Therefore, it is the responsibility of the universities to train new profiles adapted to the new requirements, both in terms of knowledge and skills.

The integration of the BIM in recent years is being chaotic and asymmetric [1] and where the technical side is playing a major role without taking into account the cultural dimension of this methodology.

Working the competencies is as important, if not the most, as using the tools. This article brings together research work on the state of higher education in Spain in industrial engineering programs related to BIM and the skills required. The paper presents a model proposal that includes the main lines of work to integrate BIM so that the training of future graduates will be effective for the sector.

2. Methodology or Experimental Procedure

The line of research followed has been based on knowing the state of the implementation of BIM in higher education in Spain, focusing the information on industrial engineering programs; knowing the implementation strategies followed both at national and international level; knowing the barriers that higher education has found at an international level; learning about the competencies that are taught in higher education in industrial engineering programs in Spain; and knowing the competences that the sector demands from new professionals who develop their work in the field of this methodology.

3. Results and Discussion

The integration strategy proposed is based on establishing, as a first step, an implementation model that can be complemented by future initiatives. These potential actions will be, in a second phase, based on changes to curricula and the incorporation of specific topics or postgraduate courses on BIM methodology.

This model aims to launch a BIM Implementation Plan (PIB) integrating subjects from the four courses of the degree including manufacturing processes among others. BIM can significantly improve the planning quality and efficiency, not only for conventionally but also for additively manufactured building components [2]. The challenge of not changing their syllabuses, desired competences and expected learning outcomes is a target. Considering BIM as an essential skill implies that it should be taught early in engineering school as a central component of a student's ability to communicate graphic information. Six main backbones have been considered (Figure 1).

Figure 1. Six main backbones for a BIM effective integration strategy

4. Conclusions

The need to manage change becomes evident. Approaches to implement BIM methodology in the university must be strategic, firstly, and operational, secondly. Among other objectives, the aim is to minimize the effect of graduates' perception of the differences between the academic and working world as being enormous after completing their studies and beginning their professional careers.

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Flipped Classroom and Gamification in Automated Manufacturing Lab Classes

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Keywords: Flipped classroom; gamification; kahoot; manufacturing; teaching innovation.

1. Introduction

The *flipped classroom* methodology is being adopted in higher education as a transformative element for methodological change in the traditional teaching-learning process. What is traditionally done in the classroom is now done at home, and what is traditionally done as homework is now done in class, being a tool with great pedagogical potential [1].

This methodology improves engineering skills, influences cooperation, innovation and task orientation and, in general, as an active learning methodology, increases student performance in science, technology, engineering and maths [2].

On the other hand, one of the most common concerns of teachers is the achievement and maintenance of student motivation during classes [3]. To improve this situation, the *Kahoot* platform is outlined as a self-assessment tool within the classroom that integrates gamification and the use of mobile devices to improve the learning of the subject, encourage the study habit among university students and motivate them through competitiveness.

2. Methodology or Experimental Procedure

The inverted class methodology was applied in different lab sessions of the Automated Manufacturing subject of the Mechanical Engineering degree. It was found that the teaching staff complemented its function as a source of knowledge with guidance and coordination of discussions, and that the students developed a more active work in the classroom. It was necessary to reorganize the classes according to the new methodology, planning the sessions so that the teaching material (documentation and videos) would be available in advance so that the students could prepare the corresponding activities before the lab session.

Videos related to each topic were recorded and edited in order to raise questions about the main concepts to be discussed. Instructions were prepared for the students about the new methodology to be followed during the face-to-face sessions and questionnaires were prepared for each topic which, by using the Kahoot platform, the students had to solve as a contest through their mobile devices at the beginning and end of each session.

3. Results and Discussion

The main objective was for the students to acquire habits of planned and autonomous work that would allow them to make better use of the face-to-face sessions and become more motivated to participate actively in the classroom.

