An Analysis of the Effect of Discontinuity Surface Matching on Shear Strength by Image Processing

M.Unal & B.Unver
Department of Mining Engineering, Hacettepe University, Ankara, Turkey

ABSTRACT: There are many factors affecting the shear strength of rock masses. The shear resistance of discontinuities could probably be regarded as the most critical factor in mis respect. As the roughness characteristics of discontinuity surfaces have a great influence on the shear behaviour of discontinuity, it is of primary importance to study the roughness characteristics of discontinuity surfaces. The shear resistance of a discontinuity is a function of the amount of friction created due to contact between two surfaces during shear displacement. Therefore, it is also necessary to analyse the contact characteristics, called the matching degree, together with the roughness properties of discontinuities. The effect of the degree of surface matching on the shear characteristics of a discontinuity has not yet been fully described. In this paper, the aim is to determine the degree of matching of surfaces under different normal loads and state its significance in the shear behaviour of discontinuities. In order to visualise the effect of the degree of matching, both surfaces were dyed with a low absorbable paint in the form of a thin film. The shear strength of discontinuities at different normal loads was determined and photographs of the surfaces were taken using a digital camera with 1600x1200 pixel resolution. The photographs were analysed on the basis of colour difference. Thus, the parts of the surface where the paint was eroded due to friction could be identified and analysed. This made it possible to isolate the effect of the degree of surface matching together with the discontinuity surface roughness characteristics.

1 INTRODUCTION

There is a significantly close relationship between the roughness of a discontinuity surface and interaction between two surfaces, which greatly influences the stability of rock masses. Therefore, visual observations and quantification of the characteristics of erosion and friction on sliding surfaces are of great interest in determining the shear behaviour of discontinuities. This is because the discontinuity surfaces are rough and contact areas between the two surfaces change during shearing. Contact areas, i.e., matching areas between two surfaces, essentially depend on the magnitude of normal load, shear displacements and the direction of sliding. The contact mechanisms of discontinuities have been studied by various researchers (Barton and Choubey, 1977; Kwafnievski and Wang, 1997; Re et al., 1997; Zhao, 1997).

Discontinuity surfaces should be kept as close as possible in order to increase the shear resistance of a discontinuity and, hence, to increase the strength of a rock mass. The loosening of surrounding rock around an excavation eventually leads to a decrement in the amount of matching degree of discontinuity surfaces. The purpose of support is to keep the rock mass in the vicinity of an excavation as close as possible to the original conditions. The main idea behind contemporary support strategy is to use the rock mass itself as a supporting element. This can only be achieved by preserving the strength of the rock mass. Fissures and cracks can be held tightly by preventing the loosening of the rock mass. This is of critical importance, especially in the case of the application of rock bolts, since rock bolts are very sensitive to deformation, having a lower deformation tolerance. Therefore, the degree of surface matching at different normal loads assumes critical importance İn terms of rock support design (Unver, 1999).

The purpose of this paper is to determine the degree of matching of surfaces with an analysis of damaged zones during shear tests under different normal loads. This analysis is based on the acquisition of grey level images of surfaces created by erosion as a consequence of friction. Segmentation of the images depends on the colour difference to identify the damaged zones clearly, and then calculation of the matching degree is performed by histogram analysis.

2 SAMPLE PREPARATION AND TESTING

2.1 *Preparation of specimens*

Two different kinds of marble sample having fine and coarse grains were used in this study. A senes of 8 x 8 x 12 cm^3 and 5 x 7.75 x 10 cm^3 prismatic marble specimens were used. The prismatic specimens were split into two pieces to get a 8 cm x 8 cm and 5 cm x 7.75 cm joint surface by applying an indirect flexure test.

2.2 *Acquisition of images of the sheared area*

The characteristics of contact areas between two surfaces cannot be clearly defined by an examination of the surfaces after shearing. In order to facilitate the visual identification of the degree of matching at different norma! loading conditions, the surfaces were painted prior to testing. Since the colour of the samples was white, a black paint was selected so as to increase the contrast. This process was repeated for every test before shearing.

Before and after shearing, photographs of the surfaces were taken with a PDC 2000/40 digital camera with V600xl200-pixe\ resolution Then the digital images were transferred to a computer using auxiliary software called TWAIN.

