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ASSESSMENT OF ROCK JOINT ROUGHNESS USING IMAGE ANALYSIS OF DAMAGED AREA IN DIRECT SHEAR TESTS

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ABSTRACT

This paper describes the applicability of greyscale images to develop a relationship between the brightness integers in damaged areas subjected to direct shear tests, and asperity angles, which can cause the joint roughness coefficients (JRC) values to be affected. The areas damaged during the shearing stage are formed at contacted areas, which appear to be strongly related to the loss of asperity height of the roughness profiles. The photographs taken before and after shearing stages show differences in brightness and sizes of the damaged areas based on consistent light conditions. An image processing method which converts image types and extracts brightness integers from greyscale images, was employed to define damaged areas on the joint surfaces after the process of shearing. In this study, direct shear tests were performed on four core specimens of sandstone and argillite with joint surfaces, and the JRC values of the joints were calculated using roughness parameters obtained from analyses of the measured profiles. Images of the joints taken before and after the tests were then processed using a MATLAB simulation model. The results recommend that the JRC of rock joint specimens can be estimated by analysing 2D images based on a relationship between brightness integers and asperity angles of the roughness profiles.

KEYWORDS

JRC, greyscale image, damaged area, direct shear test.

INTRODUCTION

Joint roughness coefficient (JRC) has been used for investigations on rock joint shear behaviour. The values are estimated by comparing a measured profile of joints with typical roughness profiles (Barton et al., 1977). However, the determination of JRC values from the comparison can lead to inaccurate estimation, especially when the sizes of samples for the measurements are insufficient to compare with the standard profiles. For this reason, to quantify JRC values objectively remote sensing techniques, such as laser scanning and photogrammetry have been employed to extract coordinated roughness profiles in three dimensions (e.g. Grasselli et al., 2002; Hong et al., 2006; Fardin, 2008). In those cases, quantification of JRC from the profiles have been calculated by means of mathematical functions related to roughness parameters based on Barton’s typical roughness profiles (e.g. Tse and Cruden, 1979; Maerz et al., 1990). Although 3D imaging techniques are more effective, various surface features are investigated using 2D images with image analysis techniques. In geological areas, image analysis is employed to study ground erosion (Filin et al., 2013) and to determine mineral composition of rocks, or for identifying individual grain sizes of deposits and geological settings (McEwan et al., 2000; Trauth, 2010).

This paper describes the correlation between brightness values, obtained from digital images, and roughness parameters, on joint surfaces of specimens, during direct shear tests. The relationship permits the estimation of JRC values with non-contact methods. The roughness profiles were measured and compared with the brightness integers obtained from greyscale images. The results show that the relationship between the brightness intensity of images and the asperity angles can be used for the purpose of estimating JRC values from 2D image analysis.

IMAGE PROCESSING

To identify the surface roughness on the rock specimens, image pixels which contain surface data can be efficiently analysed. As an example, Saito et al. (2010) investigated rock surface roughness by means of local roughness patterns using downscaled topography data. In this paper, 2D greyscale images are employed to investigate a pattern which expresses variances of asperity angles on rock surfaces. A digital image can be regarded as a group of discrete pixels, each of which has information of colour and brightness. In case of a greyscale image (8 bit), it carries only intensity of light or brightness and can simplify the image structures. Each pixel of greyscale images has a luminance value which can be measured on a scale from black (0 intensity) to white (255 intensity, if the image is 8 bit) as described in Figure 1. Therefore, if the colour formations and textures of rocks are simple, the differences of the brightness between before and after shearing stages in direct shear tests can be regarded as the differences of asperity angles arising from the different reflection of light.

In this study, greyscale images of sandstone and argillite core samples are used to obtain brightness values along the centre lines by which the roughness profiles are manually measured. The integer values obtained from the pixels of the images are then extracted using the image processor, MATLAB code. The results are then analysed using correlations with the asperity angles calculated from the measured profiles.

