Image analysis of carbides in high speed steel rolls and their relationship with the mechanical properties

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Abstract

Image analysis is used to describe quantitatively various different natures of carbides in high speed steel rolls. After an etching judiciously selected, the identification and the extraction of the carbide types are based on spectral differences. For every carbide type, three parameters are measured : the size, the spatial distribution and the volume fraction. The size of martensite grains is also measured.

Introduction

One goal of the COST 517 project entitled "Effects of inclusions and carbides on the mechanical properties of alloyed steels" is to establish quantitatively and statistically relations between the microstructural and the mechanical properties of high speed steels. Mechanical tests will provide quantitative parameters like the tensile strength, the wear resistance, the hardness, the toughness, the resilience. The microstructure is characterised by quantitative parameters measured by image analysis.

The materials studied are rolls formed by a high speed steel shell (60 mm thick) and a nodular graphite iron core manufactured by a vertical spin-casting process. The shell, directly in contact with the rolled products, is submitted to high solicitations. So, its microstructure is the only one to be characterised. Preliminary observations of the shell under an optical microscope show microstructural differences from the surface to the shell-core limit. To characterise these differences, samples are cut off radially all along the thickness of the shell. The core-shell limit, that is visible on the samples, allows to orientate them.

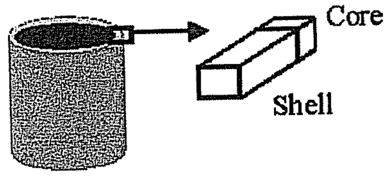

Fig. 1 : Sampling for microscopic observations

Image acquisition

Acquisition system

The acquisition system combines an optical microscope, a black and white CCD-camera and a set of interference filters. The camera has a large spectral sensitivity spectrum (350 nm to 1000 nm) and a high resolution (1280 by 1024 pixels). An interference filter in front of the camera selects only the wavelengths belong to a very narrow interval (10^{-2} µm width at half maximum transmission peak). The wavelength of the interference filter is chosen to maximise the contrast between phases when taking pictures.

Sample preparation

First, polished samples were submitted to a 7A etching (1) which attacks carbides and lets appear them in white without affecting the martensitic matrix which appears in black, Fig. 5. Three different types of carbides are identified from the textural criteria (shape, position along or inside grains,...). The MC carbides have globular shape and are along or inside grains. The M_2C carbides form fibrous structures and the M_6C carbides form fishbone-like structures. These two types are present only along the grains boundaries, Fig. 2-4.

Fig. 2 : MC carbides

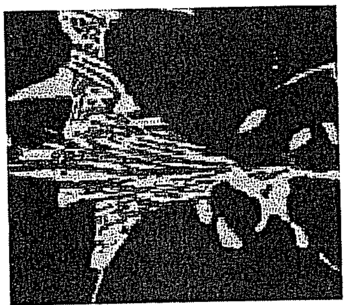

Fig. 3: M_2C carbides

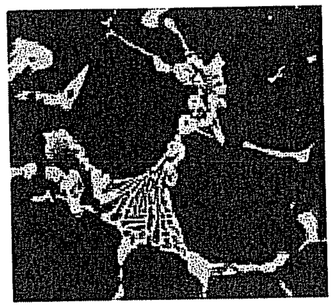

Fig. 4: M_6C carbides

The human brain can differentiate phases thanks to textural criteria. Unfortunately, in image analysis, the textural segmentation is often not very reliable. In other words, for the separation of phases, image analysis techniques are more efficient when a spectral contrast (a colour difference) exists between the phases. So, we found an etching which gives a different spectral response to each carbide type. The Groesbeck's etching (2) attacks the M_2C and the M_6C carbides and does not affect the bright matrix and the pink MC carbides. After the etching, M_2C carbides appear in dark brown; M_6C carbides in yellow or blue according to the etching time. To improve the contrast between the phases, images are acquired with an interference filter centred on 489 nm.

