



Weld method and filler metal for “hand welding”

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MÉTODO DE SOLDURA Y MATERIAL DE APORTE METÁLICO PARA “SOLDADURA MANUAL”

1 Introducción

Luossavaara-Kirunavaara AB (LKAB) es una compañía minera sueca. Extrae mineral de hierro en Kiruna y en Malmberget, en el norte de Suecia. El mineral de hierro es procesado en pellets que son transportados trenes a los puertos de Narvik y Luleå y a la fábrica de acero de Luleå (SSAB).

La granulación de mineral de hierro es un proceso complicado: El hierro extraído de la mina es mezclado con agua, se obtiene así una mezcla llamada lodo. En la siguiente fase, el lodo es transformado en pellets. Estos pellets se deshidratan y se mezclan con un aglutinante transformándolos en esferas, pellets de mineral de hierro. El tamaño solicitado se clasifica y continúa su camino hacia el horno de rejilla para obtener suficiente fuerza. En el horno de rejilla, los gránulos se secan antes de entrar en la etapa de sinterización. Por último, los gránulos se enfrian en un refrigerador rotatorio antes de ser transportados al cliente.

El exceso de calor del refrigerador rotativo es transportado, mediante ventiladores, a través de conductos hacia el horno de rejilla, utilizado para el secado de los pellets. En Kiruna Pelletizing Plant 2 y Svappavaara Pelletezing Plant, uno de los impulsores está particularmente expuesto al desgaste. La producción se detiene para el revestimiento de la zona dañada, mediante la soldadura por superposición de capa. Este desgaste causa alrededor de 2-4 días extra de mantenimiento al año. El gran desgaste que sufre este ventilador es debido a que no hay separación de partículas en el conducto desde el refrigerador al horno.

1.1 Objetivo del proyecto

El objetivo de este proyecto es examinar el metal de relleno más adecuado para reducir la pérdida de material en el impulsor entre paradas de mantenimiento.

2 Teoría

Comprender el daño causado en las superficies es una parte importante para la compresión de la tribología de componentes. Cuando el daño de la superficie implica la pérdida de material, el proceso se conoce como desgaste.

2.1 Entender el tipo de desgaste

Anticipar el tipo de desgaste en los componentes es la parte más difícil, ya que el desgaste, o resistencia al desgaste, no es una propiedad intrínseca del material, como lo son la tensión o la dureza.

Una superficie atacada por partículas sólidas transportadas por en un fluido se describe como erosión. La erosión es un problema continuo en lugares como turbinas hidráulicas.

Para simplificar el concepto de erosión, se dividirá en dos partes.:

- Una parte donde están las variables que afectan a la erosión y están determinadas. Estas variables de tres tipos: variables de incidencia (que describen la velocidad de la partícula, el ángulo de incidencia y el flujo de la partícula); variables de partículas (forma, tamaño, dureza y fragilidad); variables del material (dureza, comportamiento de endurecimiento del trabajo y microestructura).
- Una segunda parte donde se calcula la cantidad de material eliminado de la superficie. Para un primer análisis el comportamiento del material se clasifica en dúctil y frágil. En materiales dúctiles el material será eliminado por la acción de corte de la partícula erosionada, un proceso de deformación plástica. En un material frágil, el material se eliminará por la propagación de grietas, que comienza desde el punto de impacto.

La resistencia relativa de los materiales al desgaste erosivo es generalmente similar a su resistencia al desgaste abrasivo. Por lo general, son materiales que resisten el rayado, como cerámica, materiales de carburo, hierros fundidos y aleados y aceros de aleación endurecidos.

Algunas de las soluciones para minimizar la erosión son: usar aceros austeníticos o tratamientos de cromado; eliminación de partículas con ciclones o pantallas; aplicación de recubrimientos pulverizados o de difusión por plasma; rediseño de configuraciones de turbina.

2.1.1 Gas y temperatura

La erosión de una superficie por partículas abrasivas en un fluido inerte debería depender del número de partículas que golpean la superficie, su velocidad y su dirección relativa a la superficie. En unidades donde la dirección del flujo cambia con bastante rapidez (paletas de la turbina, válvulas, curva de tuberías, etc.) la erosión suele ser considerablemente más severa que en un tramo recto de tubería.

La temperatura del gas que alcanzó el impulsor es de alrededor de 140 grados.

Conociendo el flujo del fluido y el diámetro del impulsor, se puede calcular la velocidad del fluido:

$$\text{Fluid velocity: } v = \frac{4Q}{\pi \cdot d^2} = \frac{4 \cdot 180.556}{\pi \cdot 2.52^2} = 36.2 \frac{m}{s}$$

$$n = 920 \text{ rpm}$$

2.1.2 Partículas

Las partículas transportadas por el aire son polvo de óxido de hierro, FE2O3, no esférico y con un tamaño de 50 micras, en promedio. Se hizo una muestra de polvo, por lo que se pudo medir la dureza de la partícula. Sin embargo, debido a que la muestra era muy oscura, la medida no fue fácil ni clara. La dureza de la partícula es de unos 158 Vickers (una media de 20 medidas)

Dado que la resistencia relativa a la erosión de diferentes materiales depende del ángulo de ataque, es útil poder asignar un ángulo aproximado de impacto bajo diferentes condiciones de flujo. La velocidad y dirección de una partícula abrasiva en un fluido no son necesariamente los mismo que los del fluido.

El volumen del material desplazado es proporcional a la masa total de las partículas erosivas que han impactado contra la superficie, la tasa de erosión adimensional se mide por la relación entre la masa del material eliminado y la masa de partículas erosiva que golpean la superficie.

$$E = \frac{k\rho v^2}{2H};$$

ρ (densidad del material erosionado); H (su dureza); v (velocidad de las partícululas);

k (medida de la eliminación de material por el impacto.)

2.1.3 Ensayos de erosión

En la mayoría de las pruebas de erosión, las partículas viajan una distancia corta en el aire a alta velocidad antes de alcanzar la muestra, y su velocidad será una fracción de la velocidad del aire. El propósito de estas pruebas es comparar el comportamiento de diferentes materiales y tratar de predecir su comportamiento en el servicio.

En la siguiente figura, se puede ver un ejemplo de uno de los ensayos de medida de la erosión. Las partículas erosionadas se aceleran a lo largo de una boquilla (un cilindro paralelo) en una corriente de gas que fluye. La muestra está montada a una distancia fija del extremo de la boquilla:

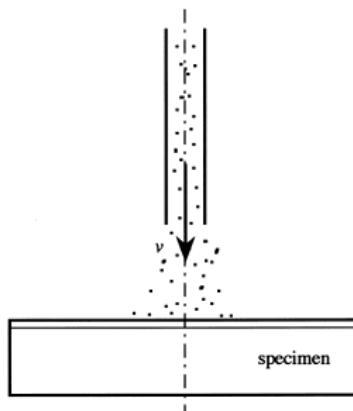


Figura 1. Ensayo erosión.

2.2 Tratamientos y recubrimientos de superficies

Cuando las superficies de los componentes no tienen las propiedades requeridas para el buen comportamiento en servicio, puede ser económicamente ventajoso hacer una modificación posterior de su superficie para garantizar un comportamiento apropiado en el servicio. Hay diferentes procesos para alcanzar distintas propiedades:

1. Procesos que modifican la superficie existente sin cambiar la composición.
2. Procesos que modifican la superficie existente de alguna manera con el cambio de composición
3. Procesos que aplican un nuevo material a la superficie, generalmente denominado revestimientos de superficie: el revestimiento producido por diferentes procesos es distinto entre sí por distintas propiedades como el espesor, la dureza, la ductilidad y el estado de tensión residual. El recubrimiento de superficie se puede utilizar como:
a) protección contra la corrosión; b) mejora de la apariencia de la superficie del producto; c) aumentar la resistencia al desgaste; d) aumentar la conductividad; e) reparar la superficie de desgaste

Normalmente para mejorar características de una superficie se utiliza un material de recubrimiento con un costo menor en su fabricación y proporcionando, mediante soldadura, una superficie con mejores características de dureza, resistencia al desgaste, etc.

El depósito producido por la soldadura se llama revestimiento. Los procesos de superficie se pueden usar para:

1. Revestimiento de la superficie: se aplica una capa gruesa de material, normalmente a un acero de carbono o de baja aleación para proporcionar una superficie resistente a la corrosión. Esto a menudo se conoce como soldadura superpuesta.
2. Revestimiento duro: se deposita una capa de un material más resistente al desgaste para proporcionar un componente que es más resistente a la abrasión, el impacto y la erosión

3. Acumulación: se agrega un depósito de soldadura a un componente para restaurar sus dimensiones originales.

2.3 Método de soldadura

La mayoría de los procesos utilizados para producir un depósito de soldadura se basan en técnicas de soldadura por fusión. Estos procesos de fusión implican que la aleación resultante que se solidifica sea una mezcla del metal de relleno y la base material, la composición de esta aleación se define como dilución. La dilución hace que la composición química del recubrimiento no sea la que teníamos antes. La cantidad de dilución obtenida está determinada por el proceso de soldadura seleccionado y los parámetros de soldadura elegidos. La posición de soldadura también influye en la cantidad de dilución.

De acuerdo con las variables de esta soldadura, el mejor método de soldadura será SMAW. FCAW y GMAW pueden ser una posible opción.

SMAW: (Manual metal Arc-MMA). Es adecuado para superficies duras pequeñas y grandes, especialmente secciones pesadas. Permite el recargue de piezas grandes sin precalentamiento. Versátil; adecuado para todas las aleaciones. El inconveniente de este método es la pérdida de tiempo en el cambio de electrodos y eliminar la escoria. Además, es un proceso manual, luego es más lento que los procesos automáticos.

GMAW: (Gas Metal Arc Welding). Proporciona una eficiencia de deposición interesante y se puede utilizar para cualquier material. En este proceso se utiliza un gas de protección, que puede ser inerte (no participa en el proceso) o activo (que si participa). Este método es más rápido que el SMAW. El inconveniente es la limitación a no trabajar fuera de la nave, ya que el gas se puede contaminar con agentes externos.

FCAW: adecuado para una amplia gama de tamaños. Es un proceso semiautomático basado en GMAW, donde la varilla continua se sustituye por un hilo tubular relleno. El único consumible de este proceso es el electrodo tubular. Esto sirve como electrodo de material de relleno y de protección de la soldadura durante el enfriamiento. La porosidad de este método de soldadura es menor que en los otros. El inconveniente de este proceso es la creación de más humos que los otros procesos, la escoria tiene que ser retirada.

Las aleaciones de endurecimiento a base de hierro ofrecen una combinación de bajo costo y resistencia al desgaste moderada. Las aleaciones de bases duras basadas en hierro se pueden clasificar de acuerdo con su microestructura de la siguiente manera:

1. Aceros ferríticos
2. Aceros austeníticos
3. Aceros martensíticos semiausteníticos
4. Hierro fundido de alta aleación

El revestimiento de metal más duro es el cromo. El recubrimiento con cromo es recomendado para aplicaciones que requieren resistencia al desgaste por abrasión y erosión por partículas. Revestimientos más duros que el cromo son los compuestos cerámicos.

Selección para escoger la aleación del recubrimiento:

1. Se requiere resistencia al desgaste
2. Coste
3. Material base
4. Proceso de deposición
5. Resistencia al impacto
6. Resistencia a la corrosión
7. Resistencia a la oxidación

3 Material y método

3.1 Sugerencia sobre que método y material de aporte debe ser usado.

Cuando se trata de revestimientos duros, la preocupación principal es la formación de martensita en la zona afectada por el calor de la soldadura, que conduciría a la formación de una capa frágil.

Por lo tanto, la velocidad de enfriamiento debe controlarse. La velocidad crítica de enfriamiento es la velocidad de enfriamiento más baja para obtener, a temperatura ambiente, una estructura completamente martensítica. El equivalente de carbono es una medida indirecta utilizada a menudo para cuantificar el riesgo de endurecimiento del acero. Con el equivalente de carbono, se puede controlar la velocidad de enfriamiento y se puede evitar el agrietamiento inducido por hidrógeno. Debido a la presencia de martensita no templada, la martensita podría ser susceptible a agrietamiento inducido por hidrógeno.

El metal de aporte utilizado ahora es “” Elgaloy Hard 100”(3.5 %C-30%Cr-0.5%Mo-0.4%V), cuya dureza es 58-61 HRC, 700-740 HV, algunos materiales de aporte con dureza similares serán soldados para compararlos:

- Castomag 45351 (FeCr-A) : 0.5C- 9.15Cr-0.5Mn-3Si

$$CE(\%) = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15} = 2.41 \%$$

Reconstrucción y endurecimiento de piezas que están sujetas a la abrasión combinadas con un fuerte impacto. A pesar de la alta dureza, se pueden aplicar varias capas sin riesgo de romper o astillar. Se utiliza para reciclaje de automóviles, bombas o trituradoras de piedra. 58-60 HRC.

- Hardface (EFe15): 5C-0.2 Mn- 1.0 Si- 27Cr.

$$CE(\%) = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15} = 10.43 \%$$

Este electrodo es de hierro fundido con alto contenido de cromo para los componentes de recargue sujetos a desgaste abrasivo, se utiliza, por ejemplo, en equipos de minería y movimiento de tierra o placas de desgaste.

El depósito contiene una alta proporción de carburos de cromo en una matriz ferrítica. Depósito de 3 capas de dureza en acero dulce: 60-60 HRC

- Corodur 600 OA (CrMoV): 0.5C-6.5Cr-2.2Mn-1Si-0.6Mo-0.2V

$$CE(\%) = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15} = 2.33 \%$$

Alta dureza en una pasada, buena calidad contra la abrasión, baja dilución del material base. Este electrodo se utiliza para herramientas de corte, molinos Hummer y herramientas de forjado. Dureza de 55-57 HRC.

3.2 Preparación de la muestra

El recargue por soldadura se realizó en Kiruna. Se realizaron tres experimentos, uno por cada metal de relleno. El metal base son placas de S355. La soldadura fue manual, por lo que se desconoce la velocidad y el ángulo. Se cortaron dos piezas más pequeñas de cada muestra. Entonces, se usaron seis muestras en este proyecto.

3.2.1 Grabado

Para ver la microestructura del acero se realizó el grabado con Nital 3% durante 5 segundos.

3.3 X-RAY

Se usó XRD para medir la composición de las muestras. El análisis de XRD se realizó con un difractómetro PANalytical Empyrean con tamaños de hendidura de 1/4, ½ y una máscara monocromática de 5 mm de grosor. Se pulió una sección transversal de la muestra y se montó en el portamuestras.

