Rock water interaction on the effect of drying and wetting to the mechanical and dynamic properties of tropical weathered granite

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Abstract: This study deals with the effect of water on the tropical weathered granite and sandstone rock characteristics. Water act as an agent in the weathering process that lead to the weakness of the cementation and bonding condition. The process of wetting and drying are able to take place with the presence of water inside the rock microstructure, then further created the numbers of micro-pore which contributing to weakens the rock structure. Thus, this study is focusing to analyses the effect of the presence of water on the mechanical and dynamic properties of granitic rock depending on its weathering degree. The interaction between water and rock was observed through the water-rock interaction test by using saturation and caliper method, where all the rock samples, totalling 81 samples allowed to experience the wet and dry conditions for 21 days, 56 days and 90 days. Uniaxial compressive strength test, indirect (Brazilian) tensile strength and point load tests were conducted to determine the strength of the rock. Meanwhile, P-wave velocity test was conducted to measure the wave velocity that able to penetrate through the intact rock. In conclusion, the increasing of weathering degree, will allowed the rock to absorb the water as their particles has not more tightly bonding. Therefore, it found that the strength of tropical weathered granite was decrease as the interaction with water causes the interlocking of the rock particles is reduces from the process of weathering.

1. Introduction

Weathering is a physical, chemical and mechanical processes that occurred mainly in tropical climate like Malaysia, where at some places the combination either two or more mode of weathering will accelerate the process. The physical weathering basically is the process of disintegration of bonded particle while the chemical weathering will alter the composition of mineralogy thus sometimes will change the chemical behaviour of rock. [1] and [2] has also confirmed the weathering is a unique phenomenon in tropic climate country where rocks on the surface of the Earth are exposed to the various mode as such chemical (decomposition), physical (disintegration) and mechanical (biological). Besides that, the intensity of rain in Malaysia is considered high thus the weathering will be more rapid and aggressive [3]. The bonding between bonded particle weakened as the microcrack developed along the mineral grains, thus the structure of rock will loose and eventually reduce the ability to withstand imposed load.

In the tropical climate, the effectiveness of weathering is much higher as the presence of water and high temperature as the activity has increased tremendously as reported by [1] and [4]. Hence, water plays as the main role in the weathering process because when there is presence of the water in the rock
structure, the micropore within the rock structure will absorb the water instantaneously. Then, the interaction between water and micro particle of weathered rock will alter the physical, mechanical and dynamic properties of the respective rock structure.

At the other hand, [5] explained that, the presence of water is significantly altering acoustic wave propagation of rocks, as the rocks are frequently exposed to water through rainfall. Water caused rock to go through the process of chemical decomposition, where the mineral compositions in rocks are change or decomposed into another type of minerals. Also, [6] noted that the differences in mineral composition of rock can changed due to the alteration process.

There are total number of 81 samples of tropical weathered granite were collected at Kuad Quarry, located at Penanti, Bukit Mertajam, Pulau Pinang for laboratory testing and analysis. The objective of this research is to analyse and characterize the interaction of rock and water for the tropical weathered rock of granite in various weathering grades by focusing on their physical, dynamic and mechanical properties.

2. Methodology

2.1. Samples preparation
Samples (bulk) that collected on site location were identified its grades using Rebound Hammer (grades identification), to separates them into Weathering Grade II until IV. The bulk samples then were transferred to the laboratory to be shaped into cylinder size 100 mm x 50 mm for uniaxial compressive strength test and 50 mm x 50 mm for tensile strength test. Only rocks with no presence of bedding were selected to avoid any anisotropic and heterogeneous effects on testing results. Rebound hardness was used as an initial identification of the weathering degree of granitic rock mass. 3 samples were prepared for each respective test, which each test was conducted at interval time of 21, 56 and 90 days.