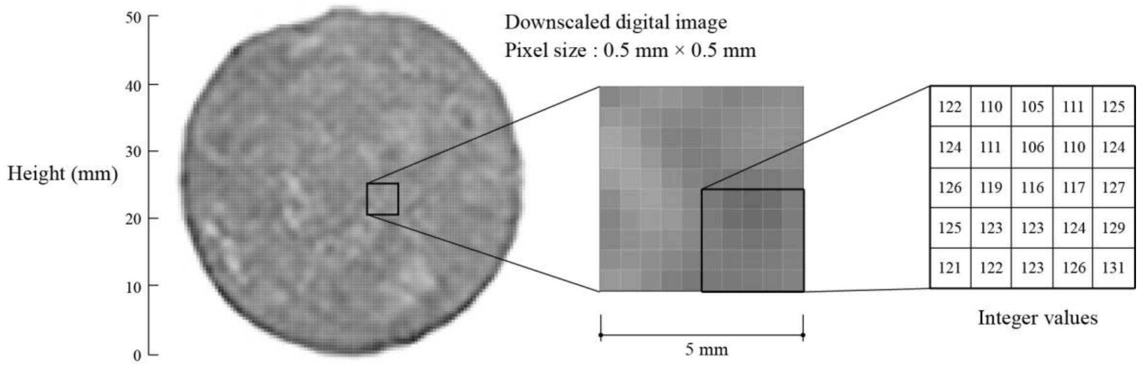

Figure 1. Greyscale digital image of a joint surface and integer values

JRC ESTIMATION

For quantification of JRC using measured roughness profiles, roughness parameters are employed to characterise amplitudes of the profiles. Tse and Cruden (1979) proposed to estimate JRC values using a roughness parameter Z_2, which is a discrete form as shown in the following equation.

$$Z_2 = \left[\frac{1}{M(D_x)^2} \sum_{i=1}^{M} (y_{i+1} - y_i)^2 \right]^{1/2} \tag{1a}$$

where M is the number of intervals, D_x is a constant distance lag and the sum of the squares in adjacent y-coordinates is divided by the product of the number of intervals,. In Eq. (1b), the relation with JRC was suggested by a statistical approach based on Barton's standard joint profiles.

$$JRC = 32.2 + 32.47 \log Z_2 \tag{1b}$$

Using a shadow profilometry technique based on photo analysis, Maerz et al. (1990) investigated a relationship between JRC values and a roughness parameter, R_p which is related to the inclination angle (i) of the teeth of a sawtooth surface. This value can be estimated by the equation (2a), where i_a is the micro-average angle. Maerz et al. (1990) compared R_p with JRC values and suggested the following linear equation as shown in Eq. (2b).

$$i_a = \cos^{-1}\left[\frac{1}{R_p}\right] \tag{2a}$$

$$JRC = 411(R_p - 1) \tag{2b}$$

EXPERIMENTAL STUDIES

Direct Shear Tests

Four sets of jointed core specimens (two sandstones and two argillite specimens) were used for direct shear tests. The samples were obtained from an excavation site in the Gold Coast (Kim et al., 2013). To estimate strength properties of the rock samples, point load tests were performed. The average values of the unconfined compressive strengths of the sandstone and argillite cores were 19.5 MPa and 27.4 MPa respectively.

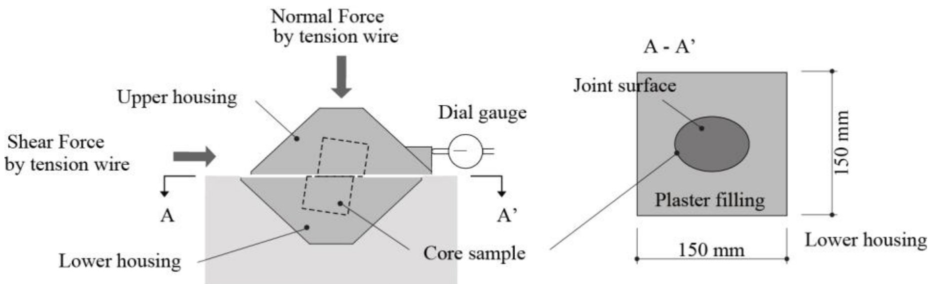

Figure 2. Setup for direct shear tests

Direct shear tests were performed to investigate the changes of joint surfaces by means of taking photos and measuring roughness profiles after shearing stages. The diameters of the specimens were 50mm and the tests were performed using the portable shear box SL900 as demonstrated in Figure 2. During the sample preparation stage, the specimens were placed in plaster bases and cured together for 1 week. The ranges of normal stresses were selected from 0.5 to 4.0 MPa according to the strength conditions of the samples. The results of the direct shear tests are summarized in Table 1.

Table 1. Results of direct shear tests

Specimens	Normal Stress (MPa)	Max. Shear Stress (MPa)	Ratio of Damaged area (%)	Max. loss of asperity height (mm)
Sandstone (1)	0.5	0.6	36.5	3.9
Sandstone (2)	2.5	1.6	37.5	5.7
Argillite (1)	3.0	4.5	23.3	1.4
Argillite (2)	4.0	2.9	8.1	0.8

Damaged areas after direct shear tests were studied by comparing both images taken before each shearing stage and pictures of sheared specimens by visual observations (Fig. 3). As a result, even in lower normal stress conditions, sandstone samples showed large portions of damaged areas and corresponding loss of asperity depths compared to argillite samples due to its low compressive strength.