The main indicators used to evaluate the success of the implementation of this teaching methodology, were: the high degree of satisfaction of the students, the attendance to class with the tasks previously done, the high number of students who passed the three topics that cover the lab activities of the subject and a general improvement of the results with respect to previous courses. Figure 1 shows an example of the results met on a robotics test.

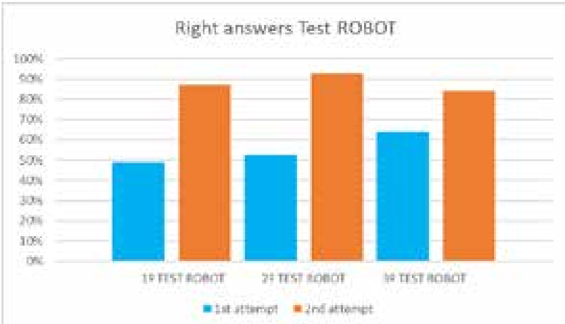

Figure 1. Comparative results of the first and second attempts on a robot test

4. Conclusions

Development of practical classes by means of the *flipped classroom* methodology combined with evaluation elements through questionnaires carried out as a competition has been shown to be an effective methodology in achieving the objectives set out in the subject of Automated Manufacturing.

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Performance Analysis of Teaching Methodologies Applied to Graduate Subjects on Risk Engineering and Management in Industrial Environments

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Keywords: Industrial risk; quantitative analysis; teaching innovation; methodology.

1. Introduction

For risk engineering and management teaching, Technical Notes Prevention along with the technical guides, both issued by the National Institute of Safety and Health at Work (INSST), need to be complemented with standards, regulations, guides and professional criteria of Spanish and international prestigious institutions. This circumstance allows the extension of teaching opportunities, oriented to design of activities focused on the analysis and knowledge of considered industrial safety technologies [1]. The growing need to provide students with solid enough foundations that allow them to successfully enter a world that is changing rapidly, leads to propose a new direction in teaching practice that favours the development of essential skills and competencies in the risk management professional field. Competences are understood to be the set of knowledge, skills, abilities and attitudes that are integrated into certain personal characteristics [2]. Thus, in this work, an analysis of the student's opinions on the teaching methodology of several National Distance Education University (UNED) subjects related to industrial risk engineering and management is performed. The study covers a period of 5 academic years, collecting a total of 232 surveys.

2. Methodology

The analysis is performed based on a 9 questions survey specifically designed for this issue (Table 1).

Table I. Survey

Nº	Question (to be valued with 1 to 5 points)
Q1	The contents of the subject seem interesting to me
Q2	The methodology followed in the subject seems interesting to me
Q3	The follow-up of the subject has been flexible enough and adapted to my personal requirements
Q4	In carrying out the set of activities for this subject, I have used a total of 120 hours
Q5	The activities carried out contain sufficient practical and application content
Q6	The focus and sequencing of the activities have seemed didactic to me
Q7	The level of difficulty of the activities carried out seems adequate to me
Q8	Following the course has provided me with enough information from the point of view of my curricular interests
Q9	I am satisfied with the "evaluation model" of the subject

3. Results

Figure 1 provides the participation (expressed in %) along 5 academic years.

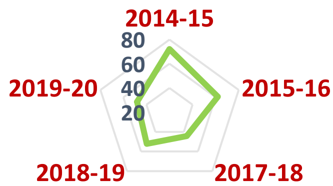

Figure 1. Participation (in %)

Once analysed the 232 surveys, the main results can be observed in Figure 2.

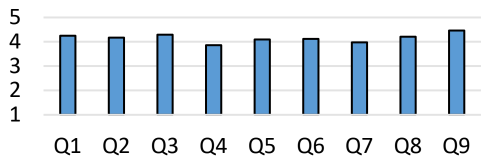

Figure 2. Results of survey

4. Conclusions

The analysis methodology has allowed to obtain a general view related to the student satisfaction. It can be highlighted the satisfaction with evaluation model (Q9), the flexibility (Q3), the quality of contents (Q1) and the teaching methodology (Q2). Another important aspect is the student's feedback on time dedicated to these risk engineering and management subjects.

