Characterization of duplex steels through analysis of image-based on co-occurence matrix (GLCM)

F. R. Renzetti, L. Zortea
"Sapienza" Università di Roma, Dip. ICMA via Eudossiana, 18 – Roma

INTRODUCTION

Duplex Stainless Steels, widely used in industry, are characterized by two phase microstructure composed by almost the same level of ferrite and austenite. This DSS microstructure provides high resistance to stress corrosion cracking and generally good mechanical properties between -50°C to 250°C [1].
In this paper the image structure of the DSS observed by an electron microscope is compared with another image specially constructed.
Great importance for this type of survey is given to the co-occurrence matrix from which appropriate indicators will be derived to describe the image.

INTRODUCTION TO IMAGE ANALYSIS

The application of this method is widespread in many fields in particular every time an image analysis is required. The interest in this technique is grown because it is a non-destructive and minimally invasive analysis. The technique is based on manipulation of images converting one into another one with few levels of grey.
The texture of a metal can be observed in detail through an image obtained by electron microscopy. Through the image it's possible to see tool marks, the presence of surface defects and also the grain boundaries of each phase.

METHOD OF ANALYSIS

The spatial relationship of grey levels is expressed by the co-occurrence matrix suggested by Haralick [2, 3] in the 70's.
The properties of a system are detected indirectly by exploiting the co-occurrence matrix from which special indexes called "image indicators" are extrapolated. The grey level co-occurrence matrix (GLCM [4]) is just the tool to start and then get the 14 indicators defined in the Haralick's theory, among which there are Energy, Contrast and Entropy [5].
The numerical variation of these indicators allows to get information regarding the structure of the image or highlight interesting details within it.
The displayed image with 256 grey tones is reduced into one with 16, 8 or 4 tones by which the co-occurrence matrix is determined. For each pixel component is then associated a particular shade of grey. For example, consider the matrix in 4 shades of grey, Fig.1.
In Fig.2 there is the corresponding matrix of image.
At the end of the process, the element (i, j) represents how many times the grey levels i and j appear as a sequence of two pixels located at a defined distance along a chosen direction. For example, assuming that the way is from left to right with one pixel at one time, from the image above it's obtained the following GLCM, Fig.3.

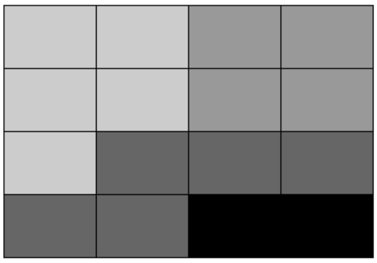


Figure 1

	1	2	3	4
1	192	192	150	150
2	192	192	150	150
3	192	128	128	128
4	128	128	0	0

Figure 2

	1(0)	2(128)	3(150)	4(192)
1(0)	1	0	0	0
2(128)	1	3	0	0
3(150)	0	0	2	0
4 192)	0	1	2	2

Figure 3

	1	2	3	4
1	0.083	0	0	0
2	0.083	0.25	0	0
3	0	0	0.166	0
4	0	0.083	0.166	0.166

Figure 4

The next step is to express GLCM's terms as probabilities; they are divided in all possible combinations within the matrix of image along the selected direction.
Then it's considered the normalization equation whose formula follows:

$$P(i,j)=\frac{C(i,j)}{\sum_{i,j=1}^{N}C(i,j)}$$

where C(i, j) the value in cell (i, j), P(i, j) the probability, N the number of rows and columns. The final configuration of the co-occurrence matrix by 4 grey levels is shown in fig.4.
The indicators calculated in this work are:

$$\textbf{Entropy}=-\sum_{i,j=1}^{N}P(i,j)\log P(i,j) \qquad \text{(by convention if P(i, j)=0 then log P(i, j)=0)}$$

The highest value of Entropy is found when the values of P(i, j) are allocated quite uniformly throughout the matrix. This happens when the image has no pairs of grey level, with particular preference over others.

$$\textbf{Energy}=\sqrt{\sum_{i,j=1}^{N}P(i,j)^2}$$

This parameter indicates how much the texture is homogeneous, i.e. the GLCM contains values distributed fairly uniformly over all boxes.

$$\textbf{Contrast}\text{ or inertia}=\sum_{i,j=1}^{N}P(i,j)(i-j)^2$$

A low value of Contrast is obtained when the image has almost constant grey levels, vice versa this indicator presents high values for images with strong local variations of intensity.

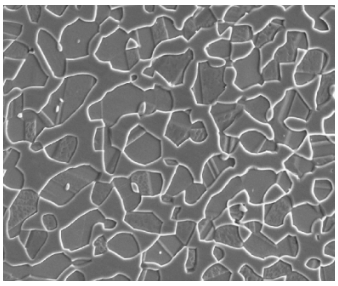
APPLICATION

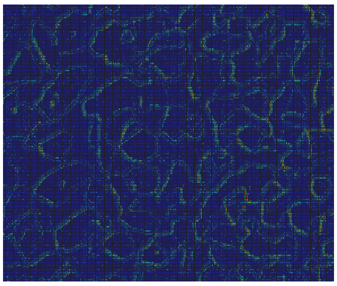
The duplex steel images examined have been obtained by electron microscope.
Three samples of 2205 duplex steel were evaluated, one as received, one cold rolled (33%), and one heat-treated at 800°C for 10 hours.

