Microsc. Microanal. Microstruct. **7** (1996) 521–526 OCTOBER/DECEMBER **1996**, PAGE 521

Classification
Physics Abstracts
89.90.+n

Binary Images of Sheared Rock Joints: Characterization of Damaged Zones

Joëlle Riss (1), Sylvie Gentier (2), Katia Laffréchine (1), Rock Flamand (4) and Guy Archambault (4)

(1) CDGA, Université Bordeaux I, avenue des facultés, 33405 Talence, France
(2) BRGM DR, BP 6009, 45060 Orléans, France
(3) CERM UQAC, Boulevard de l'université Chicoutimi, Canada

Résumé. — Le comportement mécanique des massifs fracturés dépend du comportement de chacune de ses fractures. Les surfaces de fractures rocheuses sont des surfaces irrégulières et anisotropes ; afin de bien cerner le rôle de la morphologie dans le comportement mécanique des joints rocheux, des essais de cisaillement en laboratoire ont été réalisés sur des répliques en mortier d'une même fracture dans des conditions expérimentales bien définies. On dispose alors, tout à la fois, des données mécaniques enregistrées au cours des essais et des images des épontes de la fracture saisies après chaque essai. On présente, dans cet article, les modalités d'acquisition des images, leur traitement, et les résultats qui en découlent.

Abstract. — The mechanical behaviour of fractured rock masses depends on the behaviour of each of its fractures. Fracture surfaces are non planar anisotropic surfaces and to understand the role of the morphology in the mechanical behaviour of rock joints, direct shear tests have been performed using mortar replicas of a natural fracture under specific conditions: normal stress, shear rate, shear displacements. Both, mechanical data and images of the sheared fracture surfaces are recorded. This paper presents the acquisition procedure of the images, their segmentation, and the derived results.

1. Introduction

The mechanical behaviour of jointed rock masses is highly dependent on sliding on discrete discontinuities in rock masses [1]. The visual observations and the quantification of the features developed on the sliding surfaces of the discontinuities are of main interest to determine the behaviour of rock joints during shearing [2]. As joint surfaces are not flat, the contact areas between the two surfaces of a joint are essentially dependent on the normal loads and amounts of sliding. The understanding of the mechanical behaviour of rock joints during shear displacement, the progressive degradation and gouge material produced on a single irregular anisotropic joint has to be analysed and quantified.

Article available at http://mmm.edpsciences.org or http://dx.doi.org/10.1051/mmm:1996153

This paper is a contribution to the characterization of damaged zones occurring during shear tests with under various normal stresses, shear directions and shear displacements. This characterization is based on the acquisition of grey level images of the joint surfaces followed by segmentation which enables to identify the damaged zones and generate binary images. The damaged areas were identified in such a way that the damaged contours can be superimposed on a topographic map of the corresponding joint wall. Then it would be possible to determine the 3D structural morphological factors such as the position, elevation, extension and dipping of asperities, and the relative position of asperities that are essential to analyse the shear behaviour of rock joints.

2. Experimental Testing

A series of identical replicas of a natural fracture in a granite (Guéret, France) was constructed using a cement mortar. The original sample was a 9 cm diameter core with a natural fracture perpendicular to the axis of the sample. The upper parts of the replicas were dyed in grey while the lower parts were stained in pink. Each part of the replicas was adjusted carefully in a steel box, to ensure their mutual position and orientation. Applied normal stresses on the shear plane were 7, 14 and 21 MPa. Shear displacements ΔU were interrupted for each applied normal stress in the following sequence $\Delta U = 0.35$ mm, $\Delta U = 0.50$ mm, $\Delta U = 1.0$ mm, $\Delta U = 2.0$ mm and $\Delta U = 5.0$ mm, and the shear rate was 0.5 mm/min. Four directions of shearing were chosen 0°, −30°, 60° and 90°. Three applied normal stresses cumulate with five shear displacements and four directions of shearing result in sixty shear tests specimens and twice more images.

3. Image Acquisition

Image acquisition was carefully designed by mean of a black and white CCD (COHU 4712-7000) camera with strictly constant conditions: identical position of the replicas in regard of the camera and light sources. The illumination was diffused so as to scatter the light in all directions. The power supply was of standardized power without device for adjusting the electric current to a constant voltage.