5. Acknowledgements

This work has been performed in the frame of the Teaching Innovation Project of the GID2016-28 group, focused on *"Reliability and Advanced Failure Prognosis in industrial applications applied to the teaching of Materials Technology and Processing".*

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Design and Fabrication of Prototype of Extrusion Equipment for Research and Teaching Purposes

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Keywords: Metal forming; extrusion; prototype; laboratory; teaching.

1. Introduction

Direct extrusion is a metal forming process in which a metallic billet is forced by compression to flow through a die to produce a long profile with a defined cross-sectional shape [1]. In Engineering Schools, metal forming teaching laboratories are not always equipped with all the suitable equipment to show the students how metal forming operations are performed in industrial facilities, due mainly to space and/or economical limitations. Often, competences and skills related to laboratory practice have to be acquired through physical and numerical simulation [2-3]. In this work, a proposal of design and fabrication of prototype of extrusion equipment is presented, mainly for teaching purposes, but also, for research activities in extrusion processes.

2. Methodology

To reach the aim, the components of the prototype are integrated in a universal testing machine Hoytom HM-100kN with control software Howin 32 RS. This kind of equipment is available in any Engineering School, which makes the proposal accessible to any lecturer interested in metal forming teaching. The final design of the prototype was made taking into account the possibility of using standardized components to facilitate both installation and maintenance tasks. It is also important to emphasize the modular nature of the design to allow its adaptation to different applications and case studies. Analytical calculations based in Johnsons' semiempirical model presented in Eq.1 and Eq. 2 and finite element simulations were also accomplished to estimate the required load depending on the material and other technological factors:

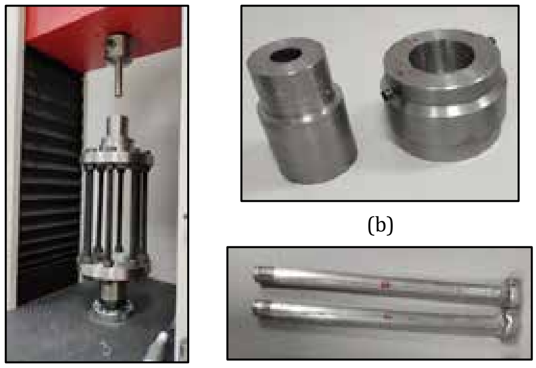
$$F = A_0 \cdot Y \cdot \left(\varepsilon_x + \frac{2L}{D_0}\right) \quad [1]$$

$$\varepsilon_x = \mathrm{a} + \mathrm{b} \cdot \ln r_x \quad [2]$$

These factors include the geometrical and friction conditions with a clear influence on the forming capacity of the prototype and its limitations.

3. Results and Discussion

Figure 1a shows the final configuration of the prototype integrated in the universal testing machine along with some components of the tooling system: container and auxiliary component to locate the die (Figure 1b). Tin extrudates fabricated by the prototype are also shown in Figure 1c.



(a) (b) (c)

Figure 1. Prototype of extrusion equipment and results

4. Conclusions

The prototype presented has demonstrated to be able to produce long profiles by cold extrusion, not only with plasticine (typically used in physical modelling) but with a metallic material, as tin. This prototype could be used as an example of extrusion equipment to be reproducible in metal forming laboratories of other universities.

5. Acknowledgements

The authors acknowledge the support of the Industrial Production and Manufacturing Engineering (IPME) Research Group and the funds provided by the Annual Grant Call of the Industrial Engineering School-UNED through the projects REF 2020-ICF04/A, REF 2020-ICF04/B, REF2020-ICF03, REF2020-ICF07.

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Historical-technological Study, Modeling and Reconstruction to Scale of the Six-Cylinder Pump of Taqī ad-Dîn

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Keywords: History of machines and mechanisms; geometric modelling; mechanical design; additive manufacturing.

