CHANGES IN JOINT SURFACE ROUGHNESS OF TWO NATURAL ROCKS DURING SHEARING

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ABSTRACT: This study seeks to investigate the effect of joint surface damage on the shear strength of two natural rocks, namely sandstone and argillite. A series of shear box tests were performed on the jointed rock specimens with different joint roughness coefficients (JRC). The joint surface roughness of each rock specimen was estimated by means of Barton's comb before and after the shear test as well as it was obtained experimentally using the measured peak shear stress. The laboratory data indicated that some damage of joint surface occurred during shearing, which affected the overall shear strength of the jointed rock specimens. The damage coefficient (M) initially introduced by Baron and Chubey (1977) was modified so that it can be used to estimate the joint surface damage of the tested rocks; that is, no or small damage may occur when M<1 while considerable damage to the joint surface can be expected when M>1. Due to the inhomogeneous of the rock samples, there are two modulus presented for the damage coefficient. This study seeks to find a more accurate relation between the JRC value and the damage coefficient based on the Barton and Choubey theory.

Keywords: Rock joint, Joint surface roughness, Shear strength, JRC, damage coefficient.

1. INTRODUCTION

Failures in jointed rock mass commonly occur in shear along weak discontinuities (or joints). A good deal of research has been conducted to investigate the effect of joint characteristics, including the joint surface roughness, on the shear strength of rock mass. In these studies, the shear strength of jointed rock was estimated using Barton's criterion (Eq.1) as recommended by ISRM [1, 2].

$$\tau = \sigma_n \tan \left(\phi_r + JRC \log_{10} \left(\frac{JCS}{\sigma_n} \right) \right) \quad (1)$$

where, τ is the shear stress, σ_n is the normal stress acting on the joint surface, JCS is the joint wall compressive strength (which is approximately equal to unconfined compressive strength of rock), JRC is the joint roughness coefficient that varies from 0 (smooth, flat surfaces) to 20 (irregular surfaces), and ϕ_r is the residual friction angle. JRC seems to play an important role in the strength of jointed rocks; i.e., irregular surfaces with higher values of JRC tend to produce greater values of shear strength. There are different approaches to obtain JRC, including direct measurements of rock surfaces and estimation of JRC from a series of shear box tests conducted on jointed rock specimens.

Previous research indicates that during shearing, the rock surface can experience damage due to high normal stresses or relatively weak strength of the tested rock. This can change the joint surface characteristics (including JRC) and affect the overall shear strength of jointed rock. To estimate the level of damage that can occur due to high shear forces, a damage coefficient (M) was proposed by Barton (1977) [3], which can be estimated as shown in Eq. 2

$$M = \frac{JRC}{12 * \log_{10}\left(\frac{JCS}{\sigma_n}\right)} + 0.7 \quad (2)$$

This damage coefficient suggests that joints with higher values of JRC (JRC>10) may undergo greater damage. If M is relatively high, then greater damage to the joint surface may be expected. Yet, it is still unclear whether Eq 2 can accurately estimate the damage of different rock types as it was experimentally obtained from a series of model fracture tests, and thus it may significantly vary for natural rocks, depending on rock's geological origin.

This study seeks to better understand the effect of joint surface damage on the shear strength of jointed rocks and clarify the role of damage coefficient in the estimation of rock strength. A series of shear box tests on two natural jointed rocks were performed and changes in the joint surface roughness before and after shear were recorded and analyzed. This paper presents and discusses the obtained results.

2. EXPERIMENTAL PROGRAM

2.1 Rocks Used

Borehole core samples (diameter of 50 mm) of two rock types (namely argillite and sandstone)

were collected from the Gold Coast area (Queensland, Australia) (Fig. 1). These rocks were part of the Neranleigh-Fernvale bed formation [4, 5] which are commonly associated with slope stability issues and also, especially the stability can be wrecked during or after a heavy rainfall [6]. The rock core sample was excavated from this area which has already happened several rock slope failure. Although the core specimens contained joints, they were identified as fresh to slightly weathered, following [7, 8]. The strength characteristics and mineral composition of these rocks are summarized in Table 1. In this study, the samples of sandstone are labeled as "S" while the specimens of argillite are referred to as "B".