2.3 *Shear tests*

Shear tests were carried out by using standart portable shear box, under different normal stresses on marble specimens of different dimensions and degrees of roughness. The marble specimens had similar mechanical characteristics, with uniaxial compressive strength values of around 62 MPa. The magnitudes of the normal stresses were selected as 0 5, 1, 1.5 and 1, 2, 3 MPa for specimens with sizes of 8 x 8 cm and 5 x 7.75 cm respectively for the simulation of different loading conditions. The peak shear strength of the rock joint corresponding to each applied normal stress was measured during the shear test.

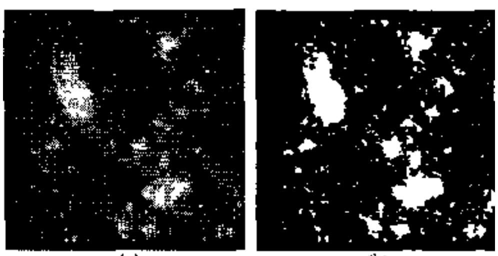

Figure İ Threshold filtering on the images of asheared joint surface a) before filtering b) after filtering

3 DETERMINATION OF DEGREE OF MATCHING

3.1 *Modelling of the surface topography*

In order to obtain 3-D models of the rock surface, a close-range digital photogrammetric technique was used. The test results show that it is possible to model the surface roughness of discontinuities by means of a digital photogrammetric method. The method is fast and of low cost. Details of discontinuity surface roughness determination by means of a photogrammetric technique can be found elsewhere (Unal et al., 2000; Ünal, 2000)

3.2 *Analysis of images*

The logic of the method for determination of matching degree depends on the fixing of the eroded area due to friction of the surfaces during shearing under different normal stresses and different shear displacements (Riss et al., 1997; Power and Durham, 1997; Reid and Harrison, 1997).

The degree of matching is the percentage of the part of the surfaces in contact. The ratio of the contact area to the whole area is defined as the coefficient of matching. Hence, the coefficient of matching takes a value between 0 and 1. (Zhao, 1997).

The eroded area can easily be identified by the removal of paint from the surface, creating a colour contrast. Advances in computer technology have reflected important improvements in the logic of image processing. These improvements provide a viable new approach for determination of the contact area of matching surfaces and now make it possible to calculate the contact area using simple and practical methods. In this study, the digital photographs of the surfaces were analysed in three stages'

- The photographs were dimensioned so as to include the surface for analysis, and colour images were converted into black and white.
- The contrast between the black and white regions was improved by the application of threshold filtering (Fig. 1). After threshold filtering, the ratio of the white regions as an indication of contact and change on the surface could be determined. Then, a histogram distribution of the change in colour was used to calculate the degree of matching of the two surfaces digitally. This analysis was repealed for each test. White regions on the photograph denote the eroded areas due to matching of the two surfaces, whereas black regions are the areas where there was no contact.
- The contour maps of the surfaces were drawn from the black and white photographs by

obtaining a threshold value, and these counter maps were superimposed with the contour maps obtained by means of digital photogrammetric maps. In this way, the eroded areas could be defined, as shown in Figure 2.

At the end of these analyses, the degree of matching (percentage of contact area) of the sheared surfaces and the peak strength values corresponding to these matching characteristics were determined. A summary of the results is presented in Table 1.

