New technique for centre line segregation measurement in steel slabs

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A new technique for automatic assessment of centre line segregation based on image analysis is presented. This innovative tool can detect both centre line segregation and centre line cracks from digitalized sulphur prints giving an objective result. A data base containing process data from the caster and the new index for segregation measurement have been created. First analyses of this data base by data mining tools have been performed showing very promising results.

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■ INTRODUCTION AND OBJECTIVES

Centreline segregation is an internal defect appearing in cast products due to the solidification process that may be very detrimental for the final product. The steel composition, the casting process and the condition of the machine have an influence on the segregation severity. Nevertheless, there are some countermeasures such as the electromagnetic stirring in CC (1, 2) that can reduce the appearance of this phenomenon.

Analyses about segregation have been reported in the literature, focused on the main parameters and also trying to develop models to explain or predict this phenomenon (2, 4, 5, 6). Although these models analyze the solidification process and afford a mathematical formulation of the problem they do not use the Machine Learning (10) techniques that are introduced in this paper.

A common practice to evaluate segregation in continuous cast slabs is to use sulphur prints. They are evaluated by an expert who compares them with some pattern images and determines a segregation index. Since this method is very subjective, this paper describes the development and use of an automatic tool based on image analysis. This tool is able to detect and evaluate both segregated spots and internal longitudinal cracks. This evaluation system has been developed for slabs cast in two continuous casting machines of Arcelor España, in a project funded by the EU RFCS-Steel Program.

There are other methods for segregation evaluation like the one developed in ECSC project (7) that combines macro electrolytic etching with image analysis, the one reported in (8) or the one based on the use of ultrasonic and computer aided analysis with a micro probe (9).

The first results of evaluation with this innovative tool have already been obtained and a data base created containing data from the caster and the new segregation index. First analysis of this data base by means of data mining tools has been done with the objective of developing a model of segregation.

It is an objective to replace sulphur prints by a digital image taken directly from the slab sample surface by means of a camera which eliminates the need of obtaining the sulphur print. This implies an economical benefit, a reduction in environmental impact and a saving in process time. Moreover the traditional system of filing the sulphur prints is modernized, thus allowing faster access to previous images. The system will be fully integrated with the steel shop database.

The main advantage of this tool against the current method of evaluation is that this system does not suffer from the subjectivity of the operator and provides therefore a very objective and homogenous result. Once it is installed and running it will

Nouvelle technique pour mesurer la ségrégation centrale dans les brames d'acier

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Objectifs

Un nouvel outil pour l'évaluation de la ségrégation centrale des brames d'acier a été développé par Arcelor España. Cet outil innovant, appelé MESEG, peut détecter la ségrégation centrale à partir d'empreintes Baumann ainsi que les criques longitudinales centrales.

L'empreinte doit être digitalisée pour effectuer l'analyse. Dans une première étape, la zone ségrégée est détectée, et seule cette zone est analysée, pas toute l'empreinte. Après quelques étapes de traitement, comme la conversion en image binaire et un filtrage, les points ségrégés sont isolés. Fondés sur l'épaisseur et la continuité de ces points, de nouveaux index sont calculés qui représentent la sévérité de la ségrégation. L'index le plus significatif est appelé C_Factor (représentatif de la continuité de la zone ségrégée), il est employé comme variable objective pour la suite du développement d'un modèle.

MESEG peut aussi détecter les criques longitudinales, avec la même procédure que pour l'évaluation de la ségrégation. Effectivement, avant tout traitement (évaluation de la ségrégation) l'outil distingue la zone de l'empreinte affectée de ségrégation de la zone présentant une crique. Les criques sont détectées á partir du facteur de forme; la tache d'une crique est caractérisée par un facteur de forme plus élevé qu'une tache de ségrégation. MESEG donne comme résultat la longueur de la zone affectée par une crique.

MESEG offre une interface conviviale pour l'opérateur. Il peut en effet changer la position de la zone centrale dans l'empreinte sélectionnée pour réaliser la mesure. Cette interface lui montre les résultats après le traitement.

Il est envisagé de remplacer l'empreinte Baumann par une image obtenue directement par caméra vidéo de la surface de l'échantillon. Cette image sera employée par MESEG pour faire les mesures. Il est également prévu d'intégrer MESEG dans l'aciérie.

L'avantage la plus important de MESEG c'est qu'il donne un résultat plus objectif que l'évaluation faite par l'opérateur. Dans le futur des niveaux de variation du C_Factor seront établis pour que l'interprétation des résultats soit plus facile.