Fig.1 A view of tested specimens

Table 1 Rock properties

Sample Name	Sandstone	Argillite
Porosity (%)	16.7	4.9
Density (g/cm^3)	1.99	2.55
Unconfined Compression Strength (MPa)	31.2	39.4
Major minerals	Quartz, Feldspar, Kaolinite	Quartz, Feldspar, Kaolinite, Calcite, Illite, Muscovite

2.1 Testing Procedure

The experimental program included a series of the shear box, tilt, and Barton's comb tests [3].

Shear box tests. Rock specimens with natural and manually created joints were prepared for shear box tests by sizing the core samples to a length of 70-80 mm, which is corresponding to ISRM (2015) [9]. The test plane of the sample is approximately 50mm long, which is 10 times than the maximum asperity height. It is also indicated that the height of the shear plane is over than 50 mm.

The top and bottom parts of each specimen were

secured together with string, an encapsulating mixture of cornice cement (the water-cement ratio was 1:2) was prepared and poured into the direct shear test molds in which the sample was partially submerged (Fig. 2a). When the cement material was strong enough to hold its shape, another pour of cement mixture was placed into a second mold and the other half of the sample was turned upside down and submerged into the new mold. The specimens with the cement cap were then removed from the molds and placed into a dehydrating oven (temperature of 100°C) to cure for about 100 hours. Figure 2b presents the specimen setup before a shear box test.
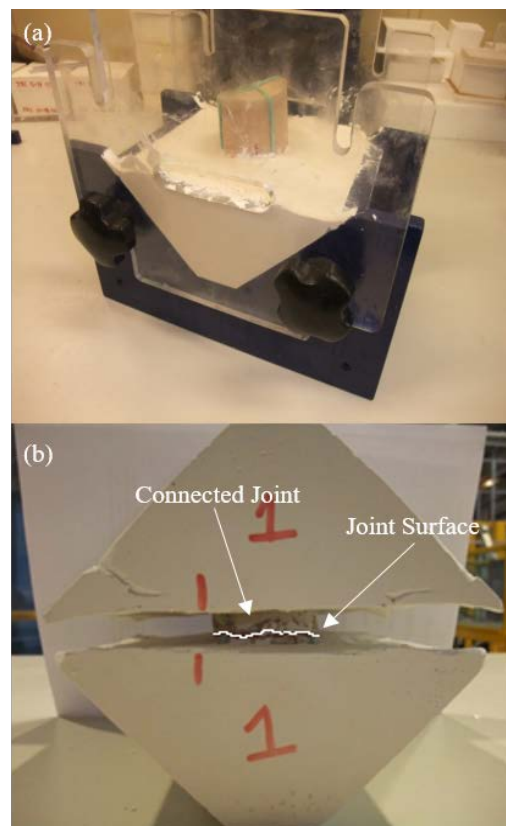

Fig.2 Preparation of rock specimens for shear box tests: a) rock core cast in concrete, and b) set up before the shear box test

For each test, normal stress was first applied: 1, 3, 5 MPa for the sandstone specimens, and 2, 4, 6, 8 MPa for the argillite specimens. The shear force was then applied in steps to shear the specimen by 0.1 mm until the peak shear stress was achieved.

Barton's comb measurements. Barton's comb was used to measure the specimen surface and obtain the corresponding values of JRC before and after shear box tests.

Table 2 Summary of JRC values measured before and after a shear box test and damage coefficients

Sample Number	Estimated JRC		Shear box test	JCS/σ_n	Damage coefficient	Modified damage coefficient
	Barton 's Comb					
	before shear	after shear				
S1	8	8	8.4	20.80	1.21	0.91
S2	8	6	5.7	12.48	1.31	1.01
S3	10	10	11.4	62.40	1.16	0.86
S4	12	8	13.0	20.80	1.46	1.16
S5	14	12	11.4	20.80	1.59	1.29
S6	14	14	8.5	12.48	1.76	1.46
S7	14	14	15.7	62.40	1.35	1.05
A1	5	2	6.3	9.85	1.12	1.02
A2	6	4	7.6	13.13	1.15	1.05
A3	4	4	10.7	13.13	1.00	0.90
A4	8	8	9.1	15.76	1.26	1.16
A5	12	8	12.4	15.76	1.54	1.44
A6	16	12	16.2	13.13	1.89	1.79
A7	16	14	16.8	13.13	1.89	1.79

