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SEGMENTATION OF GRAIN BOUNDARIES IN WC-Co CERMETS

Gervais GAUTHIER, Jean-Louis QUENEC'H, Michel COSTER,
Jean-Louis CHERMANT

Laboratoire d'Etudes et de Recherches sur les Matériaux, LERMAT URA CNRS n°1317,ISMRA, 6 Boulevard du Maréchal Juin, 14050 CAEN Cedex, FRANCE

ABSTRACT

Segmentation of cermets is a very important problem to solve for morphological investigations by automatic image analysis. An automatic method is proposed on SEM images (in BEC and BET modes) based on directional operations in mathematical morphology and i)a distance function, ii)a discrimination of convex grains and grain clusters, and iii)a watershed. Good results are obtained.

Keywords : directional mathematical morphology, distance function, segmentation, watershed, WC-Co cermets.

INTRODUCTION

WC-Co cermets are two-phase materials used very often by industry. The WC phase is made of polyhedral grains giving a nearly continuous framework. The Co phase is a matrix which fills complementary space.

The metallographic observation of polished and etched samples can be made by optical or scanning electron microscopy. Whatever method of observation, all grain boundaries are not revealed; nevertheless, the grey tone levels between WC and Co phases differ enough to allow an easy threshold (the grey tone level histogram is bimodal).

Then, in using automatic image analysis, two processes are possible. The first one consists of analysing both phases without taking into consideration the granular structure. The second one consists of developing an algorithm of segmentation to analyse the WC grains.

The first method has been used by Quenec'h et al. (1992) whereas the second is the scope of this work.

OBSERVATION AND ACQUISITION

Due to the size of microstucture, the use of a scanning electron microscope (SEM) is better than optical microscope. Moreover SEM supplies a variety of signals allowing to obtain more information.

In order to reach a large segmentation of WC-Co cermets, two signals are used (Fig. 1) :

- backscattered electron composition image (BECI),
- backscattered electron topography image (BETI).

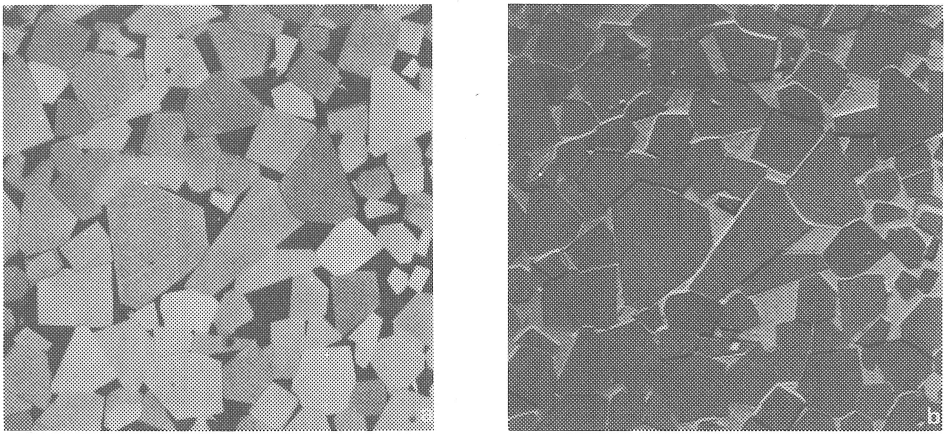

Figure 1 : Images in backscattered electron composition (BECI) (**a**) and backscattered electron topography (BETI) (**b**) of WC-Co.

a) Backscattered electron composition image

The signal intensity from backscattered electrons depends on the atomic number of analysed material : so WC and Co phases are dissociated by their photometrical range. Moreover, this signal yields a contrast depending on crystallographic orientations (channelling contrast). That allows to differentiate some adjacent WC grains.

b) Backscattered electron topography image

The average grey tone levels in the Co matrix and the WC grains are not very different because the relief is almost non-existing (due to a polishing effect). Nevertheless, the etched grain boundaries are marked by high or low grey tone levels, according to the orientations of the relief and the detector. This image makes up the information about grain boundaries.

c) Optimization of acquisition

The quality of an image acquired by scanning electron microscopy is essential and determines strongly the result of the segmentation. So the adjustments of SEM must be optimized : a voltage of 10 to 15 kV is used and the sample has to be very close to the detector.

