Relationship of Microcrack Pattern and the Shear Strength of Granitic Rock

M. P. Nur Irfah, M. R. Mohd Shahril and O. Husaini

Abstract Granitic rock can be found in abundance at the Banjaran Titiwangsa main range as the most dominant geology. The granitic slope with the fracture surface has produced the microcrack pattern that can affect the stability of the slopes at the Pos Selim area, which is located at the Banjaran Titiwangsa. The relationship of the microcrack pattern and the shear strength of the granitic rock is investigated as to know the behavior of the crack pattern with the shearing force. The granitic samples are collected at Pos Selim area which is identified as grade II slightly weathered conditions. The samples which are then tested using rock shear box test are applied with increasing normal load of 5, 10, 20, 30, and 40 kN, respectively. The microcrack pattern is observed using SEM image. The analysis of SEM image shows that the behavior of microcrack starts from the crack initiation with the small point at the center. The microcrack length extends into a larger crack and transverse from the center toward the side of the sample. When stress increases, the microcrack length tends to also increase until it reaches the peak point. Finally, further addition of shear stress will result in a decrease of microcrack length. The relationship of microcrack length and the shear stress is in the form of polynomial curve with second order ($R^2 = 0.955$). In conclusion, based on the relationship of microcrack pattern and shear strength, the highest shear stress is 6 MPa producing the 200 μm of microcrack length.

M. P. Nur Irfah (✉)
Civil Engineering Department, College of Engineering, Universiti Tenaga Nasional,
Jalan UNITEN-IKRAM, 43009 Kajang, Selangor, Malaysia
e-mail: irfah@uniten.edu.my

M. R. Mohd Shahril
UEM Construction Sdn. Bhd, No 21-1, 22-1, First floor, Jalan Impian Mahkota 1,
Taman Saujana Impian, 43000 Kajang, Selangor, Malaysia

O. Husaini
Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang,
Selangor, Malaysia

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1 Introduction

The microcrack pattern occurs mainly within the mineral compositions. For example, granite rock consists of mica, feldspar, and biotite minerals. Thus, it can be seen that the cracks occurred within feldspar and oriented parallel to the drill core axis. The cracks are less abundant in feldspar because there is a disturbance of the crystal lattice if the feldspar is altered. Furthermore, the crack propagation is improved in micas and opaque due to the difference in the mechanical strength and E-modulus [1].

The shear strength where the slip surface of the rock tends to slides has effected the microcrack pattern. Microcrack highly dependents on the mineralogy, fabric, and microstructure of a given rock type. The deformed granite has about twice the crack density (crack length per unit area) as compared to undeformed granite. Based on its microcrack densities, the densities of microcracks have increased tremendously at the fracture tip, and the magnitude of fracture increases more in deformed rock as compared to undeformed rock [2].

The shear failure of brittle rock can be more complicated process involving a number of stages of damage accumulation rather than tensile failure. It is generally accepted that brittle fracture results from the interaction of microcrack within a rock mass [3]. In this study, the microcrack pattern is analyzed based on its macroscopic image during pre-shear and post-shear stage. The microcrack length and the crack pattern are analyzed and measured at pre-shear and post-shear stage.

2 Microcrack Pattern of Granitic Rock

Granitic rock, which consists of biotite, feldspar, quartz, and mica minerals, has a unique microcrack pattern. The granitic rock has a crack initiations pattern that starts from the small point and extended to a larger crack. The larger crack was then split the samples into two. As compared to limestone rock, the microcrack pattern in limestone starts from small micropores. The micropores start to extend, and it propagates into microcrack length. The microcrack length is then transverse from the left side to the right side. Some of the micropores from limestone tend to dissolve [4].

Based on the granite microcracking pattern studied by [5], they observed the transgranular microcracks are formed in a plane perpendicular to the core axis. To know the degree of stress-induced core damage, the ratio horizontal to axial transgranular microcracking could be an indicator. The dominant mode of microcracks can be termed as naturally occurring for the core depth less than 200 m. The stress-induced microcracks are linearly proportional to the grain boundary, intergranular, and transgranular microcracks, which are constant regardless of any depth of the core. The indicator of the degree of stress induced in core damage is depending on the ratio of horizontal to axial transgranular microcrack. Most of the transgranular microcracks are formed in a plane perpendicular to the core axis [5].