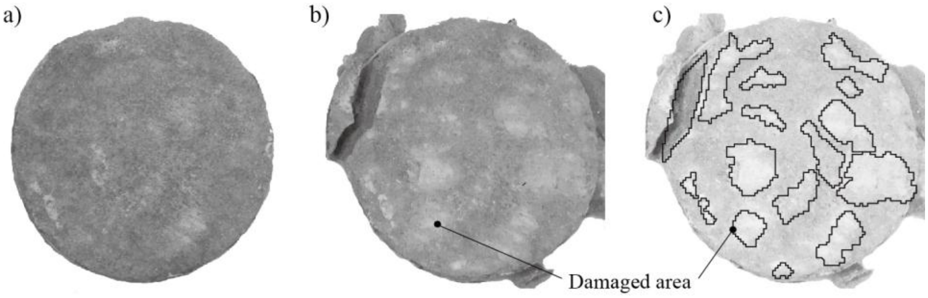

Figure 3. Greyscale images of sandstone samples before shearing (a), after shearing (b) and damaged areas determined by visual observation (c) (Sandstone (1))

Estimation of JRC Values

The joint roughness profiles were measured by a profile gauge with 1mm interval over the centre lines of the sample surfaces before and after shearing as shown in Figure 4. JRC values were then calculated using the roughness parameters (Z_2 and R_p) as described above.

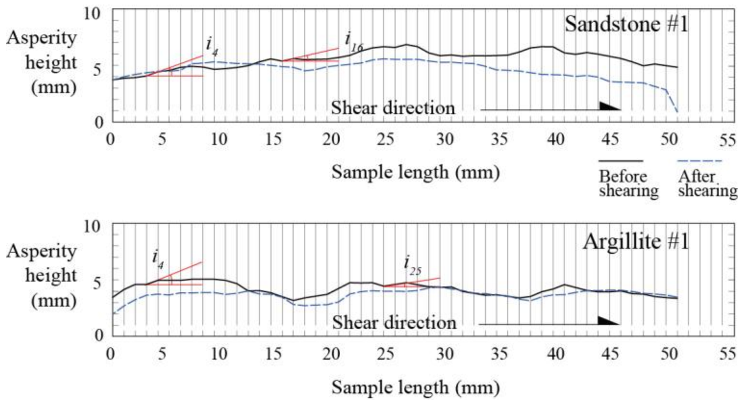

Figure 4. Joint roughness profiles of core samples measured by a profile gauge

Table 2 demonstrates the calculated JRC values. After the shearing stage, the JRC values were significantly reduced and the differences were ranged from 0.4 to 3.7. However, sandstone (2) after the shearing stage, showed considerable increase of JRC values producing large variations of the joint profile due to sharp points created by shearing.

Table 2. Calculated JRC values using surface parameters

Core Samples	Tse and Cruden (1979)		Maerz *et al.* (1990)	
	Before shearing	After shearing	Before shearing	After shearing
Sandstone (1)	10.6	7.3 (-3.3)	9.4	5.7 (-3.7)
Sandstone (2)	7.4	10.3 (+2.9)	6.0	11.1 (+5.1)
Argillite (1)	10.9	10.0 (-0.9)	9.3	8.9 (-0.4)
Argillite (2)	1.5	0.8 (-0.7)	2.7	2.1 (-0.6)

Image Analysis

Digital images were created using a CCD digital camera (6mm focal length lens). The images of sample area were composed around 1,200 rows by 1,200 column and the pixel size of the images was 20 pixels/mm. The colour images were then converted to greyscale with 8 bit pixel depth (255 shades of grey) to simplify the image data using the image processing code, MATLAB R2014a (Mathworks, 2014). The resolutions of the images were then downscaled by two pixels per mm. The purpose of downscaling was to reduce the number of data to compare the reference profiles obtained from the calculations as described above.

