Cyclic Loading Effect on the Uniaxial Compressive Strength of Weathered Rock

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Abstract

Previous studies on unweathered rock material under cyclic loading demonstrated that intact rock material fails at a stress level below than its static strength. This phenomenon is commonly known as fatigue. However, BS5930, 1999 has recommended a mandatory rock classification by weathering grade for rock mass in tropics. Hence, this study is conducted to determine the effect of cyclic load on the uniaxial compressive strength of weathered rock. The consequence of cyclic loading on weathered rock is crucial to investigate since cyclic loading may affect the long-term stability of rock mass. By exploring the mechanical behavior of weathered rock under cyclic loading, fatigue failure can be foreseen. Fatigue failure of rock corresponds to the rock lithology, physical and mechanical properties of rock. Analysis of weathered rock behaviour to the quality of rock microstructure shall be summarized. This paper shall elaborate the hypothesis of weathered rock behavior due to cyclic loading.

Key words: Cyclic Load, Weathered rock, Fatigue, Microstructure

1. Introduction

In general, rock is classified as an inhomogeneous material that contains many flaws (Wong et. al, 2001). Rock can be extremely variable substance that consists of mineral crystals, voids, grains, cracks and the like. These natural microstructures are acknowledged to react with atmospheric agent such as water and this process is known as weathering. However, careful attention has to be paid to the tropical climate, where chemical weathering is strongly dominant and this climate causing the rapid process of weathering. Governs by weathering condition, the rock mass usually experience in mineralogical changes. The occurrences of physical and chemical changes in weathering process, can lead to significant reduction in strength value (Sadisun et. al, 2001). Mohamed et. al (2008) suggested that it is important to determine the quality of tropical weathered rock because it has great impact to the strength and performance of rock structure.

Cyclic loading could be contributed by dynamic load such as earthquakes, blasting, coring, traffic loading etc. (Lee and Rhee, 1992; Ko, 2005; Bagde and Petros, 2009). The effect of cyclic loading on rock material is crucial to investigate as it determine the long term stability of rock mass hence the safety of rock structure (Zhengyu and Haihong, 1990; Jiang et al., 2009). Studies in cyclic loading have shown that intact rock failed between 24 percent to 80 percent of its static strength (Burdine, 1963; Haimson and Kim, 1972; Attewell and Farmer, 1973; Ishizuka et al., 1990; Fuenkajorn & Phueakphum, 2009). Previous studies have evidently indicated that even fresh rock material is able to fail at less than half of its static loading.

Significantly, it is expected that weathered rock may respond sensitively to cyclic loading. The wide range of rock failure in cyclic loading is believed to be inter-related to its microstructural features such as grain size, rock fabric and microcracks. Hasley et al. (1998) affirmed that fatigue is likely to be of crucial importance in weathered rock. Therefore, rock behaviour due to cyclic loading is discussed and hypothesis of rock behaviour subjected to tropical weathering shall be elaborated.

2. Data and Material

This study was carried out on tropically weathered granite. The air-dried sample were prepared in height-to-diameter ratio of two (H: D=2) as stipulated in ISRM (1981). Rock samples were chosen carefully by their physical properties to reduce sample variables. The samples weathering grades are classified using Schmidt rebound hammer and the classification was referred to the weathered rock classification by Brand and Philipson (1984). The work presented herein extends consideration to cyclic load in the laboratory to improve the understanding of weathered rock behaviour and also the effects of such loading on rock microstructure.

3. Research methodology

There are two stages of test conducted for this study and tests were conducted using GCTS rock testing machine (RTX-3000). In the first stage, the uniaxial compressive strength of weathered granite samples was determined initially. The uniaxial compressive strength (UCS) of six samples was computed at a strain rate of 0.02 mm/sec and used as a base strength in the subsequent test. For the next stage, another six samples were subjected to number of loading cycles prior applying the compression loading. The test was designed using sinusoidal wave with fixed stress level and loading frequency; where the tests were conducted at 50 percent of rock uniaxial compressive strength with frequency of 1 Hz. The tests conducted were meant to establish the relation between the number of cycles applied and the percentage decrease in uniaxial compressive strength. Finally, the effect of weathering on granite surface was observed using dino-lite digital microscope.

4. Result and Analysis

In cyclic test, six samples were subjected to varying number of loading cycles of 25, 50, 75, 100, 125 and 175. Samples which undergo varying number of cycles were then tested for their compressive strength. The samples were classified as Grade II granite and have rebound number of 45.

Table 4.1 indicates that with the increase in number of cycles, the percentage of strength reduction in uniaxial compressive strength increases. At certain number of cycles the percentage decreases in uniaxial compressive strength do not increase uniformly. The data was then tabulated in Fig 4.1.