1. Introduction

In the middle of the 16th century A.D., the ottoman mechanical engineer Taqï Al-Dïn compiled in his work Al-Turuq Al-Samiyya fi Al-Alat Al-Ruhaniyya ("The Sublime Method of Machines") various mechanisms with a simple, precise style and with interesting diagrams of them. This work was influenced by Ahmed Y. Hassan [1] treatise.

Taqï Al-Dïn treatise collects clepsydras, mechanisms for lifting weights and drawing water, and a rudimentary steam turbine. Among the mechanisms for raising water, we focus this work on the six-cylinder pump (Figure 1-2). Taqï Al-Dïn described it as "an immaculate method and the most perfect of any of the previous ones" compared to other engineers of the time, such as Agricola or Ramelli.

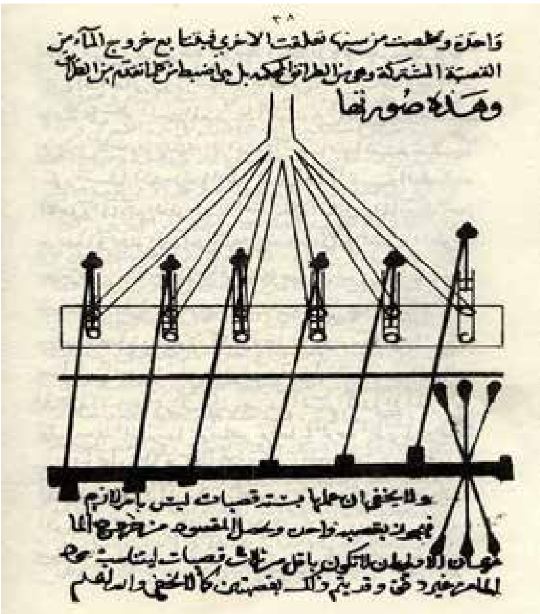

Figure 1. Illustration of the six-cylinder pump, in the book "Al-Turuq Al-Sammiyya fi Al-Alat Al-Ruhaniyya"

2. Methodology

First of all, the existing documentation will be compiled, and the description and analysis of the pump's operation extracted from that information.

The mechanism's geometric modelling will then be carried out, based on the few data available and subsequent interpretations and studies [2]. The Inventor Professional software was used for the design, modelling, and assembly of the mechanism.

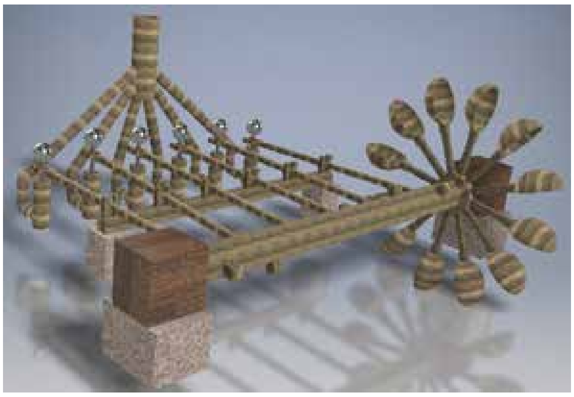

Figure 2. Six-cylinder pump digital model

This model is exported to SolidWorks, where it is used for the system simulation and mechanical analysis.

Finally, the mechanism's real scale reconstruction will be carried out, using different manufacturing techniques, mainly additive manufacturing through 3D printing.

3. Results and Discussion

Through geometric modelling, simulation, and analysis of modern techniques, we can carry out a virtual reconstruction of ancient mechanisms and real scale reconstruction. Therefore, we can understand and analyse their modes of operation.

4. Conclusions

The methodology used may apply to other ancient mechanisms within the field of the History of Machines and Mechanisms.

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Sugar Cane Industrial Heritage in Oriental Coast of Malaga. A Tourist Route Opportunity

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Keywords: Sugar cane; industrial heritage; tourism; Málaga.