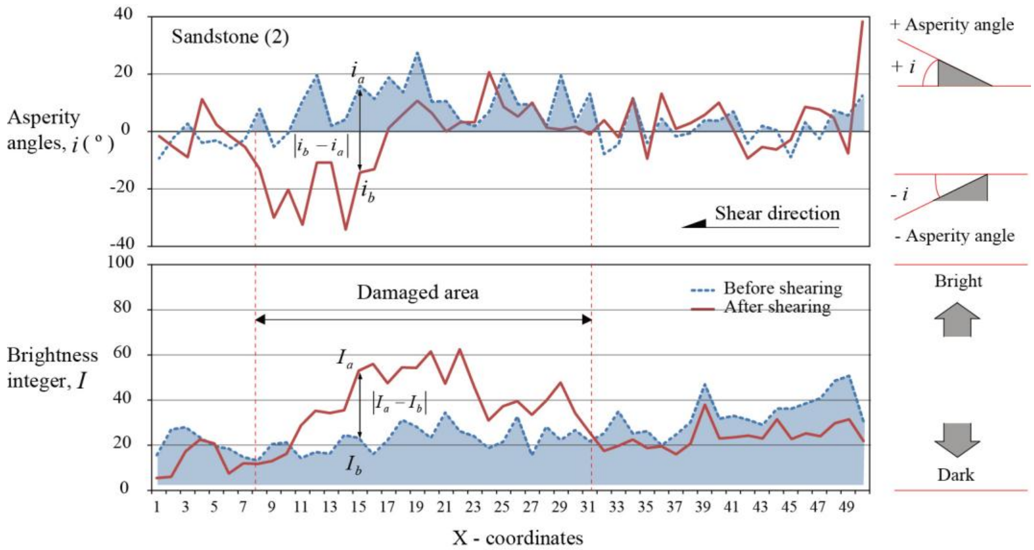

Figure 5. Brightness integers of greyscale images and asperity angles, sandstone (2)

The range of brightness integers varied from 0 to 255. The values were extracted from the images of joint surfaces on the areas of the measured roughness profiles using MATLAB code. The values were compared to asperity angles calculated from measured profiles. Figure 5 demonstrates the brightness integers and the asperity angles at the same positions along the profiles before and after shearing stages for the sample of sandstone (2). It was observed from the results that the variances of brightness integers (I) obtained from greyscale images can correlate with the variances of asperity angles (i) of roughness profiles after shearing stages. Large variations of I values occurred at the same areas where large variations of i were observed. It was also observed that shearing can reduce asperity angles and the areas damaged from shearing were able to be identified using the variance of brightness integers. In damaged areas from the direct shear tests, brightness integers increased more than the barely or non-damaged areas nearby as shown in Figure 5.

CORELLATION BETWEEN JOINT ASPERITY ANGLES AND IMAGE BRIGHTNESS

Lighting, camera angles, lens aperture values and the surface conditions of samples at the moment of photographing can influence on the brightness integers of images. Therefore, in order to minimize the influence of those factors, the camera and samples were placed in the same positions before and after shearing. Consequently, the variances of brightness integers in the same types of rock samples showed similar patterns due to their having the same geological conditions. Thus, the data of the correlation between the variances of asperity angles (i) and the variances of brightness integers (I) can be formed in the groups of sandstones and argillite as demonstrated in Figure 6. The data used in this correlation were carefully chosen from the analyses in the damaged areas obtained from the test results.

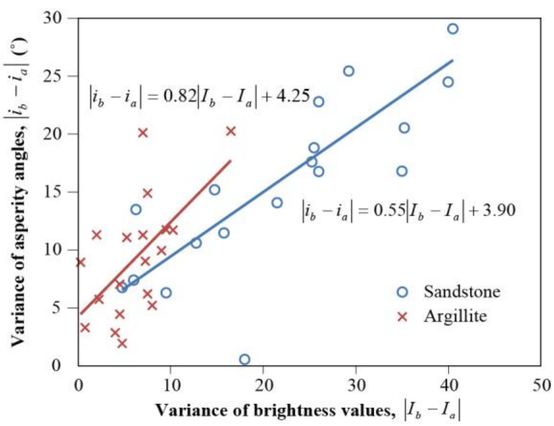

Figure 6. Correlations between variances of brightness index (I) and asperity angles (i)

The distributed data indicate that the variance of bright integers increases with the variance of asperity angles and that sandstone samples showed large values of bright integers compared to argillite due to its bright geological colour base. The results from the data regression suggest that brightness integers according to the rock types can be used for estimation of JRC.

CONCLUSIONS

This study demonstrated that brightness integers (*I*) using greyscale images can provide a relation with asperity angles (*i*) for estimation of JRC values. Direct shear tests using four core jointed specimens (two sandstone and two argillite) were performed to calculate joint roughness parameters and JRC values, and to identify damaged areas. Images taken before and after the shear tests were analysed using the MATLAB image processing code to extract brightness integers on greyscale images. As a result, the absolute values of integers obtained from both before and after shearing stages showed a linear regression with the variances of asperity angles of roughness profiles according to their rock types. This experimental study showed the applicability of image analysis to obtain the variance of asperity angles for joint surfaces from simple 2D greyscale images.

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