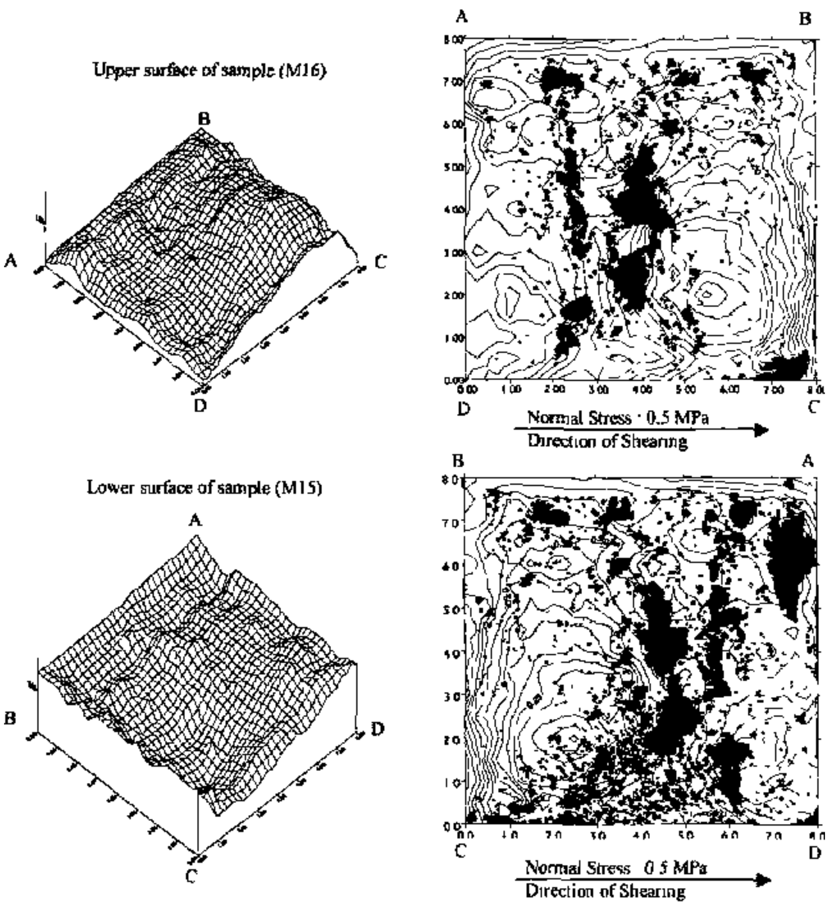

Figure 2. Determination of the topography and contour diagram of the sample joint surfaces together, black regions denote the contact area

4 DISCUSSION OF THE RESULTS

The effect and significance *of roughness* and the degree of matching on shear strength was demonstrated by employing a relatively simple method. The parameters that influence the shear strength of discontinuities are not independent of each other. There is interaction between these factors. The degree and nature of roughness have a great influence on the decree of matching.

As can be seen in Figures 3 to 5, there is a close relationship between normal stress, peak shear strength and the degree of matching. The relationship between normal stress and peak shear strength and the degree of surface matching in logarithmic scale (Figures 3-5 (a)) exhibits a similar trend. As the roughness of the samples increased, an eventual increase in the peak shear strength values was observed. On the other hand, the roughness and the degree of matching were found to be inversely proportional. In other words, as the roughness of the surfaces increased, interlocking of these rough surfaces became more difficult during shear displacement, as had been predicted. Due to dilatation, the degree of matching was decreased. However, the effect of normal stress on the peak shear strength value was greater. In addition, there seemed to be a difference between the degrees of matching of the lower and upper surfaces after shearing, as can be seen in Table I

Table 1. Summary of the results (Unal. 2000).

Specimen Code	Surface Dimensions (cm x cm)	^ JRC	Shear Displacement (mm)	Normal Stress(MPa)	Peak Shear Strength (MPa)	Contact Area (%)	
						Lower Surface	Upper Surface
*				0.5 -	1.055	11.83	10.66
Ml -M2	8 x 8	8-10	10.0	1.0	2.109	21.98	20.74
				1.5	2.617	34.21	27.56
*+				1.0	0.839	11.38	9.26
M4-M3	5x7.75	4-6	10.0	2.0	1.419	33.1	27.17
				3.0	2.065	48.43	42.71
+*				1.0	1.161	26.97	25.72
M6-M5	5 x 7.75	4-6	10.0	2.0	2.129	52.25	40.02
				3.0	2.839	68.55	63.14
**				1.0	0.981	20.14	17.61
M8-M7	5 x 7.75	4-6	10.0	2.0	1.742	35.79	35.54
				3.0	2.581	61.08	51.94
*•				1.0	1.032	22.49	18.8
MI0-M9	5 x 7.75	4-6	10.0	2.0	1.858	56.94	49.76
				3.0	2.348	64.73	54.95
*				0.5	1.016	14.62	5.86
Mil -M12	8 x 8	8-10	10.0	1.0	1.877	26.11	15.62
				1.5	2.422	33.97	25.32
*				0.5	1.250	17.69	14.44
M13-M14	8 x 8	8-10	10.0	1.0	2.1875	27.69	21.46
				1.5	2.539	35.11	30.81
**				0.5	0.820	23.98	13.43
MI5-M16	8 x 8	4-6	10.0	1.0	1.172	42.46	42.48
				1.5	1.484	58.42	57.35
**				0.5	0.703	15.57	10.47
M17-M18	8 x 8	4-6	10.0	1.0	1.016	41.06	25.38
				1.5	1.799	59.62	51.02
«w				0.5	0.703	16.4	11.8
M19 - M20	8 x 8	4-6	10.O	1.0	1.016	42.02	28.67
				1.5	1.289	51.02	39.05

