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EFFECT OF WET TROPICAL WEATHERING ON THE STRENGTH OF SANDSTONE

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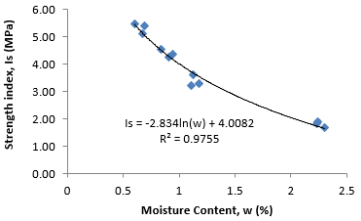
Graphical abstract



Abstract

The influence of moisture content to the strength of wet tropically weathered sandstone of Jurong Formation found in Nusajaya, Johor was studied. The rock materials have been affected by weathering action; hence the alteration of its engineering properties is incontestable due to these effects. A total of 36 samples representing various weathering grades were collected from the field and tested at various moisture content by immersing them in water at different duration of time, ranging from 15, 30 and 60 minutes. Point load tests for the determination of the strength index $Is_{(50)}$ of the rock were then carried out. For weathered sandstone (Grade II to IV), the moisture content ranges from 0.15% to 11.00% respectively, while the initial mean strength index has maximum and minimum values of 7.76 MPa and 0.38 MPa. The results reveal that there is a significant relationship between the weathering grades, moisture absorption and strength. The moisture absorption is dependent on the amount of clay minerals present in the rock material, which indirectly affects the strength, as observed with the increment of weathering state. In conclusion, this study indicates that sandstone with higher moisture content and increase in weathering grade exhibits lower strength values.

Keywords: Weathering; sandstone; wet tropical; moisture effect; point load strength

Abstrak

Pengaruh kandungan lembapan terhadap kekuatan batuan pasir terluluhawa tropika lembap dari formasi Jurong di kawasan Nusajaya, Johor telah dijalankan. Batuan tersebut telah mengalami proses luluhawa berterusan; maka perubahan yang terjadi pada sifat-sifat kejuruteraan batuan tersebut sememangnya tidak dapat dinafikan. Sejumlah 36 sampel yang terdiri daripada pelbagai gred luluhawa telah dikumpul dari tapak dan kajian dijalankan pada kandungan lembapan yang berbeza-beza, dengan merendam sampel tersebut dalam air pada jangka masa yang berbeza, antaranya, 15, 30 dan 60 minit. Ujian kekuatan beban titik kemudiannya dijalankan untuk menentukan indeks kekuatan $Is_{(50)}$ batuan tersebut. Purata kandungan lembapan permulaan untuk batuan pasir terluluhawa (Gred II ke IV) adalah dalam lingkungan 0.15% ke 11.00%, manakala purata kekuatan index permulaannya mencatatkan nilai maksimum 7.76 MPa dan nilai minimum 0.38 MPa. Keputusan kajian mendedahkan hubungan yang nyata wujud antara gred luluhawa, penyerapan lembapan, dan kekuatan batuan. Kadar penyerapan lembapan adalah bergantung pada jumlah mineral lumpur yang hadir dalam bahan batuan. Kadar penyerapan lembapan ini mempengaruhi kekuatan batuan, sebagaimana yang boleh diperhatikan melalui corak luluhawa yang dialami batuan tersebut. Kesimpulannya, kajian ini menunjukkan bahawa batuan pasir dengan kandungan lembapan dan gred luluhawa yang lebih tinggi, menunjukkan nilai kekuatan yang lebih rendah.

Kata kunci: Luluhawa; batu pasir; tropika lembap; pengaruh lembapan; kekuatan beban titik

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1.0 INTRODUCTION

Weathering is the alteration and breakdown of rocks near surface, mainly by reaction by water and air to form clay, iron oxides and other weathering products [1]. Weathering is the irreversible response of soil and rock materials and masses to their natural or artificial exposure to the near surface geomorphological or engineering environment [2]. In tropical region, high temperature is usually being experienced and in dry air, rocks decay very slowly but the presence of moisture hastens the rate of decay. Sandstone is composed of sand grains that are cemented by clay, carbonates, iron oxides, or silica. Most sandstone is relatively soft, but some is hard enough that it can be used as coarse aggregate [3]. Sandstone rocks are often found to be easily broken into flakes and tend to split unevenly under applied loads or influence of weathering agents, especially water.

