Some Examples of Quantitative Fractographic Investigations

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ABSTRACT

The aim of this paper is to present briefly some experimental results obtained from quantitative fractographic methods in order to show what this technic can bring to fracture mechanic investigations.

KEYWORDS

Quantitative fractography.

INTRODUCTION

Progress in the field of fracture mechanics requires a better understanding of the behaviour of materials to rupture. But experimental results and theoretical models proposed are not always sufficient to enable a correct interpretation of the mechanical results if the morphology and features of fracture are not known sufficiently well. This can be done by using quantitative fractography which is based on the same principle as quantitative image analysis, but which works on non-planar surfaces. After having chosen the correct direction of observation, it is then possible to describe quantitatively the morphology of a fracture either from fractured surfaces or from fracture profiles or even from deformed or partially fractured plane sections. This brings some quantitative microscopical information to the mechanical engineers. Connected with mechanical test results, it allows one to propose and to describe mechanisms of fracture of materials.

The aim of this short paper is only to show what quantitative fractography can bring in the field of fracture mechanics. We shall give briefly some examples obtained from image analysis of fractured surfaces, then of profiles and finally of polished sections of deformed and/or partially fractured materials. For general information on quantitative fractography, the reader can refer to El-Soudani (1974, 1978), Coster et al. (1979, 1983) and Underwood (1987).

FRACTURE FEATURES ANALYSIS

Presently fractured surface features cannot be investigated quantitatively with automatic image analyzers as it is necessary to differentiate the fracture features : brittle, ductile or intergranular. We can use digitalization table as only the human eye is capable of determining rapidly the nature of the features encountered. In these conditions, as we work on a 2 dimensional projected image, classical methods of quantitative metallography can be used to investigate these features. The microprocessor is thus programmed to calculate the principal fundamental parameters, such as S_S, the fractured surface area ; L_A, the specific perimeter ; N_A, the connectivity number in $\mathbb{R}^2$, which characterizes each feature in terms of coordinates of their own contour and this with respect to a predetermined frame of measurements.

A brittle-ductile transition of two steels was determined from Charpy V notch specimens fractured by an impact tester (Lavolé, 1981). The first steel, noted FE, is a soft ferrito-pearlitic steel, whereas the second one, noted 30, is a Cr-Mo steel. Figure 1 presents 2 micrographs of surfaces fractured at -60°C and + 80°C of the FE steel and the curves of the changes in the proportion of brittle fracture, S_S, with test temperature for the two steel grades. Comparisons are given with results obtained from IRSID method (measurement of the crystallinity ratio) and with energy method giving the ratio of brittle fracture X measured during Charpy test from totally ductile or brittle fracture energy and experimental energy. A good correlation is also obtained between the proportion of brittle fracture measured by image analysis methods and the ratio between the brittle energy and the total energy (fig. 2). From L'_A (projection of the specific perimeter L_A) and the linear roughness (Coster et al., 1985), it is also possible to calculate the mean free path, L_1, in the brittle fracture. When L_1 is plotted as a function of the test temperature, we observe a sharp decrease in the size of the brittle regions at the ductile-brittle transition temperature for the FE grade and a less pronounced decrease for the 30 grade (fig. 3).