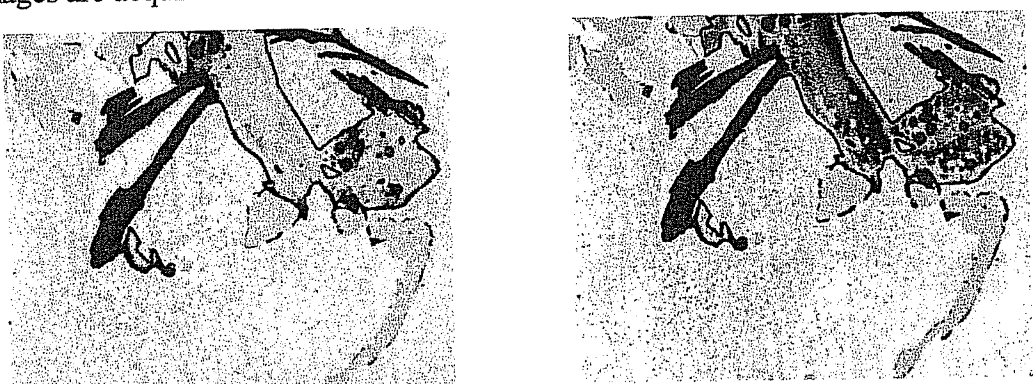

Fig. 5 : High speed steel. Groesbeck's etching. (a) without an interference filter. (b) with an interference filter centred on 489 nm.

Image analysis

Observations

The region near the surface cools more rapidly than any deeper region. The effect of this cooling difference is observed in the microstructure. The most the depth increases, the most the martensite and carbides increase in size. As carbides are mainly situated along the grain boundaries, their interdistance is directly related to the grain size, increasing with depth. The goal is to quantify these differences by image analysis.

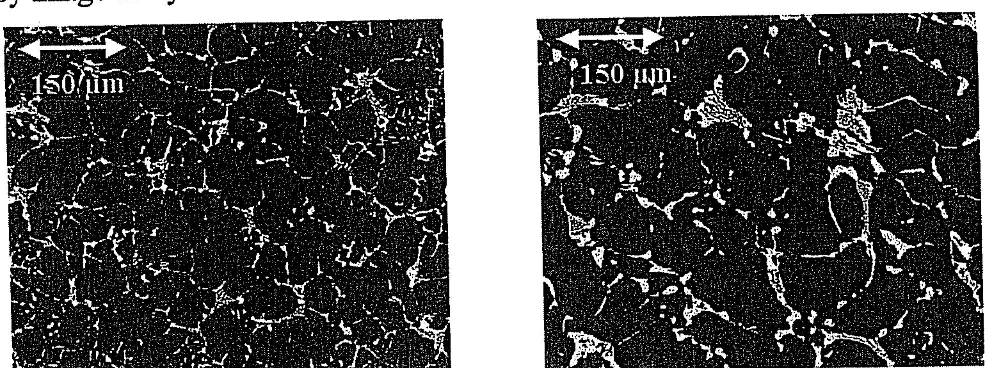

Fig. 6 : High speed steel, 7A etching, carbides in white and matrix in black. (a) at 5 mm from the surface roll. (b) at 55 mm from the surface roll.

Quantitative parameters
Three parameters are measured to characterise the carbides. After the 7A etching, they are computed globally without distinction of nature. After a Groesbeck's etching, each carbide type can be characterised separately. The first parameter is the area fraction of the carbide defined as the ratio between pixels belonging to carbides and the total number of pixels in the image.

The intercept method (ASTM El 12-63) allows to calculate a number of intercepts. The same principle has been applied in digital images by Launeau (3). The algorithm allows to compute automatically the number of intercepts and the mean intercept length in several directions with a nine degrees angular resolution. The grain and carbide sizes can be evaluated from the omnidirectional mean intercept length inside each phase. Although the grain boundaries are only partially delimited by the carbides, the mean intercept length is a meaningful parameter for the characterisation of the grain size. As the MC carbides are preferentially located inside grains, the mean intercept length of the martensite must be measured on images containing only the M6C and the M2C carbides to avoid an underestimation of the value.

The carbide interdistance is characterised by the mean radius of the maximum inscribed discs between carbides. First, every pixel of the matrix receives a value equal to the smallest distance from the nearest carbide boundary. Afterwards, pixels equidistant from at least two carbide boundaries are conserved and formed the SKIZ (Skeleton by influence zones). The value associated to a pixel of the SKIZ is the radius of the maximum inscribed disc between carbides.

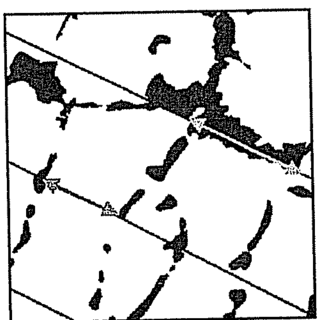
Fig. 7 : Intercept length.

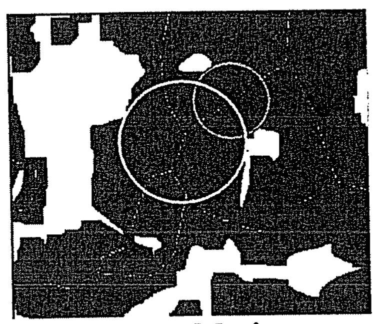
Fig. 8: SKIZ. Maximum inscribed discs between carbides.