Développement du modèle

Un processus d'évaluation et de collation des données est en cours dans l'aciérie d'Arcelor España, où MESEG a été développé. Une base de données a été créée à partir des données de la machine de coulée continue et des résultats d'évaluation des empreintes. Avec ces données deux approches de développement d'un modèle ont été suivies à l'aide d'un type spécial de réseau de neurones appelé Self Organizing Maps (SOM).

La première étape du développement consiste en la sélection des variables qui seront introduites dans le modèle, parmi les très nombreuses variables enregistrées au process aciérie.

L'aciérie d'Arcelor España dispose d'un modèle de la qualité qui tient compte du risque de ségrégation grâce à un index calculé à partir d'une formule fondée sur l'expérience. Le SOM a d'abord été éduqué avec les variables de cette formule empirique: teneur en soufre au répartiteur, vitesse de coulée, surchauffe et refroidissement. La variable objective est le C_Factor.

Les données ont été réparties en deux groupes, un pour éduquer le modèle et l'autre pour le valider. L'erreur moyenne obtenue est 0.2373

Cependant, l'expérience montre que d'autres variables influencent également la ségrégation, telles les teneurs en C, en Mn et en P. Ces variables ont été ajoutées au groupe initial et un nouveaux SOM a été éduqué. Cette fois l'erreur a été ramenée à 0.1186.

Conclusions

Un outil innovant pour l'évaluation de la ségrégation centrale a été développé par Arcelor España. Il fournit un index précis et objectif de la ségrégation et il pourra être intégré au process de l'aciérie. Cet outil, appelé MESEG, donne aussi une mesure de la longueur des criques longitudinales éventuelles. MESEG peut très facilement être transposé à une autre aciérie avec de très faibles modifications.

Avec les données fournies par MESEG et celles issues des machines de coulée, deux essais de développement d'un modèle on été réalisés avec des très bons résultats. Dans le futur la base de données sera enrichie et de nouveaux essais avec différents groupes de variables seront réalisés

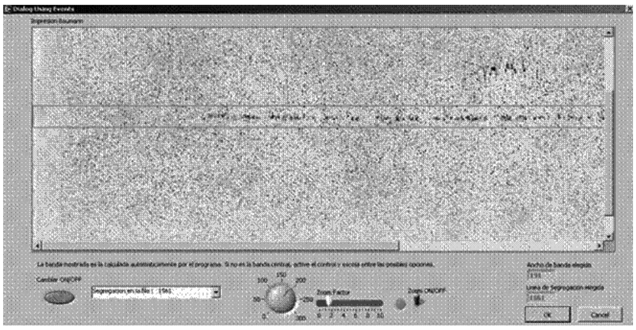

Fig. 1 - Example of the user interface.

Fig. 1 - Exemple de l'interface utilisateur.

easy up evaluation and will provide all staff of the steel shop with the available pertinent information.

Furthermore, the development of a Model of Segregation allows introducing the necessary corrective actions when some specific parameters deviate from their expected value and may increase segregation severity.

■ TECHNICAL DEVELOPMENT

The system for segregation evaluation is based on image analysis, while the first approach for the development of the model has been done with a specific type of neural networks, called Self Organizing Map (SOM) (11).

The new system developed for segregation measurement, from now on referred to as MESEG, is a Graphical Image Processing application which derives information from the scanning and digitalization of the available sulphur prints. Then it performs several stages of image processing.

The paper sulphur print is digitalized in a wide format colour scanner at 300 dpi, 24 bit depth. The image is immediately converted in 8 bit grey scale image because colour does not provide any information.

Once the image has been digitalized the image processing stages take place.

First the central band of segregation is detected and isolated from the rest of the image. MESEG has available a friendly and flexible interface with the user in which the detected band is showed to the operator allowing him to validate the selection and start the evaluation or to modify the position and width of the selected band. An example of the interface is shown in *figure 1*. Another advantage of the interface is that it makes it possible to work on full automatic or alternatively to include the staff valuable experience.

The second step is a filtering to refine segregation borders. Then the image is binarized to black and white and features are extracted. Finally, a new filtering is applied to eliminate isolated points that must not be considered as segregation. This is shown in *figure 2*; it can be noted that the processing is only applied to the segregated band.

MESEG performs the evaluation of segregation based on two characteristics of the segregated band: the continuity and the width of the spots and provides four appropriate indexes: a continuity percentage, a factor called C_Factor, and the average and maximum width of the spots. The most representative of segregation severity is C_Factor.