2.2. Experimental setup
This study was focused on to determine the effect of drying and wetting cycle of tropical granitic rock to the uniaxial compressive strength and tensile strength. The cylindrical specimen has been cured in specific tank full of water for 21, 56 and 90 days for wetting process, meanwhile the process of drying is by oven dried the samples for 24 hours at 104 °C. This process was repeated every day, alternately to simulate the actual process of tropical humid climate (dry and wet all over the year).

The sample then was test for uniaxial compressive strength and tensile strength, where the test was carried out in accordance with the International Society of Rock Mechanics Standard Procedures (ISRM, 1981). The test was conducted at different set of time as to study on the effect of drying and wetting on the mechanical properties of tropics rock and to simulate the process of weathering. For uniaxial compressive strength test, the sample was prepared at size of 100 mm x 50 mm (cylindrical specimen). Then, the sample was placed into the unconfined compression machine to determine the maximum load it can sustain before failure. Therefore, the strength of the sample can be calculated. Meanwhile, for tensile strength test the sample size is 50 mm x 50 mm. The rock specimen with the thickness to diameter ratio of 1:1 is subjected to a uniform vertical line load that is directly applying to the entire thickness of the metal disc as shown figure 1. The sample generally splits along the vertical diametrical plane, as the load is increased to failure. The diametric loading of a small rock disc is performed accordance to the ISRM requirements (ISRM 1981 Part 2) for the indirect testing of tensile strength.

Dynamic properties that are measured in this study is P-wave velocity, which measure using device that called Portable Ultrasonic Non-Destructive Indicating Tester (PUNDIT). There are two cables were put at the surface of the rock core specimen that allows measuring the travel time between the transmitting and receiving probes. The main component of PUNDIT was generating wave and emit through the probe, then the wave will go through the rock specimen. Next, the receiver will receive wave and the time taken of wave to travel per unit length will be display on the indicator tester.
3. Results and discussion

3.1. Dynamic properties

All 81 samples were determining their ability to transmit the wave from the transmitter to receiver. The wave travel time is much depending on the particle arrangement of the rock microstructure [3]. As the arrangement of the particles closer, the wave penetration is required more time as the wave must pass through solid barrier compared to the rock with higher porosity (highly weathered). This is due to increases of clayey minerals during weathering process hence made the interlocking texture of microstructure [7]. Thus, with the presence of water during the process will created more pores inside, and the drying will further weaken the interlocking between grain. The test results of PUNDIT for P-wave velocity are summarized in Table 1.

From Table 1, it can be summarized that the wave travel time has shorten as the cycle time increases. The time taken for wave to travel across the rock specimen were decreases almost 10% to 20% as the time elapsed, and it represent that this process has created pore and weaken the interlocking between grain thus the percentage of solid in the rock specimen is reduced. Therefore, the absorption of water and the process of drying and wetting that naturally occurred during the weathering process has given significant effect to the dynamic properties of tropical granitic rock. It has shown that this process has changing the properties by the creating new formation of minerals and microstructure arrangement.

| Weathering Grade | Avg. P-Wave Velocity, \( V_P \) (m/s) |
|------------------|-----------------------------------|
|                  | 21 days  | 56 days  | 90 days  |
| WG II            | 5721     | 5275     | 4332     |
| WG III           | 5182     | 4472     | 3807     |
| WG IV            | 3293     | 2837     | 2242     |

Table 1. P-wave velocity at different wetting and drying cycle time.
3.2. Mechanical properties

3.2.1. Uniaxial Compressive Strength (UCS). Figure 2 shows the effect of water absorption on rock mechanical properties with respect to the degree of weathering. Based on the figure 2, it can be concluded that the UCS decreases as the days of wetting cycle increases, which the percentage of strength drop is 26% to 48% by wetting cycle. The strength decreases for all three weathering grades show similar pattern, with the highest drop was strength of specimen of WD II with the strength drop from days 21 to days 90 almost 60 MPa. On the other hand, by calculating the drop-in percentage the highest drop is specimen of WD IV with 48% drop which from average UCS of 78 MPa to 38 MPa.