Based on [6], the initiation and propagation of microcracks in granitic rock under stress are highly dependent upon the mineralogical and textural characteristic of the various lithotypes. Detailed observation and quantification of microcracks before and after uniaxial compression test were conducted. During uniaxial compression, the intergranular microcrack, which is the dominating crack type, is gradually transformed or organized into transgranular cracks. Knowledge of the mineralogical and textural characteristics may assist in the prediction of potential development of failure surfaces of an ultrabasic rock in service.

It can be summarized that the microcracking behavior based on the literature, the microcrack is stress induced, and its initiation and propagation are highly dependent upon the mineralogical and textural characteristics of the various lithotypes. Microcrack starts in feldspar and oriented parallel to the drill core axis. However, if the feldspars are altered, cracks are less abundant because of the disturbance of the crystal lattice.

3 Methodology of Research

The methodology of the research starts from identifying the problem statement. In Malaysia, especially at the mountainous, areas such as Cameron Highland area have many landslide events. The landside of rock slope is caused by the fracture of the rock which extends into rock slope failure. The fracture which is studied in the microscopic scale with stress induced as to get the microcrack pattern analysis is the main objective of this research. The behavior of microcrack pattern of granitic rock is reviewed in the literature review. Two experimental works are conducted such as Robertson direct shear box test and scanning electron microscope. Granite core samples were collected at Pos Selim area 20 km away from Cameron Highland. For the direct shear box test, the shear stress is applied to the rock with increasing normal stress. The applied normal stress are 5, 10, 20, 30, and 40 kPa. The SEM image is taken before the direct shear test and after the direct shear test. The microcrack pattern for pre-shear and post-shear was recorded and analysis has been done. SEM is scanning electron microscope which used the electron to magnify the microcrack on the rock surface. The correlations of the microcrack with the stress induced are obtained from the analysis of the result. The detailed methodology of the research is shown in Fig. 1.