* Coarse-grained marble
** Fine-grained marble
***Joint Roughness Coefficient

Examination of the lower and upper surfaces after shearing revealed that the amount of erosion due to friction was higher on the lower surfaces. Theoretically, surfaces of higher roughness are expected to show more erosion. This phenomenon could not be explained since the roughness of the upper and lower surfaces was almost identical. It was assumed that this occurred arbitrarily or due to difficulties experienced in keeping the rate of loading constant during the tests. The relationship between the peak shear strength values and the degree of matching is presented in Figures 3 to 5 (b).

As the figures show, the peak shear strength of discontinuities was found to be high at higher degrees of matching. The same trend was observed for all tests carried out on samples having various levels of roughness. It can be seen from a comparison of Figure 4 (b) and Figure 5 (b) that an increase in the joint roughness coefficient led to an increment in the value of peak shear strength.

During the calculation of normal stress on the shear surface, it is obvious that stress concentrations at different points are not constant. Therefore, the magnitude and nature of stress concentrations, especially at the tips of asperities, will be very high, eventually leading to failure of these parts. Therefore, depending on the value of normal stress, the dilatation of a discontinuity will be affected during shear displacement. At higher normal stress levels, better interlocking between discontinuity surfaces will obviously be achieved, and the stress concentration at the tips of asperities will tend to be lower due to the greater contact area. This phenomenon is thought to be the front line of support strategy for rock structures.

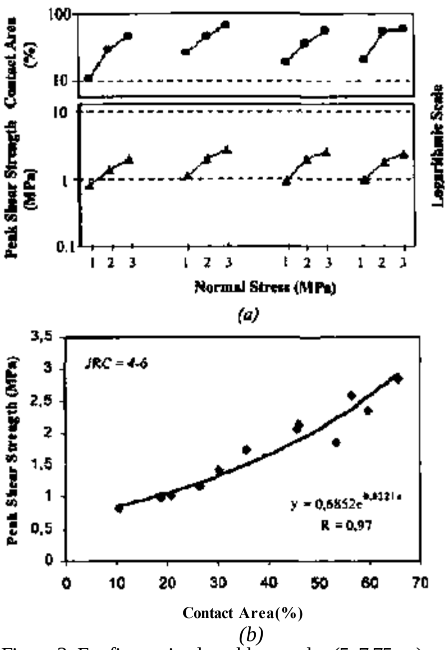

Figure 3 For fine grained marble samples (5x7.75cm)
a) Relationship between peak shear strength and the degree of matching at different normal stress levels, b) Relationship between peak shear strength and the degree of matching

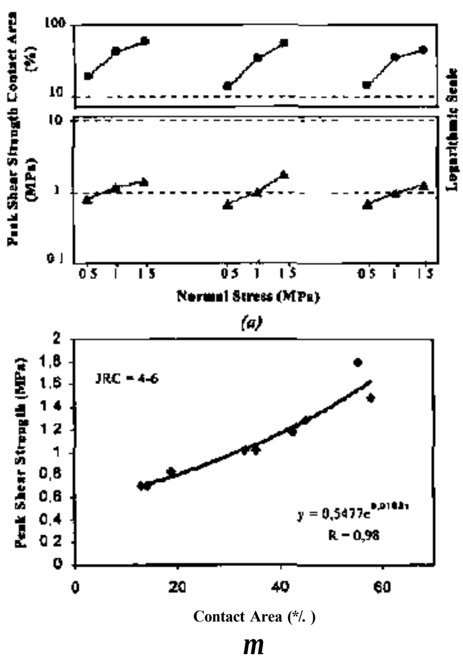

Figure 4 For fine grained marble samples (8x8 cm):
a) Relationship between peak shear strength and the degree of matching at different normal stress levels, b) Relationship between peak shear strength and the degree of matching.