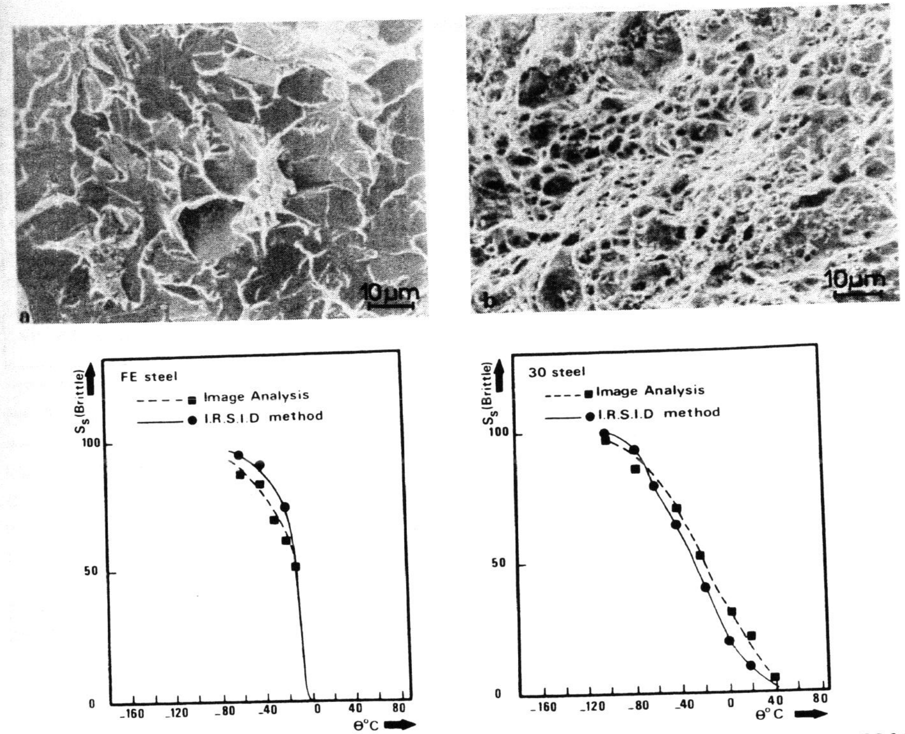

Fig. 1 : Microfractographs of the FE steel fractured at -60°C (a) and +80°C (b) and brittle-to-ductile fracture transition curves using image analysis techniques (IA) and IRSID method.

Another example which can be presented is the comparison between the grain sizes of fractured crystals with respect to that in the bulk material. In the case of WC-Co composites, some distribution curves are presented in figure 4. The comparison of these results for the three mean grain sizes analyzed - small, S ; medium, M ; large, L - indicates that for S grade, the fracture is essentially intergranular and in the cobalt phase as there appears on the fractured surfaces a lower number of WC crystals than in the bulk material, while for L grade the fracture is essentially transgranular as it appears a greater number of fractured WC crystals than in the bulk material (Chermant et al., 1976). In the case of ceramic materials, such as alumina, it has been shown that for materials of 150 µm mean grain size, the size distribution is the same for the Al_2O_3 crystals fractured intergranularly and for that in the bulk material, but the Al_2O_3 crystals fractured transgranularly have a surface ten

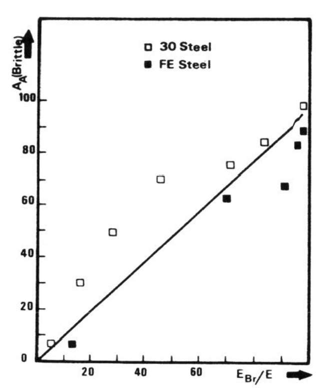

Fig. 2 : Change in the ratio of brittle fractured surface area as a function of the ratio of crystalline energy for the two steels analyzed.

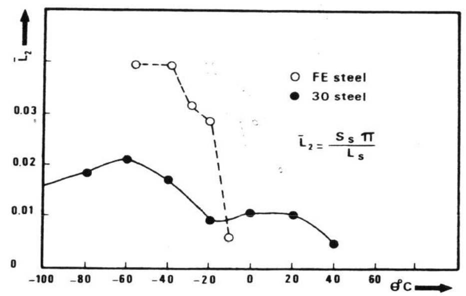

Fig. 3 : Change in the mean free path in the brittle fracture as a function of test temperature for the two steels fractured by Charpy tests.

times greater than that in the bulk material. All these largest grains are fractured : they are the sites for the initiation of the fracture (Lavolé, 1981).

In the case of polyphased materials, it is possible to obtain automatically quantitative information of the different fractured components when the automatic image analyzer is interfaced with scanning electron microscope and X Ray spectrometer (Jeulin, 1983).

