ACTA STEREOL 1998; 17/3: 303-308
ORIGINAL SCIENTIFIC PAPER

SHEAR BEHAVIOUR OF ROCK JOINTS : PREDICTION OF DAMAGED AREAS

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ABSTRACT

The roughness i.e. the morphology of rock joints is the dominant factor affecting mechanical behaviour of rock masses (stability, fluid circulation, etc.), but unfortunately, an adequate and unique mathematical representation of roughness has not be yet established and remains a great challenge. Since a unique representation of the roughness seems to be very difficult this paper is an attempt to describe it keeping in mind the ultimate objective of our work : prediction of damaged areas. We have computed a grey level image from geostatistical 3D reconstruction of a natural fracture surface. Applying classical tools of mathematical morphology we analyse morphological features contributing to the roughness of the fracture. Then we try to link them with damaged areas occurring during sliding (mechanical deformation depending on applied normal stress and shear displacement) and we propose some criteria to predict these damaged areas.

Key words : Fracture, Joint, Mathematical morphology, Roughness.

INTRODUCTION

Just as well for finding oil in specific field as for rock excavation design and stability or understanding of seismicity, the prediction of the hydromechanical behaviour of fractured rock masses at the field scale is an important challenge. Making the links between what is currently known about the hydromechanical behaviour of fractures at the laboratory, intermediate and field scale would be essential to predicting the hydromechanical behaviour of fractured rock masses. In this paper we focus our attention on the laboratory scale. Through laboratory research performed over the past ten years, many of the critical links between fracture characteristics and hydromechanical and mechanical behaviour have been made for individual fractures. One of the remaining challenges at the laboratory scale is to directly link fracture morphology (roughness) with shear behaviour with changes in stress and shear direction. Another remaining challenge is also to link fracture morphology with a flow, and to the changes in the flow that occur with changes in the stress and shear direction. The ultimate objective of this work is to determine the 3D structural morphological factors (asperities, summits, ridges, channels, etc.) affecting mechanical and hydromechanical properties of a single fracture.

Since up to date, there is no law for friction quantitatively built upon micro-mechanical framework because of the complexity of shear contacts, the topography of contacting surfaces and the evolving of surface topography during sliding (Stephanson, 1995). We can write :

$$\tau = f\left(\sigma_n, \dot{v}, \Delta u, \Delta z, \vartheta, \{x, y, z\}\right) \tag{1}$$

with (Fig. 1):

- τ is the shear strength (measured during shear test).
- σ_n is the normal stress acting on the fracture ; we have used 7, 14 and 21 MPa .
- $\dot{v}$ is the shear rate (0.5 mm/mn).
- Δu is the horizontal displacement during shearing (up to 5mm).
- Δz is the vertical displacement (measured during shear test)
- θ is the shearing direction ; 4 various directions were used (0°, -30°, 60° 90°).
- $\{x,y,z\}$ is a geometry of the fracture and the void space (co-ordinates are recorded using a profilometer and apertures of the void space are available from its cast).

An analytical solution for this kind of problem is quite impossible even if such a solution would be appreciated in geological civil engineering ; a numerical discrete solution, taking the morphology of the fracture point by point, is more realistic. So our goal is to determine some criteria allowing us to predict what parts of the fracture will be damaged during a shear test.

CHARACTERIZATION OF THE FRACTURE AND ITS VOID SPACE

Experimental mechanical tests are performed on replicas of a natural fracture that has been cored across the well studied granite de Guéret (France). Basic geometrical data are on one hand the co-ordinates $\{x,y,z\}$ registered along profiles of both upper and lower surfaces and on the other hand the cast of the void space (Gentier et al., 1996). Based on these data, 3D geostatistical reconstruction of both upper and lower surfaces are computed and a grey level image is acquired from the cast (Gentier et al. 1996, 1997). Fig. 2 (a) and (b) show the two surfaces of the fracture. The upper surface (a) is turned over then, to get it with its right position onto the lower surface, a 180°rotation about the y axis must be done. Fig. 2 (c and d) are grey level images of the previous surfaces. For both surfaces, grey levels are proportional