Note: σ_n – normal stress; JCS – unconfined compression strength; JRC – joint roughness coefficient
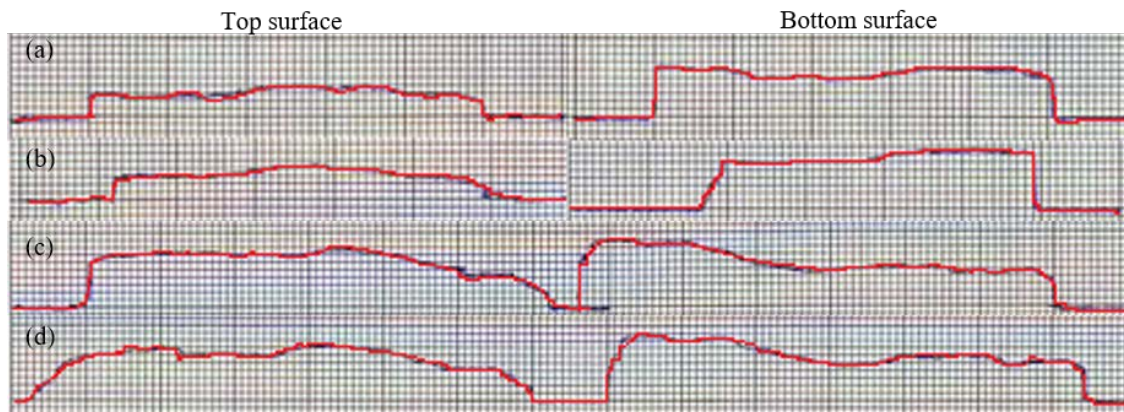

Figure 3 A view of rock surface before (a,c) and after (b,d) shear box test. Top and bottom surfaces of S3 (a,b) and A7 (c,d)

The JRC values of these samples varied from as low as 2-4 to as high as 14-16. Table 2 summarizes the JRC values of each specimen before and after each test while Figure 3 gives an example of changes in the rock surface caused by shear. From Figure. 3, the result of sandstone shows there is a huge block missing at the bottom surface after the shear test, which compared with the argillite sample and the top surface of the sandstone are only more smooth which indicated the JRC values have been decreased after the shear.

Tilt tests. A series of tilt tests were conducted to obtain the basic friction angle of rock specimens with smooth surfaces according to the USBR standards[10] The test procedure is described in detail by [10, 11]. It was found that an average angle for the sandstone and argillite was 29.8° and 27.8°, respectively.

3. TEST RESULTS AND DISCUSSION

3.1 Shear Box Tests

Typical results of shear box tests are given in Figure 4 showed the effect of JRC on the shear strength of jointed rock. For sandstone (Fig. 4a), the specimens with higher values of JRC tend to produce greater values of peak shear strength. The same tendency is observed for argillite (Fig. 4b); that is, the specimens with JRC≈10 have slightly greater values of shear strength.
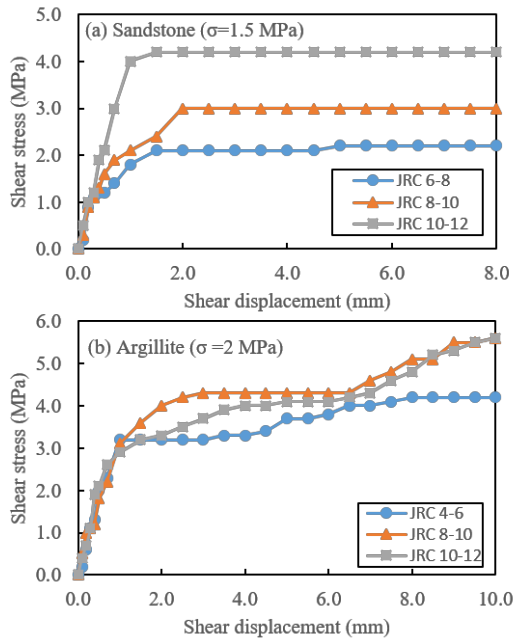

Fig.4 Typical shear box test results obtained for a) sandstone, and b) argillite

All tests results were replotted in Fig. 5 to better demonstrate the effect of surface roughness on shear strength. Regardless of rock type, the shear strength of jointed rock tends to increase with increasing values of JRC.