1. Introduction

Nowadays, industrial heritage has been accepted internationally as a heritage typology. Furthermore, a society interest in the industrial past has grown [1]. Along the 19th century, different sugar cane factories were developed in the oriental coast of Málaga. The mountain orography near the coast and the weather conditions favoured the sugar cane cultivation in this area. In addition, the possibility to distribute the sugar cane production by ship gave national and international recognition to this manufacturing activity [2]. This activity was gradually closing along the 20th century due to the tourist development of this area. This fact has caused the loss of relevant witnesses of this industrial activity. In spite of this, current different sugar cane manufacturing assets remain in this area with various states of conservation [3]. Taking in to account the national and international tourist relevance of this area and the proximity of the assets, creating a tourist route around the different sugar cane factories can contribute to promote the knowledge of this industrial heritage in the society and the local economy. Therefore, in this work, different sugar cane factories in the oriental coast of Malaga have been analysed to value the tourist interest of these industrial heritage assets.

2. Methodology

Geographical information has been evaluated, being the geographical location and the distance between the sugar cane factories the main factor to select it. A visit to the different sugar cane factories designated has been carried out. Furthermore, several photographs of the assets have been taken, using an Unmanned Aerial Vehicle (UAV) and a conventional camera. Finally, the actual state of the assets has been evaluated and a numerical touristic interest rating to each one has been applied.

3. Results and Discussion

Six sugar cane factories assets have been selected, showing different conservation states. All of them were visited and the most relevant characteristic of the factories were photographed (Figure 1). An initial tourist route, taking into account tourist interests, has been proposal.

Figure 1. Ingenio San Joaquín (Nerja, Malaga)

4. Conclusions

In this work, an important sugar cane industrial activity, along a fairly defined time course, in the oriental coast of Malaga has been considered. Six factories have been identified in this area with a distance that covers about 25 km. Furthermore, the heritage interest and the conservation state have been analysed. Conventional and aerial photography with an Unmanned Aerial Vehicle have been used to collect the main characteristics of the heritage assets. Finally, a joint presentation of these sugar factories has been proposed, in order to carry out intervention projects and a possible tourist route.

5. Acknowledgements

The authors thank University of Malaga-Andalucía Tech Campus of International Excellence for its economic contribution on this paper. Furthermore, the authors thank to Manufacturing Engineering Society (MES-SIF) and to the work group about industrial heritage (PATRIF) for it advice support.

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Impact of Technological Facilitators in the Design and Artisanal Production Processes. The Guarda Ninhos Project – Craft and Design of Gonçalo's Basketry

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Keywords: Design; handicrafts; prototyping; digital fabrication; design process.

1. Introduction

This research analyses the impact of the use of prototyping and digital manufacturing tools in the design process to develop new products based on the theme of Basketwork from Gonçalo, Guarda - Portugal.

It seeks to outline forms of cooperation between artisanal activities and current concepts and methods of industrial development, recover and consolidate ancestral artisanal knowledge and processes, and implement a strategic plan to dynamize the interdisciplinary relationship between artisans and designers.

2. Methodology or Experimental Procedure

The research was applied to a collaborative project that involved a wide network of designers, artisans, engineers, collaborators and administrative staff in the development and prototyping of thirty-three new products [1]. The methodology applied to this case study was divided in the following phases: (1) Identification of contact points, interrelationships and convergences; (2) Identification of areas of opportunity for the implementation of technological and digital facilitators; (3) Development of a strategic plan and (4) Validation of the implementation of technological and digital facilitators in the project "Guarda Ninhos" - craft and design of basketry from Gonçalo.

3. Results and Discussion

In the case of the Guarda Ninhos project, the use of digital fabrication and augmented reality brought great challenges and opportunities to all stages of the process: to the conceptualisation (incubation); to the creation of the design (insight) and to the final development phase (transformation). The creation of 3D models for digital manufacturing allowed: (1) a greater rationalisation of the physical characteristics of some products that took into account the dimensions and characteristics of the prototyping equipment; (2) the optimisation of raw materials and of the production processes and (3) the improvement of the communication between stakeholders (artisans, designers and production engineers) throughout the creative and prototyping processes.