3.4 Dureza

Las mediciones de dureza se realizaron con una carga de 50 gramos en la parte superior de la soldadura, cerca de la baquelita, y una carga de 100 gramos en el resto de la sección transversal, con un intervalo de 500 µm.

3.5 Microscopio óptico y SEM

El objetivo del microscopio óptico es observar la microestructura de la muestra, tratando de ver cualquier diferencia entre las muestras y encontrar qué tipo de microestructura da mejores propiedades para resistir el desgaste por erosión. El SEM se usó para llevar a cabo un examen adicional de la microestructura de la parte revestida y comparar muestras, buscando la presencia de cualquier inclusión o porosidad que pudiera producir una soldadura frágil.

4 Resultados

4.1 Castomag

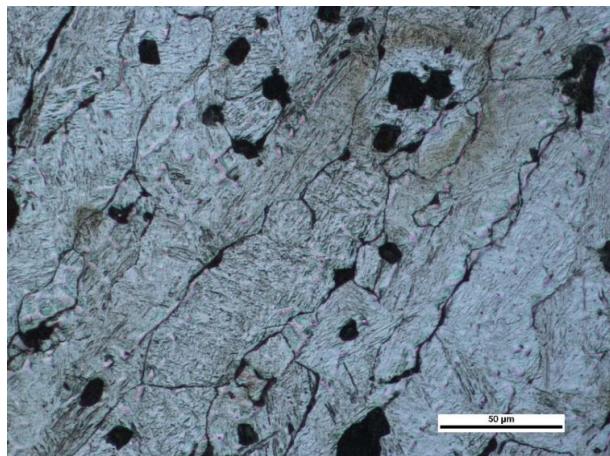


Figura 2. Castomag microscopio óptico.

Foto del microscopio óptico: se puede ver una matriz martensítica con carburos, y los puntos negros podrían ser algunas impurezas que se solidifican al final.

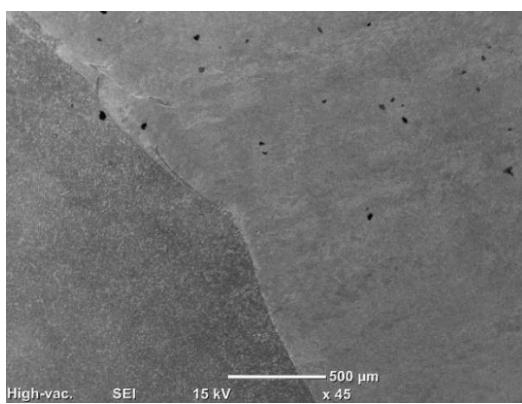


Figura 3. Castomag, SEM

Con el microscopio SEM se puede ver que algunos de estos puntos negros son porosidad.

4.2 Corodur

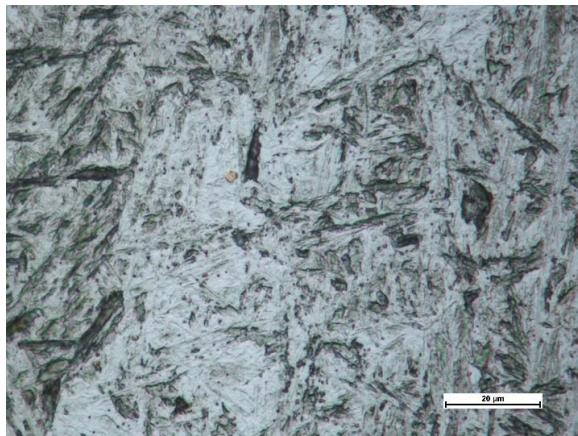


Figura 4. Corodur, microscopio óptico.

Desde el microscopio óptico, se puede ver una matriz martensítica y algunos carburos pequeños.

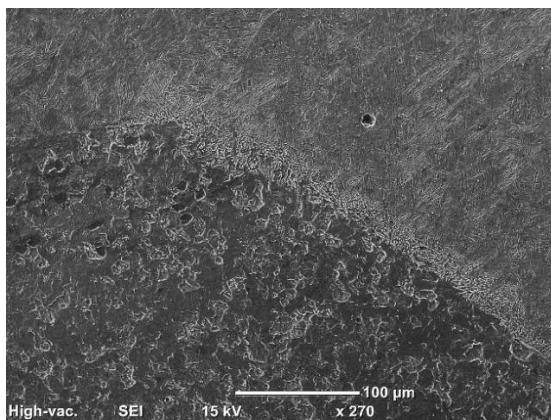


Figura 5. Corodur, SEM

En el microscopio SEM se pueden ver algunos puntos aislados de porosidad.

4.3 Hardface HC-E

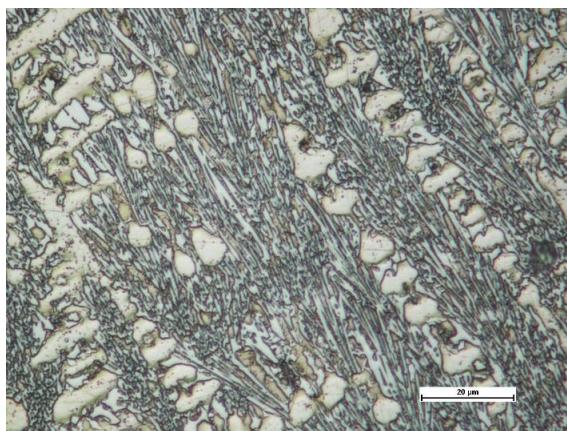


Figura 6. Hardface, microscopio óptico.

Fotos del microscopio óptico: se puede ver una estructura dendrítica, donde la zona blanca es carburos que son los últimos en solidificarse, y la zona más oscura puede ser losa de martensita con carburo retenido.

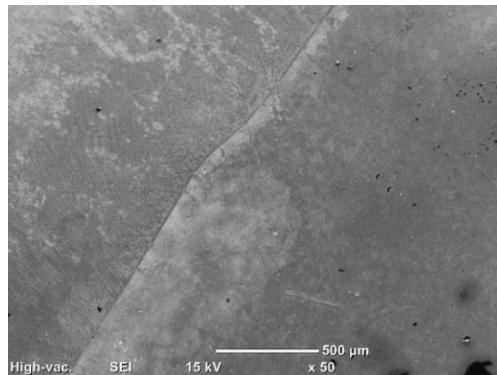


Figura 7. Hardface, SEM

5 Debate.

La solidificación de la muestra de Castolin presenta en el fondo de la soldadura varios puntos de porosidad o algunas impurezas (el último material en solidificar). Esto conduce a un aumento en la fragilidad de la muestra.

La muestra de Corodur se soldó con GMAW, que es más rápido que SMAW, y no es necesario un gas inerte. La microestructura es una estructura martensítica, estos depósitos tienen una resistencia al impacto inferior a las aleaciones perlíticas o austeníticas pero una mayor dureza y una mejor resistencia al desgaste por abrasión.

La Hardface tiene una microestructura con estructura dendrítica de carburos y una matriz martensítica. Una matriz martensítica es beneficiosa para la resistencia a la abrasión de alto estrés debido al apoyo adicional que la martensita proporciona a los carburos de la superficie.

La dureza es casi la misma en cada muestra. Y la prueba de rayos X muestra una composición de acero normal para las muestras de Castolin y Corodur y algunas austeníticas en Hardface.

6 Conclusiones.

- En la muestra de Castolin, la soldadura fue ejecutada por GMAW. Este electrodo no era posible de soldar sin un gas inerte. Cuando se realiza una soldadura con un gas de protección, la soldadura puede contaminarse porque algunos agentes atmosféricos podrían dispersar el gas de protección produciendo una soldadura porosa y débil. Otras desventajas en el uso del gas de protección es que un equipo más pesado y más grande es difícil de mover. . Estas son las razones por las cuales una soldadura

con gas de protección a menudo se realiza en interiores y por qué no se puede usar para este proyecto.

- Después de la investigación microestructural de las muestras Corodur y Hardface (el SEM no detecta nada especial) y la prueba de dureza de las muestras, no se pudo detectar grandes diferencias entre ellas. Esto significa que, la elección, a primera vista, no es clara. Pero se descubrió que una posible forma de minimizar la erosión es utilizar un acero austenítico. De acuerdo con los datos de XRD, la muestra Hardface tiene una microestructura austenítica.

7 Trabajos futuros.

Se deben realizar más pruebas para verificar que las muestras de Hardface tengan la mejor resistencia a la erosión entre los materiales probados. Algunos posibles trabajos para medir la resistencia podrían ser algunas de las pruebas de erosión que se mencionaron anteriormente. Otra prueba que podría hacerse para buscar porosidad o impurezas en la muestra como el uso de partículas magnéticas, inspección ultrasónica.

Abstract

A flux, of gas or fluid, which go through the turbine can contain sometimes solid particles in it. This solid particles produce a loss of material in the impeller when the fluid go through it. When a surface is attacked by solid particles transported in a gas flux, the wear is described as erosion.

A cladding of chromium carbide is the most beneficial solution against the wear erosion.

When a surface has not the properties adequate to support the wear, a material with the appropriate properties should be applied on the surface. There are different method to change the composition of the surface, one of them is hardfacing, where a new material is put over the base material.

A new material can be put over the surface with different methods, in this project welding has been used, and this is a method by which a relatively thick layer can be achieved.

The welding has been done with three different filler metal and their microstructure has been studied with an optical microscope, SEM microscope and XRD and the microhardness has also been measured.

Comparing the three hardfaces, some differences appear, but have not been enough for the selection. The microhardness of each sample is almost equal. The XRD show that there are two samples that have a ferritic composition and one with austenitic composition

The sample with an austenitic composition, the Hardface- HC-E, has a dendritic structure. This will be the sample selected although some erosion tests should be realized to prove if this material will be really resistant for the application in question.

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8 Introduction

Luossavaara-Kirunavaara AB (LKAB) is a high technological mineral company producing iron ore products. Pelletizing iron ore is a complicated process, combines mixing of the slurry, forming the pellet and a thermal treatment baking the soft raw pellet to hard spheres.

The iron ore is finely divided and mixed with water, called a slurry. The slurry enter the pelletizing plant and are dewatered, mixed with a binder and rolled into spheres, iron ore pellets. The requested size are sorted out and continue its way to grate-kiln to gain sufficient strength. In the grate kiln the pellets are dried on a belt before entering the sintering stage in a rotating furnace. After that the pellets cools down in a rotary cooler before further transportation to the customer.

The excess heat from the rotary cooler is transported with process gas fans through ducts to the grate furnace to dry the raw pellets. In Kiruna Pelletizing Plant 2 and Svappavaara Pelletezing Plant, one of the impellers is particularly exposed to wear causing around 2-4 extra days of maintenance per year when the production is stopped for overlay welding to maintain the function and safety. Process gas fan with high wear on the impeller due to there's no separation of particles. Material loss also leads to uneven balance of the impeller.

8.1 Project Aim and Goal

The objective with this project is to examine the most suitable filler metal to reduce the loss of the material in the impeller between the maintenance shutdowns.

9 Theory

Surface damage is a microstructural change in a surface layer. Understanding the damage caused in the surfaces is an important part for the understanding of the tribological components. When the surface damage involve loss of material the process is known as wear.

Fundamental elements in the process of material removal can be: shear fracture, extrusion, chip formation, tearing, brittle fracture, fatigue fracture, chemical dissolution, and diffusion.

9.1 Understanding of the wear

The wear can be defined as the process where the material is cut away from one or both surfaces that are in contact, taking place when are in relative motion to each other.

Anticipate the type of wear in the components is the difficult part in solving wear problems. The reason of this is that wear or wear resistance is not an intrinsic property of the material, as is the strain or hardness.

Wear classification takes two aspects into consideration; the first is based on how the wear on parts or components occurs, such as pitting, degradation and striation among others. The second aspect takes into consideration the foundations of mechanism or tribological action.

Most common types of wear:

Table 1. Common wear types. (Belzunce, 2012)

Elements in contact	Movement	Wear type
Solid-Solid	Glide	Adhesive
	Rolling	Abrasive
	Impact	Fatigue
	Oscillation	
Solid- Fluid	Impact	Cavitation
Solid-Fluid, with particles	Impact	Erosion

In many applications a surface is attacked by solid particles carried by a fluid flowing. This type of wear is generally described as erosion, which is a continuing problem in such places as coal turbines or hydraulic turbines.

To simplify the erosion concept, it can be divided in two parts. The first part where the variables affecting erosion are determined. These variables can be separated into three types: impingement variables (describing the particle velocity, angle of incidence, and flux –particle concentration), particle variables (shape, size, hardness, and brittleness), and material variables (hardness, work hardening behaviour, and microstructure).

The second part is a calculation of the amount of surface material removed. For a first analysis, the material behavior is classified in two types, ductile and brittle. In ductile materials the material will be removed by the cutting action of the eroding particle, a process of plastic deformation. In a brittle material, the material will be removed by crack propagation, which starts from the point of impact of the eroding particle, and flaking.

The relative resistance of materials to erosive wear is generally similar to their relative resistance to abrasive wear. They are typically hard materials that resist scratching, as ceramics, carbide materials, alloyed white cast irons, and hardened alloy steels. "Chromium was the most beneficial alloying element to increase the hardness of steels," according to Wood R.J.K & Mellor Dr. B. G. in *Surface coatings for protection against wear*

In addition, these and other materials can be put on the surface of many less-abrasion-resistant materials by welding, plasma spraying, flame spraying and other techniques.

Wellinger and co-workers carried out some erosion tests with different angles of impingement and showed that part of the erosion resistance of different materials, could change as the

angle of impingement changed. They found for a steel with a Vicker's hardness of 125 kg/mm² that the maximum weight loss occurs when the fluid is at angles of about 30° to the surface, while for the hardest steel, 840 kg/mm² the maximum erosion weight loss occurs at fluid angles close to 90°.

As a general guide to metals that will resist abrasive wear, it has been found that:

- High hardness is the primary requirement
- Abrasion resistance tends to increase with additions of carbide-forming metals
- Carbides are useful additions to metals when they are large in relation to the size of the abrasive.

Some solutions to minimize the erosion are: Using austenitic steels or chromizing treatments, particle removal with cyclones or screens, application of plasma-sprayed or diffusion coatings to blades, and redesign of turbine configurations

9.1.1 Gas and temperature

The erosion of a surface by abrasive particles in an inert fluid should depend on the number of particles striking the surface, their velocity, and their direction relative to the surface. In units where the flow direction changes fairly rapidly (turbine blading, valves, pipe bends, etc.) erosion is usually considerably more severe than in a straight run of piping. Local turbulence due to a roughened surface or misaligned parts may greatly increase erosion.