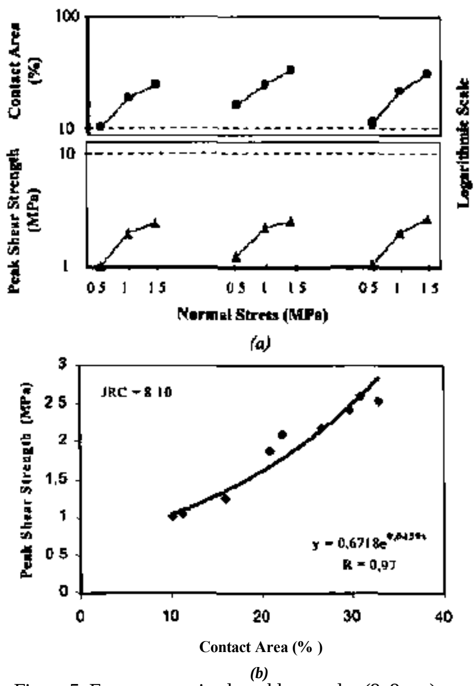

Figure 5 For coarse grained marble samples (8x8 cm):
a) Relationship between peak shear strength and the degree of matching at different normal stress levels, b) Relationship between peak shear strength and the degree of matching

5 CONCLUSIONS

This paper reports part of a comprehensive research study carried out on the modelling of discontinuity surface roughness by the application of a digital photogrammetric technique and subsequent fractal and variogram analyses for significant and successful modelling of discontinuity surface roughness. The conclusions of the study presented in this paper can be summarised as follows:

- The value of the peak shear strength and the degree of matching of discontinuity surfaces are a function of normal stress.
- The peak shear strength of a discontinuity increases with an increase in the degree of matching.
- The degree of matching of surfaces assessed with a high roughness coefficient tends to be lower during shear displacement.

The relationship between the roughness, degree of matching and shear characteristics of discontinuities for different types of marble sample has been demonstrated in a quantitative manner. A numerical solution and the simulation of shearing activity in different conditions are suggested for further research.

REFERENCES

Barton, N. & Choubey, V. 1977. The shear strength of rock joints İn theory and practice *Rock Mechanics.* Vol: 10, pp.1-54.

Kwafhiewski, M. A. & Wang, J. A. 1997. Surface roughness evolution and mechanical behaviour of rock joints under shear. *Int. J. Rock Mech. Min. Sel,* Vol: 34 (3-4), pp. 157-161.

Power, W. L. & Durham, W. B. 1997. Topography of natural and artificial fractures in granitic rocks. *Int. J.Rock Mech. Min.* Sei.. Vol: 22, pp. 979-989.

Reid, T. R. & Harrison, J. P. 1997. Automated tracing of rock mass discontinuities from digital images. *Int. J. Rock Mech. Min. Sei..* Vol: 34 (3-4): Paper no. 256.

Re, F., Scavia, C. & Zaninetti, A. 1997. Variation in contact areas of rock joint surfaces as a function of scale, *Int. J. Rock Mech. Min. Sei,* Voi: 34 (3-4): paper no. 254.

Riss, J., Gentier, S., Archaumbault. G. & Flamand, R. 1997. Sheared rock joints: dependence of damage zones on morphological anizotropy. *Int. J. Rock Mech. Min. Sei.,* Vol: 34(3-4), paper no. 258.

VJnal, M., Unver, B. & Tercan. A.E. 2000. Modelling of discontinuity surface roughness by digital phologrammetry and geostatistical methods, *Proc. of 9 Int. Symp. On Mine Planning and Equipment Selection,* Athens, Greece, pp. 391-396.

Unal, M. 2000. Modelling of discontinuity surface roughness and investigation of its effects on shear strength, PhD. Thesis, Hacettepe University, Ankara, 219 p. (in Turkish).

Unver, B. 1999. Methods related to use and performance of monitoring of rock bolts in underground coal mines. *Bulletin of Chamber of Mining Engineers of Turkey,* Vol: 28, No: 4, pp.3-20 (in Turkish with English Abstract)

Zhao, J. 1997. Joint surface matching and shear strength. *Int J. RockMech. Min. Sei.,* Vol: 36(2): pp. 179-185.