The acquisitions of images were carried out using image analysing computer (Matra MS2i Pericolor 3100) with interface computer/SEM (MS2i Prisme) controlling the scanning rate of the SEM (Jeol T330).

DETECTION OF Co PHASE

The detection of Co phase is complicated by chemical etching since the threshold will include strongly marked grain boundaries in the matrix phase. In order to avoid that, a median filtering smoothes the image. Afterwards Co phase is detected by automatic threshold based on the maximization of weighted interclass variance. This method (Zéboudj, 1988) is an optimization of the algorithm based on the maximization of interclass variance due to Otsu in 1979. The idea of Otsu was to use the discriminant analysis of the grey tone level histogram to threshold the image. The results are satisfactory when the dispersions of classes are almost identical. Yet, as soon as one of both classes of grey tone levels is more dispersed than the other, the threshold belongs to the most extensive class. In order to find a solution, Zéboudj proposed to weight the Otsu's expression.

$$S = \frac{M_1 + M_2}{2} \qquad \text{(Otsu, 1979)} \qquad [1]$$

$$S' = \frac{\sigma_2 M_1 + \sigma_1 M_2}{\sigma_1 + \sigma_2} \qquad \text{(Zéboubj, 1988)} \qquad [2]$$

with M_1, M_2 : centers of class and σ_1, σ_2 : standard deviations.

The threshold S′ is properly determined when the grey tone level histogram is bimodal and the classes are not very disproportionate.

DETECTION OF GRAIN BOUNDARIES

A difference in crystallographic orientations between two adjacent grains is marked by photometrical gradient on BECI. Therefore, a gradient filtering must be used to smooth the grain boundaries marked by the channelling contrast. These grain boundaries are obtained by automatic threshold based on the maximization of weighted interclass variance. At this stage of process, only few etched grain boundaries are detected.

Therefore, BETI is employed to that purpose. The use of oriented transformations to display the grain boundaries of whose geometry is rectilinear allows to deal the judicious information. First, BETI is smoothed by oriented convolutions according to the direction ω. Secondly, by the difference between the image and its linear opening, whose size is λ and direction is ω+π/2, displays the grain boundaries oriented in the ω direction with high grey tone levels. Contrarily, the grain boundaries with low grey tone levels are obtained by the difference between the linear closing and the initial image.

$$f' = f \otimes M \qquad [3]$$

$$f_h = f' - ((f' \ominus \lambda \check{l}_\omega) \oplus \lambda l_\omega) \qquad [4]$$

$$f_l = ((f' \oplus \lambda \check{l}_\omega) \ominus \lambda l_\omega) - f' \qquad [5]$$

with M, the mask of oriented convolution; l_ω, the linear structuring element whose direction is ω (0, π/4, π/2 and 3π/4 for square grid); λ, the size of the structuring element (slightly higher to the width of grain boundaries).

At last, the automatic threshold based on maximization of the entropy, introduced by Pun in 1981 and improved by Kapur et al. in 1985, allows to detect the etched grain boundaries. The threshold S is the grey tone level k for which the following expression reaches its maximum :

$$H(k) = -\sum_{i=0}^{k} \frac{n(i)}{N_1} \ln\left(\frac{n(i)}{N_1}\right) - \sum_{i=k+1}^{N_{MAX}} \frac{n(i)}{N_2} \ln\left(\frac{n(i)}{N_2}\right) \qquad [6]$$

$$N_1 = \sum_{i=0}^{k} n(i) \qquad [7]$$

$$N_2 = \sum_{i=k+1}^{N_{MAX}} n(i) \qquad [8]$$

with N_{MAX}, the maximum grey tone level; n(i), the number of pixel whose grey tone level is i.

This method of threshold is particularly convenient when ranges of classes are very different. Indeed, the use of logarithm allows to detect the class of low probability.