From Fig. 5, the shear strength for the samples with the different JRC values shows, in general, with the higher JRC and normal stress, it increased. However, due to the special of the material, when the JRC value higher enough, with the applying the normal stress, it is easy to cause failure with lower shear strength. It is also indicated by Sow, the normal stress is less 1 MPa, may lead to the asperity shearing [2].

3.2 Changes in Joint Roughness after Shearing

Table 2 summarizes laboratory data of JRC values measured before and after the shear box tests as well as the JRC values estimated using Eq 3, where values of σ_n and τ were obtained from a series of shear box tests.

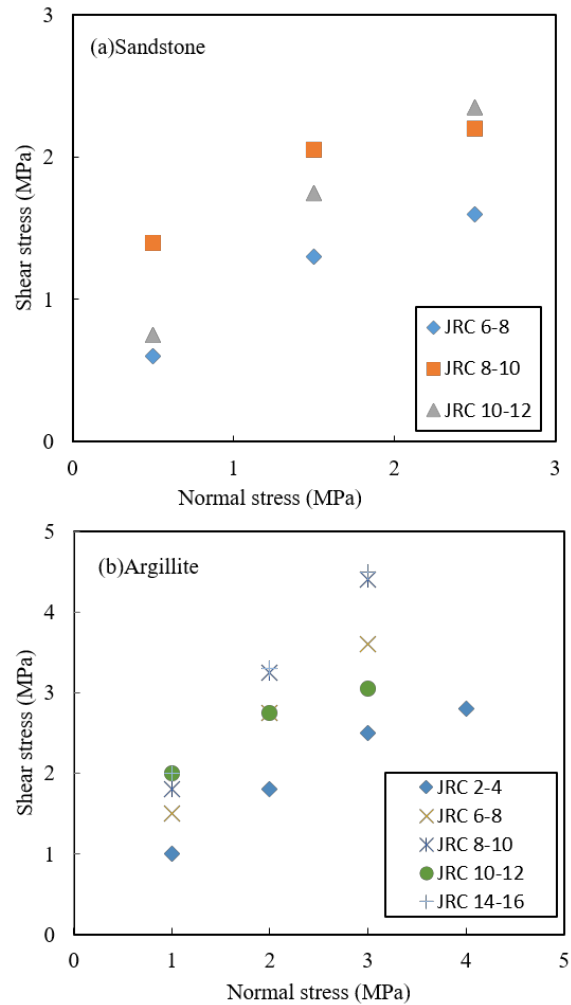$$\mathbf{JRC} = \frac{arctan(\tau/\sigma_n) - \phi_r}{\log_{10}(JCS/\sigma_n)} \qquad [3]$$

Fig.5 Summary of shear box test results plotted as peak shear stress at corresponding values of normal stress: a) sandstone, and b) argillite.

To better understand the effect of shear on joint surface roughness, the laboratory data was re-plotted in Fig. 6 as JRC measured by Barton's comb before and after the shear box test and JRC obtained from the shear box test using Eq. 3. It is evident from this figure that for both rocks, the JRC value tends to decrease after the shearing process. It can be attributed to the breakage or smoothing of surface irregularities caused by normal and shear forces acting on the joint surface. It is interesting to note that changes in JRC of argillite also occurs for relatively smooth surfaces (low JRC values). In contrast, Eq 2 tends to overestimate the JRC for both rocks, which is more pronounced for argillite.

Compared with the sandstone JRC value, the argillite result has presented that the shear box results are always higher than the measured results which have been indicated by [2].
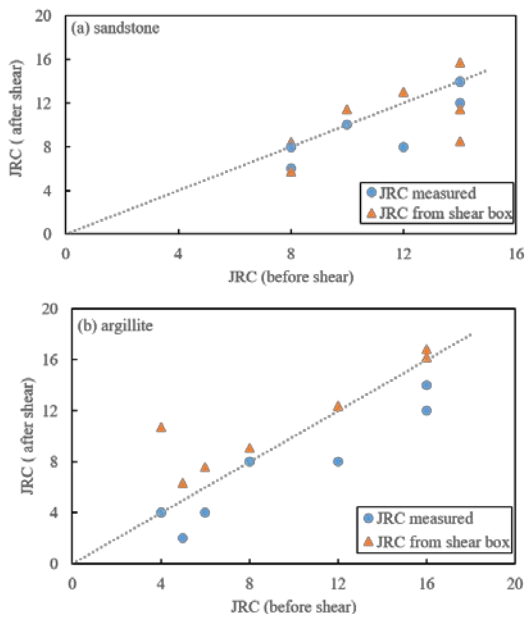
Fig.6 Summary of data on JRC values before and after shear: a) sandstone, and b) argillite

