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THREE-DIMENSIONAL ORIENTATION AND ROUGHNESS OF SURFACES

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ABSTRACT

A new method is presented which allows the quantification of the orientation and the roughness of surfaces in three dimensions without restrictive assumptions. It is based on the measurement of x-y-z coordinates from stereopair SEM photographs and the determination of intersections between the three-dimensional surface and lines in 13 directions represented by the unit vectors of structuring cubes.

INTRODUCTION

With the characterization of rough surfaces a new field of image analysis has evolved which has its major application in quantitative fractography. There are various methods for obtaining data from fracture surfaces. We prefer stereometric (photogrammetric) evaluation of SEM stereopairs by an instrumented stereometer yielding quick and sufficiently accurate evaluation of x-y-z coordinates. The details of this technique have been given elsewhere (Bauer et al., 1981, 1982); similar approaches have been described by other authors (Boyde, 1973, Howell, 1978, Howell and Boyde, 1980, Roberts and Page, 1981, Kolednik, 1981). These data can be evaluated in various ways which have been reviewed recently by Chermant and Coster (1979, 1983) and Wright and Karlsson (1983a). Some of the parameters derived (like roughness factors and angular distribution) have proven useful for the quantitative description of fracture surfaces while others (like fractal dimension) are of rather doubtful value (Wright and Karlsson, 1983b). The characterization of

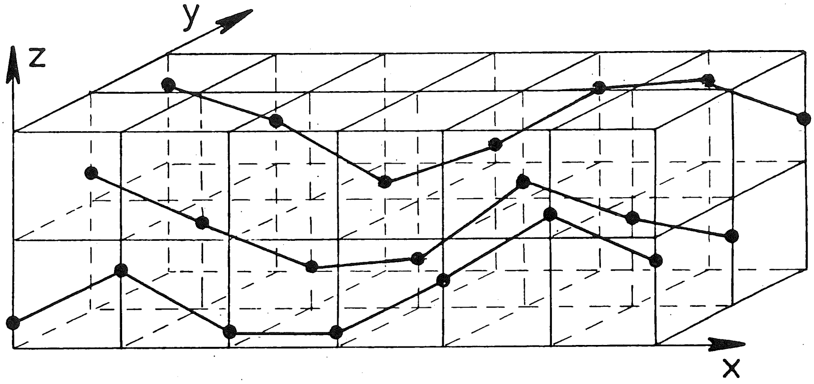

Fig. 1 Equidistant profiles and unit cubes used for evaluating intersection points between unit vectors shown in figure 2 and the rough surface.

real fracture surfaces has relied nearly exclusively upon the evaluation of profiles; three-dimensional treatments were restricted to computer generated data (Underwood and Underwood, 1981, Wright and Karlsson, 1983a). In this paper a method for evaluating three-dimensional orientation and roughness of fracture surfaces (useful for any other type of rough surfaces as well) is described. This method yields the number of intersections of lines in numerous directions (rose of orientation) and the ratio of true and projected fracture surface (surface roughness) in a straightforward way without making any restrictive assumptions on the nature of the surface or other approximations.

DETERMINATION OF INTERSECTION DENSITIES

Lines are placed across the untilted image at equidistant spacing and the coordinates of these profiles are measured for all those points corresponding to changes of profile direction. The coordinates of points equally spaced are found by interpolation. In this way, a square arrangement of height coordinates (z-direction) in the projection of the fracture surface to the x-y plane is obtained as shown in figure 1. In order to find the number of intersections for the directions indicated by the vectors shown in figure 2a (which correspond to 13 directions of the normals of faces of the polyhedron shown in figure 2b) we divide the z-direction in equidistant sections thus obtaining small cubes which include the total fracture surface in the field of view.

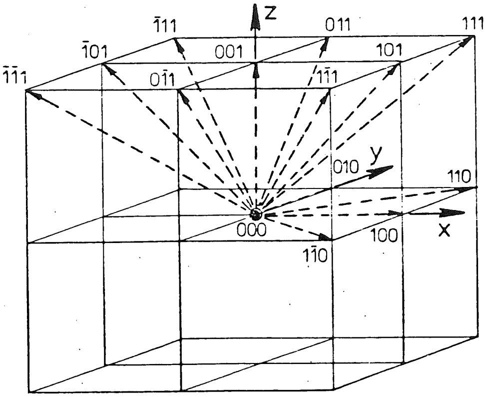

Fig. 2a Structuring cube and unit vectors.

