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Behaviour of weathered granite under cyclic loading

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ABSTRACT : *To determine the behaviour of weathered granite under cyclic loading, some laboratory work has been carried out. Weathering grade II, III and IV granite specimens were tested under cyclical loading condition to comprehend the deterioration of material quality to the subjected load. The influenced of tropical weathering on rock specimens were seen to influence the result in cyclic test. Grade IV specimen did not fail after more than 10^6 cycles although has reached the maximum limit in fatigue test.*

Keywords –*Weathering, granite, cyclic load, fatigue limit*

1. INTRODUCTION

Mechanical property of weathered rock can be unpredictable as quality decrease as degree of weathering increase. In Malaysia alone a few major dams were constructed on weathered granite rock foundation since granites are the most abundant igneous rock in Peninsular Malaysia, forming approximately 40 % of its surface area [1]. In addition, weathering zone consisting of the decomposed granite can be found to a depth more than 100m [2].The ongoing process of weathering in the tropics produces progressive changes in the chemical, mineralogical of rock and subsequently weakened the rock structure. Until now, few efforts have been carried out to classify weathered rocks for engineering purposes [3]. Thus, this paper will give an insight on the effect of rock material quality subjected to cyclic under tropic environment. The work presented herein extended to also determine the effect of rock microstructure by such loading.

2. LABORATORY TEST AND SPECIMEN

Weathered granite specimens namely Grade II, III and IV were samples carefully prior laboratory testing. The specimens grade of weathering were sampled by using Schmidt rebound hammer and the classification was referred to the weathered rock classification by [4]. Cylindrical specimens were prepared in line with ISRM standard which has height to diameter ratio of 2 was used. The tested specimens were medium-grained granite and light grey to grey in colour with some iron staining. Physical and mechanical properties of sample were adequately scrutinized to reduce the sample variables.

2.1 Test Procedure

Static uniaxial compressive strength of specimens was set as the fundamental strength prior performing the cyclic compressive test. The test was conducted on 10 specimens for each weathering grade at 0.2%/mm strain rate. The mean strength value is then used in designing the cyclic compressive strength. The specimen was adequately selected and categorized to ensure the deviation of the static rock strength value is within an appropriate range.

Cyclic test was then conducted with stress-control condition and the cyclic load specified was sine cyclic compressive using UTM-1000 digital servo-control testing machine. The details on various nomenclatures were provided in Table1. Two specimens for each weathering grade were tested to achieve their fatigue limit with different stress ratio. Stress ratio is a ratio of minimum stress to maximum stress in one cycle of loading in a fatigue test.

Table 1: Nomenclature with loading condition applied

Sample No.	Weathering Grade	Loading Condition			Stress Ratio
		Waveform	Frequency (Hz)	Amplitude (MPa)	
GR8G2	II	Sine	1	68	0.14
GR24G2	II	Sine	1	40	0.49
GR9G3	III	Sine	1	26	0.14
GR157G3	III	Sine	1	25	0.17
GR13G4	IV	Sine	1	8.6	0.14
GR14G4	IV	Sine	1	8.3	0.17

3. RESULT AND DISCUSSION

3.1 Microstructure of weathered granite

Microscopic texture of specimen was investigated to study the mineralogy of weathered rock material and thus classification based on grain size can be made. Granite is mainly composed of feldspar, quartz and biotite micas. However, weathered specimen uniquely consists of many altered minerals. The analysis on mineral composition of randomly selected specimens of grade II granite was carried out to distinctly examine the degree of alteration displayed in each specimen as summarized in Table 2.

Table 2: Mineral composition of sample

Minerals (%) / Sample	Quartz	Plagioclase Feldspar	Alkali Feldspar	Secricitized Feldspar (Altered)	Biotite	Chloride (Altered biotite)	Muscovite	Matrix (Filler minerals)
1	8.1	20.9	37.5	6.5	3.5	-	-	23.2
2	2.7	23.8	35.2	7.3	4.1	-	-	26.7
3	5.2	6.6	32.7	3.8	1.2	3.1	5	38.6
4	6.6	11.4	39.0	1.1	1.3	-	-	40.3
5	6.6	20.0	36.2	3.0	-	4.7	-	29.1
6	3.1	35.6	46.5	-	0.4	-	-	14.1