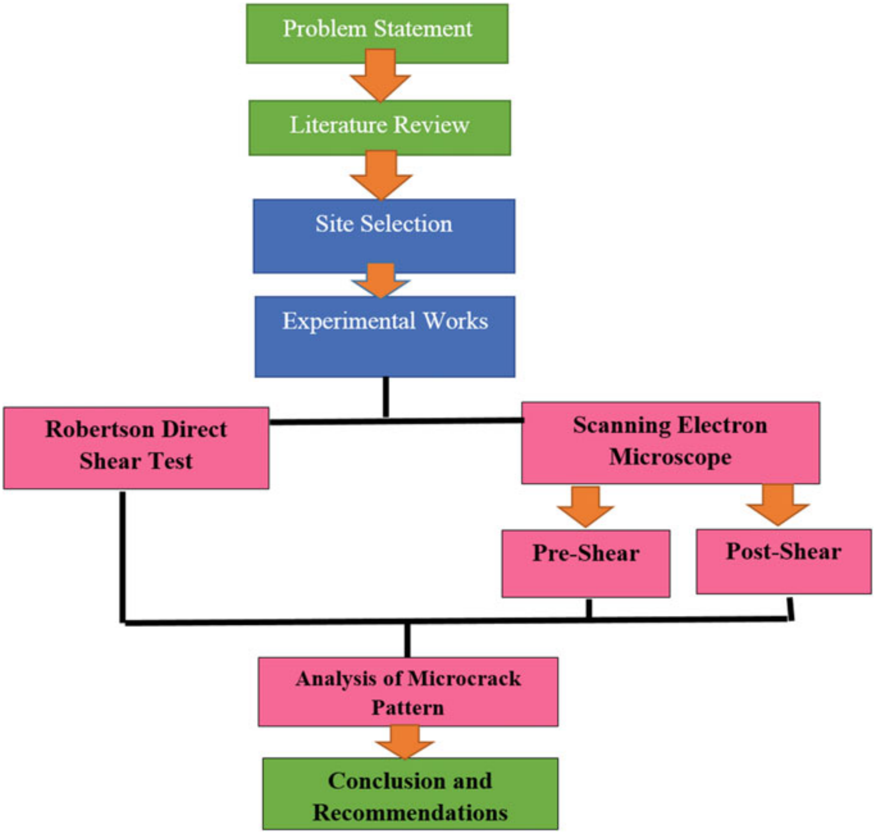


Fig. 1 Methodology of research

4 Results of the Microcrack Pattern and Shear Strength

4.1 Microcrack Pattern for Grade II

The results of SEM image for grade II of weathered granite are shown in Figs. 2 and 3. Figure 2 shows the microcrack pattern before applying the shear stress, and Fig. 3 shows the microcrack pattern after the shear stress test. Table 1 shows the SEM image analysis, and Table 2 shows the shear strength and microcrack pattern. Figure 4 gives the graph of shear stress versus microcrack length.