No.	No. of cycles applied (N)	Observed UCS (before cyclic loading) (MPa)	UCS after cyclic loading (MPa)	Strength reduction (%)
1	25	96.5	96.1	0.4
2	50	94.6	92.6	2.1
3	75	91.2	84.1	7.8
4	100	86.5	77.8	10.0
5	125	74.5	61.6	17.3
6	175	65.0	50.0	23.1

Table 4.1: Summary of result

The curve is divided into two zones. In the first zone, there is a small reduction in strength observed between 25 to 50 numbers of cycles applied. Meanwhile in zone 2, as the number of cycles was increased to 50, the reduction of uniaxial compressive strength apparently begins to increase. There was a significant decreased in uniaxial compressive strength as the loading is further increased to 100. It is thereby indicating that rock begins to suffer at more than 100 cycles as compared to small cycles in zone 1. This result was previously proven by Ray et. al (1999) in Fig. 4.2, where after more than 100 cycles, the distinction between the observed uniaxial compressive strength and the UCS after cyclic load of intact sandstone was noticeably increasing.

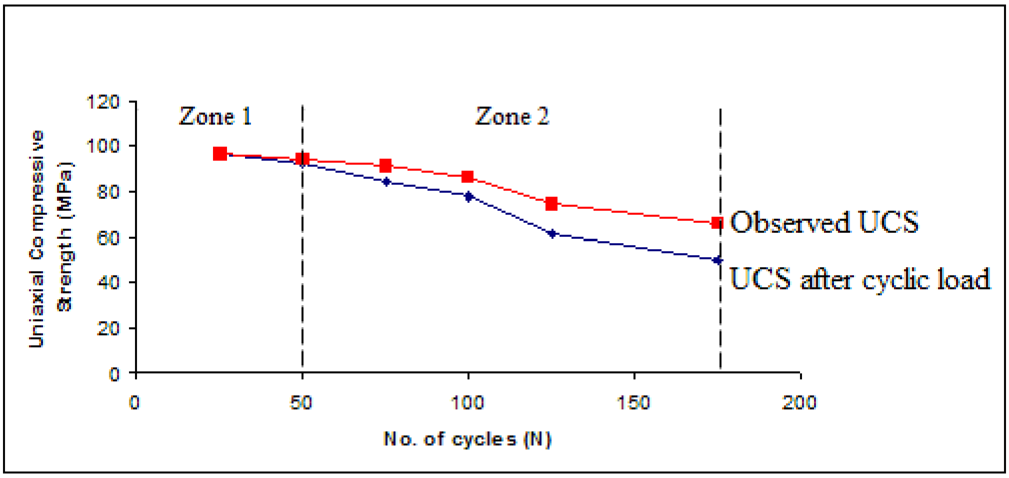


Figure 4.1: Effect between UCS and number of cycles.

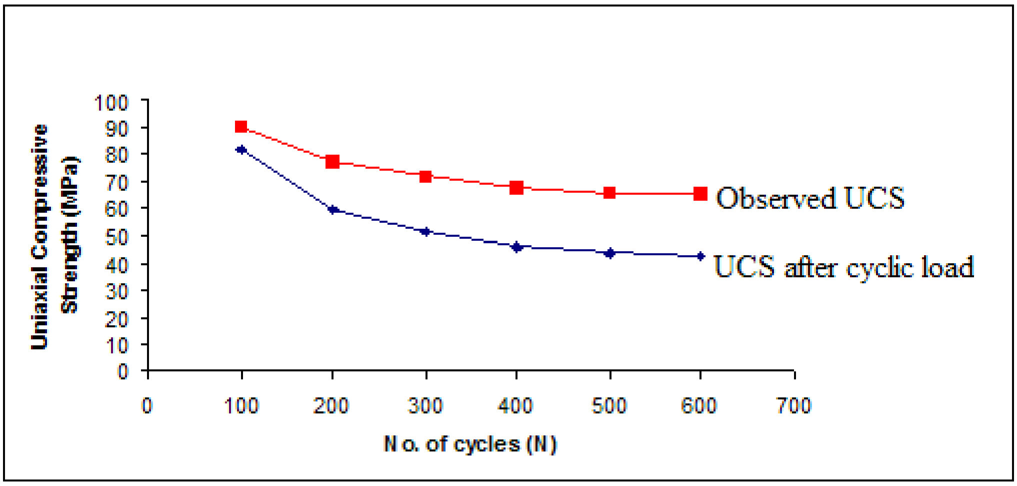


Figure 4.2: Effect between number of cycles on the decrease in UCS (modified from Ray et. al, 1999).