Each recorded image (512 × 512 pixels wide and 8 bits deep) comes from averaging four accumulated images. It must be noticed that the total image area is wider than the specific image area of a sheared surface because it is circular and also because, for other purposes, we must acquire the image of the totality of the experimental box containing the sheared walls. So one has to mask some part of the image. The useful part of the image contains about 44 000 pixels that are rectangular with a 0.429×0.286 mm^2 surface area.

As images are grey level images, it could be difficult to observe the gouge material: pink material on the grey joint surface and grey material on the pink one. Fortunately, gouge material is generally white due to the cataclasis process during shearing. Increasing displacements and increasing applied normal stresses induce more and more white material not uniformly distributed over the joint surface. Figure 1 shows a subset of the images: images of the pink lower part of the fractures replicas that have been sheared under 7, 14 and 21 MPa and for a tangential displacement of $\Delta U = 5$ mm. Each image is roughly made of a non uniform grey background and a more or less white foreground (gouge material) to be segmented.

4. Algorithm of Segmentation

Sub-domains to be segmented are the more or less white zones corresponding to gouge material or crushed material. The amount of white domains and their distribution depend first on the level

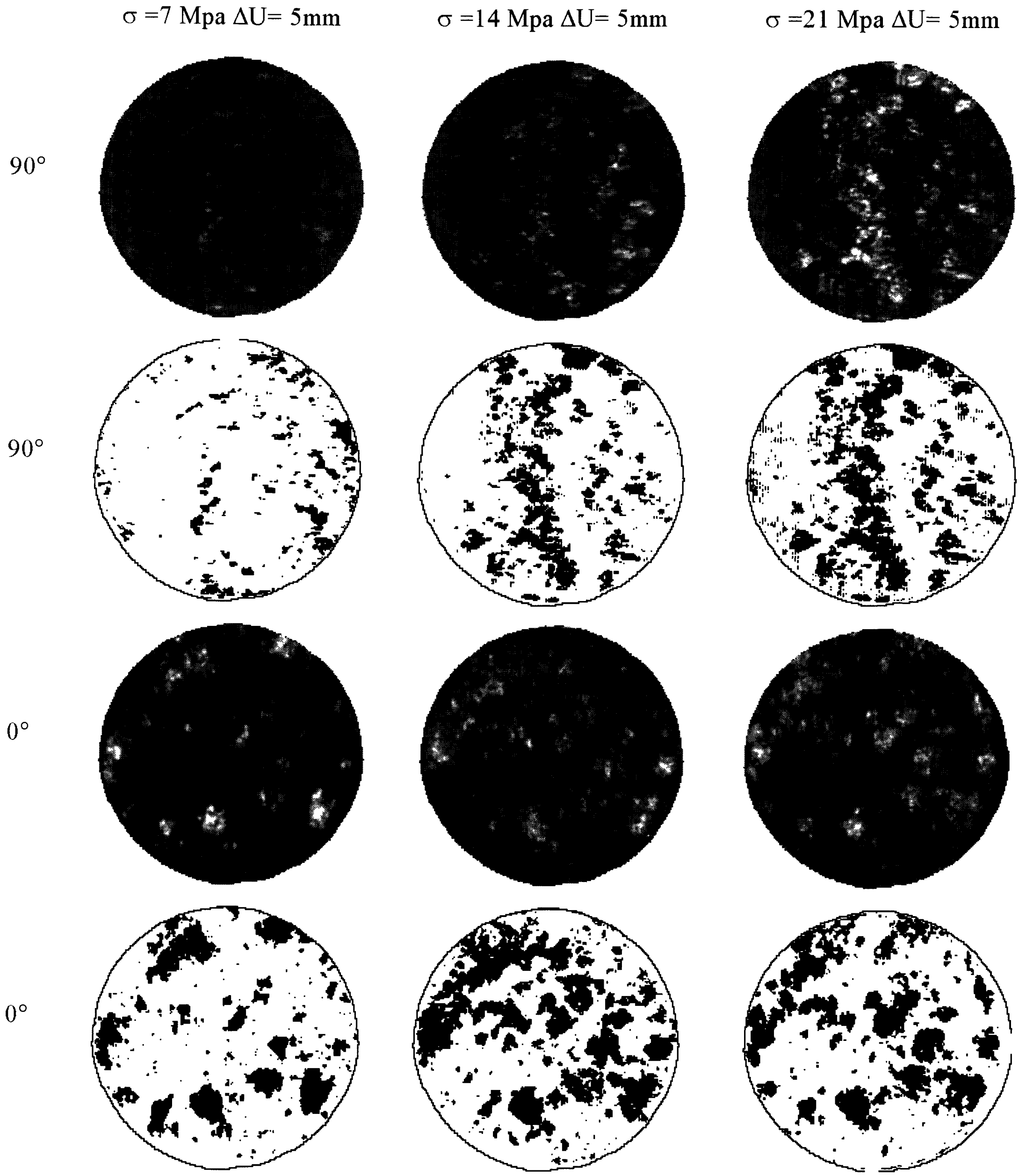

Fig. 1. — Grey level and binary images of some joint lower walls: white zones on grey level images and black zones on binary images correspond to damaged areas. Shear directions are vertical (0°) with a downward displacement and horizontal (90°) with a displacement from right to left.

of normal load and on the length of tangential displacement as well as the shear direction. On the one hand, the greater the normal load and the sliding length are, the greater the total surface area of the damaged zones is, because of the irregularity (anisotropy and heterogeneity) of the morphology of the fracture surface [3, 4]. On the other hand, the size and shape of the damaged zones are different when the shear direction is changing, even if the other parameters are similar.

None of these classical methods of segmentation [5, 6] can be considered as an automatic universal method for thresholding images of the fracture surfaces and this is a consequence of the large variation of the size and shape of damaged areas and also of the change in the brightness of their pixels. So an histogram based method for thresholding these images was inferred.

Pixels representative of white zones after the surface has been damaged during the shear test, contributed initially to the normal distribution of the image grey levels. As some pixels with original grey levels became whiter during shearing, the grey level distribution is shifted toward the right. The segmentation is based on this observation.