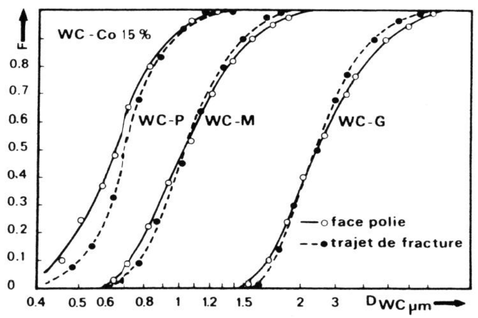

Fig.4 : Distribution curves of WC crystals on fractured (doted lines) and polished WC -15wt % Co specimens of three different mean grain sizes : S, M, L.

PROFILE ANALYSIS

Several presentations have been made during ICF-7 on profile and roughness analyses. It has been shown that it can lead to linear and surface parameters, R_L or R_S, and to fractal dimension, $\mathfrak{D}$, (see for example : Underwood, 1987 ; Underwood et al., 1986). Fractal concept (Mandelbrot, 1977, 1983) is used more and more, but one of the problems encountered is to interpret the exact meaning of the numbers obtained and of their change ! Nevertheless correlation between morphological characteristics of a material and its fractal dimension exist and can be shown.

To investigate a profile it is necessary to polish a section of a fractured specimen, taking care not to damage the fracture profile, using nickel deposit for example. In some cases, authors have used replica of the fractured surfaces and they have cut it using a microtome in order to reconstruct the fracture surface from serial sectioning (Bauer et al., 1981). Then it is possible to analyze such profiles by using either the covering method of Minkowsky with an automatic image analyzer (Coster et al., 1978)or the divider method of Mandelbrot-Richardson with a digitalization table (Coster et al., 1980).

The fracture profiles of bend specimens of white lamellar cast iron have been thus investigated. These materials present imbricated structures : a microstructure (eutectic lamellae) and a macrostructure (eutectic cells) (fig.5). The cell size (~ 80µm), the interlamellar spacing (3 µm) and the cementite thickness (1.8 µm) were determined using a method based on the properties of angular variograms and covariance (Camard et al., 1978). The linear roughness and fractal plots for surfaces fractured in tension are also shown. We note sharp peaks corresponding to values of H close to 2.5, 4.5 and 80 µm, values which, in fact, correspond to the specific values of the micro- and macrostructure of this material. The lamellar structure and the cells size both influence the direction of crack propagation.

Such roughness or fractal analyses can be also used to predict values of some mechanical parameters. If you establish the change in the roughness or in the fractal dimension as a function of the crack propagation velocity, it is possible to predict this parameter on a part fractured in service. This has been done in the case of steels employed for aeronautical parts : $\mathfrak{D}$ and R_L were measured on specimens fractured under stress corrosion at different known velocities (fig. 6). A good order of magnitude has been obtained for a part fractured in service. This is an

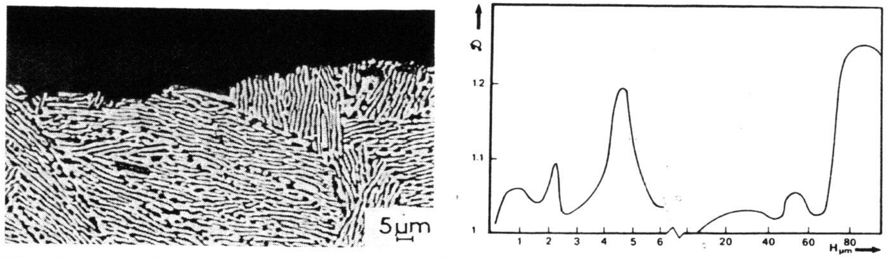

Fig.5: Fracture path on the tension surface for a white lamellar cast iron and change in the roughness, R_L, and in the fractal dimension, $\mathfrak{D}$, as a function of the size of the divider, H.

important result as it makes it possible to investigate the fracture of engineering structures in service. It is also to be noted that such profiles can be also characterized by Fourier analysis (Passoja <u>et al.</u>, 1978, 1981).