Perhaps, the crack closure was completed after reaching this stage and new microcrack started to form. As the cycles are further increased, the suffered rock started to weaken and more cracks begin to develop. As appointed by Gupta and Rao (2000) from Beavis (1982), the development of microcracks is in charge for the loss in strength. This may explained the obvious strength reduction occurrences after reaching 100 cycles. It is apparent that even a small number of cycles applied onto weathered rock, the reduction of strength can be observed. Although it is a small percentage of strength reduction, the result is found very significant. The result proved that even a slight weathering in rock material may affect the strength and consequently shows that weathered rock behaves sensitively to the cyclic load.

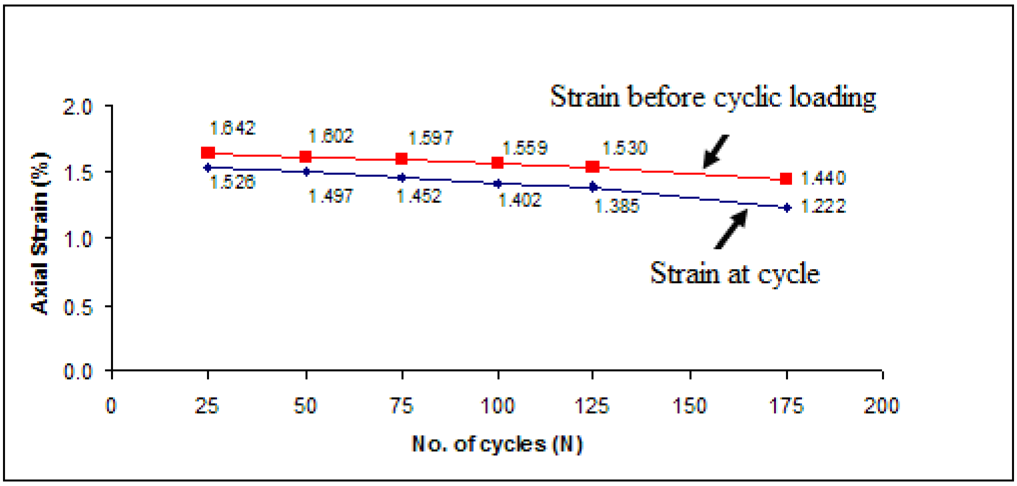
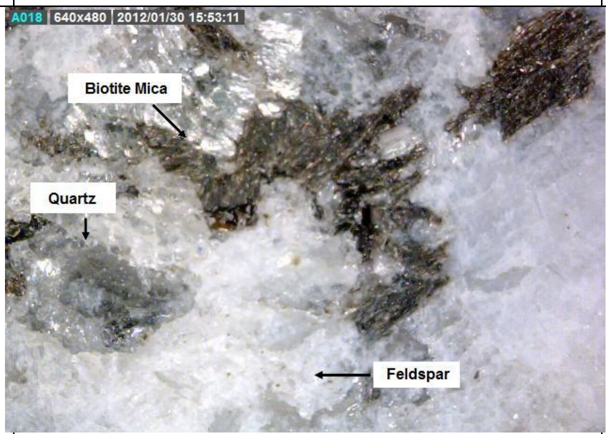
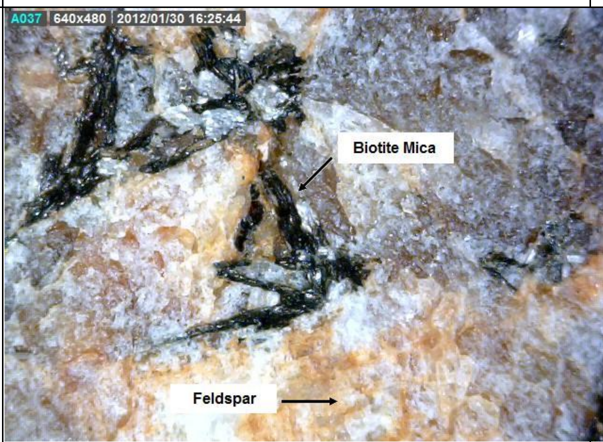


Figure 4.3: Effect between axial strain with number of cycles

This set of experiments is also useful to obtain a relation between number of cycles and axial strain as shown in Fig. 4.3. Gradual decreased was observed between axial strain before subjected to loading cycles with the axial strain at each cycle. Furthermore, the axial strain was also found decreases with the increase in loading cycles.