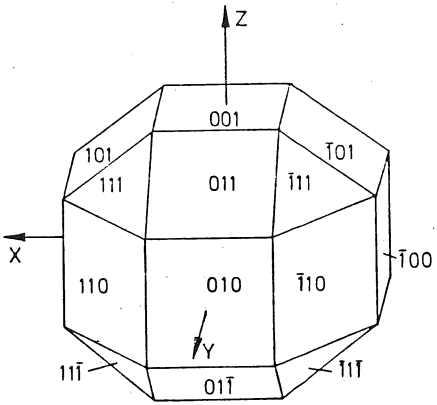

Fig. 2b Polyhedron formed by faces which are normal to the 13 vectors shown in figure 2a and have the same distance to the center.

Fig. 2 Unit vector representation of intersection lines. (In figure 2b, the axes are rotated by 180° around the z-axis compared with figure 2a for better visualisation. Corresponding vectors are $1\bar{1}0=\bar{1}10$, $0\bar{1}1=01\bar{1}$, $1\bar{1}1=\bar{1}1\bar{1}$ and $\bar{1}\bar{1}1=11\bar{1}$).

A simple procedure allows us now to determine if a vector in a unit cube penetrates the fracture surface or not: Obviously, if the center point 000 falls on the other side of the surface as the end point hkl of the vector, there must be one intersection point; if both are on the same side this vector does not penetrate the surface. A computer program makes this decision for the 13 directions for each unit cube in sequence simply comparing the z values of the actual profile points with those of the cube corners. Thus the number of intersection points for each of the 13 directions are found. The intersection densities are obtained by normalization to the total length of the vectors in z-direction (001) by dividing the numbers for the directions of the face diagonals (110, 101, 011, $1\bar{1}0$, $\bar{1}01$, $0\bar{1}1$) by $\sqrt{2}$ and for cube diagonals (111, $\bar{1}11$, $\bar{1}\bar{1}1$) by $\sqrt{3}$. (This normalization eliminates the effects of the nonuniform vector length, see Fig. 2a).

THREE-DIMENSIONAL CHARACTERISTICS

The intercept densities can further be normalized to the 001 direction (which represents the x-y plane and thus usually the plane of fracture) and then be plotted in a stereographic projection or as the three-dimensional rose of intersections. From these plots, the nature of orientation is easily visualized and the three-dimensional orientation coefficients as proposed by Saltykov (1958) for the orientation of bulk grain structures are easily found (see Underwood, 1970). An estimate of the true surface area is obtained by averaging the intersection densities weighted with respect to the spatial angle represented by each unit vector (Serra, 1983). The weighting factors are given by the relative areas of the faces of the polyhedron shown in figure 2b, i.e. 1 for the edges and face diagonals (represented by the square faces) and $\sqrt{3}/4$ for the cube diagonals (represented by the triangular faces). From this average $\overline{N}$, the three-dimensional surface area of the field evaluated in the stereopairs is given by

$$S = 2\,\overline{N} \cdot A'/N_{001}$$

where A' is the projected area in the untilted SEM photograph considering the magnification at which the image was taken. This equation is derived in the same way as the equation for the density of internal boundaries in three-dimensional structures (Smith and Guttman, 1953). In this way we easily find the areal roughness factor defined as the ratio of true and projected surface area:

$$R_s = S/A' = 2\,\overline{N}/N_{001}$$

The method is easily implemented in any general purpose computer. We have used the KONTRON Videoplan; our program is written in FORTRAN and limits the number of coordinate points to 500 which can be arranged in rectangular sets of any aspect ratio from two profiles (2 x 250) to a square (22 x 22). Computer time for the calculations is negligible compared to the time needed for measuring the coordinates. Full automation can presumably be achieved in the near future by using more powerful instrumentation.

We have used this technique for analyzing fracture surfaces of a ceramic material which showed that the orientation and roughness parameters vary systematically with the conditions at which the fracture occurred. These results will be published in a forthcoming paper (Exner and Fripan, 1984).

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