Table 2 showed that some primary minerals such as feldspar and biotite have been altered to secondary minerals. Specimens are dominantly composed by alkali feldspar followed by plagioclase feldspar. High percentage of fine-grain matrix was also found embedded in specimens; consist about 14.1 per cent up to 40.3 per cent in specimen. The rock which has been altered by weathering processes generally shows some inconsistent engineering characteristics such as strength in comparison with fresh rock. Thin section was done to visually observe the mineral alteration on rock specimen by weathering. Fig. 1 shows the alteration of mineral due to weathering under microscopic image of 40x magnification. Feldspar and biotite were prone to alter by weathering while quartz remained as high resistant to decomposition mineral.

It is a tedious work when dealing with natural material, where it is hard to microscopically classify specimen precisely. The alteration of mineral can be greater or lesser according to the mineral characteristic and the result of laboratory test is undeniably influenced by the microstructure especially mineral composition. Each mineral has a very distinctive characteristic and it could be defined under empirical analysis such as subjected to loading. The discussion is explained in subtopic 3.2.

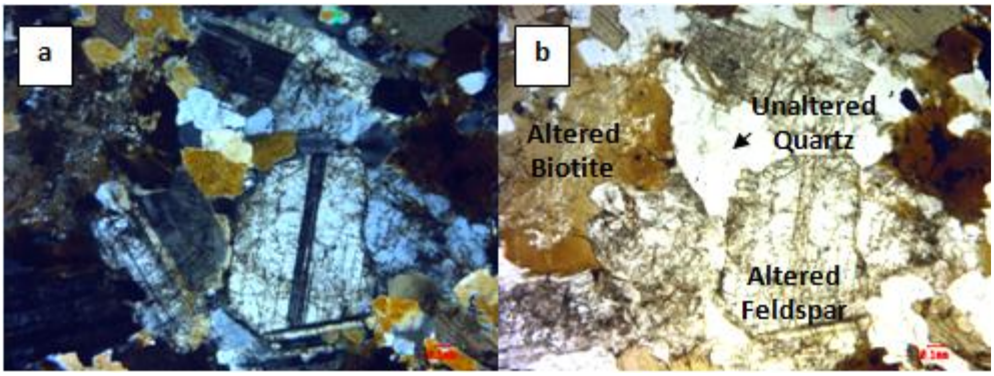

Figure 1: Alteration in minerals a) image under polarized light; b) image under plane light

3.2 Properties of weathered granite

Physical properties determined included rebound number, moisture content, porosity, dry density and primary velocity (Vp) is according to the method suggested by ISRM (1981). The mean physical properties of rock specimens are provided in Table 3. The strength of rock depends on the strength of the constituting minerals including the cementing materials [5].

Table 3: Physical and mechanical properties of weathered granite

Weathering Grade	Physical Properties (Mean Value)					Mechanical Properties (Mean Value)		
	Rebound No. (R)	Moisture Content (%)	Porosity (%)	Dry Density (kg/m^3)	Vp (m/s)	UCS (MPa)	Young Modulus (GPa)	Poisson Ratio
II	46	0.114	0.886	2660	6715	112.903	34.525	0.330
III	34	0.305	0.896	2602	3365	42.297	21.251	0.334
IV	19	0.964	0.908	2505	2092	13.628	5.361	0.345

As in Table 3 the properties of rock is shows some variation in each weathering grade. Majority of the properties decreases with higher weathering grade except for porosity, moisture content and Poisson's ratio. These properties were increasing with higher weathering grade. The increasing value of moisture content, porosity and density is increasing in higher weathering grades are due to the existent of clay mineral in weathered specimen. Clay mineral is defined as phyllosilicate minerals which the minerals are impart plasticity to clay state [6]. However it is not restricted to only phyllosilicate minerals; non- phyllosilicate which convey to plasticity to clay state also be referring to as clay minerals. This clay mineral has the ability to absorb water and thus explaining the higher moisture content in grade IV sample as compared to grade II and grade III. With the increasing of weathering grade, the amount of microcracks and voids increases. The voids however become interconnected thus explaining the high porosity in higher weathering grade. Hence, it is reveal that the state of weathering significantly affects the engineering behaviour of rock materials and not only depends on stress state and stress history.

