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QUANTITATIVE CHARACTERIZATION OF FRACTURE SURFACES

Zoltán Gácsi, Gábor Sárközi, Jenő Kovács*
Materials Science Institute, University of Miskolc, H-3515 Miskolc, Hungary

ABSTRACT

The stereological parameters of fractures are functions of the applied stresses and the mechanical and structural properties of the material. The characterization of 3D surfaces by means of consistent mathematical methods and the possibilities of the well-known microscopic techniques give new ways of scientific cognition of fracture processes. Recently profilometric characterization of fracture surfaces of unalloyed steel samples was carried out. The samples had been broken with standard Charpy examination. The samples had to be mounted to protect the profiles while polishing. Next the surfaces were sectioned vertically. This paper deals with modes of polishing and mounting the samples in order to prepare them for evaluation by image analyzer. Morphological transformations of the binary pictures are necessary to obtain the matrix of pixels appropriate for further investigations.

Key words: Charpy examination, fracture, image analyzer, mechanical and structural properties, profilometric characterization, stereological parameters.

PROFILOMETRIC CHARACTERIZATION OF FRACTURE SURFACES

An important geometric parameter of a fracture surface can be the value of its roughness, its so-called surface roughness parameter. Its measurement can be carried out by several methods, for example by examining the irregular curves (profiles) obtained on a vertical section of the surface.

Let us define the surface roughness parameter (R_S) of the fracture surface by the ratio of the area of the surface (S) to the projected area (A). The value of the surface roughness parameter is 1 in case of a plane, generally it varies from 1 to the infinity.

$$R_S = S / A \qquad (1)$$

Analogously, let the profile roughness parameter (R_L) be the ratio of the length of the profile (λ) yielded by sectioning with a vertical plane to the projected length (L).

$$R_L = \lambda / L \tag{2}$$

Although these two parameters have well-defined physical meanings, they cannot characterize an irregular surface or curve alone. For example, several different profiles can have the same profile roughness parameter. This difference derives from the angular distribution of the profile or surface elements. The distribution of the segments by their angles with a chosen direction can provide further information about the fracture process, because it is influenced by mostly the stress and microstructural inhomogeneities.

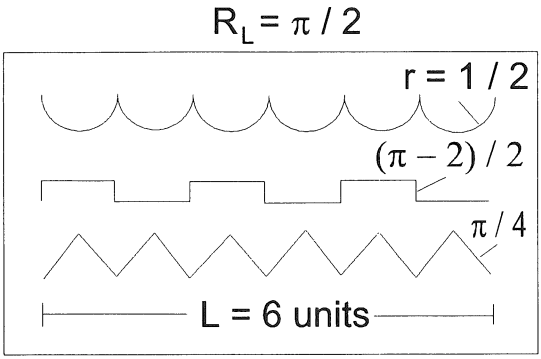

Fig. 1. Different profiles having the same roughness

A brittle, transgranular fracture composed of approximately flat elements has an angular distribution showing smaller fluctuation than that of a ductile fracture, which has surface elements oriented to every direction.

It can be shown that the profile roughness parameters and the surface roughness parameters are not independent (Gokhale and Underwood, 1990). The unbiased mathematical method worked out by Gokhale in 1990 has no prerequisites of the surface, and is based on the followings (Gokhale and Drury, 1990):

- Let us approach the profile with its smallest, linear segments (η) observable at the used magnification characterizing the profile by the orientation distribution function of the segments with respect to the vertical direction.
- Let us construct a connection between the two roughness parameters in a statistical way:

$$R_S = \overline{R_L \Psi} \tag{3}$$

where Ψ is the structure factor of the profile, which contains the orientation distribution function of the profile elements and the statistical weighting.

So the determination of the surface roughness parameter requires the following steps:

- Preparation of the vertical section of the surface and segmentation of the profile.
- Determination of the profile roughness parameter as the ratio of the total length of the segments to the projected length.
- Measurement of the angles of the segments and calculation of the structure factor.
- Calculation of the surface roughness parameter by the average of the products of the profile roughness parameters and the structure factors.