It is assumed that the distribution of the grey levels (irradiance) of an intact surface image is normally distributed with a given mean m and a given standard-deviation σ, so the probability to have pixels with grey levels greater than a given value is well known. As several regions of a sheared surface are not damaged, the original grey level distribution can be inferred from these regions. Then the mean and the standard deviation of the original grey level distribution can be estimated. Taking into account that pixels with grey levels greater than $m + 1.96\sigma$ outcome with a 0.025 probability before shearing, we assume that pixels with grey levels greater than $m + 1.96\sigma$ after shearing are pixels representative of damaged areas.

So the segmentation principle is that pixels with a grey level greater than $m + 1.96\sigma$ are not in statistical agreement with the original distribution. They are assumed to belong to the damaged areas. The method to infer the model of the normal grey level distribution for each of the 60 images is the following [7]:

- loading image,
- extracting regions considered not to be damaged,
- computing the grey level histogram of these regions,
- computing the mean, and the standard deviation of the histogram,
- verify that the mean is statistically in confidence with the mode and the median,
- inferring the Laplace Gauss model,
- calculating the threshold $t = m + 1.96\sigma$,
- thresholding the grey level image to get the binary image where damaged zones are well defined,
- calculating areal densities, and others characteristics.

5. Results

Results consist mainly in binary images showing the damaged zones. Then two kinds of results are derived. First, one can describe the position and evolution of the damaged zones in regard of both the mechanical conditions (σ, ΔU, *etc.*) and the shear direction taking into account the morphology of the fracture. In a second step, one can quantify the size, the shape and the spatial distribution of the damaged zones so one can superimpose the damaged contours on a topographic map of the corresponding joint wall. As detailed results are out of the scope of this paper, only qualitative results will be presented.

The damaged area are distributed over the joint surfaces without concentration (Fig. 1) at some specific locations. It may be seen that corresponding damaged areas exist on each joint wall (Fig. 2) and it is possible to estimate their relative position when both surfaces are superposed (Fig. 2). These damaged areas increase with increasing applied normal stress mainly by dilation and connection of them (Fig. 1). The trend of the linked damaged zones, regardless of their size, is in an orientation almost perpendicular to the shear direction. Further developments in analysing the damaged zones, would be to correlate these areas with their altitudes in relation to the mean plane of the fracture. Figure 3 shows how contours of damaged zones can be superposed on the topographic map of the fracture.