The gas temperature of the fluid that reached the impeller is around 140 °C.

Knowing the flux of the fluid, and the impeller's diameter, the fluid velocity can be calculated:

$$\text{Fluid velocity: } v = \frac{4Q}{\pi \cdot d^2} = \frac{4 \cdot 180.556}{\pi \cdot 2.52^2} = 36.2 \frac{m}{s}$$

$$n = 920 \text{ rpm}$$

9.1.2 Particles

The particles transported by the air are iron oxide dust, Fe₂O₃, not spherical and with a size of 50 µm, in average. A sample of dust was made, so the particle hardness could be measured, however, due to the dark sample, the measure wasn't ease or clear. The particle hardness is

about 158 Vickers, (an average of 20 measures, these values are in the appendix 1). In the figure 1 a sample of dust can be seen, in this sample is where the hardness were performed.



Figure 1. Iron dust sample.

Since the relative erosion resistance of different materials depends on the angle at which a surface is being attacked, it is of value to be able to assign an approximate angle of impaction under different flow conditions. The velocity and direction of an abrasive particle in a fluid are not necessarily the same as those of the fluid. Experimenters have usually expressed weight loss as a function of fluid pressure or fluid velocity and the relationship of these quantities to particle velocity depends on the particle size and shape as well as the particular flow conditions of the experiment.

The volume of surface material removed by the particle is then taken as the product of the area swept out by the particle tip and the width of the cutting face. In the figure 2 can be seen the idealized picture of abrasive grain striking a surface and removing material, initially the velocity vector of the particle's center of gravity makes an angle α with the surface

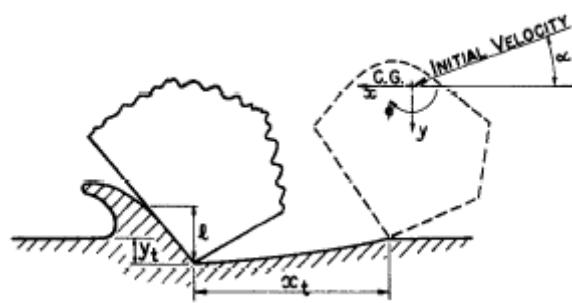


Figure 2. Finnie I. "Erosion of surfaces by solid particles"

The volume of the displaced material is proportional to the total mass of the erosive particles have impacted against the surface, the dimensionless erosion rate E is measured by the ratio between the mass of material removed and mass of erosive particles striking the surface.

$$E = \frac{k\rho v^2}{2H};$$

ρ (density of the eroded material); H (its hardness); v (speed of the particles);
 k (measure the efficiency of the process of removing material from the impact of particle)

9.1.3 Erosion tests

In most erosion testers the particles travel a fairly short distance in the high-velocity air before reaching the specimen, and their velocity will thus be only a fraction of the air velocity.

The purpose of these tests is both, to compare the behavior of different materials and try to predict their behavior on service.

Wear experienced in any real material service is always very difficult to predict, therefore, these tests should be designed to reproduce as closely as possible the real situation. Some example of tests are in figure 3.

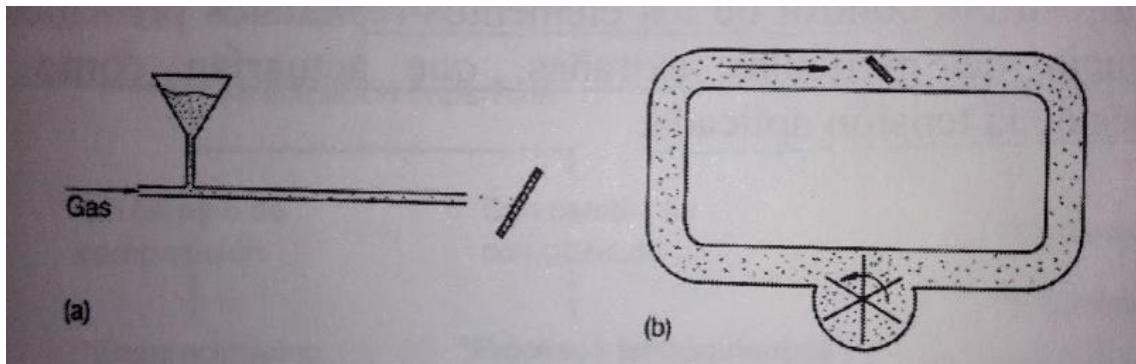


Figure 3. Test for erosive wear: a) with water b) with air (Belzunce; 2012)

Erosion test with a gas-blast (figure 4): erodent particles are accelerated along a nozzle (a parallel cylinder or complex shape) in a flowing stream of gas. The specimen is mounted at a fixed distance from the end of the nozzle:

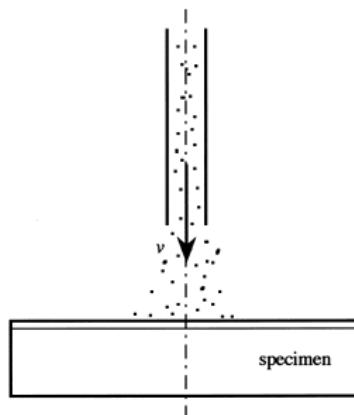


Figure 4. Gas-blast the particle strike a plane coated specimen (Hutching; 1998)

Centrifugal accelerator (fig. 5) in which particles are fed into the centre of the rotor and move outwards along radial channels. On leaving the rim of the rotor they strike fixed specimens mounted around the circumferences. The apparatus can be used to test more than one specimen simultaneously:

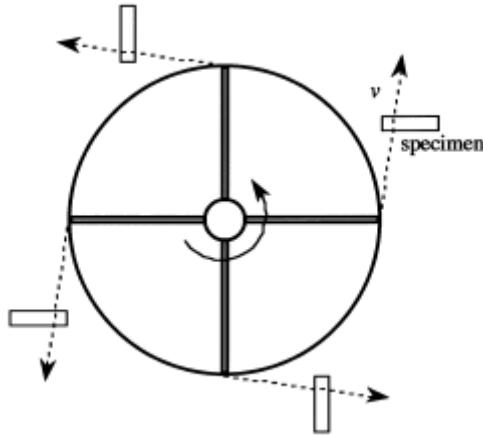


Figure 5. Centrifugal accelerator. Hutchings I. M. (1998)

9.2 Treatments and surface coating

Sometimes, the surfaces of the components has not the required property for the good behavior in service. In these situations, it may be economically advantageous to make subsequent modification of its surface in order to ensure appropriate behavior in service. The enhancements of the surface to achieve the required property can be as diverse as aesthetics, optical properties, and wear and corrosion resistance. There are different processes for the property which has to be reached, that processes may be divided into three groups:

1. Processes which modify the existing surface without changing the composition.
2. Processes which modify the existing surface in some way with composition's change.
3. Processes which apply a new material to the surface, generally referred to as coating processes

Surface coatings: The coating produced by different processes are distinct from each other by properties as thickness, hardness, ductility and residual stress state.

Surface coating can be used as:

- a) Corrosion protection
- b) Improve the surface appearance of the product
- c) Increase the wear resistance
- d) Increase the conductivity
- e) Repair wear surface

There are a number of processes where substrates are coated or cladded with a material which remains in the solid state. Using a coating material with a lower cost in its fabrication

and providing, by welding, a surface with better characteristics of hardness, wear resistance, etc.

The deposit produced by welding is called a hardfacing or weld overlay while the technique itself is often referred to as surfacing. Surfacing processes can be used for:

1. Surface cladding: A thick layer of material is applied, normally to a carbon or low alloy steel, to provide a corrosion-resistant surface. This is often referred to as overlay welding
2. Hardfacing: A layer of more wear-resistant material is deposited to provide a component which is more resistant to abrasion, impact, and erosion or galling. That material could also have to control combinations of wear, corrosion and oxidation.
3. Build-up: A weld deposit is added to a component to restore its original dimensions.
4. Buttering: An intermediate layer of material is deposited on the surface of the component for metallurgical reasons before depositing the final top coat.

For this project, hardfacing will be a more complete process.

With that case of surface coating, a thicker layer can be achieved. The material for the coating is heated until its fusion, after that, it has to solidify on the base material, which means its fusion temperature should be minor or equal to the coated metal.

9.3 Welding method

The main differences between the welding processes are the nature of the heat source, the form of the hardfacing welding consumable and the method of shielding the hot molten material from oxidation during the welding process.

Most of the processes used to produce a weld deposit are based on fusion-welding techniques which were originally designed to weld joints. These processes involve melting back, which means that the resultant alloy that solidifies is a mixture of the filler metal and the base material, the composition of this alloy being defined by dilution.

An important factor to consider in these processes is the dilution, which represents the percentage of the base metal that melts and, therefore, is incorporated into the deposited layer. The dilution makes that the chemical composition of the coating is not the one we had anticipated. In these processes, a thermally affected zone is generated where its microstructure and properties depend on the thermal history that has suffered in the process, resulting often required prior preheating (to slow cooling) or postheating (tempering) to avoid the presence of fragile structures. The amount of dilution obtained is determined by the welding process selected and the welding parameters chosen. The position of welding also influences the amount of dilution. Depending on the welding position or work inclination, gravity will cause the weld pool to run ahead of, to remain under or to run behind the arc. Inclining the workpiece at an angle and welding downhill produces minimum dilution.

In general, a welding process and technique should be selected to give less than 20% dilution for the hardest (top) layer.

The size, shape and weight of the workpiece influence the choice of hardfacing process selection. For large heavy work pieces it is usually more convenient to move the hardfacing equipment to the workpiece and so manually operated portable welding processes.

The welding method being used has a significantly influence on the cost. Before choosing the method some points should be revise:

- a) *Structural responsibility of the component.* In that point the importance of the component for the behaviour of rest of the structure is checked. It is, the extent of the damage that can be caused if the failure occurs in an element/component. This point can be divided in three grades: principal, secondary and no critical.
The principal structure, it is an element whose failure would damage the existence or usefulness of the overall structure or a substantial part of it.
The secondary structure, the element failure would produce only local damage or local decrease of the usefulness of the structure.
No critic structure, the failure of the element would produce only minor damage and easily repairable.
- b) *Welding position.* Should be check which method can be used in the required position.
- c) *Assemblage.* The possibility of moving the equipment and the pollution of the shielding gas by the atmospheric or external agents.
- d) *Thickness.* There are some recommendations on the suitability of different welding processes for the execution of joints according to the thickness of the welding.
- e) *Welding material.* There are some recommendations for welding of various materials.
- f) *Cost*

Table 2. Choose of the best welding method for that case.

	Shielded Metal Arc Welding (SMAW)	Flux-Cored Arc Welding (FCAW)	Gas Metal Arc Welding (GMAW)	Submerged Arc Welding (SAW)	Gas Tungsten Arc Welding (GTAW)
Structural type: Principal	good	good	good	good	Very good
Assembly	Very good	Good	Good	NO	G
Thickness 12-24	Very good	Very good	Very good	Good	Regular
Thickness > 24	Very good	Very good	Very good	Very good	Regular
High resist. steel	Good	Good	Good	Good	Good

According to the variables of this welding, the best welding method will be SMAW (2 Good and 3 Very good). FCAW and GMAW may be a possible option (3 Good and 2 Very good):

SMAW: (Manual Metal Arc-MMA). Suitable for hardfacing small and large areas specially on heavy sections. Permits hardfacing of large parts without preheat. Little distortion when hardfacing small areas of components. Versatile; suitable for all alloys. Good accessibility; all position welding possible low equipment portable. Used on infrequent repairs.

GMAW: Provides an interesting deposition efficiency and can be used for any material. No flux, gas shielding, versatile; can hardface complex shapes; Deposit visible during process enabling high-quality deposition.

FCAW: Suitable for full range of sizes, flat, horizontal and vertical positions. Low equipment costs; portable. Easy to use; good visibility of deposit during welding; moderate operator skill level. Used on more frequently repaired parts. The only consumable of this process is the tubular electrode. This serves as filler material electrode, to blow the arc melting bath and protection of the welding during the cooling.

9.3.1 SMAW

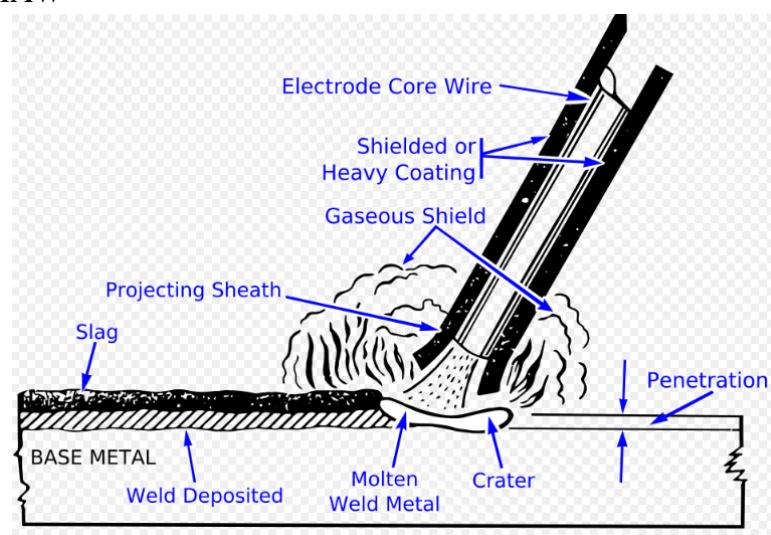


Figure 6. SMAW sketch (García Prieto, 2015)

SMAW, Shielded Metal Arc Welding, also known as MMA (Manual Metal Arc), is one of the most used, due to its simplicity. In the figure 6, a sketch of the SMAW process can be seen.

In this method, as can be seen in the figure 6, a molten weld metal is created, the electrode is melted and also the surface of the base material. With a light contact between electrode and base material the circuit is closed, creating the electric arc that produces the melt. An important and difficult part of the electrode melt is to ensure that the electrode coating disintegrates at the same time that the electrode wire. The shielded coating of the electrode provides a layer of slag, which protects the weld area from atmospheric contamination.

The drawback of this method is the time spent on changing the electrodes and removing the slag, which reduces the operator factor. This is a manual process, hence, it is slower than the automatic processes.