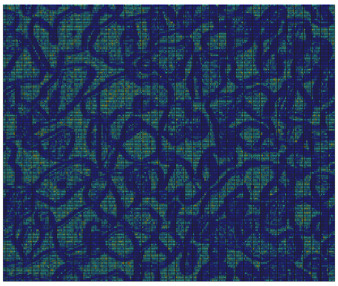
To highlight the amount and morphology of phases, an electrolytic etching in 10% acid oxalic solution was carried out (V=4V; i=0.05A; t=90s).
The image analysis was performed by defining a detection window smaller (5×6 pixels) than the original (1000×1200 pixels). The parameters were calculated in detection windows arranged so as to cover all the image, equally spaced in both horizontal and vertical directions. For each position of the detection window the co-occurrence matrix was calculated for the image reduced to 8 grey levels.

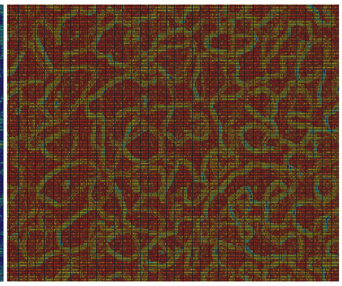
RESULTS

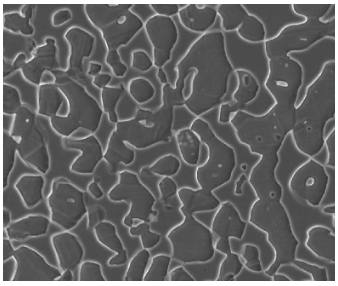
A Matlab® program has been developed for calculating the co-occurrence matrix and the indicators. The results provided by the chosen indicators show a good ability to describe the duplex steel "texture", meaning in this case the grain boundaries, geminates and any impurities present in the sample. The following images are obtained by the used algorithm.

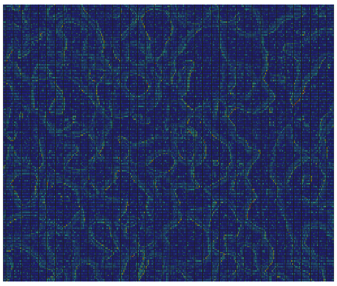

Duplex as received

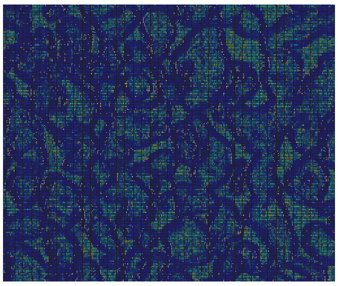

Energy Indicator

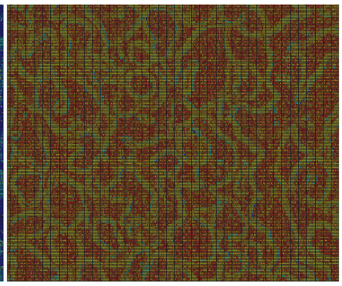

Contrast Indicator

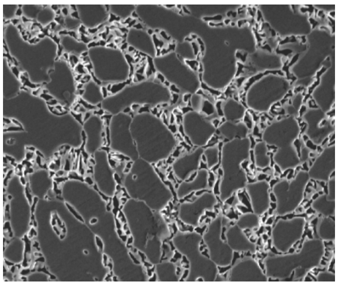

Entropy Indicator

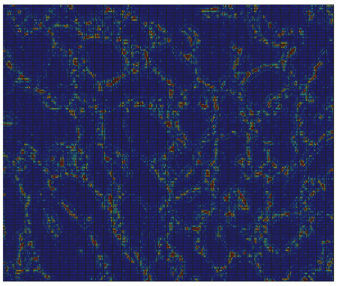

Cold rolled Duplex

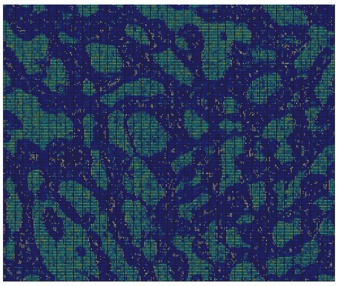

Energy Indicator

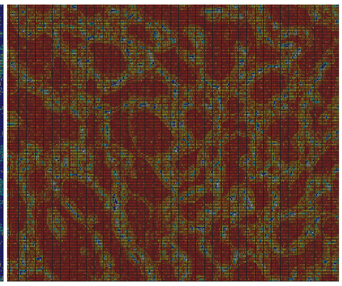

Contrast Indicator


Entropy Indicator


Heat treated Duplex


Energy Indicator


Contrast Indicator


Entropy Indicator

CONCLUSIONS

The GLCM image analysis method is quite effective to classificate materials textures. Encouraging results are achieved especially when the material has a structure that is fairly homogeneous i.e. when within the image there are patterns that repeat themselves continuously (grain size quite similar and uniformly distributed). The Entropy indicator is appropriate to identify the grain boundaries and presupposes the presence of some geminates. The Contrast indicator, although able to detect the continuity of tones, doesn't permit identification of the components of the duplex morphology. The best information obtained by the Energy indicator is instead the presence of impurities.

BIBLIOGRAPHY

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