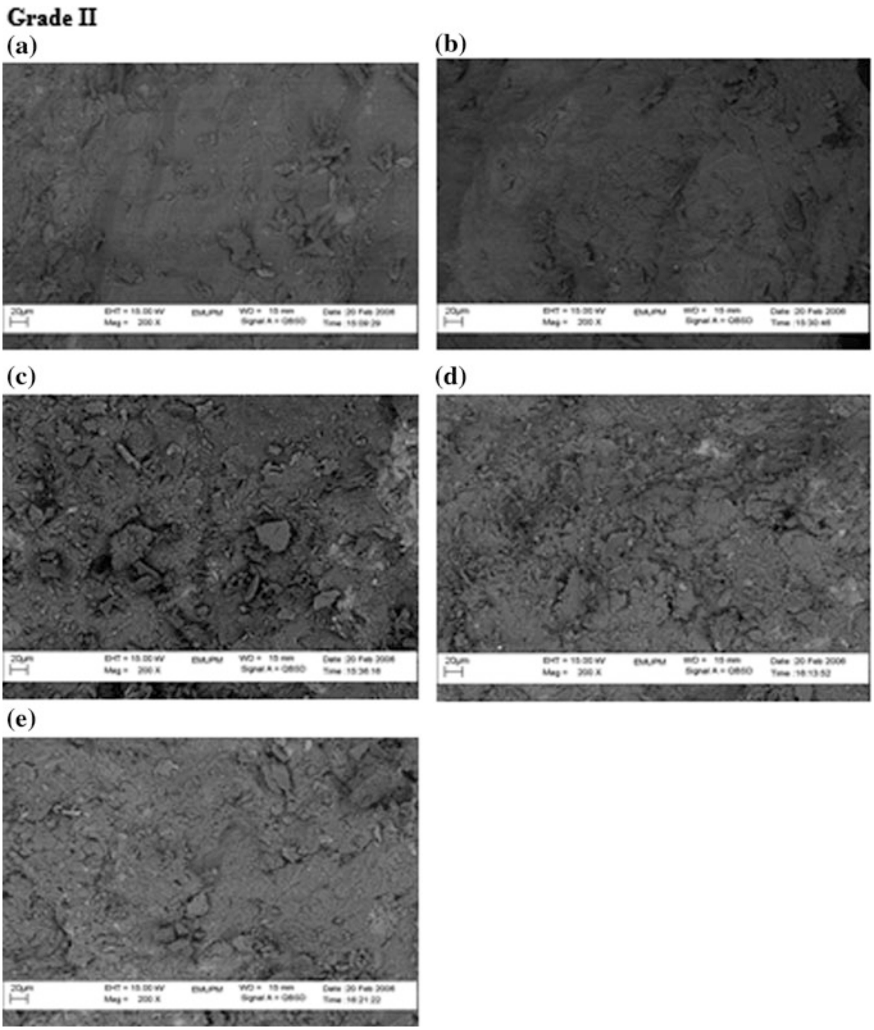


Fig. 2 Pre-shear SEM image of microcrack pattern of grade II granitic rock

5 Discussion of Shear Stress and Microcrack Length

The results for sample S21–S25 during the pre-shear stress show that the shear surface is slightly fractured with no transgranular crack. After the sample is sheared by applying the normal stress of 2.7 MPa, there is a presence of open crack at the top and below of the specimen. The SEM image is shown in Fig. 3. The open crack occurs along the feldspar area, and the intergranular crack has gradually become the transgranular crack. As the normal stress is increased to 5.9, 11.4, 16.6, and 21.8 MPa, the optimum microcrack length is at 30 kN loading with the longest

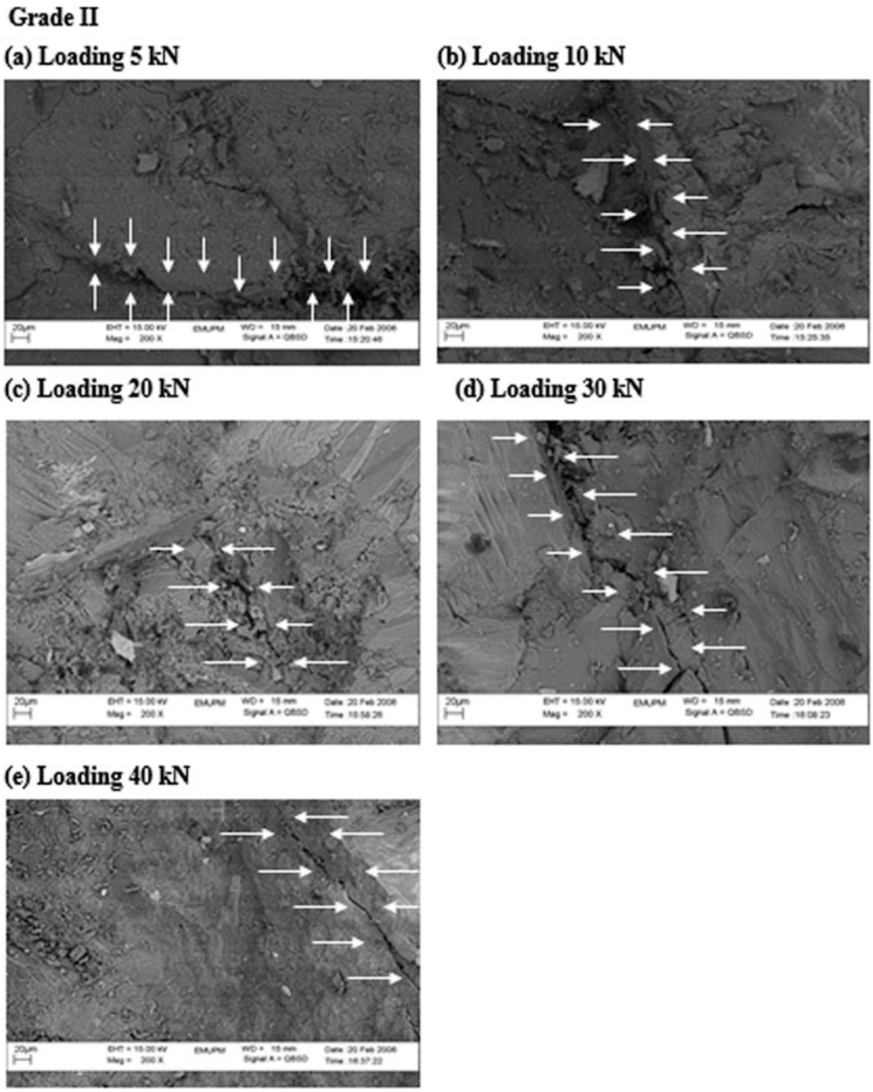


Fig. 3 Post-shear SEM image of microcrack pattern of grade II granitic rock

microcrack length of 260 µm. The largest crack which started from one side travels to another side. The presence of large transgranular crack at the center enlarging toward the outer of the sample. As the normal stress is at the maximum, which is 21.8 MPa, the crack length reduces to 200 µm. Based on the SEM image, only small fracture presence and the open crack at the outer of the specimen.