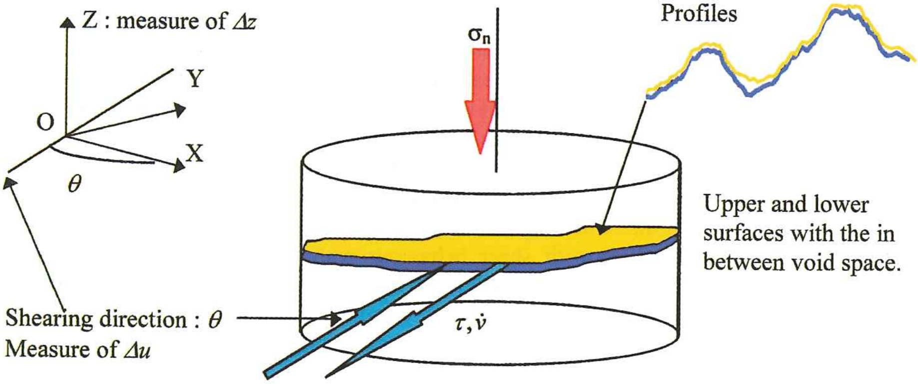
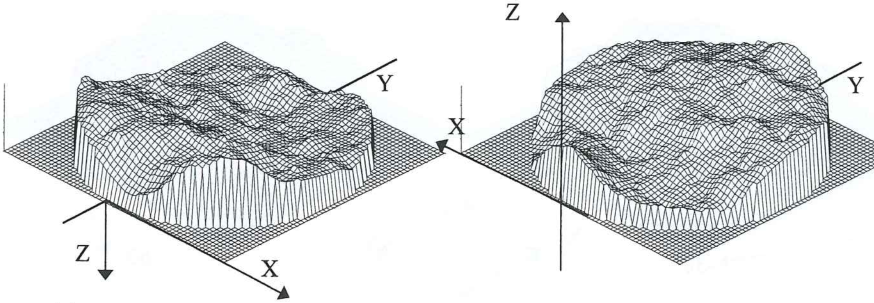
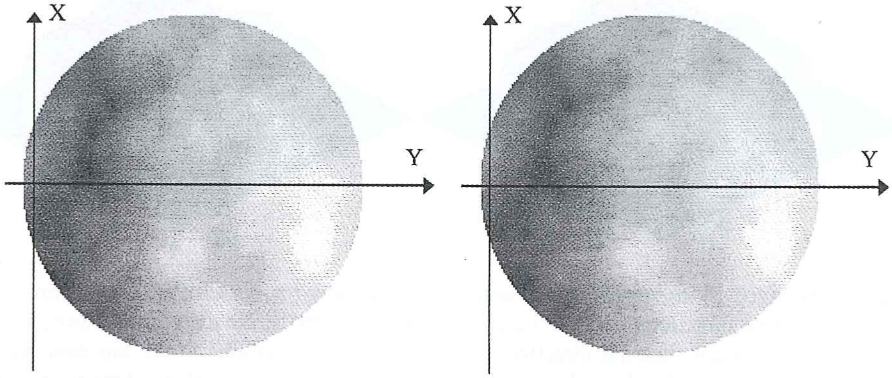


Fig. 1 - Schematic diagram showing the physical meaning for the terms of equation (1).



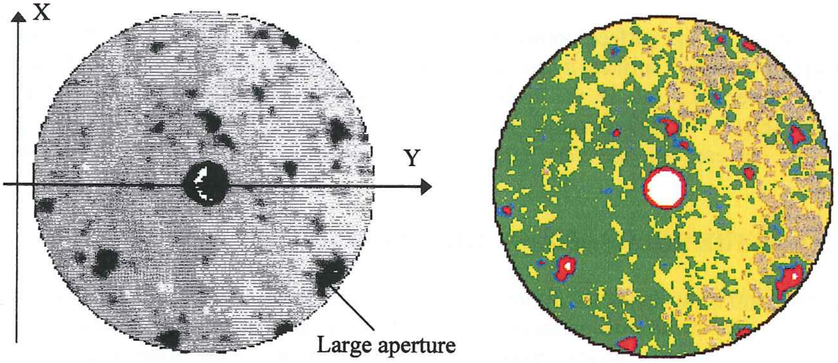
(a)-Upper surface of the fracture.

(b)-Lower surface of the fracture.



(c)-Grey level image of the upper surface.

(d) -Grey level image of the lower surface.



(e)- Image of the void space, dark to white pixels are coding for thick to thin apertures

(f)-. Map of the void space. Grey<100µm, yellow <140µm, green< 280µm, blue< 500µm, red>= 500µm.

Fig. 2 - The two fracture surfaces {(a), (b)}, their corresponding grey level images {(c), (d)} and the grey level image of the cast of the void space (e) ; (f) global aperture distribution. Diameter of the core is 90mm.

