Shear strength behaviour of rock joint material influenced by different weathering grade

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Abstract. Shear strength parameter is a crucial in designing the rock mass structures such slope and tunnel. Stability of rock mass structure is affected by apparent joint sets and discontinuities present in the rock mass especially when the joint interfaces degraded and physically altered due to weathering effect. The weathered condition imposed on joint surface importantly play the role to control the shear strength characteristic and sliding behaviour. A comprehensive study and focussing on effect of weathering grade to the rock joint surface particularly for granite type of rock was introduced. A set of granite samples were collected from a quarry then been classified into respective grade of weathering based on surface hardness by using Schmidt rebound hammer and rock material density by using PUNDIT test. The standard laboratory testing of direct shear test that accordance to ISRM suggested method were carried out on jointed block samples with different grades of weathering. Detail assessment on rock joint samples were evaluated to characterize the physical appearance of different weathered joint surface condition. The rock joint surface assessment made based on Joint Roughness Coefficient (JRC) then been correlate with thin section petrographical results for justification with respect to mineral composition contents. As the result, the shear strength of weathered rock joint significantly influenced by the weathering grade due to changes of microstructure behaviour of the granite. Moreover, the lower grade of the granite sample has low frictional resistance force to against the sliding, hence indirectly produced low shear strength of the rock joint.

1. Introduction

Joints are the most critical discontinuities and influence the strength of rocks mass structure [1]. A gathering of parallel or sub-parallel joints is known as a joint set, and joint sets cross to shape a joint system. The joint is very important to be analysed not for infrastructure development only, but also for the stability of the rock mass itself. Furthermore, it is crucial because the countries who had located in tropical region potentially facing with wetting and drying throughout the years that accelerating the disintegration and dissolution process of rock mass. There are many factors influence the shear resistance and stability of the jointed rock. According to [2], they found that the weathering process has changed the mineralogy and texture of the granite and also influenced the strength of the rock material in terms of point load strength index, uniaxial compressive strength and tensile strength. [3] mentioned that the weathering process has affecting the stability of rock slope. However, shear strength is the important parameter need to be considered in order to analyse the stability of rock mass. Several researchers, including [4], [5], [6], [7] and [8] have investigated this problem in laboratory and numerical testing using Direct Shear Test. The normal pressure applied on the rock joint also giving changes to the
peak shear strength of the rock joint for sedimentary rock done by [9] and [10]. Besides, previous researchers done by [10] and [11] had used cylindrical and square shape of rock material to conduct Direct Shear Test. It is unnecessary to fix the shape of rock joint, as long as the contact area should be larger than 1900mm² [12]. In Malaysia there is no researchers had conducted the weathering effects to the shear strength of jointed granite in the terms of microstructure changes. Therefore, this study focuses on the shear strength behavior of rock joint material influenced by different weathering grade of granite rock from Penanti, Pulau Pinang. The tests involved are thin section study, Joint Roughness Coefficient Test and Direct Shear Test. All these methods showing the relationship between weathering effect to the mineralogy composition associated with the shear strength characteristics of the granite rock joint.

2. Sample preparation
Granite samples were collected in Kuad Quarry Penanti, Penang and classified based on weathering grades (I, II, III and IV) using Rebound Hammer. Figure 1 shows the dimension of granite sample with the size of 7 inch in length, 4 inch in height and 4 inch in width respectively. The desired contact surface of jointed rock is set to 4 inch X 4 inch equivalent to 100cm². The contact area of rock joint is split using compression machine and divided by splitter. Cross-sectional area of regular geometrical shapes, the relevant dimensions of the specimen at the shear zone cross section is measured to the nearest 0.025 mm using caliper. Then, the apparent cross-sectional area of the intact specimen is calculated.

![Figure 1](image1.jpg)

**Figure 1.** The dimension of rock sample 100 X 100 X 200 mm with natural.

3. Experimental test
There are several laboratory works were conducted in the laboratory to characterise the shear strength of jointed granite such as Density test, Petrographic Test, Schmidt Rebound Hammer test, Pundit test, Joint Roughness Coefficient test, and Direct Shear test.

3.1. Rebound hammer test
The Rebound Hammer test is a simple, portable and inexpensive device that gives the rebound hardness value of R for an intact rock specimen in the laboratory or the rock mass in situ. Figure 2 shows the Rebound Hammer used to classified the weathering grade of the granite sample. Rebound hardness R is a number that varies in the range of 0 – 100. Different weathering grades of granite were used in order to run this experiment. Since the rebound hammer measures the surface hardness of the rock, it is important to understand all the items that might affect surface conditions of the rock and thus, the rebound hammer numbers [13].