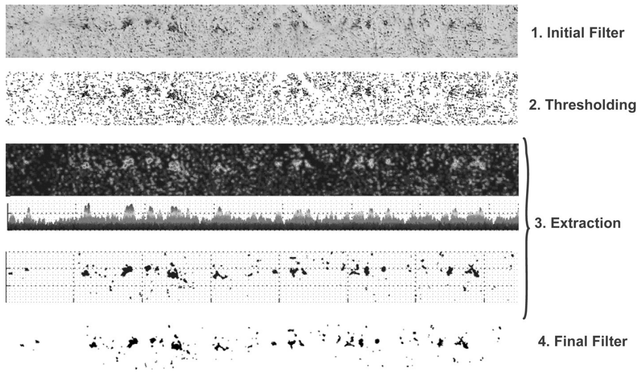

Fig. 2 - Image processing for segregation evaluation.

Fig. 2 - Traitement d'image pour évaluation de la ségrégation.

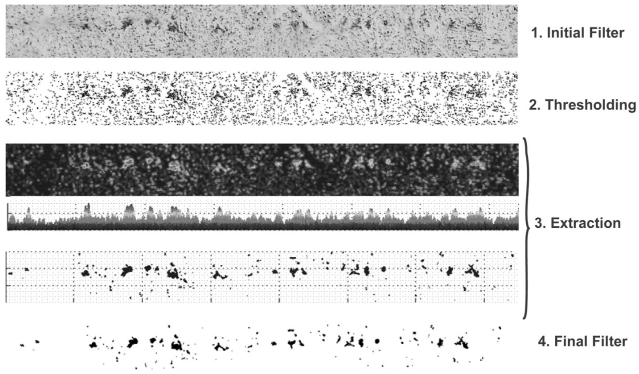

Fig. 3 - Example of different sulphur prints with different levels of segregation.

Fig. 3 - Exemple d'empreintes Baumann pour différents niveaux de ségrégation.

Figure 3 shows three different sulphur prints with different levels of segregation. The value of C_Factor is also shown and it can be seen that it is in good agreement with these levels.

MESEG can also detect and evaluate internal longitudinal cracks. Crack detection is applied after obtaining the segregation band. This band is separated in two different zones: segregation zone and crack zone. C_Factor, continuity percentage, average and maximum width of segregation are calculated for the former area while the crack length is measured in the latter.

Figure 4 shows the way to pre-process the crack area in order to obtain a clean b/w image. Evaluation is then based on the shape factor of the spots. Crack's spot tend to be longer when measured in the direction of the segregation, while segregated spots are rounder; therefore they have a higher shape factor.

MESEG interface offers information about the presence of a crack in a visual way which facilitates the understanding of the results *(fig. 5)*.

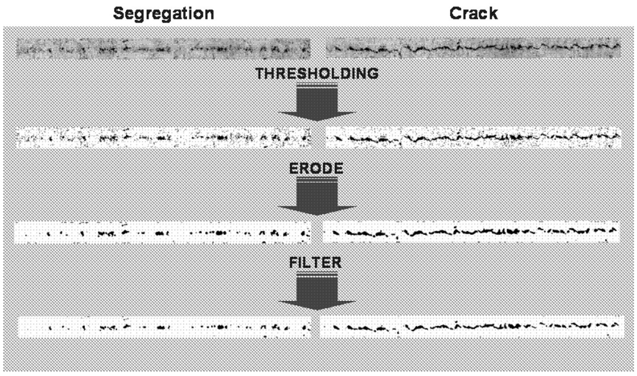

Fig. 4 - Cracks processing.

Fig. 4 - Traitement des criques.

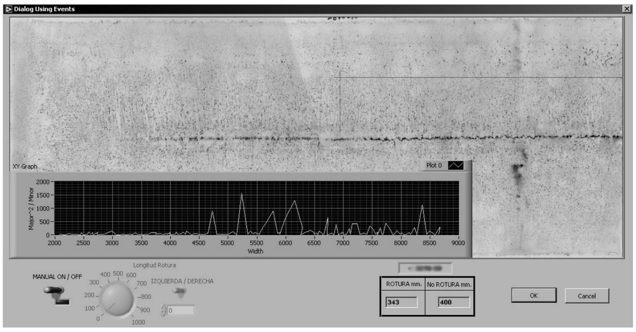

Fig. 5 - Cracks interface.