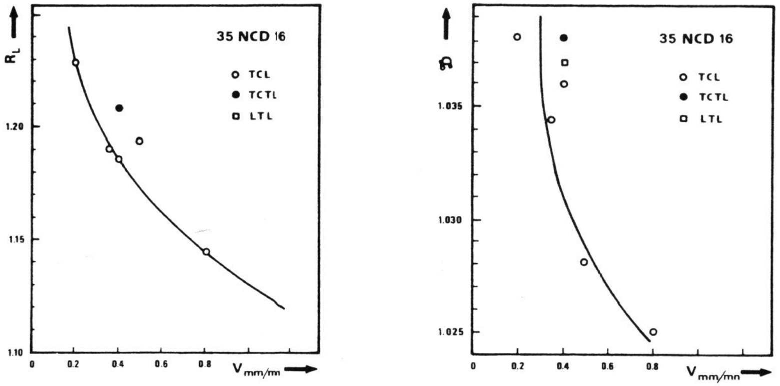

Fig. 6 : Changes in the roughness, R, and in the fractal dimension, $\mathfrak{D}$, as a function of the crack propagation velocity, v, in the case of 35 NCD 16 steel specimens of different orientations, fractured under stress corrosion.

DEFORMED OR PARTIALLY FRACTURED MATERIALS ANALYSIS

It is possible to apply directly quantitative metallographic techniques, however, to heavily deformed or partially fractured materials, if a polished section can be prepared which reveals features characteristic of the deformation or of the cracking, or if the treatment causes a change in the morphology.

For example the number of microcracks per unit surface area, their total length and degree of orientation have been obtained

by Underwood <u>et al.</u> (1979) during fatigue investigations of aluminium alloys and by Stroeven (1979) in the case of microcracking of concrete by compression, while Saxl <u>et al.</u> (1981) have studied the effect of creep on intercrystalline cavitation on polished copper sections and Nilsvang <u>et al.</u> (1987) that in a chromium ferritic steel from scanning and optical micrographs.

In our case during investigations of carbide composites subjected to very high pressures (40 to 120 kbar), for TiC-Ni or TiC-Co we observe fractured crystals while for WC -Co composites we observe slipped crystals (fig. 7), (Chermant <u>et al.</u>, 1974). Size distributions of deformed or fractured carbide crystals have been compared to that in the bulk materials. The ratio of the two distributions gives access to the probability of fracture or of slip and then to the critical diameter of fracture or of slip, D_c. We have thus been able to establish a constitutive equation of the type (fig. 7) : $D_c = K\ D^{-n} + A$, where P is the applied pressure, and K, A and n some constants. This results is of interest in order to develop new anvils for very high pres-