![Figure 2](image2.jpg)
3.2. Joint roughness coefficient test

Joint roughness coefficient (JRC), which is typically measured by means of Barton’s comb in the field, is widely used to describe the joint roughness. [14]. The profile of the joint roughness of the rock sample was taken by using then comb profiler. Figure 3 shows Typical Joint Roughness measurement using Comb Profiler and Roughness Coefficient, JRC for different surface roughness profile respectively.

Figure 2. (a) Working principle of schematic rebound hammer as referred to ISRM (2007); for (b) laboratory assessment for rock surface hardness.

Figure 3. (a) Standard JRC roughness profiles from Barton and Choubey (1977) for categories reference; and (b) method of rock joint surface characterization to capture roughness profiles.
3.3. Direct shear test

Direct Shear Test are commonly used to determine the shear resistance of jointed rock material [15]. Tests can be run under both constant and variable normal stress, depending on the boundary conditions relevant to the problem at hand [16]. The direct shear strength test was carried out in the Laboratory of the Department of Engineering Geology. The machine was operated with two hydraulic pumps, one for controlling the normal load, and the other for the shear load. The shear load is measured by a load detecting device and the normal load was read off the scale. Shear and normal displacements are measured by LVDTs. The shear test is carried out in a stage-testing form in example, within one sample, several different normal loads are used. The magnitude of the normal load was kept constant throughout the whole test. The number of stages depended on the resistance of each sample. Figure 4 and Figure 5 shows the typical jointed granite being installed in the shearing chamber and set-up apparatus of Direct Shear Test.

![Diagram of Direct Shear Test](image1)

**Figure 4.** (a) Schematic illustrating arrangement of laboratory direct shear specimen according to ISRM (2007); and (b) Setting up of jointed rock sample prior the direct shear test.

![Set-up apparatus](image2)

**Figure 5.** Set up apparatus of direct shear test.

4. Properties of granite

There are several informations required in order to relate the effect of weathering process to the shear strength of the jointed rock. The physical, mineralogical and texture properties of the rock were discussed in this study.
4.1. Physical properties
The physical properties that have been recorded are weight, volume, density, rebound number, JRC and P-wave. The physical properties of granite sample for grade I, II, III, and IV are tabulated in Table 1. The density of granite for grade I is higher than the density for grade II, III and IV. Based on the rebound hardness test, the R-value for grade I, II, III and IV are 69.13, 53.3, 31.27 and 15.27 respectively. The differences between the samples showed that the hardness for every grade are not equal. Meanwhile, surface roughness profile for grade I give the joint roughness coefficient, JRC in the range between (6 – 8). Grade II and III, the JRC is (8 – 10) and JRC ranging between (10 – 12) is recorded by granite grade IV. The differences weathering grade of rock joint, giving the different JRC values. Primary wave, P- wave for the grade I is 4678.9 m/s and for the grade IV is 3556 m/s. The happened due to the denseness of the rock sample. The higher the density of the rock sample, the high value of P – wave produced. The P-wave velocity reduced when the grade of rock reduced. This is due to the intactness of the rock that allowed the P-wave excitation that travelled smooth in the rock media. Any flaw, fissure, voids and crack which is result from weathering process may slow down the P-wave velocity.

### Table 1. Physical properties of granite sample.

| Weathering Grade | I     | II    | III   | IV    |
|------------------|-------|-------|-------|-------|
| Weight (kg)      | 4.995 | 4.825 | 4.812 | 4.798 |
| Volume (mm$^3$)  | 1.704 | 1.704 | 1.704 | 1.704 |
| Density (kg/m$^3$) | 2.9309| 2.831 | 2.823 | 2.815 |
| Rebound Number   | 69.13 | 53.3  | 31.27 | 15.27 |
| JRC              | 6-8   | 8-10  | 8-10  | 10-12 |
| Avg. P-wave (m/s)| 4678.9| 4284.3| 3865.2| 3556 |

4.2. Mineralogical and texture properties
Thin sections are prepared to study the mineralogical compositions and the textural of the granite sample. The thin sections were examined under a petrographic microscope image for mean grain size and grain shape based on Photomicrograph and cross-polarized light analysis as shown in Figure 6. This analysis significantly indicates the factor that contribute to the shear resistance thus shear behavior of jointed medium. The Phaneritic texture of different mineral can be seen clearly under microscope. The mineral compositions of each weathering grades were established through point counting as recorded in Table 2. Six hundred points were counted manually in an area of 21mm x 5mm with a fixed interval distance. The main mineral components counted using this method are quartz, alkali feldspar, plagioclase, biotite and chlorite. For the purpose of this study, altered/sericitized plagioclase and alkali feldspar were counted as plagioclase and alkali feldspar. Unaltered and partially altered biotite was counted as biotite. Fully altered biotite (which was replaced by chlorite) was counted as chlorite. The point counting results are presented in percentages as illustrated in Table 2. Based on the series of petrographic analysis, it can be inferred that the weathering process has altered the mineralogical composition and texture of the rock sample.