PREPARATION OF THE PROFILES

Recently profilometric characterization of fracture surfaces of unalloyed steel samples was carried out. The materials contained 0.13, 0.37, 0.48, 0.62 carbon. The samples had been normalized at 950°C and broken with standard Charpy examination. The samples were mounted to protect the profiles while polishing. Three kinds of synthetic resin, pure copper, brass of 37% Zn, bronze of 7% Sn, pure aluminum, Al-33.5% Cu eutectic alloy were used as mounting material. Several problems emerged.

The requirements on the mounting materials are the followings:

- It must wet the probes to penetrate into the holes, not to separate from the surface while grinding and polishing.
- It must have a hardness approximately of the probe not to smear over the profile and vice versa (avoid overlaps).
- It must have lower freezing point than the transition temperature of the probe.
- It must have a color different from the probe's for examinations with light microscope.
- It must be electronically conductive for examinations with SEM.

It seems promising using conductive bakelite resin pressed with 12,000 psi (Fig. 2). In other cases the profiles got round or separated from the surface: both yielded double-profile at higher magnifications.

Next the surfaces were sectioned partially parallel with, partially perpendicular on the notch. Each vertical section was very carefully polished. The photos of the profiles had been taken by AMRAY 1850 I SEM and a light microscope. The evaluation had been taken partly by Quantimet 570C image analyzer and partly by a specific computer program.

Fig. 2. A profile mounted in conductive bakelite (SEM, M=1000x)

THE EVALUATION PROCESS

Careful polishing makes it possible to separate the mounting material from the sample on the microscopic images. It provides a good opportunity for Quantimet 570C semi-automatic image analyzer to evaluate the profiles. Selecting the threshold of the 255 measurable gray levels at the level of the probe a binary image can be detected. Subtracting the eroded binary image from the original one a line of one pixel width is obtained, which is exactly the fracture profile being examined. Next it is desirable to determine the coordinates of the points of the line. Quantimet 570C takes only one coordinate per object into account. Every pixel – considering pixels as squares – that touch each other laterally belong to one object. Thus in practice a considerable number of points are lost for the evaluation. Although the missing points indicate linear change subsequent completion is difficult, because there is no algorithm to put the points into the proper order. Points are on an irregular curve, at various distances from each other, measured at various orders by the image analyzer.

The solution may be the transformation of the binary image. If the size of the objects was reduced to one pixel (touching each other exclusively on the corners) every pixel is taken into account. A certain sacrifice is inevitable at this stage: subtracting the appropriate grid from the binary image means cutting the objects into pieces. The questions are:

- Which grid is to subtract to reduce the size of all objects to one pixel?
- Which grid is to subtract to lose the least points?