9.3.2 GMAW

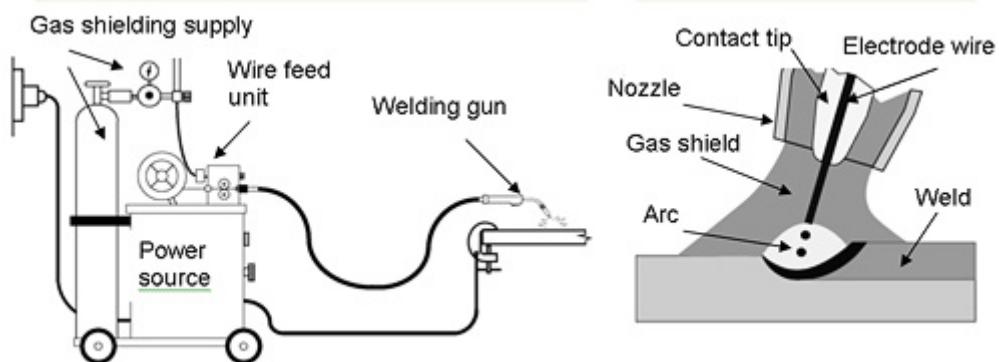


Figure 7. GMAW sketch (García Prieto, 2015)

An electric arc is formed between a consumable wire electrode and the workpiece. In this method a shielding gas is used although, sometimes, could be no used, to protect the melt. The shielding gas can be inert, does not participate in the welding, so the process is called MIG- Metal Inert Gas; or an active gas, MAG-Metal Active Gas. In the fig. 7, on the left the weld circuit can be seen and in the right the welding process.

This method can be in semi-automatic or automatic modes. Due to GMAW does not spend time on changing electrodes or removing slags, has a faster welding time than SMAW. The drawbacks of this process is its limitation to work outdoors, the arc protection created by a gas could be contaminated by the air or other external agents.

Another variable to consider is the transfer mode, which is the way how the electrode melts and is positioned in the welding. The transfer modes (fig. 8) is determined by a number of factors such as shielding gas, power supply, electrode diameter and current.

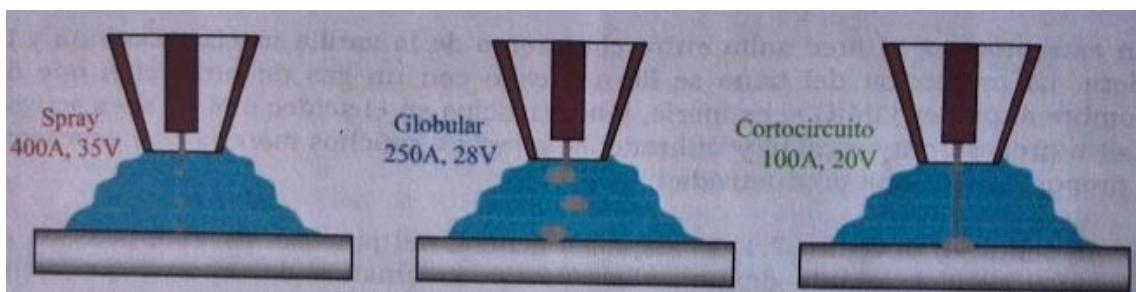


Figure 8.. Transfer modes. (García Prieto, 2015)

- Spray: This transfer mode uses a current near the critical value, the material leaves the electrode in the form of small drops and with a rate of hundreds per seconds
- Globular: Occur with a low current. The material leaves the electrode in drops, whose diameter is higher than the electrode's diameter.
- Short-circuiting: lowest welding currents and electrode diameters. The contact of the electrode and the weld produces the transfer of material from electrode to workpiece.

9.3.3 FCAW

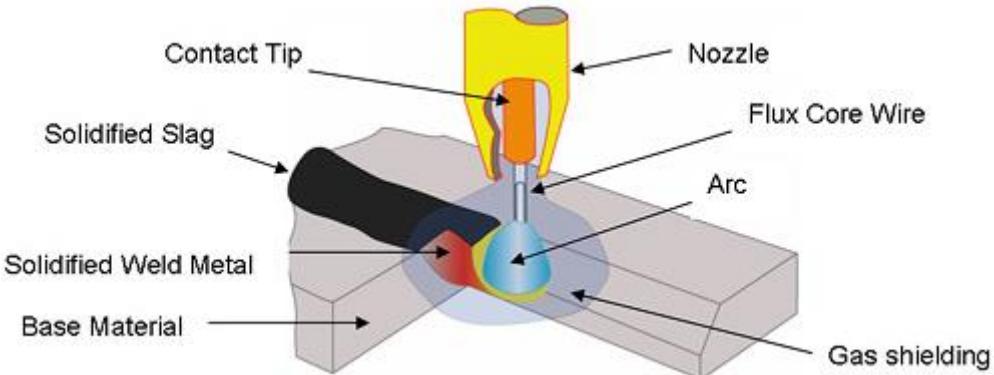


Figure 9. FCAW sketch (García Prieto, 2015)

FCAW (fig.9) is a semiautomatic welding process based on the GMAW, where the continuous rod has changed by a filling flux cored wire, known as tubular wire. Although, sometimes, gas shielding is used, there is no necessary due to this method use a self-shielded electrodes which protect the weld metal, as in SMAW, and in some cases provide their own shielding gas.

This method can be used for any of the different welding positions that exist. The need for cleaning of the metal before of the welding is smaller than other methods. The possibility of porosity in the welding with this method is less than in others methods. On the other hand; FCAW creates more fumes, slag must be removed and less portable equipment than SMAW.

9.3.4 Possible filler metal

Iron-based hardfacing alloys are the most widely used and constitute the largest volume of hardfacing materials used. They give a combination of low cost and moderate wear resistance. The iron-based hardfacing alloys can be classified according to their microstructure as follows: 1. Ferritic steels; 2. Austenitic steels; 3. Martensitic-semiaustenitic steels; 4. High-alloy cast iron.

- Ferritic steels: They are weldable steels with low carbon and limited alloy additions to ensure that the microstructure following cooling of the weld overlay is mainly ferritic (%C less than 0.2 and up to 2% Cr). A fine columnar grain microstructure gives better wear resistance than a coarse-grained structure.

- Austenitic steels: These steels contain 12-16% Mn and up to 1% C. These materials, are extremely tough, wear resistant and very susceptible to plastic deformation. This plasticity dissipates energy, and cracking and spalling are avoided; hence there is good abrasive wear resistance.

- Martensitic steels: These steels are designed to form martensite on air cooling after weld deposition. These deposits have inferior impact resistance to pearlitic or austenitic alloys but higher hardness and better resistance to abrasive wear. However, martensitic deposits can be tempered at 425-650 °C to improve toughness with some loss of hardness and abrasion

resistance. More than one layer is applied to reduce dilution (a factor explained in point 2.3) in the surface material. Composition with 0.7-2 % C and from 5-12% Cr gives a mixed microstructure of austenite and martensite after hardfacing, the proportion of each structure is governed by composition and cooling rate. *The higher carbon content in Fe-C martensites, the higher the hardness and strength, but the ductility and toughness decreases.*

-White irons: High-chromium white irons containing 8-35% Cr and 2-5% C. Depending on the carbon and chromium levels the deposits can be hypoeutectic (2-3% C & 5-30% Cr) which have the better impact resistance; near eutectic (3-4% C & 1-30% Cr) or hypereutectic (4-7%C & 14-35%Cr) which have the better abrasion resistance. The matrix around these carbides may be austenitic, pearlitic or martensitic. A martensitic matrix is beneficial to high-stress abrasion resistance because of the additional support that martensite provides to the surface carbides.

The hardest metal coating is chrome. Chromium carbide coatings are notable for several uses, one of its most significant benefits is its wear resistance at higher temperatures. Coating with chromium is recommended for applications that require resistance for wear by abrasion, hard surfaces and particle erosion. Harder coatings than chrome are the ceramic compounds, or metal-ceramic or treatments that create that type of compounds: Carbides, borides, nitrides.

Hardfacing alloy selection:

1. Wear resistance required
2. Cost
3. Base material
4. Deposition process
5. Impact resistance
6. Corrosion resistance
7. Oxidation resistance
8. Thermal properties

10 Material and method

10.1 Suggestion for which method and filler metal that should be used

When hardfacing, the main concern is martensite formation in the weld heat-affected zone, which would lead to the formation of a brittle layer. Thus the cooling rate must be controlled and control of interpass temperature is required when the carbon equivalent of the base material is greater than approximately 0.4%.

The critical velocity of quenching is the lower cooling rate for obtaining, at ambient temperature, a fully martensitic structure. The carbon equivalent is an indirect measure often used to quantify the risk of hardening of steel. With the carbon equivalent the cooling rate can be controlled and the hydrogen-induced cracking could be avoided. Because of the presence of untempered martensite, the martensitic could be susceptible to hydrogen-induced cracking.

The preheating or interpass temperature necessary can be obtained from the technical information supplied by the manufacturers of hardfacing consumables. Alternatively the

cooling rate can be calculated by the heat flow equations used for the welding. The cooling rate is a function of the net heat input rate (arc energy in joules per millimeter) defined as:

$$h_{net} = \frac{\eta EI}{v}$$

η Welding heat efficiency, a function of the welding process; E the voltage, I the current and v the welding speed.

The filler metal that is used now is " Elgaloy Hard 100"(3.5 %C-30%Cr-0.5%Mo-0.4%V), whose hardness as welded is 58-61 HRC, 700-740 HV, so some filler metals with a similar hardness from other companies will be welded to compared.

- Castomag 45351 (FeCr-A) : 0.5C- 9.15Cr-0.5Mn-3Si

$$CE(\%) = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15} = 2.41 \%$$

Rebuilding and hardfacing parts that are subject to abrasion combined with heavy impact. Despite the high hardness several layers can be applied without any risk of breaking out or chipping off. It is used for car recycling, pumps or stone crushers. 58-60 HRc.

- Hardface (EFe15): 5C-0.2 Mn- 1.0 Si- 27Cr.

$$CE(\%) = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15} = 10.43 \%$$

This electrode is a high chromium cast iron for hardfacing components subject to abrasive wear, is used, for example, in mining and earthmoving equipment or wear plates.

The deposit contains a high proportion of chromium carbides in a ferritic matrix.
Hardness 3-layers deposit on mild steel: 60-60 HRc

- Corodur 600 OA (CrMoV): 0.5C-6.5Cr-2.2Mn-1Si-0.6Mo-0.2V

$$CE(\%) = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15} = 2.33 \%$$

High hardness in the first pass, good quality against abrasion, low dilution of base material. This electrode is used for cutting tools, hummer mills and forging tools.
Hardness of 55-57 HRc.

More details of the filler metals are in the appendix 2.

10.2 Sample preparation

The hardfacing by welding was performed in Kiruna. Three experiments were performed, one for each filler metal. The base metal are plates of S355. The welding was manually so the speed and the angle is unknown. Two smaller pieces of each sample were cut. So, six samples were used in this project.

The sample preparation was performed by cutting, grinding, and polishing. After the cutting, grinding was done down to 2500 grit size followed by fine polishing in three steps by polishing with diamond disk from 9 to 0.25 µm and finishing with a colloidal silica suspension.

10.2.1 Etching

To see the microstructure of the steel with the etching was performed with Nital 3% during 5 seconds.

To see the microstructure of the cladding, according to "*Standard test methods for Microetching Metals and Alloys*" Designation: E407-70, etchant number 80 was used.

Etchant 80: 5 ml HCL

1g picric acid

100 ml ethanol

For each sample, the time for the etching varies:

- Castolin sample: 20 seconds, 40 seconds for the SEM
- Corodur sample: 10 seconds, 60 seconds for the SEM microscopy
- Hardface sample: 5 seconds, 15 seconds for the SEM

10.3 X-RAY diffraction.

XRD was used in order to measure the composition of the samples. The XRD analysis was performed with a PANalytical Empyrean (fig.10) diffractometer with slit sizes of 1/4, ½ and a monochromatic mask 5 mm thick. A cross section of the sample was polished and mounted in the sample holder.



Figure 10. PANalytical Empyrean Diffractometer

10.4 Hardness

Hardness measurements were performed with a load of 50 grams in the top of the welding, near the bakelite, and a load of 100 grams in the rest of the cross section, with an interval of 500 µm. In the fig. 11 the hadrness testing machine can be seen.



Figure 11. Hardness testing machine, Matzusawa

10.5 Optical and SEM microscope

The aim of the optical microscope is to observe the microstructure of the sample, trying to see any difference between samples and find which type of microstructure gives better properties to resist the wear by erosion.

The SEM was used to conduct a further examination of the microstructure of the cladded part and compare samples, searching for the presence of any inclusion or porosity which would make a brittle welding.

11 Results

11.1 Steel



Figure 12. Base metal, magnification of 20



Figure 13. Base metal with a magnification of 100

The microstructure (that can be seen in the fig. 12 and 13) of the base metal is ferrite and pearlite. As a result, these steels are relatively soft and have little resistance against the wear, but with extraordinary ductility and toughness. In addition, they are easily machined, weldable and cheap.

11.2 Castomag



Figure 14. Castomag cladding after 20 seconds of etching. Magnification of 2.5

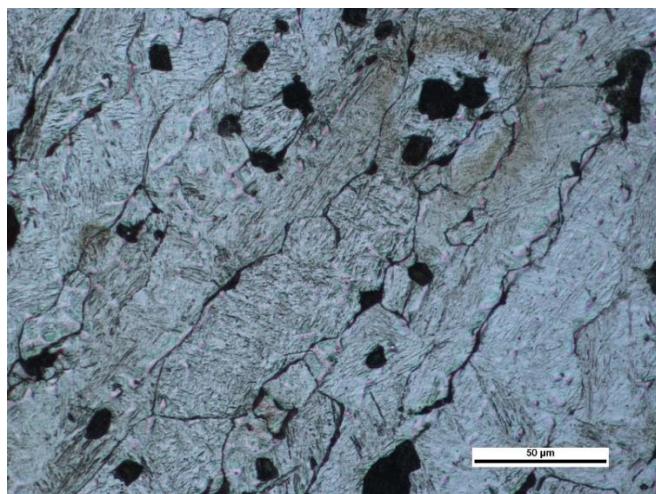


Figure 15. Castomag cladding after 20 seconds of etching. Magnification of 50

In the figures 14 and 15, which are photos from the optical microscope, can be seen a martensitic matrix with carbides, and the black's dots could be some impurities which solidify at the end. With the SEM microscope (fig. 16) can be seen that some of this black dots are porosity. More photos of Castomag's sample are in the appendix 3.