Water is the most important triggering factor in assisting weathering, where it would lead to significant changes in most of the engineering properties of rocks, particularly in slope, foundation and excavation works. Vasarhelyi *et al*. [4] reported that weathering in rock structure would affect the engineering properties of rock, such as porosity, degree of saturation, and strength. There is no doubt that it is critically important to understand the effect and influence of extent of weathering on the engineering properties of rock material, particularly on the strength.

Rock material strength can be significantly affected by weathering process, especially moisture content. Designing a structure in type of rock of different weathering degrees will create problems related to the variation in material properties. More understanding and accurate knowledge of the weathering profiles can help in optimizing the expenditure and increases the safety level of the in-progress or the future civil engineering works.

As discussed previously, the effect of moisture content can significantly influence the anisotropy strength of sedimentary rock, specifically sandstone. Considering this, the understanding of the behavior of weathered sandstone, especially when it is subjected to moisture effect, is necessary. The lack of understanding of such behavior will represent a significant hurdle in the practical industry. Study on the effects of wet tropical weathering on the strength of sandstone if believed to provide much needed knowledge of the behavior of weathered sandstone including the effect of moisture and degree of weathering. The collected data will enrich the database as the existing research on this area is particularly limited [5].

The results from this study will provide guidance, information and knowledge that can be applied in the whole spectrum of civil and mining engineering fields. This study can also help in developing the understanding the behavior of the weak rock masses and the establishment of a more suitable method to test the properties of the weak rock materials.

2.0 WEATHERING IN WET TROPICAL REGION

Weathering is an important factor influencing the behavior of rock mass [6][7]. Severe weathering in tropical regions causes different issues in determining and predicting the behavior of rock mass and rock material. These issues may conclude but not limited to thick weathering profile, abrupt changes of mass weathering grades, presence of boulders and heterogeneity of rock mass. Consequently, the prediction of rock mass behaviour for engineering purposes, including surface excavation, is closely related to extensive study of weathering and its effect on rock mass and rock material properties [8][9]. In tropical region, where there are sunny flux all year round (22-32 °C), high moisture content in the air and underground, high quantity of rain (>1200 mm) and underground water temperature of 28°C, the climate has a great influence to exogenic process, especially to chemical weathering process where the high intensity of rain and high temperature will accelerate the weathering process [10]. This consequently leads to much faster transformation of rock to soil and much thicker and irregular profiles of weathering in tropical region compared to other areas [7],[8],[11].

Water can be described as one of the major contributing factor to weathering processes in rock materials. Kwasniewski *et al*. [12] studied the effect of water on the deformability of rocks under uniaxial compression. In the study, they clearly indicated that tropical weathering had a very significant, strong effect on both the strength and deformational properties of rock material. Discontinuities are one of the major accesses of water into the rock. However, change in stress field may cause new discontinuities because of reduction of confining pressure [13][14]. The new and more opened existing discontinuities permit higher permeability and hereafter an increase in water infiltrating into and flowing through the rock mass. Weathering will then escalate and be quicker as water is one of the chief agents involved in weathering [15].

Meanwhile, Edy Tonnizam Mohamad *et al.* [16] conducted a study on the influence of moisture content to the strength of weathered sandstone where samples were soaked in water up to 15 minutes before being tested. They found that water content is an important factor that affects the strength of weak rock materials, especially on grade IV weathered materials, due to an increasing degree of micro-fracturing and pores in the rock material.

The strength of rock determines to which extent it can be used or subjected to stresses in construction works. For this crucial reason, the effect of weathering cannot be under estimated. In the past, weathering effects have been investigated in tropical environments by researchers to ascertain the influence on rocks. Weathering results in an immediate and significant reduction in the compressive strength of rocks [17]. Observation has been made by numerous researchers that rock material becomes

more porous, soft, friable and weakened as the grain to grain bonding disrupted and microfractures and new minerals are formed.