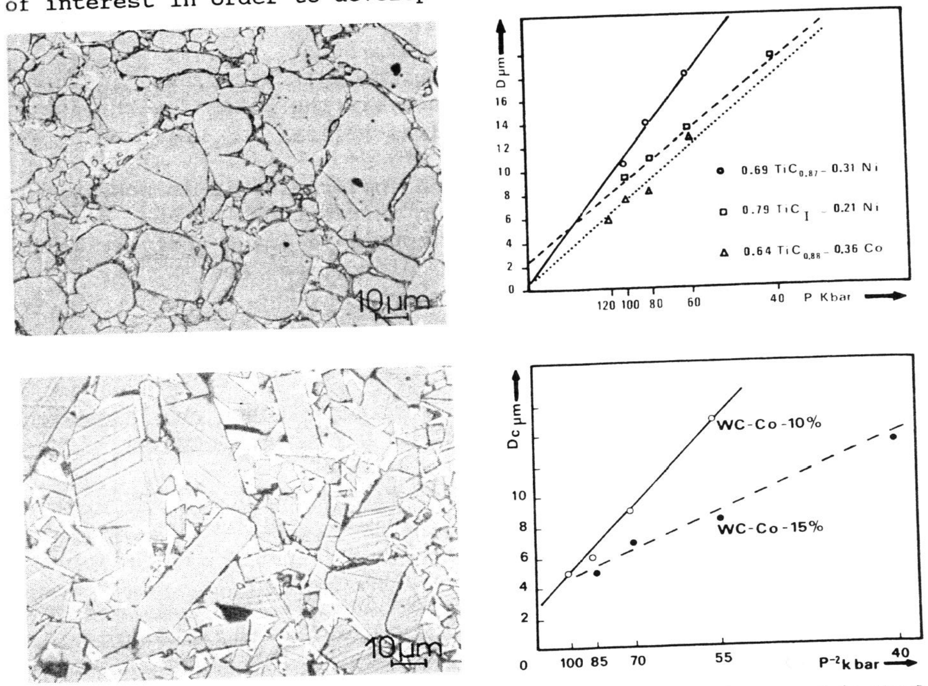

Fig. 7 : Micrographs of a 0,79 TiC - 0,2 Ni specimen subjected to 60 kbar and of a WC-15 wt % Co specimen subjected to 60 kbar and variation of the critical diameter of fracture or of slip as a function of the applied pressure, P.

sure from materials with a perfectly controlled microstructure.

CONCLUSION

The different examples presented here show that quantitative fractography can bring important quantitative information from the microscopical point of view. In order to complete these examples, it must be noted that such type of information can also be obtained sometimes from other techniques than quantitative image analysis, such as Auger spectrometry, Fourier analysis,... and that models and fracture simulations from random processes can also be used (Coster et al., 1985).

REFERENCES

Bauer, B. and A. Haller (1981). Pract. Met., 18, 327-341.

Camard, P., J.L. Chermant and M. Coster (1978). Pract. Met., 8S, 126-136.

Chermant, J.L., M. Coster, G. Hautier and P. Schaufelberger (1974). Powd. Met., 17, 85-102.

Chermant, J.L., M. Coster and F. Osterstock (1976). Metallography, 9, 503-523.

Coster, M. and A. Deschanvres (1978). Pract. Met., S61, 61-73.

Coster, M. and J.L. Chermant (1979 ; 1983). J. Mat. Sci., 14, 509-534 ; Int. Met. Rev., 28, 228-250.

Coster, M., J.L. Chermant and P. Dujardin (1980). Mikroskopie (Wien), 37 Suppl., 364-372.

Coster, M. and J.L. Chermant (1985). Précis d'Analyse d'Images, (CNRS, Ed.), Ch. XII.

El Soudani, S.M. (1974 ; 1978). Metallography, 7, 271-311 ; 11, 247-336.

Jeulin, D. (1983). J. Microsc. Spectros. Elect., 8, 1-12.

Lavolé, J. (1981). Thèse CNAM, Caen.

Mandelbrot, B. (1977 ; 1983). Fractal Form Chance and Dimension, (W.H. Freiman, San Francisco, Ed.) ; Fractal Geometry of Nature, (W.H. Freiman, New York, Ed.).

Nilsvang, N. and G. Eggeler (1987). Pract. Met., 24, 323-335.

Passoja, D.E. and D.J. Amborski (1978). Microstructural Science, (J.E. Bennett, L.R. Cornwell and J.L. Mc Call, Ed.), Elsevier, Vol. VI, 143-158.

Passoja, D. and J. Psioda (1981). A.S.T.M. S.T.P., 733, 355-386.

Saxl, I., V. Sklenička and J. Čadek (1981). Z. Metallkde, 72, 499-511.

Stroeven, P. (1979). J. Mat. Sci., 14, 1141-1151.

Underwood, E.E. and E.A. Starke (1979). A.S.T.M. S.T.P., 675, 633-682.

Underwood, E.E. and K. Banerji (1986). Mat. Sci. Eng., 80, 1-14.

Underwood, E.E. (1987). Acta. Stereol., 6/III, 855-876.