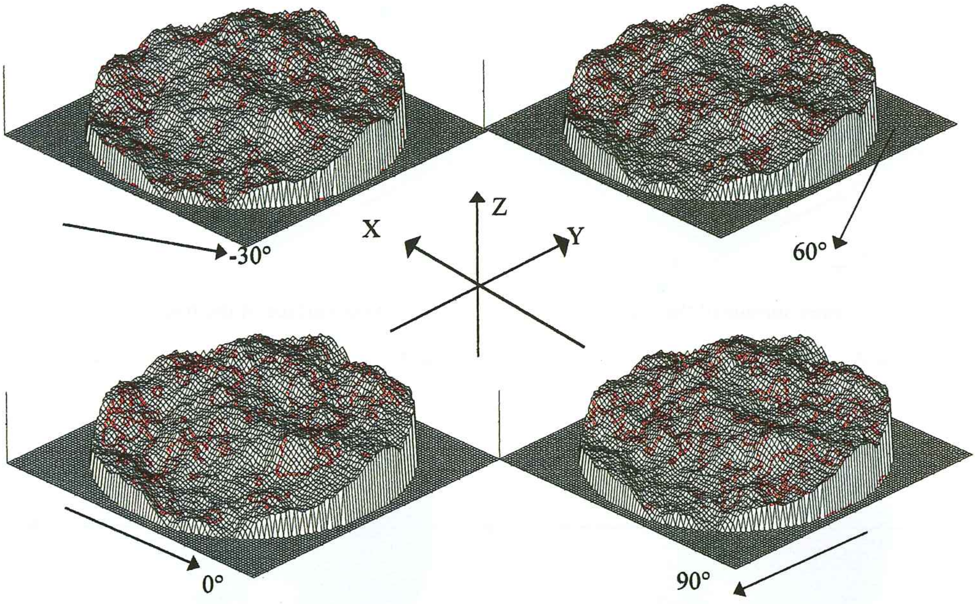


Fig. 3 - Damaged zones superimposed onto the topography ($\sigma_N = 21$ MPa , $\Delta u = 5$ mm). On the left, shearing directions (-30°, 0°) are quite parallel to the strike direction (X axis) of the fracture ; on the right shearing directions (60°, 90°) are quite parallel to the dip direction of the fracture (Y axis) ; the dip value is about 5° towards negative y values. Arrows give the direction of displacement of the surfaces (lower surfaces) during shearing.

to the elevations z of the surface points. Since the image shown in Fig. 2 (c) is the rotated (180°) image of the upper surface, it can directly be superimposed onto the image of the lower surface. The whiter the pixel are, the higher (for the lower surface (d)) and the lower (for the upper surface (c)) the elevations z are. With such grey level images defined on a square grid (8 connexity) we can use the very efficient tools of image analysis and mathematical morphology.

ANALYSIS OF THE ROUGHNESS OF THE FRACTURE

The roughness will be analysed taking into account only the lower surface and the void space since the topography of the two surfaces (upper and lower) are similar : the locations of the maxima or minima on grey levels images and the distributions of the watershed lines are similar). Seeing (Fig. 2(e) and 2(f)) that the thinner areas (<100μm) of the void space are located on its right (positive values of Y axis), we can inferred and we have computed (Hopkins in preparation), that the first contacting areas occurring during the normal stress loading are positioned on some points of this area. But looking at Fig. 3, it is obvious that damaged areas during shearing tests are those facing up the opposite (upper) surface of the fracture with an important apparent dip parallel to the shearing direction. So it seems important to pay attention to the slope of the asperities that will be damaged. Then we have analysed the grey level image using the directional gradient to predict those parts of the fracture that should be damaged during shearing tests.