THE „SUBTRACTED" GRIDS AND THE RESULT

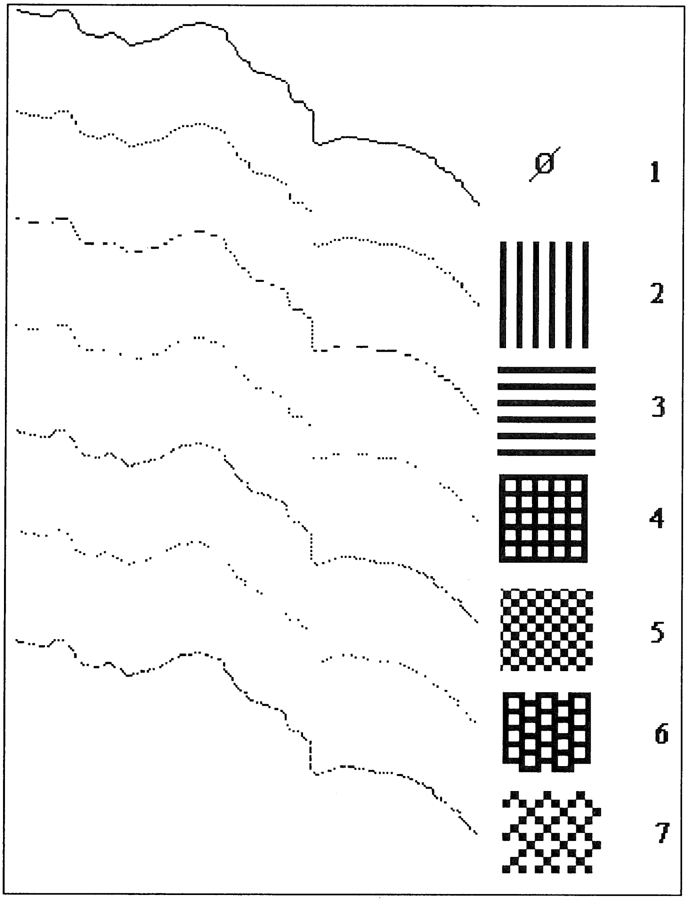

Fig. 3. The grids and their results

The grids and their results are shown in Fig. 3. The first profile shows the starting-point (M=1000x). In case of grids number 2, 3 and 7 the objects contain more than one pixels in the future too. The number 4, 5 and 6 grids are more promising: they can be applied depending on the profile and its overlaps. In this case the best result is obtained using the grid number 5. Repeating the subtraction process with another "chessboard" and assembling the two obtained sets of coordinates into one matrix *every pixel is taken into account* without loss. After all a method based on finding the next point can serve as principle of arrangement.

DETERMINATION OF THE STRUCTURE FACTOR

Segmentation of the profile gives the simplest way of calculating the structure factor. Measuring the f(α) frequency of occurrence of the a angles of the segments yields the α-f(α) histogram. Practically, sorting the angles into K classes of $(0^\circ..180^\circ)$ intervals of length $\Delta = \pi/K$ are obtained. Let $h_i\Delta$ be the total length per unit projected length of the profile elements in the interval $[(i-1)\Delta..i\Delta]$, thus h_i is the height of the i-th column of the histogram. The structure factor of the profile can be easily calculated from (Gokhale and Drury,1990):

$$\psi = \Delta \sum_{i=1}^{K} a_i h_i \tag{4}$$

$$a_i = \sin[(i-1/2)\Delta] + [\pi/2 - (i-1/2)\Delta]\cos[(i-1/2)\Delta] \tag{5}$$

THE RESULTS

Three materials were measured, 5 samples per material. One profile per probe was evaluated in 20 fields of view at a magnification of 640x. Each profile was at 1.5-1.8 mm distance from the edge of the surface opposite of the notch. The results show that the measured mechanical property vary analogously with the profile roughness as it was expected.

C%	*KCV (J/mm^2)*	*R_L*
0.35	48,473	2,481
0.45	23,082	2,072
0.60	12,695	1,745

The change of local profile roughness (that means of one field) along the profile confirms the macroscopic appearance of the fracture (Fig. 4):

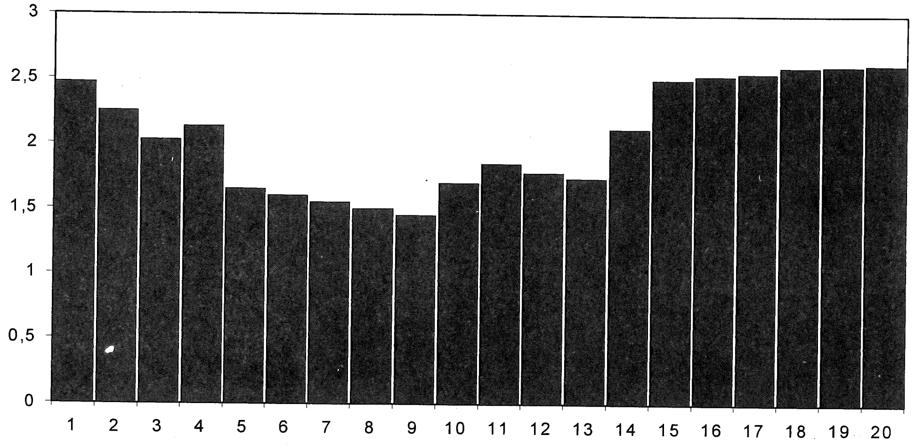

Fig. 4. The change of profile roughness of the fields along the profile

The structure factors of the profiles show that a brittle, transgranular fracture composed of approximately flat elements (0.60 C%) has an angular distribution showing smaller fluctuation than that of a ductile fracture (0.35 C%), which has surface elements oriented to every direction (Fig. 5, Fig. 6).