This phenomenon can be associated with the chemical decomposition and alteration of micromechanical interlocking grain which the solid portion has been altered into clay minerals and creating micropore inside. The presence of water has activated the chemical decomposition and would soften the bonds between mineral grains. Thus, it will increase the pore water pressure and cause instability of weak plane [7]. Besides that, the expansion of pore structure and cracks makes the rock less continuous, thereby, contact forces acting on the particle skeleton and breakability under compression increase as the porosity increases [3].

3.2.2. Tensile strength. The other test that have been conducted in this study was indirect tensile strength test (Brazilian tensile test) which to determine the tensile strength of the specimen with respect to the wetting cycle. This is mainly due to the fact that rock is made up from numerous minerals which fail to provide strong cohesive force to the surrounding particles with tensile stress is applied, causing an overall low tensile strength to the whole structure. Figure 3 summarize the findings on the effect of water absorption to the tensile strength of tropical granitic rock.

Similarly, the tensile strength drop pattern is almost identical with uniaxial compressive strength. The tensile strength of tropical granite was decrease as the wetting and drying cycles increases with respect to the decomposition and physical change of rock specimen. Based on the figure 3, the percentage strength drop is in the range of 33% to 55% with respect to the degree of weathering. The highest drop was rock specimen WD II which the drop is almost 5 MPa or 55%, while the least is WD IV with 1 MPa or 33 % drop. On the other hand, the percentage drop for WD III rock specimen was found to be at 50 % or almost 3 MPa from day 21 to day 90.
Figure 3. Tensile Strength depending on wetting cycles.

Rock is a material that have an ability to sustain the compressive strength than tensile strength, similar to concrete as stated by [8] in his statement, where he found that, the rock is weak in tensile strength and strong in compressive strength. After the granite sample have gone through the wet and dry condition through the 21 days 56 days and 90 days duration, the minerals particles that bonded them together decomposed to becoming a new mineral, thus reduced the ability of rock to withstand the imposed tensile load. Therefore, it can be summarized that the rock failed to offer the cohesive or other kind of bonding forces to resist the tension force, as the constituent of rock minerals have reduced, resulted from the weathering process.

3.2.3. Microcracks of fresh and weathered rock. Weathering process is highly involving the physical and chemical process. Quartz has been changing physically in which by the increase of degree of weathering quartz will disintegrated. The crack will eventually appear in this process of disintegration as shown in figure 5. On the other hand, feldspar has experienced chemical process where the mineral is decomposed. Therefore, feldspar will change its state along the process which eventually produced Kaolinite (clay). Clay is mineral which have ability to absorb and stored water. The microcrack developed along the weathering process as the direction of the crack will be varies on vertical and horizontal line. This will eventually reducing the ability of the rock material to withstand any imposed load either on compression or tension.

Figure 4. Microcracks pattern with respect to weathering degree.
4. Conclusion
From this study, it can be observed that the rock water interaction that has leads to the weathering process in the tropical climate can be simulate by wetting and drying cycle process which have given a significant effect to the rock micromechanical and dynamic properties. It can be concluded that the Uniaxial Compressive Strength and Tensile Strength of the tropical granitic rocks are reduce from 21 days, 56 days and 90 days of curing day by almost 50 % of its original strength. On the other hand, from the study also it can be observed that, water is the main factors that cause the loss of strength in the tropical weathered granite. As water flow through into the micropores that existed within the structure granite rocks, it has altered the composition and bonding arrangement of mineral grain. The chemical decomposition will take place as water absorbed into rock body and it will significantly alter the mineral composition of the rock samples. As the process elapsed, the decomposition process has created more micropore and weaken the interlocking between grain thus the percentage of solid in the rock specimen is reduced. Therefore, the mechanical and dynamic performance of rock eventually reduced as the process continued.

Acknowledgement
The authors are thankful to the Ministry of Higher Education Malaysia and Research Management Center (RMC) Universiti Teknologi MARA for the research grant RAGS (600-RMI/RAGS 5/3 166/2014). Special thanks also to Universiti Teknologi MARA Pulau Pinang for the facilities and fund provided.

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