Fig. 5 - Interface pour les criques.

■ MODEL DEVELOPMENT

Based on the results of the evaluation of sulphur prints by MESEG, a data base has been created that also includes operational data from the caster on evaluated slabs.

Description of the technique used (SOM)

The technique used to develop the model is Self Organizing Maps (SOM). They are a particular type of neural networks in which the net tries to approximate the distribution of the input points, and to represent these data in lower dimensional space, usually 2D.

Basically it consists of a 2D grid of neurons, in which each neuron has associated a weight vector of the same dimension as the input space, e.g., if we have an input space of 8 variables the associated weight vector would have 8 components. By means of an iterative process the neurons of the grid are brought near. Then, each point in the input space can be represented in the output one (the 2D grid) by its nearest neuron or activated neuron.

SOM allows the user to perform several graphical representations. One of the most useful and used in this work is component maps. There is the same number of component maps as dimensions (number of variables) of the input space. They represent by means of colour intensities the value of the current variable.

Variable selection

Nowadays there is a quality model running in the Arcelor España steel shop in the area of CC that follows the evolution of the value of some events related to the state of the casting process. These events include, among others, the nitrogen pick-up, the variation in the mould level, the nozzle change or the occurrence of segregation. The later that is the most relevant for this research, is expressed as a real value calculated by an empirical formula obtained after the examination of thousands of sulphur prints by an expert. The variables included in such expression are: sulphur content at the tundish, superheating, casting speed and specific cooling index.

A first attempt at the model development has been made using the above mentioned input variables and the value of the C_Factor as output variable.

However, experience shows that C content, Mn content and P content at the tundish also have some influence on the appearance of centre line segregation, therefore in a new attempt at model development a new SOM was trained including them in the input variables set.

Model development

The aim of this work is to prove both the applicability of SOM to a problem of such nature as the one analyzed in this research, and to develop a prototype of a model able to predict centre line segregation severity from process variables.

To train the SOM, a set of 233 data were available, that was split into two subgroups, one used for training with 154 register and the other one for validation with 79 registers. Data belonging to each group were chosen at random so that in each group all the possible situations were represented.

The training group includes all the input variables and the output one, while in the validation stage only the input variables are introduced to the model, since the aim is to predict the objective one.

As said before, two attempts at model development have been done, with different sets of input variables. The procedure to make the estimation of the C_Factor value for the validation set of data is the same in both cases. Once the SOM has been trained a new SOM is created from it, exactly to this, but eliminating the component that corresponds to the variables whose value is wanted to be predicted. On this new reduced SOM the data of the validation group is projected so that for each input point it is known the neuron activated. Back to the original SOM it is extracted the value that corresponds to C_Factor for that activated neuron.

Since the variable to be predicted takes real values, it is obvious that it will be very difficult to perform an exact prediction. To solve this problem and improve the model performance ranks of variation of C_Factor from 0 to 6 were established according to the values taken by this index.

In the future new trials will be done establishing a correlation between C_Factor and the index used in the steel shop. First attempts are explained in the next paragraph.

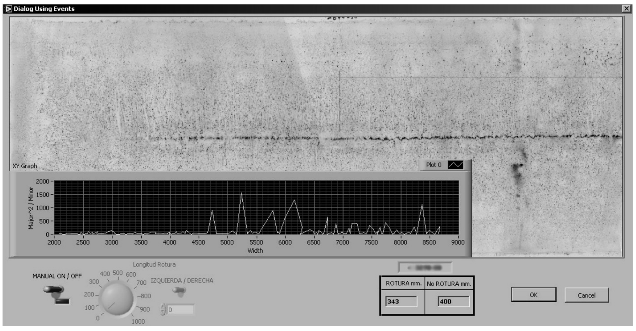

Fig. 5 - Cracks interface.

Fig. 5 - Interface pour les criques.

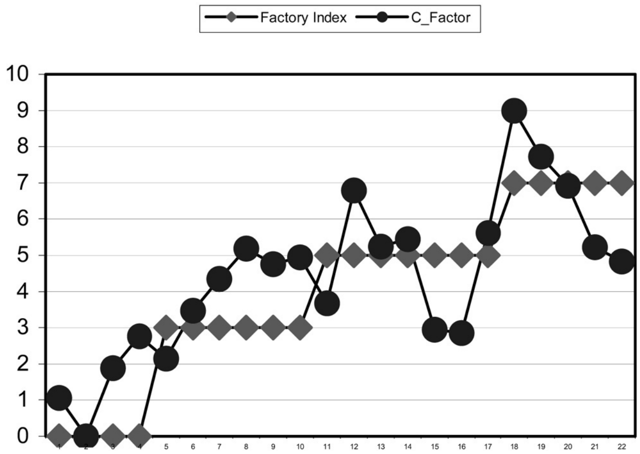

Fig. 6 - Comparison of MESEG with expert segregation index.