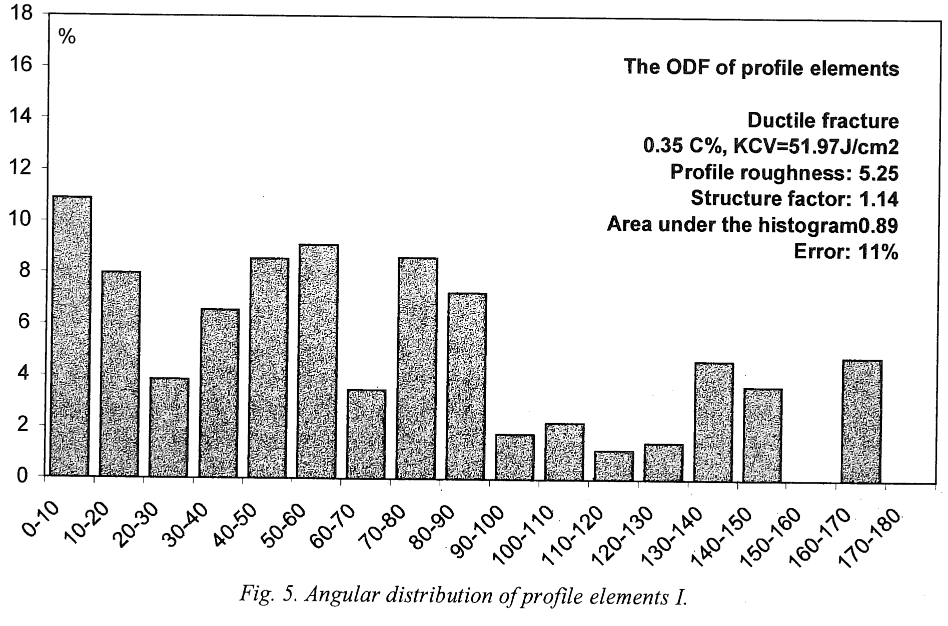

Fig. 5. Angular distribution of profile elements I.

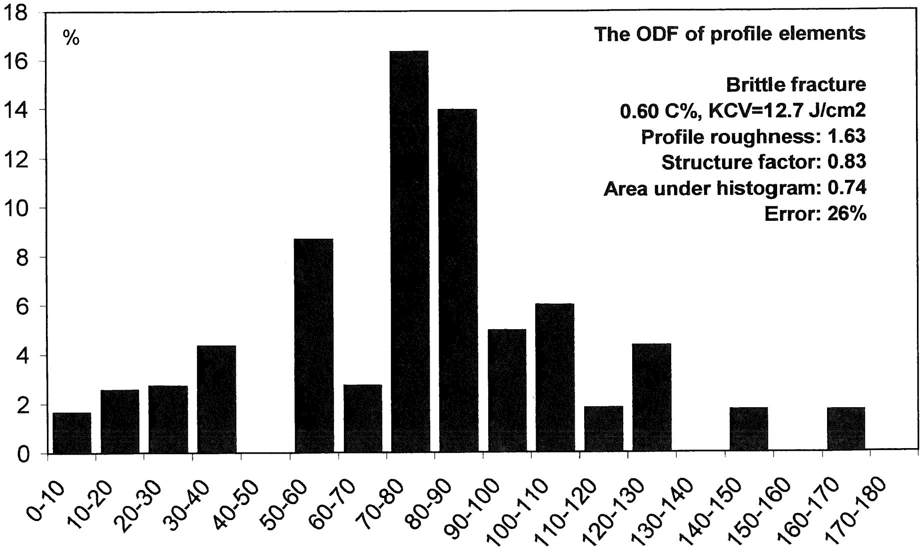

Fig. 6. Angular distribution of profile elements II.

SUMMARY

A practical method was worked out to measure the profile characteristics. Requirements on the mounting material were outlined. Subtraction of a grid was proved to be suitable to transform a binary image into a measurable form. It was shown that the mechanical properties vary analogously with the profile roughness as it was expected. The change of local profile roughness along the profile is in accordance with the macroscopic appearance of the fracture. The structure factors of the profiles show that a brittle fracture composed of flat elements has an angular distribution showing smaller fluctuation than that of a ductile fracture, which has surface elements oriented to every direction.

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