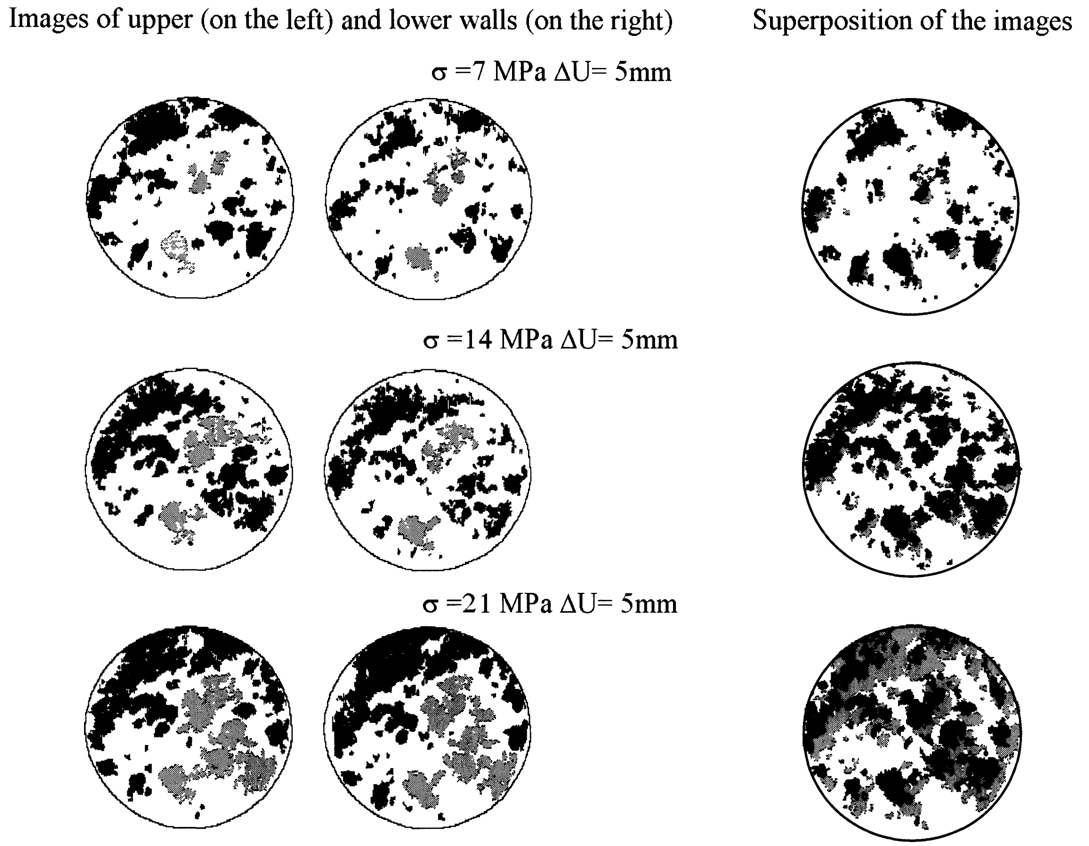

Fig. 2. — Binary images of both upper and lower joint surface walls and their superposition. Black zones are common to the two images; grey zones belong either to the image of the upper wall or of the lower wall.

6. Conclusion

The chronology of the degradation of the joint wall may be summarised by the following: first, some superficial parts of one wall is pull away and stuck on the other wall and next, as the normal stress increases, the gouge material is crushed and ground more intensively. The size and number of these regions depend both on shear displacement and stress level. Taking into account the anisotropy of the joint wall morphology, the locations of degradation depend on shear direction.

Whatever the applied normal stress and shear displacement are, the damaged regions on upper and lower walls of a joint are globally symmetrical (location and size). During the increase of shear displacement, the damaged areas grow by expansion of previous regions and by linking of themselves. Then the connected damaged areas become larger regions quite perpendicular to shear direction [8].

As the objective of this work is to determine the 3D morphological factors such as the position, elevation, extension and dipping of asperities, as well as their relative position, that are essential to analyse the shear behaviour of rock joints, one can conclude that image analysis is a very efficient method for solving such a of problem.