CONNECTION OF GRAIN BOUNDARIES

After this previous stage, there remain still incomplete or non detected grain boundaries. In 1989, M.B. Kurdy and Jeulin have developed a method using directional mathematical morphology operations to connect the incomplete grain boundaries. First, the end pixels are displayed. Afterwards, these pixels are propagated until the junction with another end pixel. However, the propagation is limited to about 10 pixels in order to avoid an over-segmentation.

SEGMENTATION BASED ON THE HYPOTHESIS OF CONVEXITY

Such grain boundaries are not very well marked on BETI and BECI. Also, they are not enough detected at this stage of segmentation. Nevertheless, a human operator will add some non-detected grain boundaries. The hypothesis of convexity of the grains based on the process of coarsening allows to reconstruct the last grain boundaries.

First, the current binary image of grain boundaries is cleaned (the holes in WC particles are deleted) and, afterwards, is complemented. The resulting binary image shows the WC grains and the WC clusters. These last ones are composed of concavities while the other ones are totally convex. The distance function of the binary image of the WC phase allows to discriminate the grains and the clusters. In fact, the WC grains have only one maximum on the distance image while the clusters have over one maximum.

a) Distance function

The distance function is a function from IR^2 into IR which represents the shorter distance of the point (x,y) belonging to surface area $\mathcal{S}$ from an edge of $\mathcal{S}$. This function has been transposed in the discrete domain by Rosenfeld and Pfaltz in 1966. Borgefors (1986) improved later this transformation to approach the euclidian distances in weighting the expression (Chassery and Montanvert, 1991). The distance transformation that we keept uses a neighbourhood of size 5, called Chanfrein's distance.

b) Discrimination of the convex grains and the grain clusters

The distance function of a convex grain have only one maximum (Fig. 2.a). On the other hand, the distance function of a cluster have more than one maximum (Fig. 2.b). The maxima correspond with the germs forming grains of cluster as, by hypothesis, all the grains are convex.

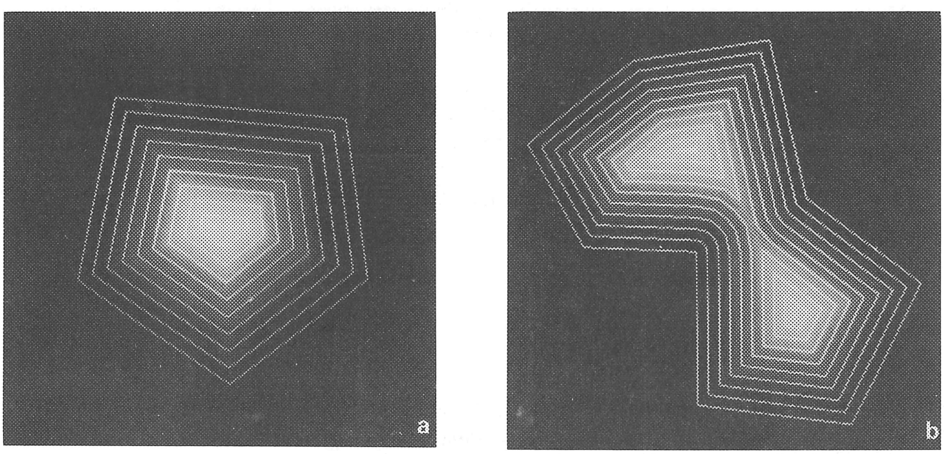

Figure 2 : Distance function of convex particle (**a**) and of non-convex particle (**b**).

Unfortunately, the euclidian case can not be transposed easily to the discrete case. Indeed, digitization induces false maxima. The distance function of the closed and convex function $\mathcal{S}$ in IR^2 have one maximum and only one. On the other hand, sometimes the discrete distance function of the digitization of the same function $\mathcal{S}$ contains several maxima (Fig. 3.a). In the discrete case, the maxima of function are displayed by the following expression (Beucher,

1980) :

$$\max(f) = f - R_f(f - 1) \quad [9]$$

$R_f(g)$ is the reconstruction by dilation of g under f.
This definition is right but is not very robust. The choice of the transformation h-convex (Beucher et al., 1987; Grimault, 1991) allows to avoid the detection of false maxima (Fig. 3.b).

$$h\text{-max}(f) = R_f(f - h) \quad [10]$$

$$h\text{-convex}(f) = f - h\text{-max}(f) \quad [11]$$

The robustness of the maxima is linked to h. This parameter is put to the value which is equal or slightly higher than the lower distance between two connected pixel.