Table 1 SEM analysis data (sample S21–S25 in grade II)

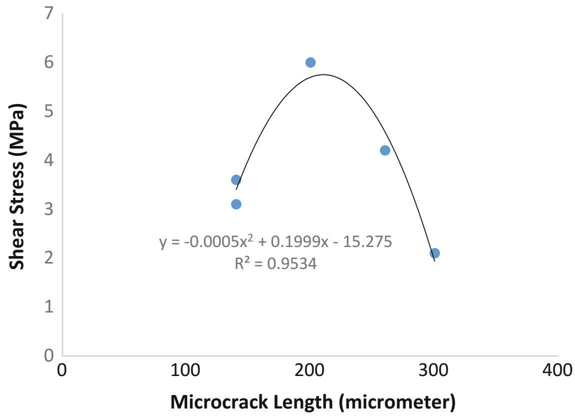
Sample no	Normal load (kN)	Crack length (μm)		Percentage of sheared surface (%)		Microscopic fracture characteristics	
		Pre-shear	Post-shear	Pre-shear	Post-shear	Pre-shear	Post-shear
S21	5	0	300 (below) 120 (top)	0	45	The surface is slightly fractured with no transgranular crack	The presence of open crack on the surface at the top and below of the specimen
S22	10	20	140 (top) 60 (center)	0	50	The is small fracture on the surface, smooth surface	Open crack at the top and center of the specimen
S23	20	0	140	0	55	Presence of small fracture area	Presence of transgranular crack which starts from outer toward the center of the specimen
S24	30	20	260	0	60	Small crack on the specimen, surface undulating	Presence of large transgranular crack at the center enlarging toward the outer
S25	40	40	200	0	65	Small fracture presence	Open crack at the outer of the specimen

Table 2 Shear strength and microcrack length

Sample no	Normal load (kN)	Normal stress (MPa)	Shear stress (MPa)	Microcrack length (μm)
S21	5	2.7	2.1	300
S22	10	5.9	3.6	140
S23	20	11.4	3.1	140
S24	30	16.6	4.2	260
S25	40	21.8	6.0	200

The graph in Fig. 4 shows the shear stress against the microcrack length for granitic sample. The shear stress and microcrack length have a polynomial with second-order relationship which can be described as follows, Eq. (1):

Fig. 4 The shear stress versus microcrack length for granitic samples



$$y = -0.0005x^2 + 0.199x - 15.275 \tag{1}$$

where x is the microcrack length, and y is the shear stress values. The shear stress increases with the microcrack length. The shear stress increases until it reaches the peak point. The shear stress reduces with the increase of microcrack length. This has been proven from the graph shown in Fig. 4. The microcrack length at the 2.7 MPa normal stress gives the microcrack length of 300 µm. The maximum normal stress of 21.8 MPa gives the microcrack length of 200 MPa and shear stress of 6.0 MPa. The bell-shaped curve with the optimum microcrack length at 260 µm is obtained from the shear stress and microcrack pattern analysis.

6 Conclusion

In conclusion, the microcrack pattern has been observed using SEM image, and the crack length started with the small intergranular crack and extended into larger cracks. The crack pattern was then transverse into boundary grain between the minerals. The microcrack length of the granitic rock increases with the increase of shear stress, and it reaches the maximum point. The maximum normal stress of 21.8 MPa gives the microcrack length of 200 MPa and shear stress of 6.0 MPa. The optimum microcrack length is 260 µm. The knowledge from this relationship will give the indications for the crack pattern with the shear strength as to study its behavior that will affect the stability of slopes. The weak surface of the rock is at the weak mineral components such as feldspars and followed by mica, biotite, and quartz.

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