### Table 2. Percentage of the main mineral composition in granite sample.

| Weathering grade | Quartz  | Alkali feldspar | Plagioclase | Biotite  | Chlorite |
|------------------|---------|-----------------|-------------|----------|---------|
| I                | 40.6%   | 25.2%           | 31.0%       | 2.2%     | 1.0%    |
| II               | 33.8%   | 29.8%           | 32.8%       | 2.3%     | 1.2%    |
| III              | 29.0%   | 50.0%           | 18.7%       | 2.3%     | 1.8%    |
| IV               | 42.2%   | 27.2%           | 20.7%       | 7.8%     | 2.1%    |
Shear strength of jointed granite

Figure 7 shows that the shear strength versus normal stress. The value of friction angle, $\theta$ and cohesion, $C$ were identified from the graphs. By referring to the normal stress that had been applied, the higher grade of the rock can cater high pressure compared to lower grade. Comparatively, rock joint for grade I can resist sliding higher than rock joint for grade II, III and IV in each different normal pressure. However, the shear strength does not influenced by the JRC values. Referred to JRC values for granite grade I, II, III and IV, it shows that the reduction of weathering grade giving the increment of JRC values which is 6-8, 8-10, 8-10 and 10-12 respectively. Eventhough the contact surface of jointed rock seems to have rougher surface, but the surface is fragile due to loose bonding interaction between mineral particles which dominantly filled with altered minerals. Furthermore, significant numbers of veins are present in this rock sample that filled with calcite and muscovite which were cut across feldspars and quartz indirectly reduced the intactness of rock.

Figure 6. Microscopic image of mineral composition that composed on respective (a) Grade I; (b) Grade II; (c) Grade III and; (d) Grade IV indicated different composition of quartz, alkaline feldspar and plagioclase which contribute to the strain behavior of joint rock surfaces.

5. Shear strength of jointed granite

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The relationship between weathering grade to the shear strength is plotted in Figure 8. At 500kPa of normal pressure, the grade I give peak shear strength 1.11MPa. Grade II give 0.82MPa of peak shear strength. At the same times, grade III gives peak shear strength 0.77MPa and grade IV give 0.68MPa. At 1000kPa of normal pressure, the grade I give peak shear strength 1.5MPa. For the grade II is 1.33MPa. Then for the grade III is 1.1MPa and grade IV is 0.97MPa. The peak strength among the grade is increasing due to the grade and the normal load applied. For the normal load at 1500kPa, grade I give 1.79MPa of shear strength. For the grade II is 1.6MPa and for the grade III and grade IV are 1.38MPa and 1.31MPa respectively. The average percentage difference is about 5% - 30%. The shear strength was directly proportional to the grade of the rock sample. It is proven by thin section sample shows that the microstructure of the rock sample is already been weathered and indirectly affecting the shear strength of rock. It is parallel finding with previous study done by [2] and [3]. The low frictional force produced low shear strength especially whenever the roughness of rock joint has broken during applying the normal pressure. As a result, the pieces of rock particles had encouraged the rolling and sliding and less resistance during shearing process. Meanwhile, grade I give the joint roughness profile in the range between 6 – 8 or almost have the flat surface compared to the weathered rock recorded by grade II, III and IV ranging from 8-10 and 10-12 respectively. However, the roughness surface is hard because there is no changes in mineral composition and considered intact. Therefore, it is not easily broken during applying normal pressure and shearing forces.

![Shear strength vs Normal stress](image)

**Figure 7.** Shear strength versus normal stress for different weathering grade.

![Shear strength of rock joint for different weathering grade](image)

**Figure 8.** Shear strength of rock joint for different weathering grade.
6. Conclusions
As a conclusion, the weathering process has altered the main composition mineral in granite rock such as Alkali Feldspar and Biotite that drives to the changes of microstructure behaviour of rock. The deformation of the microstructure indirectly influenced the shear strength of the rock joint. Comparatively, the JRC value does not affecting the shear strength of jointed rock due to fragile and loose of mineral particles for grade III and IV, but effectively resist shearing whenever the surface is hard and intact as inherent in grade I and II.

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