We are presently improving the method in order to reach more accurate binary images; but there are some obvious limitations due to the use of grey level images. On one hand, the segmentation method does not always clearly outline grey (or pink) zones from white zones that are more

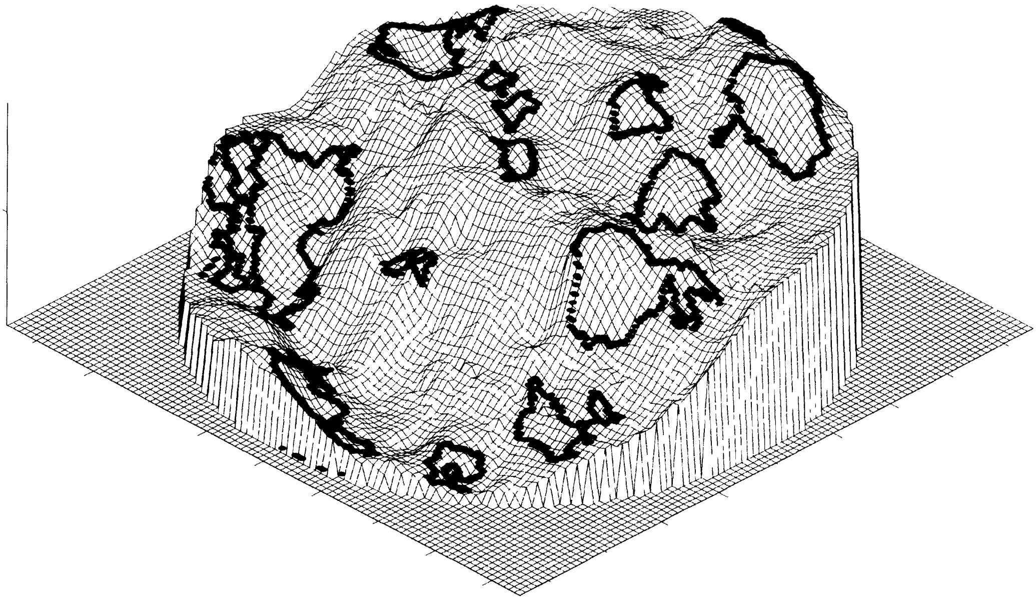

Fig. 3. — The damaged areas are superposed over the orthographic projection in such a manner we can visualize the dip of zones covered with crushed material (case: 0°, $\sigma = 7$ MPa, $\Delta U = 5$ mm).

or less coloured in grey or in pink. As these zones are gouge material pulled away from either one or the other joint surfaces and stuck down on the other surface without having been crushed, it is of great importance to separate them. On the other hand, the segmentation method is unable to separate subsets of the surface that become darker after shearing; because the irradiance of new created surfaces, where gouge material is pulled away, is lower than the pre-existing surface. Given that characterization of these zones are important from a physical and mechanical point of view, we think that new improvements can only be reached with colour images or filtered images.

References

[1] Goodman R.H., Introduction to Rock Mechanics (John Wiley and Sons, 1989) p. 562.

[2] Archambault, G., Gentier, S., Riss, J., Flamand R. and Sirieix C., A re-evaluation of irregular joint behavior on the basis of 3D modelling of their morphology: Joint mechanical shear behavior and modelling (MJFR Ed. Rossmanith, Rotterdam: Balkema, 1995) p. 163.

[3] Rivard, P., Simulation de surfaces de fracture par krigeage et simulations conditionnelles, Rapport de stage coopération franco-québecoise (1996) p. 39.

[4] Riss J., Gentier S., Archambault G., Flamand R. and Sirieix C., Irregular joint shear behavior on the basis of 3D modelling of their morphology: Morphology description and 3D modelling (MJFR Ed. Rossmanith, Rotterdam: Balkema, 1995) p. 157.

[5] Van der Heidjen F., Image based measurement systems (John Wiley & Sons, 1994) p. 338.

[6] Coster M. et Chermant J.L., Précis d'analyse d'images (Les Éditions du CNRS, Paris, 1985) p. 560.

[7] Laffréchine K., Comportement mécanique des épontes d'une fracture, Rapport de stage de DEA, DEA PAE3S, INPL (1996) p. 78.

[8] Gentier S., Petitjean C., Riss J. and Archambault G., Hydromechanical behaviour of a natural joint under shearing. 2nd North American Rock Mechanics Symposium (NARMS 96), Rock Mechanics Tools and techniques (Balkema, 1996) p. 1201.