Mechanical properties of each specimen were directly obtained from the static compression test. Based on the result, the mean value of uniaxial compressive strength (UCS) for grade II granite is 112.903 MPa, grade III is 21.251 MPa and grade IV is 5.361 MPa. The result was then plotted to elucidate the stress-strain behaviour of rock as well as to the estimate the mode of specimen failure. Typical stress-strain curve is illustrated in Fig. 2.

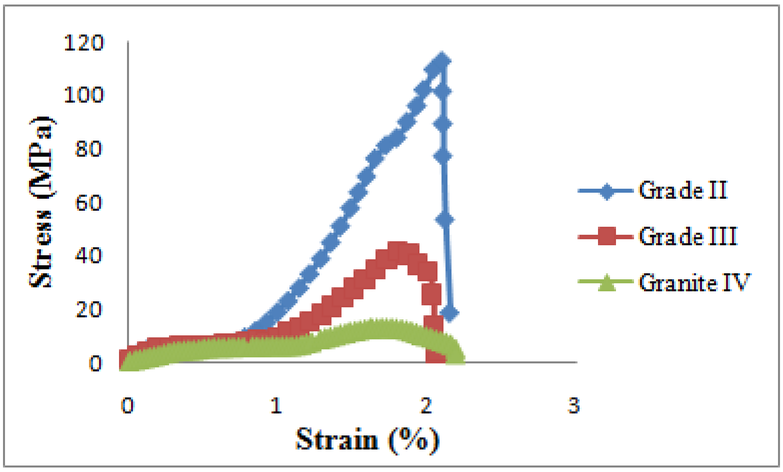

Figure 2: Stress-strain curve of different grades of granite

The shape of stress-strain curve denotes the type of failure on rock specimen. The failure mode for grade II granites are usually brittle and sudden rupture is observed in specimen. Whereas, grade III and IV the failure mode are more gentle as compared to grade II specimen. It is because grade III and grade IV have higher content of clay mineral which able to absorb better energy as compared to grade II specimen. While grade II granite normally having less amount of altered mineral which is easier to describe as clay mineral. The sudden rupture of specimen was due to the brittle nature of quartz mineral exhibited in grade II specimen. Quartz is known to has poor energy absorption as compared to feldspar and other types of minerals. It is thus indicating that the failure characteristic of rock is strongly influenced by the minerology of rock.

3.3 Effect of cyclic loading on weathered granite

To understand the effect of cyclic load on weathered rock; six specimens were subjected to cyclic load with different stress ratio as tabulated in Table 1. The specimens are subjected to numbers of loading cycle until failure to examine the ability of specimen to withstand the load at the designated loading condition. However, the test was stopped at 10^6 cycles as it reaches the desired limit of cyclic test. The number of cycles before failure is terms as fatigue limit and the result is in Figure 3. All specimens for grade II, III and IV were tested at 70 percent of its mean static compressive strength which is approximately at 79 MPa, 30 MPa and 4 MPa accordingly. The summary of result is shown is Table 4.

Table 4: Summary of tested specimens

Sample no.	Weathering Grade	Physical Properties		Maximum Stress (MPa)	Minimum Stress (MPa)	Fatigue Limit (Cycles)
		Rebound No. (R)	Vp (m/s)			
GR8G2	Grade II	47	7536	79	11	20,016
GR24G2	Grade II	46	6933	79	39	73,072
GR9G3	Grade III	34	4082	30	4.2	5,003
GR157G3	Grade III	30	3719	30	5.1	510,606
GR13G4	Grade IV	16	2161	10	1.4	83,712
GR14G4	Grade IV	16	2305	10	1.7	1,057,905