4. Conclusions

This investigation presents conclusions that can answer questions that are usually asked in projects of this nature. For example, how can prototyping and digital fabrication be introduced in the design process? How can these tools contribute to helping teams develop appropriate and inclusive solutions for all project partners?

These conclusions were obtained from several actions developed over twelve months of work - in the field and in the workshop. Strategic actions, product development and prototyping, conducting residences with invited creators, publicizing and conducting commercial tests.

5. Acknowledgments

Guarda-Ninhos is part of the Onep project. A European initiative whose main objective is the economic dynamism and the consequent creation of wealth in border areas, mainly of rural scope, between Spain and Portugal

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A Methodology for Early Detection of Potentially Low-Achievement Students by Means of On-Line Testing and Item Response Theory

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Keywords: Evaluation methodologies; Data science applications in education; Architectures for educational technology system.

1. Introduction

There is an increasing concern about the relevance of reducing university dropout, since the available information shows how dropout reaches surprisingly high values. Reducing dropout turns to be, consequently, a key factor in the educational strategy of the European Commission Union [1]. In Spain, the dropout after the first year (2012/13) reaches a 20.25%, while only 49.26% of the students obtain their degree in the expected time (data from four-year degrees analysis in course 2016/17) [2].

One of the first steps must be identifying those students more prone to fail the course. Present work proposes a methodology to implement an early detection of students in risk of failure, based on the Item Response Theory (IRT) analysis of data collected from on-line tests [3].

Questions are presented to the students according to knowledge campaigns within the frame of the course by means of an on-line knowledge management platform (ZAPIENS). Results from student´s performance are processed using IRT to obtain the value of ability for each individual [4]. This information is later used to identify those students that, with high probability, would fail the subject. Accordingly, faculty would be capable of implementing specific reinforcement strategies. Results indicate that the methodology allows for an appropriate segmentation of the students according to their capability at an early stage. This strategy could help in the development of differential learning itineraries and could also be easily adapted to different educational environments.

2. Methodology or Experimental Procedure

Methodology can be seen in Fig. 1. In order to create the structure of campaigns that the ZAPIENS platform uses, four blocks have been defined: Standardization and Tolerances; Forming and Shaping Processes; Metal-Casting Processes and Machining Processes. Thirty test questions have been included in each block.

Data collected are exported and processed through IRT, so that IRT parameters are calculated for each individual campaign and also for the four-campaign semester, taken as a whole. The IRT provides an ability value, that allows for classify students in three groups: High ability, medium ability and Low ability, those in risk of failure. Then IRT results are compared with final evaluation (success/failure) following experimental planning.

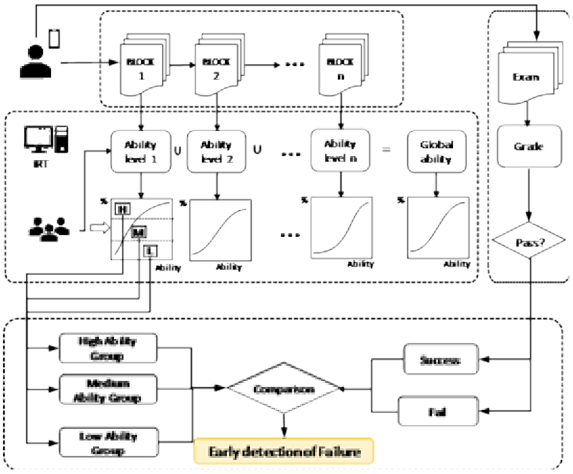

Figure 1. Logical structure of the methodology that clusters the students according to their level of ability.

3. Results and Discussion

Discriminating ability values were calculated with data from 2017-18 course.

The capability of this early indicator has been finally tested upon the students in 2018-2019 course, and the analysis indicate that this procedure do provide good results as an early clustering method.

4. Acknowledgements

The authors wish to thank the ZAPIENS team and the Teaching Innovation Committee of the University of Oviedo for their support.

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