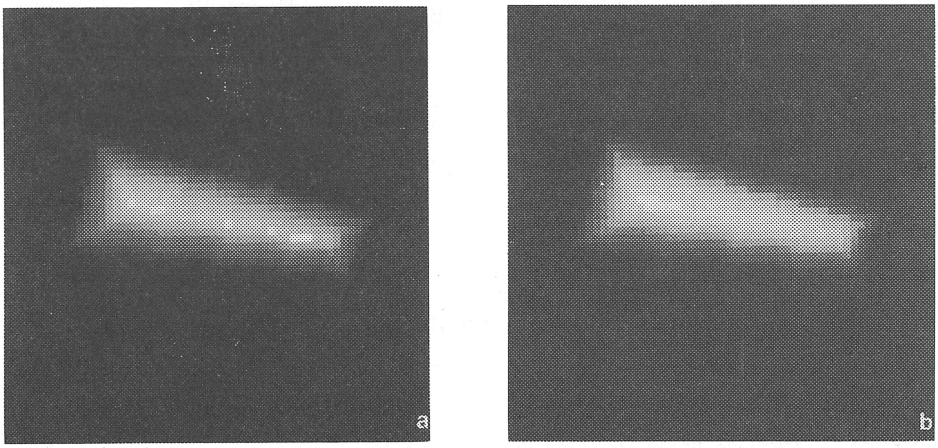

Figure 3 : The false maxima detected by max(f) (**a**); the right and thick maximum detected by h-max(f) (**b**).

c) Watershed

The h-max image is flooded by thickening from h-convex marker and the watershed is built (Beucher and Lantuejoul, 1979). In 1985, Meyer proposed an another method to obtain the watershed by searching the pixels belonging to a thalweg by configurations of neighbourhood.

The binary image resulting from the watershed transformation consists of the WC grain boundaries with the Co phase (figure 4.a et b).

CONCLUSION

During segmentation purpose, the use of BECI and BETI allows to obtain more grain boundaries than by using only one signal. The directional morphological mathematic operations close the non-connected grain boundaries. At last, the hypothesis of convexity revealed the slightly marked or non-marked grain boundaries, which are usually recognized by a human operator. Here, this method of segmentation has been applied to WC-Co cermets, but other materials can be investigated by this way. Moreover, the obtained results are reproducible.

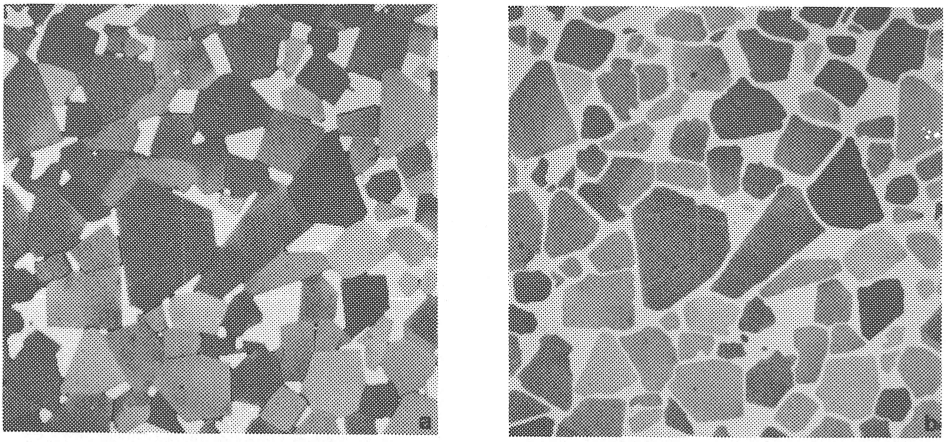

Figure 4 : Résults on WC - 9.5wt% Co : BETI with the Co phase (a), with the Co phase and the grain boundaries (b).

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