It was also stressed that in exceptionally strong rocks such as granite, the loss of strength between fresh (Grade I) and moderately weathered (grade III), varieties may be as high as 80%. The breaking of bonds between minerals grains and the development of microfractures are responsible for the loss in strength.

3.0 METHODOLOGY

A total of 36 sandstone samples, ranging from slightly weathered to highly weathered, were collected from study site, located in Nusajaya, Johor Bahru. The location of the study area is as shown in Figure 1. They were packed in plastic containers to preserve the natural state of moisture content. The weathering state was described at the site using the classification system suggested by Komoo [18] and Edy Tonnizam Mohamad *et al*. [19].

Figure 1 Location of studied area

Figure 2 Sandstone at studied site in Nusajaya, Johor

Laboratory strength tests using point load index were carried out on all rock samples. The determination of moisture content and point load index test were conducted based on ISRM [20]. Determination of natural moisture content involved dividing of the samples into four groups for each weathering grade, ranging from grade II to IV. There are 12 samples for each weathering grade. The first group (3 samples) of each weathering grade in its natural moisture state was subjected to point load test using all samples, with load applied perpendicular to lamination. The second, third, and fourth group of each weathering grade were then soaked for 15 minutes, 30 minutes, and 60 minutes. The last three groups were tested using point load test after the soaking period completed.

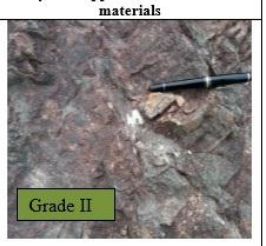
All data obtained were recorded from the tests for the determination of the correlation between moisture content and strength index, as well as weathering grades.

4.0 RESULTS AND DISCUSSION

4.1 Determination of Weathering Grades

Table 1 shows the description and characterisation of the sandstone at studied area, ranging from Grade II to Grade IV.

Table 1 Typical characteristics and appearances of sandstone obtained from this study

Weathering Grade	Description of Rock	Description of Weathering Grade	Physical Appearance on the rock materials
II Slightly weathered	**Colour:** Greyish and slightly discoloration on surface and along the joints **Texture:** very fined-grained **Structure:** Fissile and embedded	Edge is unbroken by hand while remain as mass in water. Texture will remain unchanged while the colour slightly changed but the rocks material mostly till fresh. Discontinuity spacing and surface covered by iron oxides.	
III Moderately weathered	**Colour:** Whitish grey with some discolouration on surface and discontinuities. **Texture:** very fined-grained **Structure:** Fissile and embedded	Remain as mass when slaking in water while by hand the edge can be slightly broken. Besides, the texture remains unchanged and the colour slightly changed in earth material. Inclined bedding also can be seen. Iron oxides covering discontinuity spacing and surfaces.	
IV Highly weathered	**Colour:** Greyish brown and discoloration at surface and along the joints **Texture:** very fined-grained **Structure:** Fissile and embedded	Slaking in water or by hand becomes flakes or small pieces. The texture remain unchanged. Besides, the colour changed in earth material. Inclined bedding can clearly be seen. Iron oxides covering rock surface and discontinuity spacing.	

4.2 Variation in the Absorption of Moisture Content with Time

It is important to determine the variation of water content in the selected weathering grades of sandstone with the soaking period. The moisture content at natural state, after 15, 30 and 60 minutes duration of soaking were recorded. Table 2 shows the mean values of moisture content and soaking period for each weathering grade. On the other hand, variation in the absorption of moisture content with time for each weathering grade and the pattern of moisture absorption due to weathering effect is displayed graphically in Figure 3 and Figure 4.