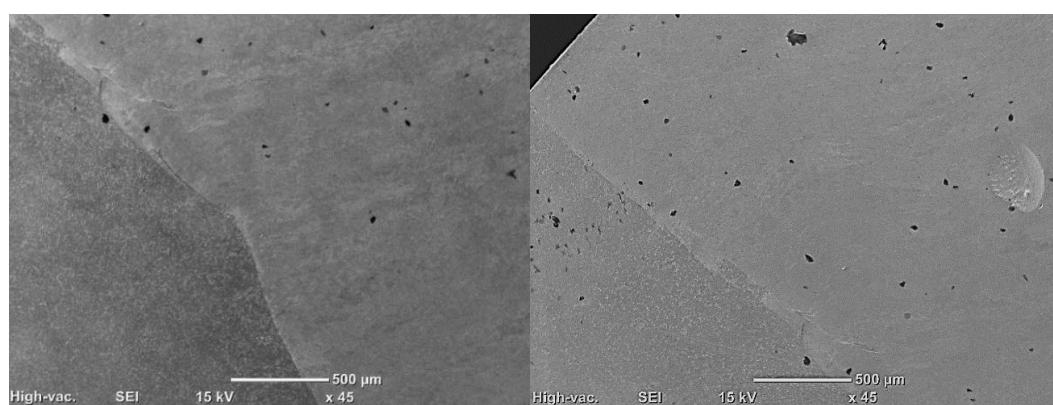


Figure 16. Photos of the union between cladding and base metal of Castomag sample in the SEM. The right part of each photo is the filler metal.

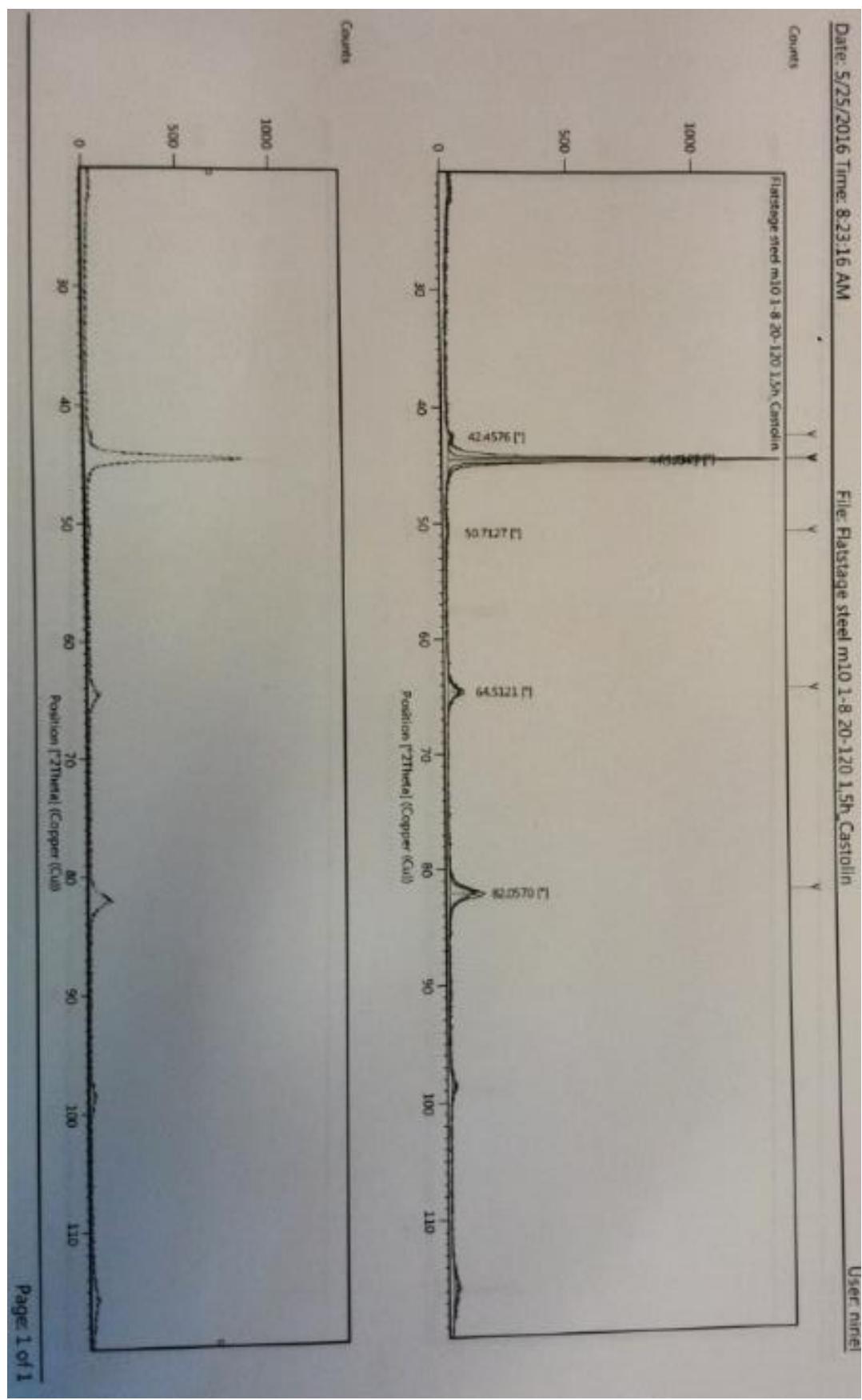


Figure 17. X-Ray result of Castomag's sample

11.3 Corodur



Figure 18. Corodur cladding after 10 seconds of etching with a magnification of 20

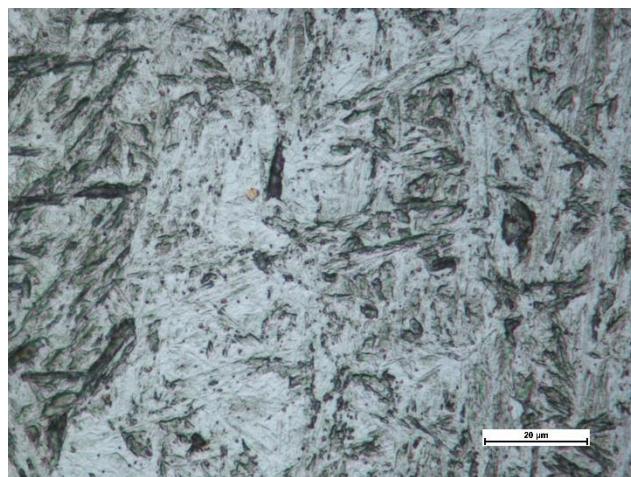


Figure 19. Corodur cladding after 10 seconds of etching with a magnification of 100

In the figures 18 and 19, which are photos from the optical microscope, can be seen a martensitic matrix and some small carbides. In the SEM microscope (fig. 20) can be seen some isolated dots of porosity. More photos of Corodur's sample are in the appendix 4.

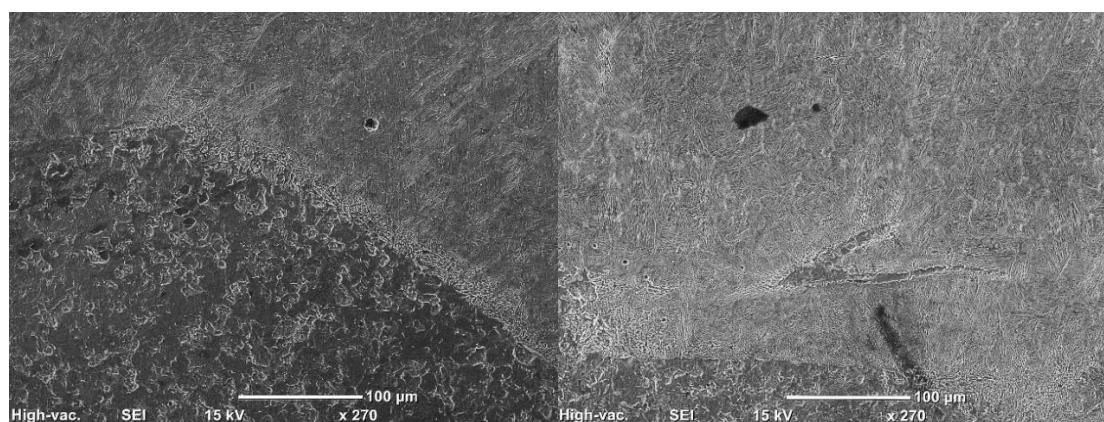


Figure 20. Photos of the union between cladding and base material of the Corodur sample with SEM. Top cladding.

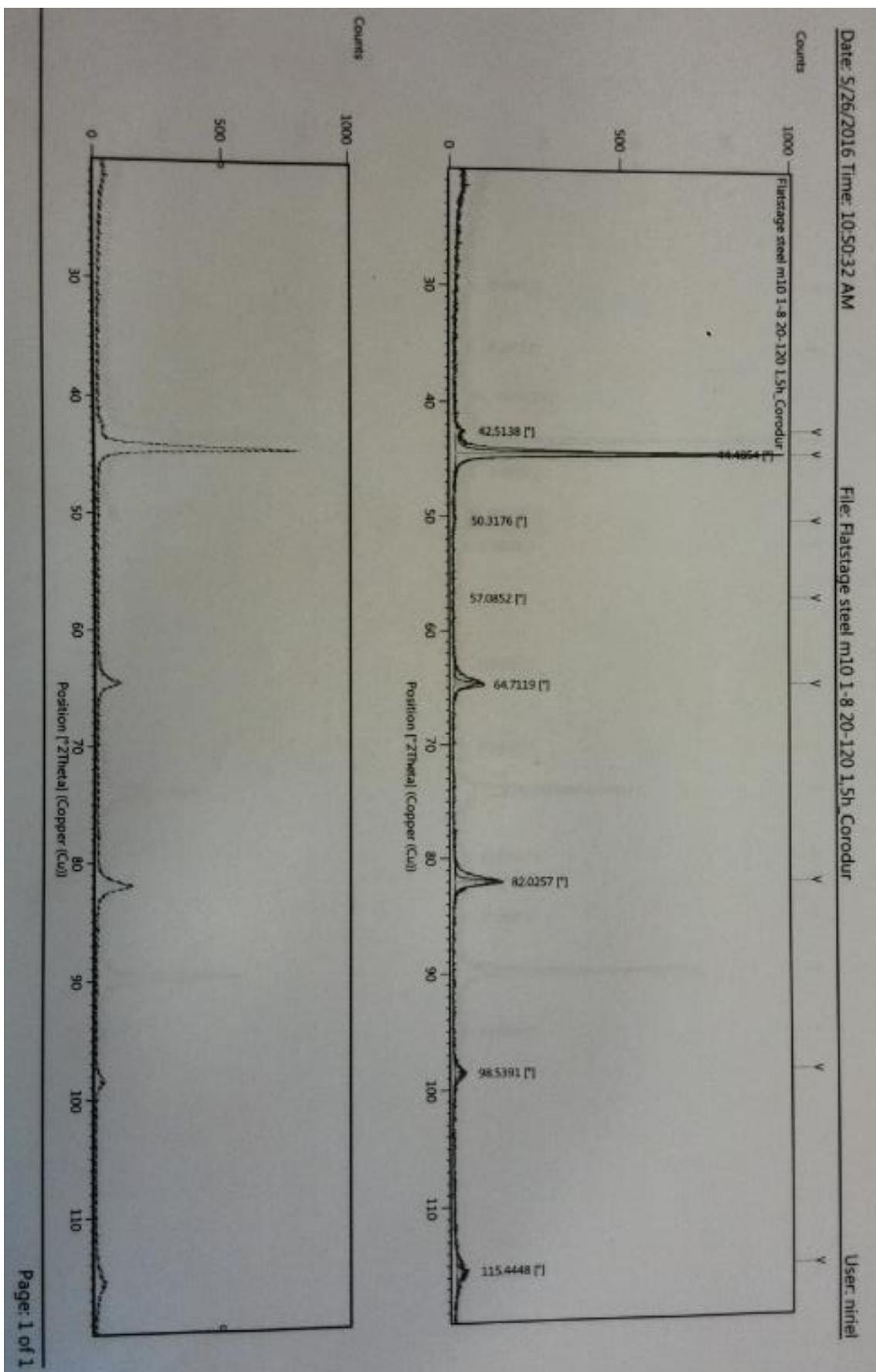


Figure 21. X-Ray results of Corodur's sample

11.4 Hardface HC-E

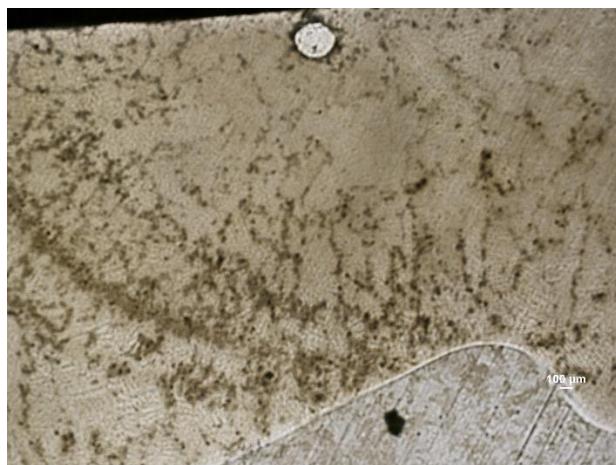


Figure 22. Hardface HC-E cladding after 15 seconds of etching with a magnitude of 2.5

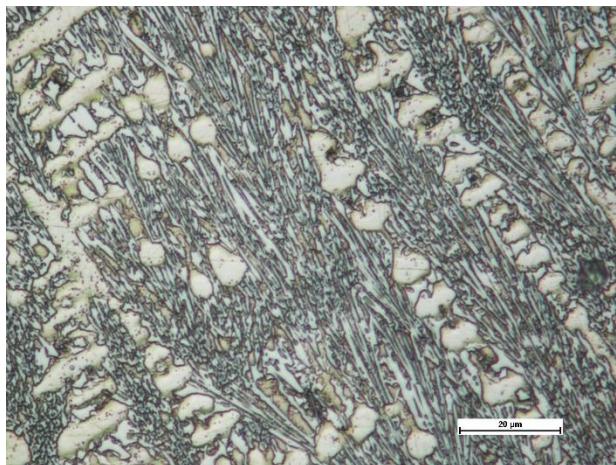


Figure 23. Hardface HC-E cladding after 5 seconds of etching with a magnitude of 100

In the figures 22 and 23, photos from the optical microscope, can be seen a dendritic structure, where the white zone is carbides that are the latest in solidifying, and darkest zone can be flagstone of martensite with retained carbide. More photos of Hardface's sample are in the appendix 5. The figure 24 is a picture of the sample using the SEM.