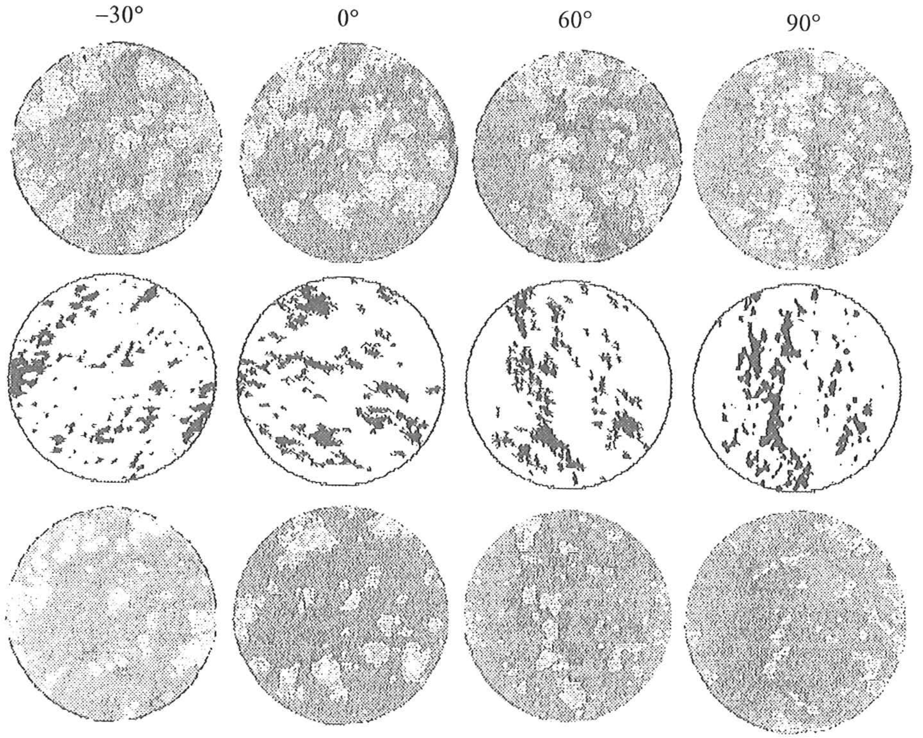


Fig. 4 - Computation of the directional gradient for the lower surface of the fracture (2nd row). Contoured areas show the damaged areas (white piwels) obtained during shearing with σ_n=7 MPa and Δu=5 mm (1st row) and with σ_n=21 MPa and Δu= 5mm (1rd row).

The directional gradient of a function f in the direction θ can be defined by :

$$g_\vartheta(f) = (f \circ T_\vartheta) - (f \circ T_\vartheta) \qquad (2)$$

where T_1 and T_2 form the two-phase structuring element $T_\theta=(T_1,T_2)_\theta$(the procedure for computing the directional gradient is given in Micromorph 1.3, 1997)
Such a gradient is available on an hexagonal grid and for all directions that can be exhibited on the digitization grid ; two of the directions of shearing (90°,-30°) correspond to the directions 2, and 6 of the hexagonal grid but for the directions 0° and 60°, we have had to rotate the images before computing the directional gradient. Fig. 4 (2nd row) shows binary images with the locations of the main maximal directional gradients that were computed for each of the shearing direction. Comparing the locations of the maximum gradient on each of these images with the damaged areas we have obtained for 21 MPa (Fig. 4, 1st row), we can conclude, thanks to the good correspondence between damaged areas and locations of maximal gradient, that the directional gradient is a good tool for prediction of the areas of the fracture surface that will be damaged during shearing. It must be noticed that the damaged areas occurring under 7 MPa (Fig. 4, 3rd row) are included in the previous one. The areas of maximum gradient are located either on the sides of extended maxima (asperities) or on the sides of crest lines ; these locations allow to infer the damaged areas during shearing but they don't indicate the extending of the damaged areas. Assuming that the volume of materials that

will be damaged during shearing, is located all around points of maximum gradient but preferentially in the shearing direction, we propose to infer the damaged areas in that way : computing the grey level gradient for a given direction, thresholding this image to get a binary image of the more representative pixels in regard of the topography, cleaning the previous image by an opening (size 1), reconstruction of the image using the previous one as a marker and at the end dilate the image of the maximum gradient using a directional structuring element of size 10 (5 mm i.e. Δu, the maximum horizontal displacement). Fig. 5 shows the results for two directions 0° and 90° ; it can be seen that the predicted damaged areas are very close to the experimental one (white areas). Obviously we can see a small offset and a few damaged areas are not predicted. Nevertheless we assume that our algorithm even if it should be enhanced is up to date very efficient.

Fig. 5- Predicted damaged areas (shearing directions 0° 90°, 21 MPa and Δu=5mm).

CONCLUSION

A unique representation of the roughness to be introduced in constitutive law for joint shearing remains up to date a great challenge ; may be, it should be impossible to establish a global representation because of the very high links between the anisotropy of the morphology of fracture surfaces with shearing. An alternative way is to consider the morphology at a local scale since we have shown that with a good characterisation of the surface topography and working with the classical tools of mathematical morphology it is now possible to predict those areas of a fracture surface that will be damaged when shearing occurs.

ACKNOWLEDGEMENT

The present research was supported by the BRGM and the University Bordeaux I (France).

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Presented at the 7th European Congress for Stereology, Amsterdam, April 20th to 23rd, 1998.