Table 2 Mean Values of Moisture Content and Time of Immersion for Sandstone

Grades	Duration (Minutes)	NMC (%)	15 min soaked (%)	30 min soaked (%)	60 min soaked (%)
II	15	0.65	0.9	1.14	2.26
III	30	1.90	2.81	3.80	4.64
IV	60	10.58	14.00	16.13	18.12

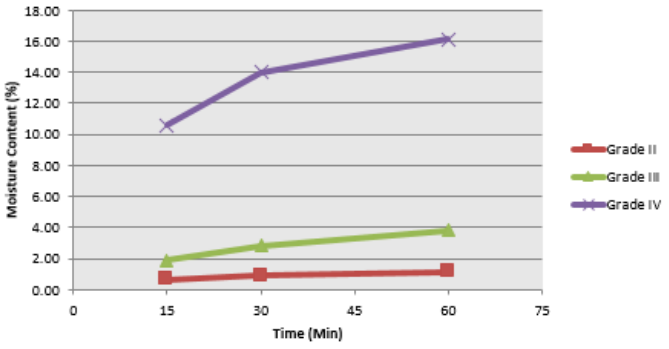


Figure 3 Variation in the absorption of moisture content with time for different weathering grade

In general, it was found that the water absorption increases with the soaking period for all weathering grades. In Grade II, the mean moisture content range from 0.65 % at natural state to 2.26 % at maximum soaking period of 60 minutes. Besides, Grade III samples exhibit more ability to absorb water compared to Grade II samples. The moisture content at natural state for grade III samples is 1.90 % and achieved absorption of 4.64 % when soaked in water for 60 minutes. Grade IV samples started with original moisture content of 10.58 % and achieved 18.12 % at maximum soaking period of 60 minutes.

4.3 Effects of Weathering Grades on Absorption of Moisture Content

The pattern of moisture absorption due to weathering is displayed graphically in Figure 4. The results show that the increase of weathering grades from grade II to grade IV, increases the moisture absorption of samples. At maximum soaking duration of 60 minutes, sandstone grade II has maximum values of moisture content of 2.26 %, while grade III and IV have maximum moisture content of 4.64 % and 18.12 %, respectively. The sharp increase in moisture content of grade IV over other grades shows high level of mineral decomposition as a result of weathering effect in the sandstone.

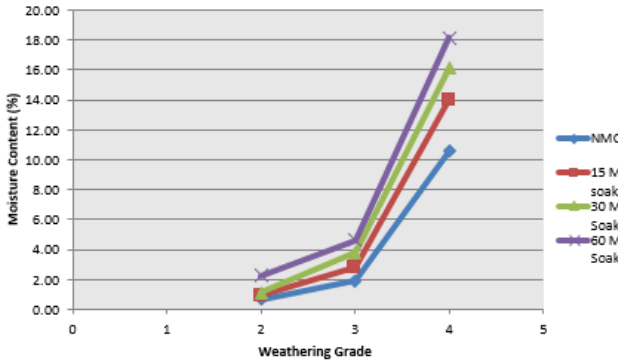


Figure 4 Pattern of water absorption with different stage of weathering

4.4 Effect of moisture content on the strength index, Is(50)

Table 3 shows the summary of results for point load test on weathered sandstone at various moisture contents. Based on Table 3, Grade II sandstone samples records the highest strength index, between 5.11 MPa and 5.46 MPa with moisture content ranging from 0.60 % to 0.69 % under its natural state. When soaked for 15 minutes and tested for point load test, the strength index ranges from 4.26 MPa to 4.52 MPa and moisture content of 0.84 % to 0.94 %. Strength index recorded for samples soaked after 30 minutes is between 3.21 MPa and 3.62 MPa, with moisture content ranging from 1.11% to 1.18 %. Meanwhile, samples of 60 minutes soaking period recorded lowest strength index between 1.67 MPa and 1.91 MPa with the highest moisture content ranging between 2.23 % to 2.30 %. The results reveal that the increase in moisture content has significant reduction in strength index of sandstone.