4.1 Microstructure of weathered granite.

Granite has three dominant minerals which are feldspar, quartz and biotite micas. Based from table 4.2, the deterioration of rock mineral was found increasing with higher weathering grade. As the rock weathers, the deterioration along the minerals boundary is progressing and can be seen clearly in higher weathering grade.

Weathering Grade	Surface structure of granite	Description
II (Rebound no. 45)		Minerals still intact to each other.
III (Rebound no. 40)		Minerals are slightly deteriorated.

IV (Rebound no. 27)		Minerals are noticeably deteriorated.

Table 4.2: Effect of chemical weathering on the granite surface

From the digital microscope observation, weaker mineral such as feldspar begins to decompose earlier as compared to strong minerals like quartz. In grade III sample, it can be seen that feldspar decayed intensively as compared to other minerals like quartz and mica. The decayed feldspar is noticeably displayed along the boundary of the mineral. The difference in discoloration and textural changes are obviously seen despite the rebound number of those samples were close. The textural changes and discoloration of minerals are more obvious in Grade IV sample which probably due to thermal expansion.

The rock samples are classified as medium to coarse grain. Finer-grained rocks are usually stronger than coarser-grained rocks (Bell, 2007). The rationale from the statement is that the number of each grain to grain contact is superior for fine-grained sample. Through microscopic observation by Mohamad et al. (2011), they have found that grade IV sample shows larger void opening and loose packing of particles. Figure 4.4 shows the minerals alteration exhibited in granite. The content of feldspar was also found reduced as weathering grade increased, whereas the quartz mineral was stable and not decomposed to other mineral (Mohamad et. al, 2011).

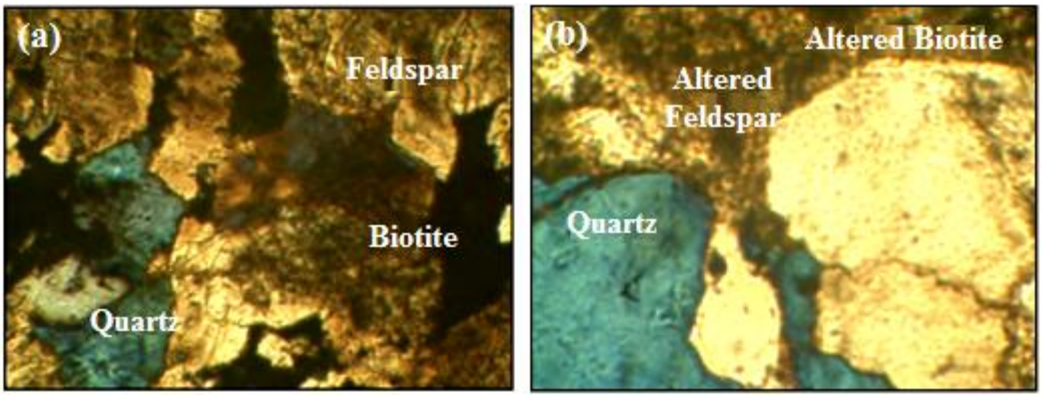


Figure 2.4: Microscopic images of weathered granite (a) Grade I (b) Grade IV (Mohamad et. al, 2011)

To relate the effect of grain size with cyclic loading, Burdine (1963) has suggested that the fatigue strength of rock is strongly dependent on its grain size. Where finer-grained rocks are having higher fatigue strength than coarser-grained rock. From this study, it seems that weathered rock contains many flaws that could affect the fatigue strength of rock. Due to the minerals decomposition and alteration, weathered rock can fail in shorter time during cyclic loading as compared to static loading. Many had agreed that fatigue failure of rocks was closely related to its microstructure (Burdine, 1963; Bagde and Petros, 2009).

5. Conclusion

From the experimental work, the following conclusions were drawn:

1. Weathered rock was found susceptible to cyclic load even with slight weathering occurred in rock material.
2. It was established that the cyclic loading affects the uniaxial compressive strength of rock. As the loading cycle's increases, the uniaxial compressive strength reduced. The strength reduction is more apparent once exceeding 100 cycles.
3. The axial strain was also found decreases with the increase in loading cycles.
4. Through the microscopic observation, feldspar is prone to decay earlier. Deterioration of rock mineral was found greater in higher weathering grade.

From the cyclic test, it is found that weathered rock responds more sensitively to cyclic loading than the intact sample. Conclusively, rock failure is found inter-related to its microstructural features such as grain size, rock fabric, existing flaws such as microcracks. Hence, fatigue life of weathered rock is assumed to be shorter than the intact rock. Though the work on intact rock under cyclic loading is widely studied, the investigation should be extended to observe the effect of cyclic loading on weathered rocks.

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