3.3 The Damage Coefficient

To estimate the damage potential of joint surfaces during shearing, the coefficient of damage (M) was obtained for each test using Eq 2 (Table 2). It is evident that for each case, M was greater than 1, suggesting considerable damage to the surface. However, visual observations and direct measurements performed after each test indicate that in some cases, the damage was rather insignificant. This discrepancy suggests that Eq. 2 may not be suitable for all rock types, and care needs to be taken when applying this coefficient for a particular type of rock. Mostly the reason for this may due to the inhomogeneous of the rock sample. That is the reason why the X-Ray diffraction of each type of sample in this study.

Considering the obtained results, the new mathematical expressions of the damage coefficient for sandstone (Eq. 4) and argillite (Eq. 5) were proposed. New values of the modified damage coefficient are given in Table 2.

$$\mathbf{M} = \frac{\mathbf{JRC}}{\mathbf{12} * \mathbf{log_{10}}(\frac{JCS}{\sigma_n})} + \mathbf{0.4} \qquad (4)$$

$$\mathbf{M} = \frac{\mathbf{JRC}}{\mathbf{12} * \mathbf{log_{10}}(\frac{JCS}{\sigma_n})} + \mathbf{0.6} \qquad (5)$$

The modified damage coefficient (M) better correlates with the changes in JRC values; i.e., no or little changes occur when M<1 while some to considerable changes can be expected when M>1.

Figure 7 plots that obtained results as the modified damage coefficient against the ratio of JCS/σ_n.

According to Baron and Chubey (1977) [3], the damage of the joint surface may occur when the ratio is relatively low. The results obtained in this study seem to be in agreement with this statement as changes in JRC occurred when the JCS/σ_n was less than 20.
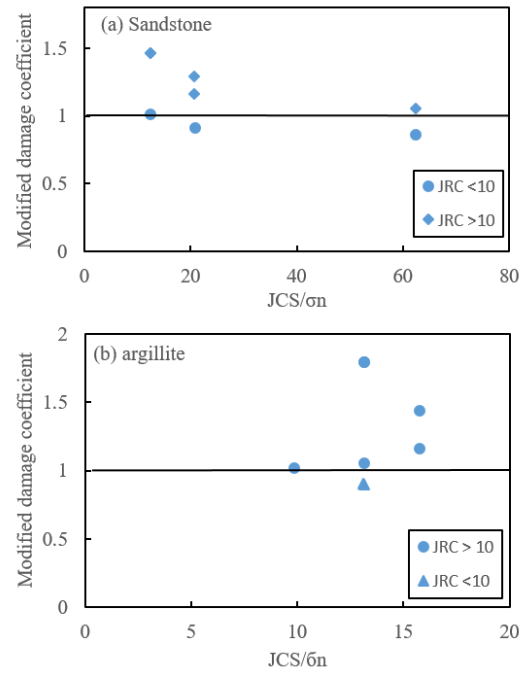

Fig.7 Relationships between the JCS/σ_n ratio and the modified damage coefficient

4. CONCLUSIONS

A series of shear box tests on rock specimens of jointed sandstone and argillite was performed to estimate the effect of joint surface damage on overall shear strength. Based on the obtained results, the following conclusions can be drawn:

- The shear strength of the tested rocks depends on the joint roughness; i.e., it increases when the joint surface becomes more irregular.
- Damage to the joint surface can occur during shear, thus affecting the shear strength of rock. It was found that the damage may even occur to relatively flat, smooth surfaces (JRC<10), and not only to highly irregular surfaces (JRC>10), as was reported by other researchers, which can be agreed with fact that has been presented with Barton and Choubey in 1977 [3].
- The damage coefficient (M) can be used to estimate the degree of damage that can occur during the shearing of jointed rocks. When M<1, no or little damage may be expected during shearing while considerable damage to the joint surface may occur when M>1. However, it was found that M

depends on the type of rock, and it varies with the rock geology, which means depends on the mineralogy and the structure of the rock sample. If the size of the sample was too coarse, or the mic-structure of the sample which can be indicated by the density and porosity of the sample.

5. REFERENCES

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