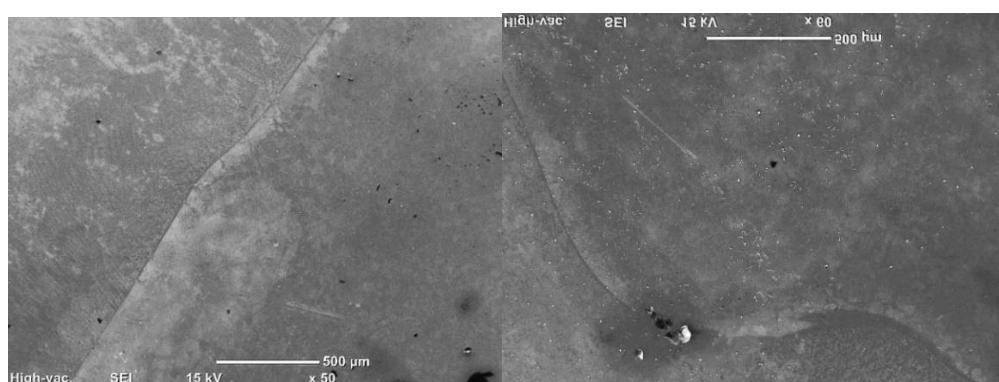
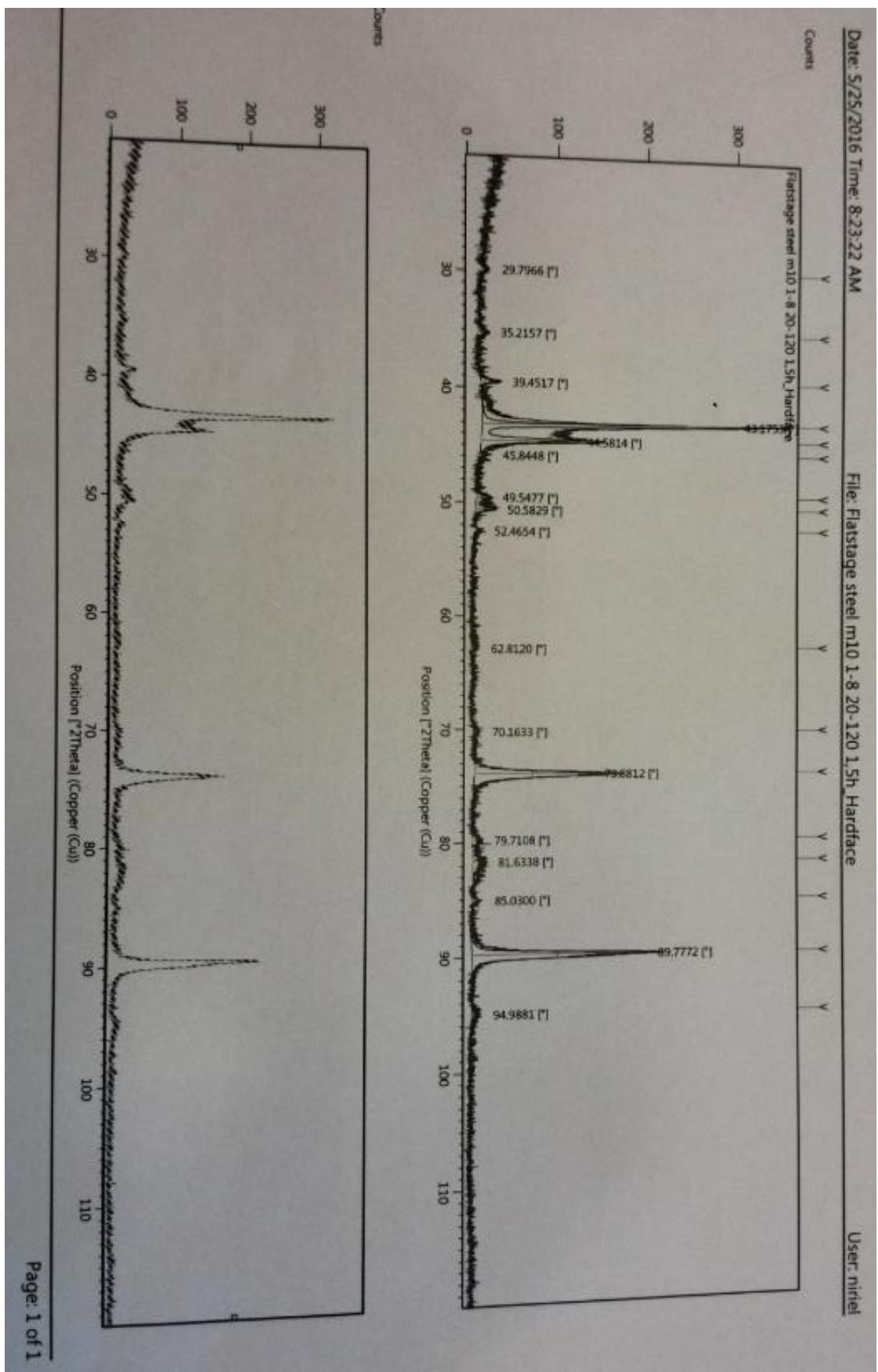


Figure 24. Photos of the union between cladding and base material of the Hardface sample in the SEM. In the photo of the left, the filler metal is the left side, in the right photo the filler metal is in the top.



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Figure 25. X-Ray results of Hardface's sample

11.5 Hardness

The figures (26-28) shows graphics of the hardness test values of each material. The position for the 0 level is the union between the welding and the base metal.

The measurement was starting in the top of the welding (the sample has a thickness about 6 mm), the part in contact with the bakelite. In this measure the mass used in the hardness test was 50 grams, only in this measure, in the rest, 100 grams were the mass used. Each measures was performed every 0.5 mm.

The negative values in the graphic are measures in the base metal.

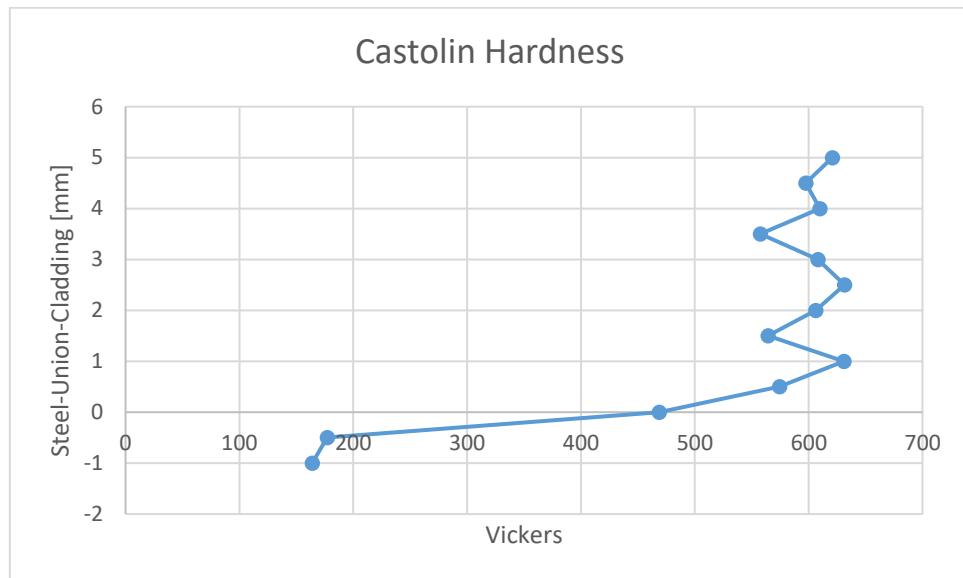


Figure 26. Castolin Hardness (values appendix 5)

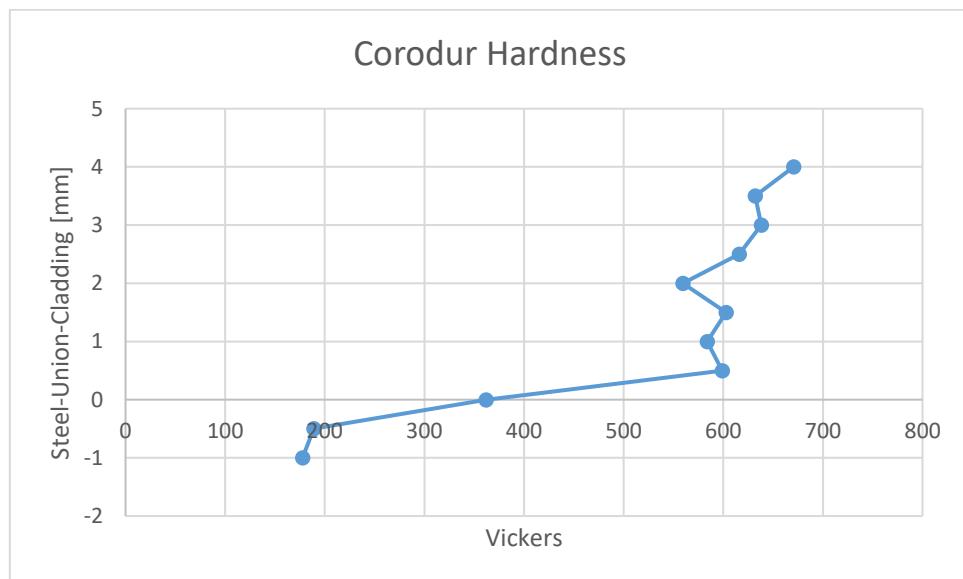


Figure 27. Corodur hardness (values appendix 5)

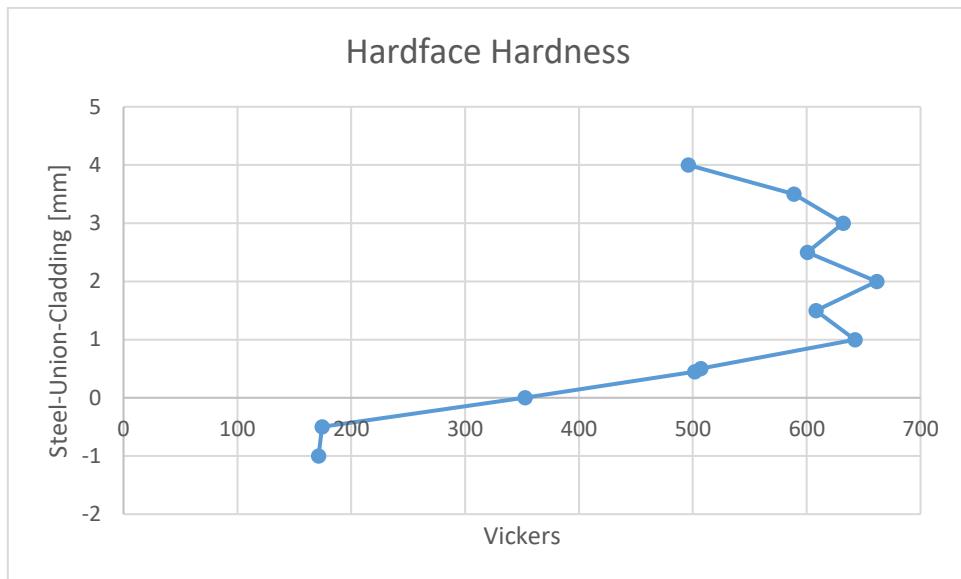


Figure 28. Hardface hardness (values appendix 5)

12 Discussion

The weld metal has a solidification structure. This structure and its mechanical properties are a direct result of the sequence of events that occur when the weld metal solidifies. As it was said before, the solidification of Castolin sample present in the bottom of the welding several dots of porosity or some impurities (the last material in solidify). This lead to an increase in the brittleness of the sample.

The Corodur's sample was welded with GMAW, which is faster than SMAW, and an inert gas isn't necessary. The microstructure is a martensitic structure, these deposits have inferior impact resistance to pearlitic or austenitic alloys but higher hardness and better resistance to abrasive wear.

The hardface has a microstructure with dendritic structure of carbides, and a martensitic matrix. A martensitic matrix is beneficial to high-stress abrasion resistance because of the additional support that martensite provides to the surface carbides.

The hardness is almost the same in each sample. And the X-Ray test shows a composition of normal steel for the Castolin and Corodur samples and some austenitic in Hardface.

13 Conclusions

- In the Castolin sample, the welding was executed by GMAW. This electrode was not possible to weld without an inert gas. When a welding is performed with a shielding gas, the welding can be contaminated because some atmospheric agents could disperse the shielding gas producing a porous and weak welding. Other disadvantages in the use of shielding gas is a heavier and bigger equipment difficult to move. These are the reasons why a welding with shielding gas are often done indoors and why it cannot be used for this project.
- After microstructural investigation of Corodur and Hardface samples (nothing special can be detected by the SEM) and hardness test of the samples, no big differences could be detected between them. This means that, the choice, at first sight, is not so clear. But it was found that one possible way to minimize the erosion by using an austenitic steel. So according to the XRD data, the Hardface sample has austenitic microstructure.

14 Future work

More tests should be performed in order to verify the Hardface samples has the best erosion resistance among the tested materials.

Some possible work to measure the resistant could be some of the erosion test that were mention before.

Other test that could be done to search for porosity or impurities in the sample like the use of magnetics particles, ultrasonic inspection.

15 References

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Appendix 1

The hardness results from the dust sample are in the table 1. With a mass of 50 grams, 20 measures were performed, and after that an average could be calculated.

Table 1. Hardness values of the dust sample

P(grams)	HV
50	125,8
50	105,5
50	100,3
50	107,2
50	81,8
50	430,4
50	326,9
50	245,8
50	117,4
50	138,7
50	53,4
50	181,9
50	495,1
50	415
50	415,2
50	342,2
50	363,7
50	275,4
50	171,2
50	163,8

Appendix 2

CASTOMAG:

The electrode Castomag 45351 is a product of Castolin Eutectic. Castolin Scandinavia AB in Sweden: Box 4193, 422 04 Hisings Backa. Besökadress: Transportgatan 37. order@castolin.se

With over 104 years of experience in protective materials, Castolin has established itself as the leader in helping companies to design, protect, repair and maintain their equipment and facilities. - See more at: www.castolin.com.