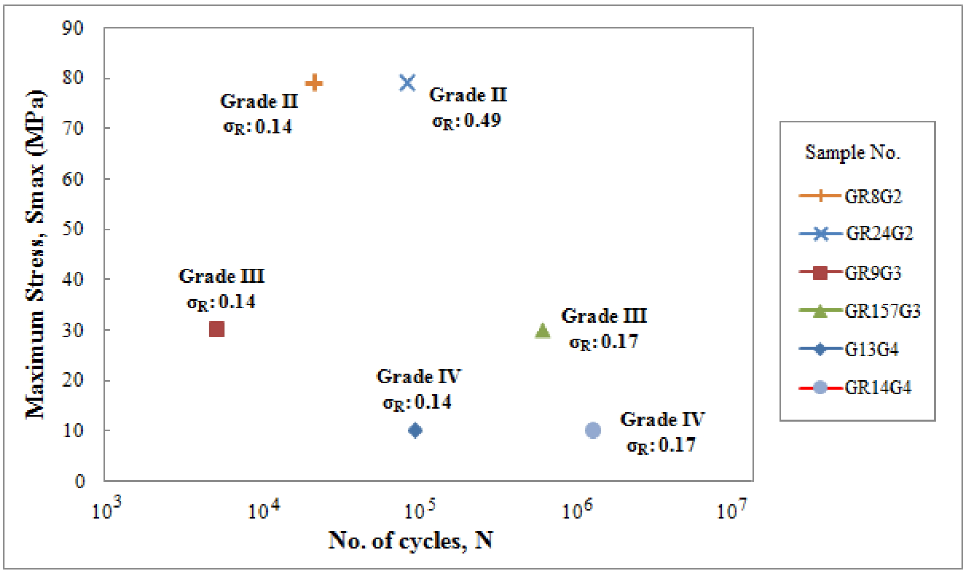

Figure 3: Fatigue limit of weathered granite

Based on Fig. 3, it was observed that specimen with lower stress ratio have lower fatigue limit as compared to higher stress ratio. It is explained by the higher amplitude applied in lower stress ratio. Fatigue strength reduces with the increased in amplitude [5]. Noted that GR9G3 and GR13G4 have failed sooner; though having slight different in stress ratio with GR157G3 and GR14G4. It is because primary velocity (Vp) is recorded at each 4000 cycles to investigate the effect of loading cycles to the structure of the specimen. The first impact by the loading piston however, usually contributes some effect on the specimen structure due to heavy load carried by the piston.

It is revealed that grade IV specimen is able to sustain larger number of loading cycles as compared to grade II and grade III specimen. This result shows different feature as in static compression test of weathered rock. Classically in static compression test, higher weathering grade such as grade III and grade IV rock will fail at lower strength value as compared to grade I and II. As weathering grade increases, the rock structure has low ability to sustain the increasing compressive load due to the deterioration in rock structure by weathering. In contrary, under cyclic compression test, the result shows that grade III and IV specimen able to sustain larger loading cycles than grade II rock. It is strongly believed the existence of altered mineral in the rock material may perhaps prolong the fatigue failure of rock under cyclic load. However, the result may also contribute by the low amplitude and the constant load applied in the cyclic load. Further investigations on amplitude and other loading conditions will be done to clarify the influence of altered mineral in weathered rock structure.

4. CONCLUSION

The work presented here was undertaken to investigate the effects of cyclic loading on the behaviour of weathered rock in uniaxial compression subjected to dynamic cyclic loading. The following conclusions were drawn from the presented study:

1. Clay mineral was found to have great influenced to the strength of rock in cyclic loading. It was found that grade III and IV specimen's able to sustain larger number of loading cycles than grade II specimen in cyclic loading. It is differs with the static compressive strength of rock; where the strength was found to be influenced by the predominance of quartz content.

2. The rock strength was found to be related to the features of cyclic loading such as amplitude and stress ratio. It is shows that, higher stress ratio will fail later as compared to lower stress ratio. Higher stress ratio in the sense having lower amplitude as compared to lower stress ratio. Fatigue strength increases with the decrease in amplitude.

3. It was concluded that the development of fatigue failure in rocks was closely related to their petro-graphical, physical and mechanical properties and microfracturing was the main cause of fatigue failure. It is strongly believed that grade IV able to sustain up to 10^6 cycles due to the energy absorption by the altered mineral exhibited in the rock material. The alteration of minerals to clay

minerals is believed to have the influenced to prolong fatigue failure of rock. However, this may also contributes by the low amplitude applied in the loading.

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