Fig. 6 - Comparaison des indices de ségrégation MESEG avec ceux déterminés par les experts.

■ RESULTS

The performance of this new tool has been evaluated by comparison with the segregation index obtained by the expert's at the steel shop. This index can take the predefined values 0, 1, 3, 5, 7, 9, where 0 represent the lowest segregation. Good results were established with the comparison of 22 slabs *(fig. 6)*. C_Factor provided by MESEG is a real number which can have four decimal numbers; it is obvious that an integer number which varies between specific limits makes it easier for the operator to get an idea of real segregation severity: therefore, based on this comparison a correspondence between C_Factor and the steel shop has been done.

Concerning the results of the model development, *figure 7* shows the component maps for the first training of the SOM. It displays a behaviour that may appear confusing since it seems as segregation is severe when sulphur is low and low when sulphur is high. To analyze this situation the scatter diagram of Sulphur content versus segregation index was done *(fig. 8)*. It reveals two clusters that may be classified according to the threshold limit of sulphur 0.005%.

For further processing, the data were divided into two groups, one with sulphur content below 0.005% and the other with sulphur content above that value. It results in two databases, one containing 54 (S<=0.005%) registers, which is not enough for model development and the other (S>0.005%) with 179 registers.

The reason for this behaviour may be that, depending on the value of other variables that have not been included in this first model development, there may appear some interactions with sulphur, which may produce higher values of segregation.

In the case of sulphur higher than 0.005% the predicted values are shown in *figure 9*, white asterisk represent failures and black ones good predictions. Although the number of white asterisks is high, they are mainly located in the limit between two areas, which indicates that the error committed is only of one unit. More accurate results could be obtained by a more precise definition of the different ranks.

The average error obtained is 0.2373 and the Root Mean Square error (RMS) is 0.9567, which is lower than 1 and therefore a very good value since each of the levels of variation of C_Factor differs from the next one in only one unit. Same process was followed for the second group of input variables, obtaining the projection shown in *figure 10*. Average error is 0.1186 and RMS 0.9297. It is improved when compared with the previous case. Nevertheless, there are still some input variables that could be included in the process to achieve even better results. This will be done in the future.

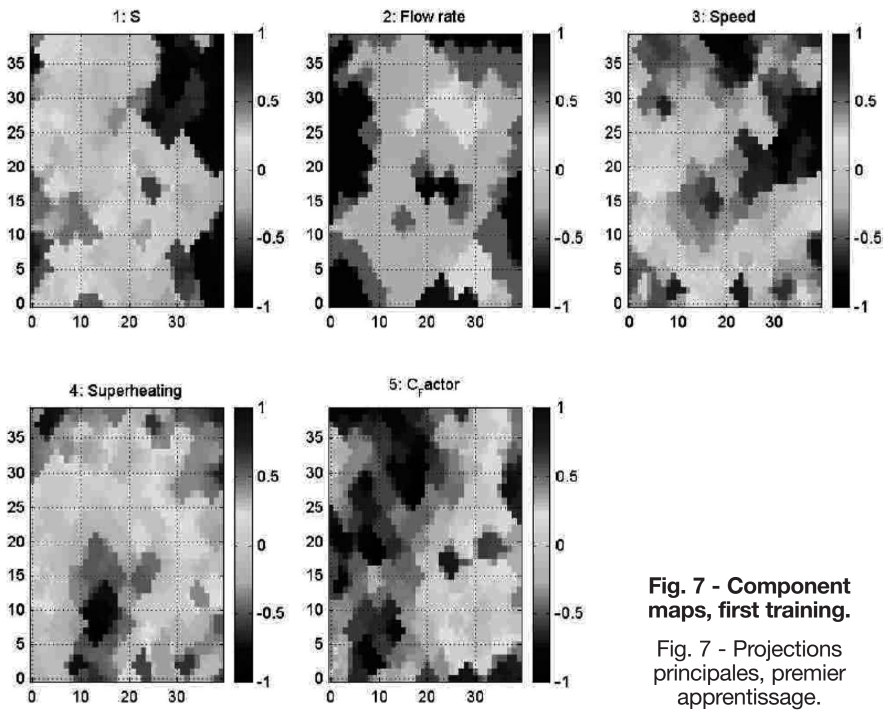

Fig. 7 - Component maps, first training.