CORODUR:

The electrode Corodur 600 OA is a product of Corodur Fülldraht GmbH. Svenska Elektrod AB. Solna, Gustafsvägen. www.corodur.de. www.svenskaelektrod.se

Many years of metallurgical experience, both on-site and in the lab. One of the applications that of this company is in the mining. Corodur's specially developed impact and abrasion resisting hard surfacing materials ensure longer life.

HARDFACE:

The electrode Hardface HC-E is a product of Welding-alloys. Welding Alloys Sweden, AB Dalforsan. Website: www.dalforsan.se.

Founded in 1966, Welding Alloys Group is specialist in: Low and high alloyed cored wires; Automated welding equipment for surfacing and joining applications; Industrial welding applications.

Welding Alloys Group manufactures the widest range of flux cored and metal welding wires in the World.

Successful applications and solutions in the industry of mining-quarries-earth moving.

Appendix 3

Castolin:

Photos of the microstructure (fig. 1 and 2), using the optical microscope, after 20 seconds of etching with different magnification:

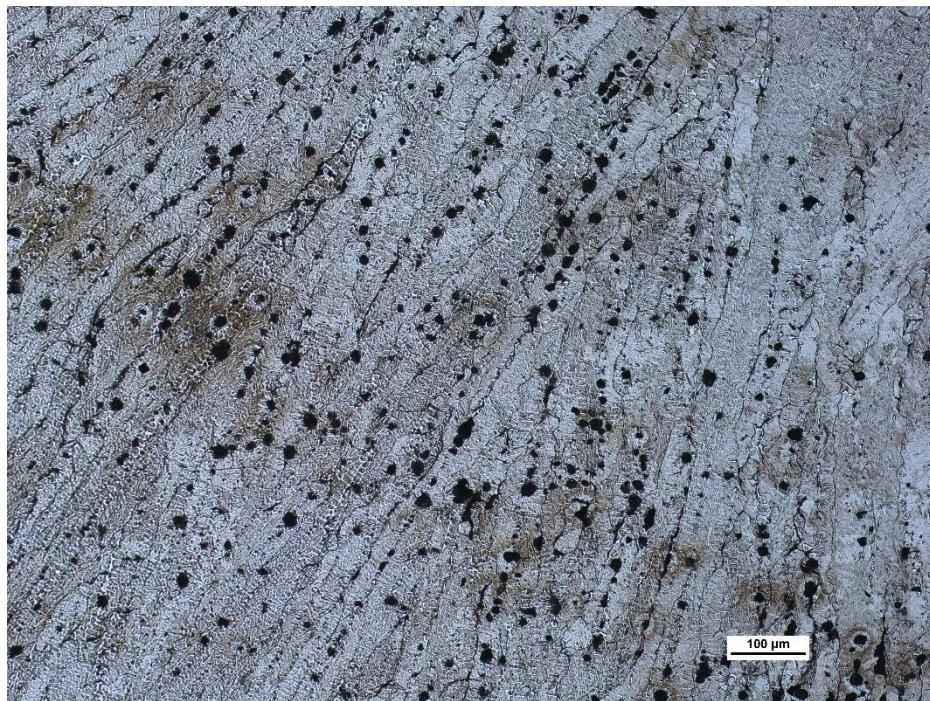


Figure 1. Castomag sample with magnification of 10

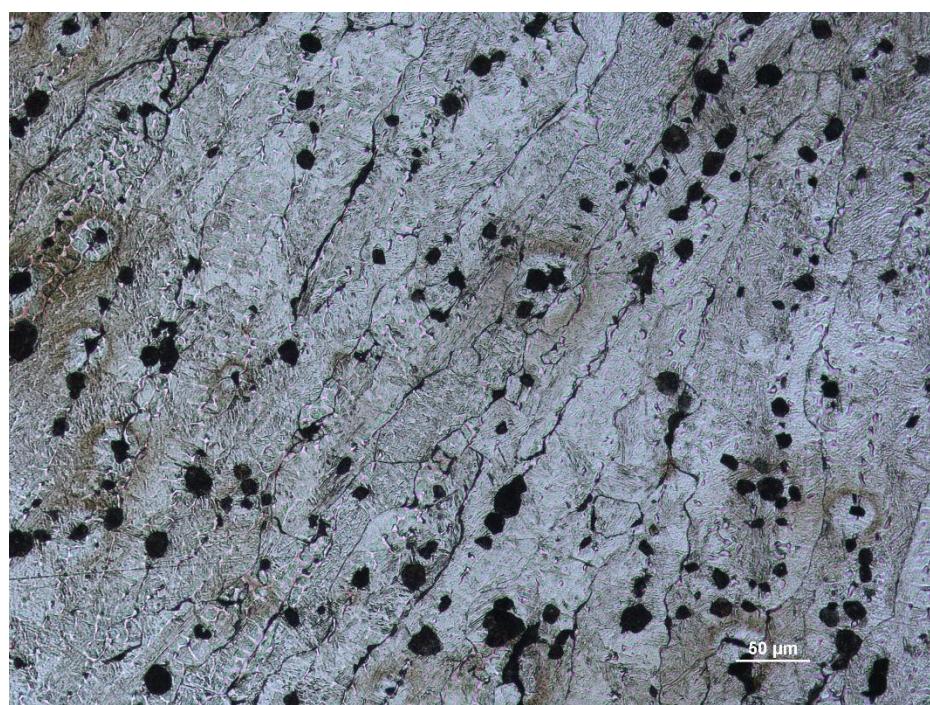


Figure 229. Castomag sample with a magnification of 20

Photos of the microstructure (fig 3 and 4), using the optical microscope, after 30 seconds of etching with different magnification:

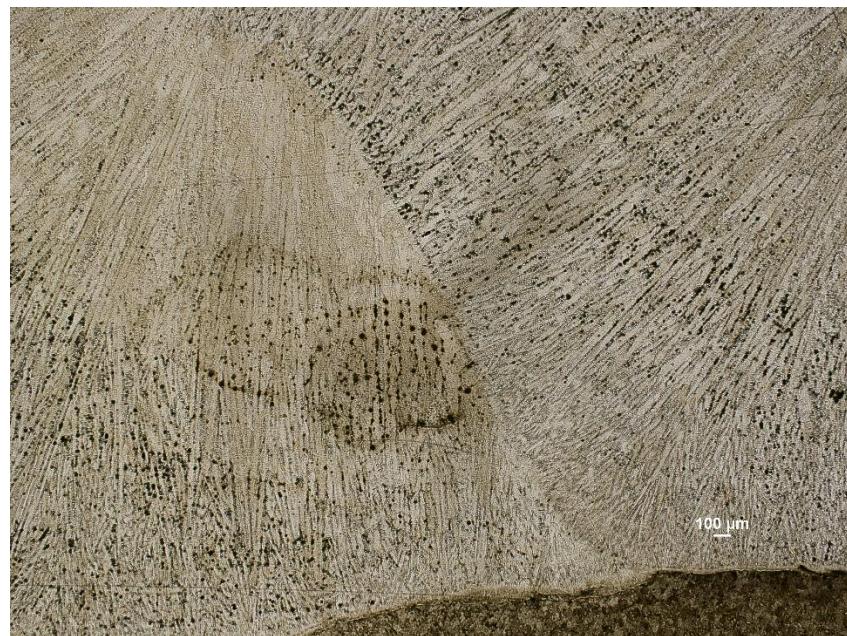


Figure 30. Castomag sample with a magnification of 2.5

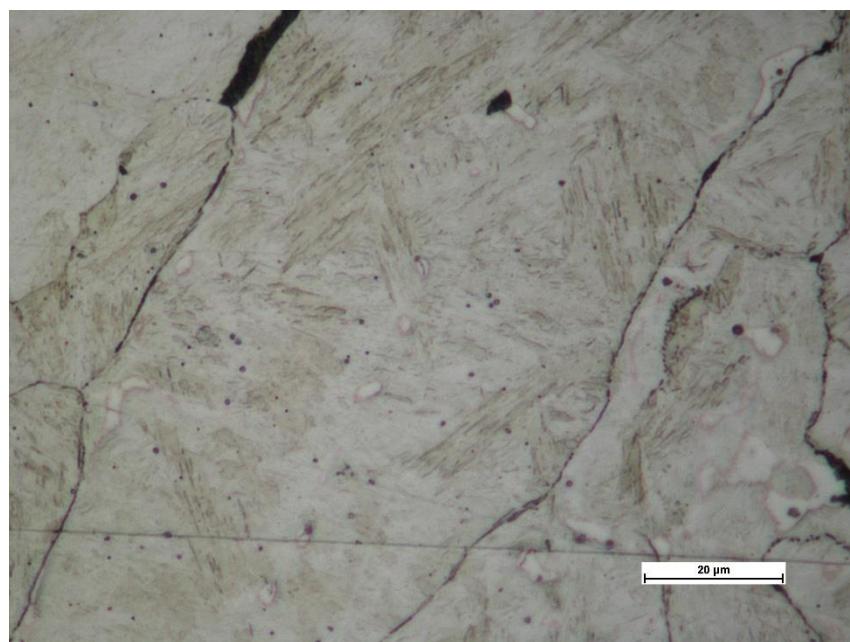


Figure 4. Castomag sample with a magnification of 100

Photos of the Castomag cladding (fig. 5), using the SEM, after 40 seconds of etching:

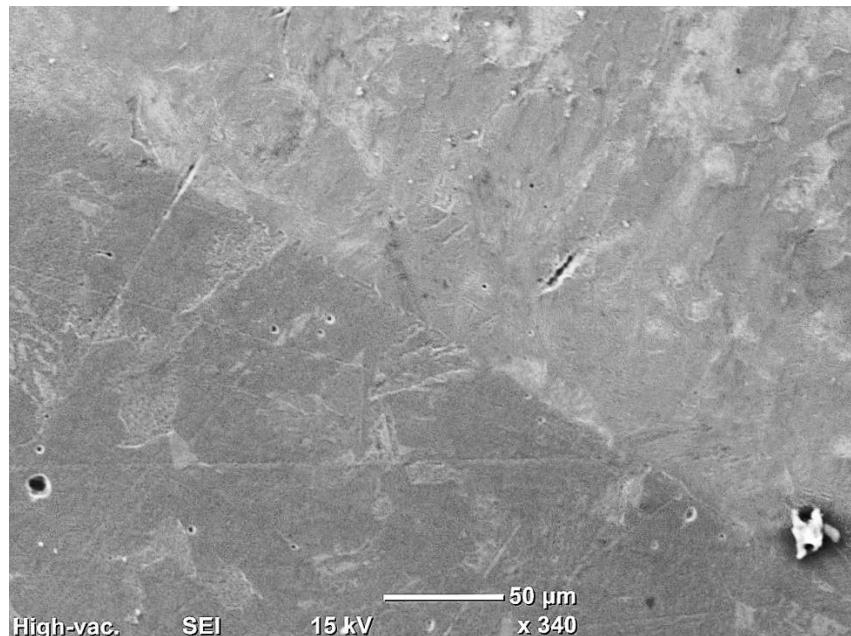


Figure 531. Castomag sample in the SEM

Appendix 4

Corodur:

Photos of the Corodur (fig. 1 and 2) cladding using the optical microscope after 10 seconds of etching:

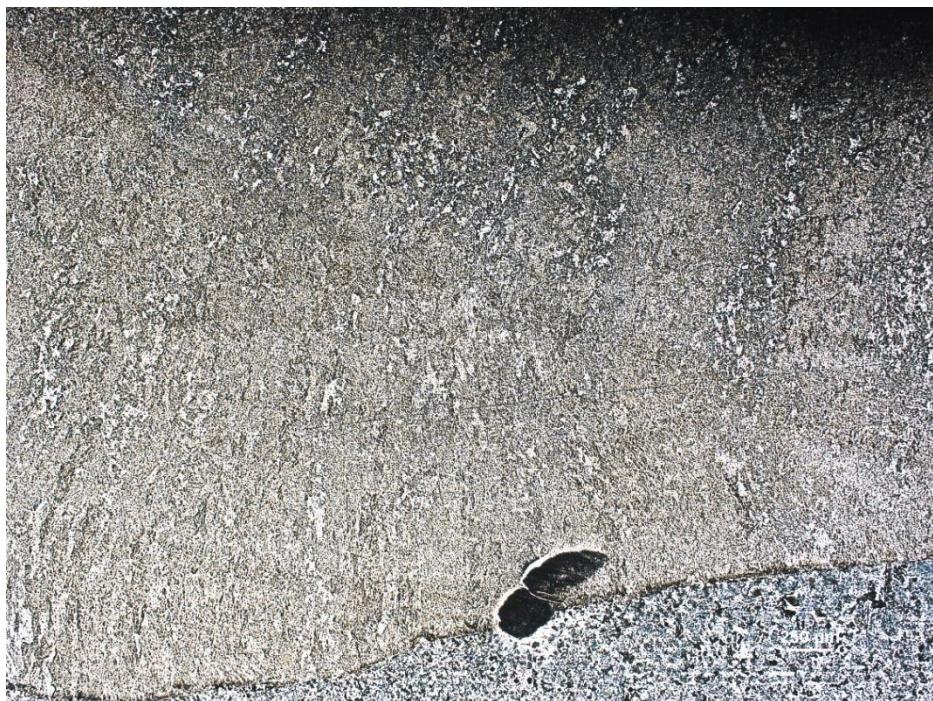


Figure 1. Corodur sample with a magnification of 2.5

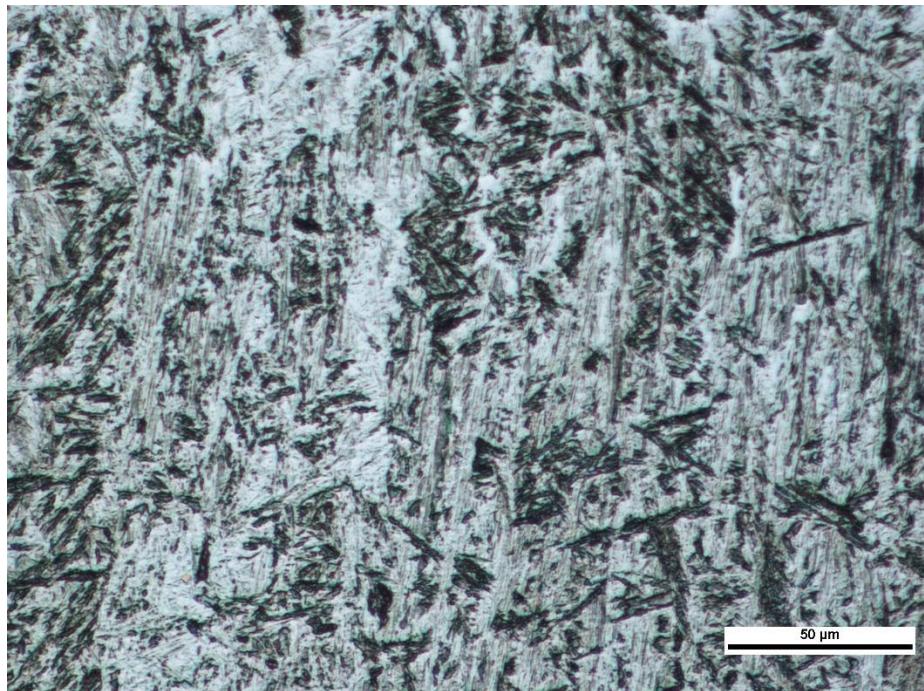


Figure 2. Corodur sample with a magnification of 50

Photos of the Corodur cladding (fig. 3 and 4) using the optical microscope after 15 seconds of etching:



Figure 32. Corodur sample with a magnification of 20

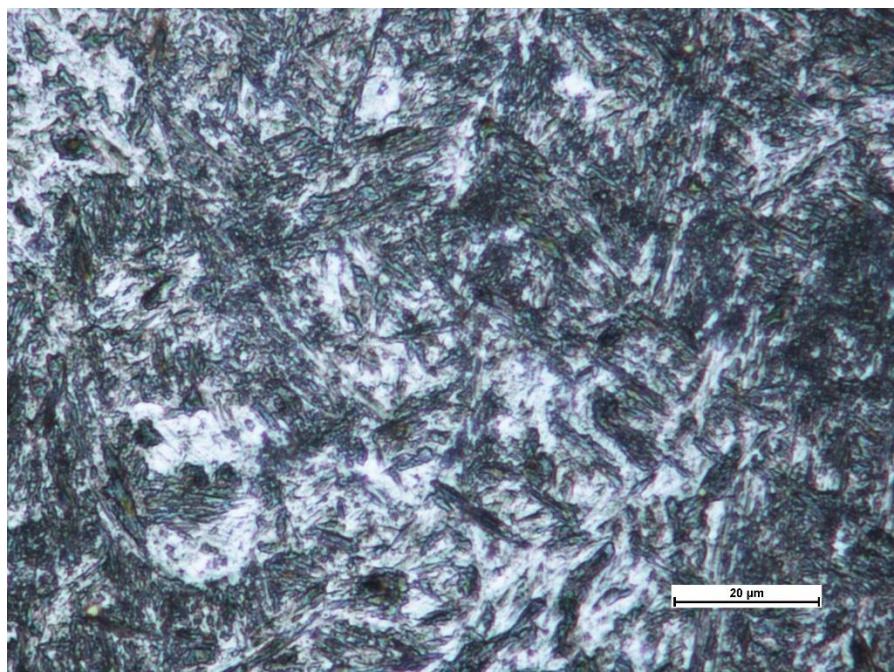


Figure 4. Corodur sample with a magnification of 100

Photos of the corodur claddig (fig. 5 and 6) using SEM after 60 seconds of etching:

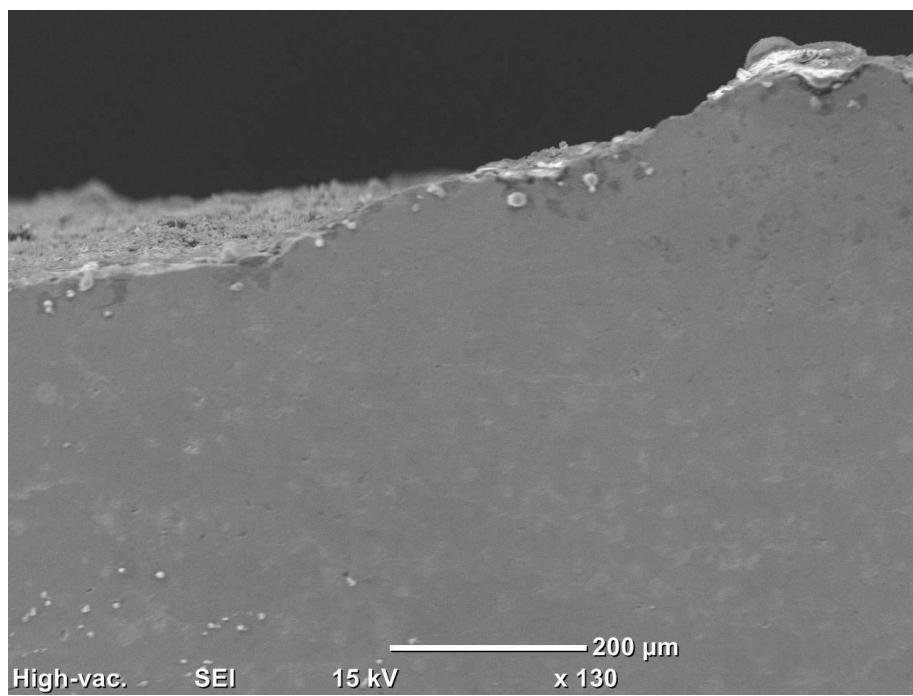


Figure 5. SEM top

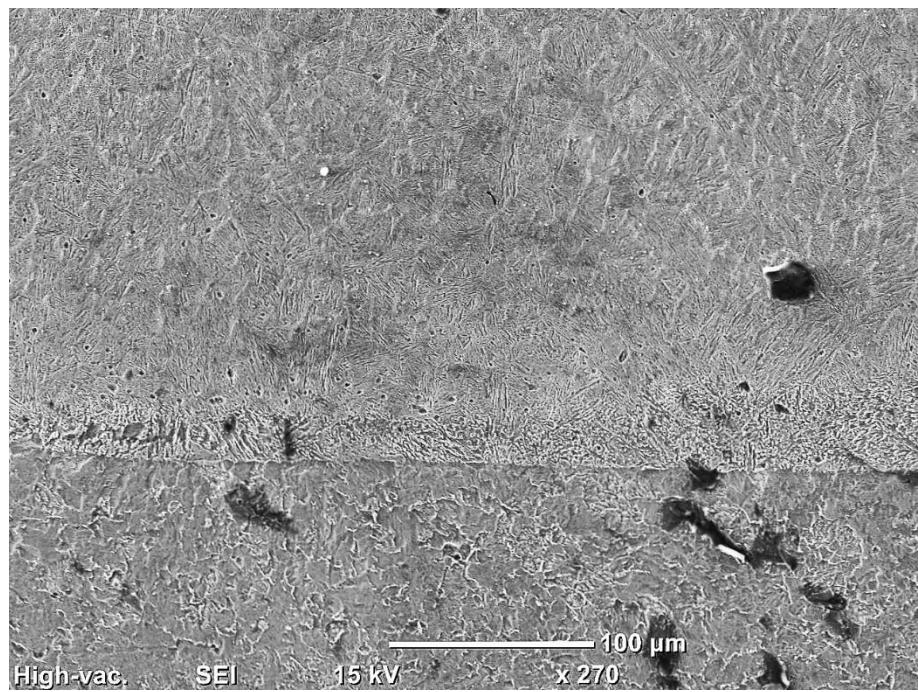


Figure 6. SEM union

Appendix 5

Hardface:

Photos of the Hardface cladding (fig 1 and 2), using the optical microscope, after 5 seconds of etching:



Figure 1. Hardface sample with a magnification of 10

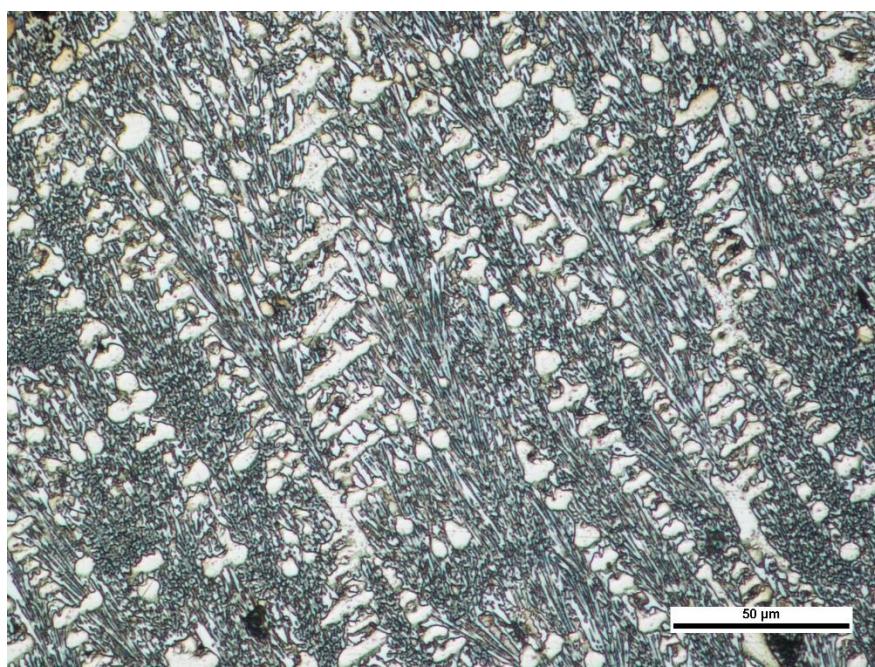


Figure 2. Hardface sample with a magnification of 50

Photos of the Hardface cladding (fig 3 and 4), using the optical microscope, after 15 seconds of etching:



Figure 333. Hardface sample with a magnification of 2.5

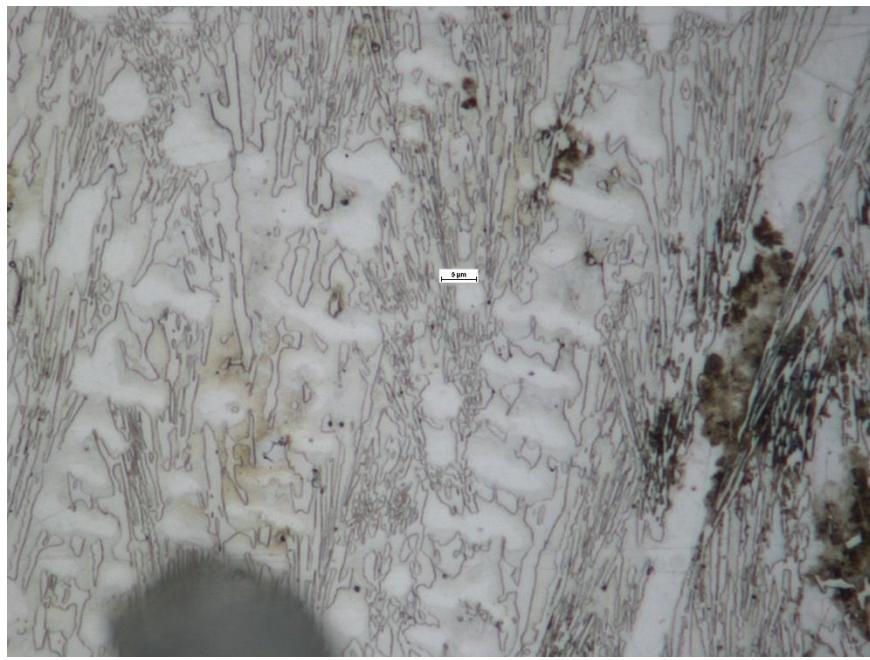


Figure 34. Hardface sample with a magnification of 100

Appedix 6

HARDNESS:

Table 1. Castolin Hardness

Castolin									
Hardness		grams	mm	HV 1	HV 2	HV 3	HV 4	HV 5	Average
		50	0	646,4	682	444,2	712,6	660,3	620,712196
		100	0,5	597,5	657,6	503	572,5	672,7	597,438112
		100	1	672,7	610,6	456,7	667,6	672,7	609,690459
		100	1,5	662,6	513,1	448,2	545,3	647,8	557,442848
		100	2	541,6	662,6	520	647,8	688,4	608,195283
		100	2,5	560,6	615,1	647,8	704,6	638,2	631,521064
		100	3	624,2	564,6	549,1	672,7	628,8	606,191732
		100	3,5	549,1	477,4	471,4	683,1	677,9	564,306004
		100	4	688,4	564,6	560,6		727,2	630,91692
		100	4,5	727,2	453,8				574,459189
	Union			409	352,4	523,5	480,5	624,2	468,747117
		100	0,5	186,2	178,2	187	180,4	156	177,181357
		100	1	163,8	163,2	184	157,2	153,2	163,950459

Table 2. Corodur Hardness

Corodur									
Hardness		grams	mm	HV 1	HV 2	HV 3	HV 4	HV 5	Average
		50	0	653,3	697,1	667,4	712,6	626,3	670,6322504
		100	0,5	628,8	647,8	657,6	572,5	657,6	632,0195544
		100	1	638,2	633,5	657,6	647,8	615,1	638,2787397
		100	1,5	628,8	601,8	619,6	601,8	628,8	616,0389449
		100	2	509,7	545,3	560,6	572,5	615,1	559,5834848
		100	2,5	584,8	624,2	576,6	619,6	610,6	602,8576761
		100	3	597,5	572,5	597,5	568,5		583,8421493
		100	3,5	624,2	589	584,8			599,076303
	Union			308,3	366,4	356,3	374,8	411,5	361,8952199
		100	0,5	193,9	185,5	193,9	192,3	180,4	189,1224433
		100	1	177,5	175,5	178,9	174,8	181,8	177,6823237

Table 3. Hardface Hardness

Hardface Hardness							
grams	mm	HV 1	HV 2	HV 3	HV 4	HV 5	Average
50	0	477,1	429	494,9	472,7	626,3	495,895806
100	0,5	549,1	545,3	503	615,1	763,1	588,676124
100	1	584,8	642,9	564,6	568,5	836,2	632,100973
100	1,5	520	593,2	633,5	576,6	693,8	600,636898
100	2	619,6	677,9	568,5	672,7	788,5	661,494332
100	2,5	677,9	647,8	471,4	619,6	647,8	608,008571
100	3	677,9	580,7	584,8	738,9	642,9	642,348602
100	3,5	431,9	597,5	406,6	642,9	496,4	506,958883
100	3,55	401,8	589		477,4	560,6	501,666596
100	Union	314,8	328,4	328,4	426,6	377	352,728575
100	0,5	173,4	181,8	165,6	169,5	181,8	174,298391
100	1	168,8	173,4	174	160,7	180,4	171,334428