Results
The results were obtained from a sample submitted to the 7A etching. Five images were acquired every 5 millimetres, from 5 to 55 millimetres depth. These results confirm well our preliminary observations, Fig. 9 to 12. The global area fraction of carbides does not vary a lot from the surface to the core, Fig. 9. The mean global value is 13.4 % and the standard deviation is 0.6 %.

The mean intercept length of the carbides and the martensite shows a general increasing tendency, Fig. 11 and 12. Before measuring this parameter on the martensite, the intergranular MC carbides were deleted manually. The variations observed on the Fig. 12 can be explained by the difficulty to recognize these intergranular MC carbides.

Two of the five images acquired at 45 millimetres depth contain more MC carbides and so their carbide interdistance is smaller. The decreasing of the carbide interdistance at 45 millimetres depth can be explained by an insufficient number of images to represent the variations of the carbide interdistance from one image to another. As the number of intergranular MC carbides is very variable from an image to another, more than five images must be acquired until the mean of the carbide interdistance converge.

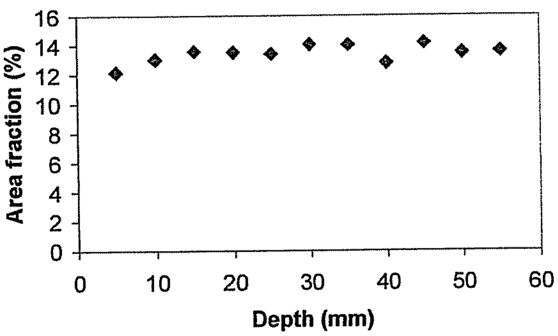

Fig. 9 : Area fraction (%) of carbides according to the depth.

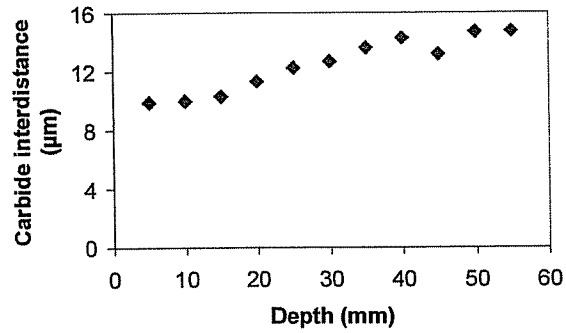

Fig. 10 : Carbide interdistance (µm). according to the depth.

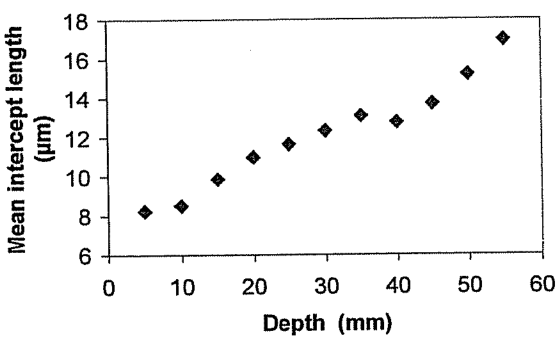

Fig. 11 : Carbide size : mean intercept length according to the depth.

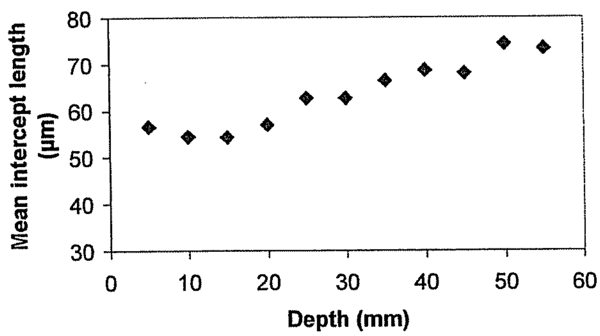

Fig. 12 : Grain size : mean intercept length according to the depth.

Conclusion and future developments

As the spectral segmentation is ,until now, more powerful than the textural segmentation, the sample preparation and the acquisition process are primordial to take pictures with the maximum contrast between the phases. A judicious etching combined with the use of narrow interference filters are in this case a good way to achieve this challenge.

The final goal of the project is to establish relations between microstructural properties and mechanical behaviour. Specimens (10 or 12 mm of diameter) cut off at different place inside the shell will be submitted to several mechanical tests. Their microstructure will be analysed from polished sections coming from the fracture zones. Possible correlations between mechanical results and image analysis parameters must be investigated.

Acknowledgement

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References

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