Fig. 7 - Projections principales, premier apprentissage.

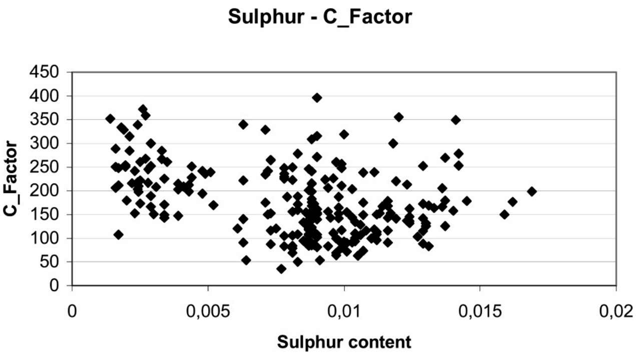

Fig. 8 - Scatter plot of C_factor versus sulphur.

Fig. 8 - Dispersion du C-factor en fonction du soufre.

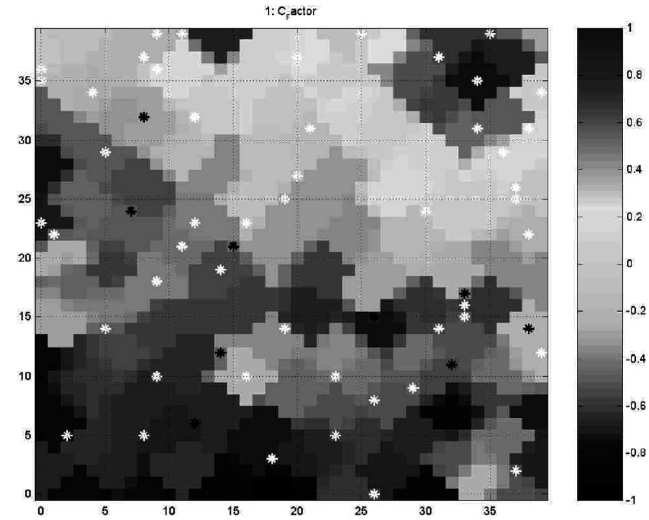

Fig. 9 - Predicted values of C_factor (first training).

Fig. 9 - Valeurs calculées du C_factor (premier apprentissage).

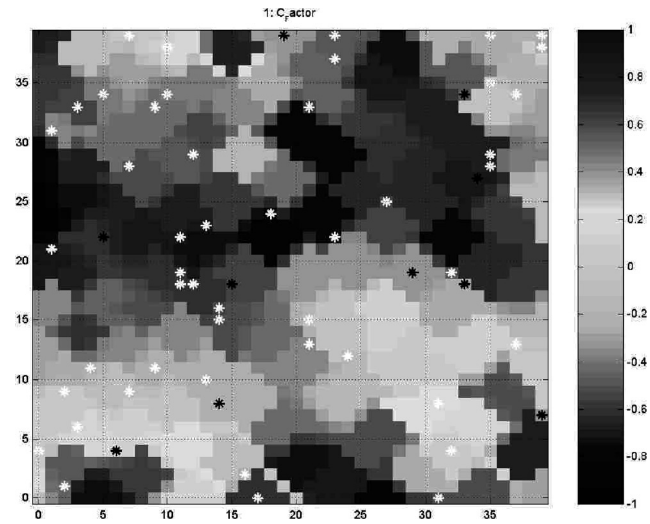

Fig. 10 - Predicted values of C_factor (second training).

Fig. 10 - Valeurs calculées du C_factor (deuxième apprentissage).

■ CONCLUSIONS

The new segregation evaluation tool, MESEG, is more objective than the current system.

The main benefits obtained with it are:

- Objective and precise measure.
- Automatic and quick measure.
- Cracks detection,
- Integration in the process application of the steel plant.

SOM was used to develop a first model of segregation. Results obtained are good showing that it is possible to develop a complete data mining project to obtain a model on this phenomenon.

In the future this new tool will be improved and integrated in the steel plant to perform segregation evaluation. It will allow a faster analysis and will provide more precise results.

On the other hand the stages of data gathering and model development will go on. It is expected to better adjust the model presented in this paper but also to try with other modelling techniques.

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