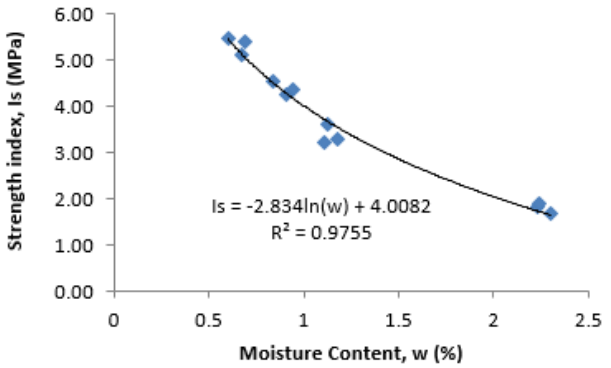


Figure 5 Reduction in strength index due to moisture content increase for Grade II sandstone

Table 3 Summary of results for point load test on weathered sandstone

Weathering Grade	Duration of Soaking (min)	Moisure Content, w (%)	Strength Index, Is_{50} (MPa)
II	OMC	0.67	5.11
		0.60	5.46
		0.69	5.41
	15	0.94	4.36
		0.84	4.52
		0.91	4.26
	30	1.11	3.21
		1.13	3.62
		1.18	3.30
	60	2.23	1.81
		2.24	1.91
		2.30	1.67
III	OMC	1.91	3.11
		1.86	3.17
		1.94	3.61
	15	2.83	2.40
		2.80	2.26
		2.80	2.39
	30	3.78	1.72
		3.80	1.93
		3.80	1.92
	60	4.63	1.03
		4.63	1.05
		4.66	1.08
IV	OMC	10.68	0.43
		10.49	0.42
		10.62	0.34
	15	14.36	0.27
		14.13	0.23
		13.23	0.23
	30	15.48	0.06
		16.36	0.07
		16.56	0.04
	60	17.78	0.03
		17.76	0.03
		18.82	0.00

(Note: OMC = Optimum moisture content)

In a similar manner, Grade III sandstone recorded strength index between 3.11 MPa and 3.61 MPa with moisture content ranging from 1.86 % to 1.94 % under its natural state. Reduction of strength index is noticed between Grade II and Grade III in which more moisture is absorbed in Grade II due to weathering effect. When soaked for 15 minutes and tested for point load test, the strength index ranges from 2.26 MPa to 2.40 MPa, with moisture content ranging from 2.80 % to 2.83 %. For 30 minutes soaking period, strength index recorded is between 1.72 MPa to 1.93 MPa with moisture content of 3.78 % to 3.80 %, while 60 minutes soaking period recorded strength index between 1.03 MPa to 1.08 MPa with the highest moisture content, ranging between 4.63 % and 4.66 %. Presented graphically in Figure 6, is the reduction in strength index due to increase in moisture content.

Meanwhile, point load test results for Grade IV sandstone at natural state show that strength index ranges between 0.34 MPa and 0.43 MPa, with moisture content ranging from 10.49 % to 10.68 %. The strength index in this case recorded the lowest values among the three grades tested, whereby the corresponding moisture content for this grade of samples recorded the highest value as compared to the lower grade samples. For 15 minutes soaking period, the strength index is between 0.23 MPa to 0.27 MPa, while moisture content is between 13.23 % and 14.36 %. The same reduction trend in the strength index with increment of moisture content were also observed for samples of this grade at 30 and 60 minutes soaking period. Figure 7 shows strength index reduction with increment in moisture content.

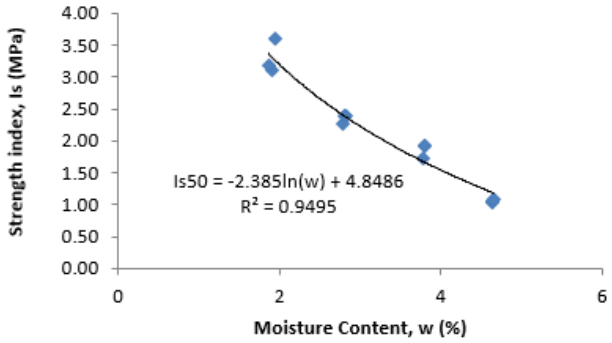


Figure 6 Reduction in strength index due to moisture content increase for Grade III sandstone

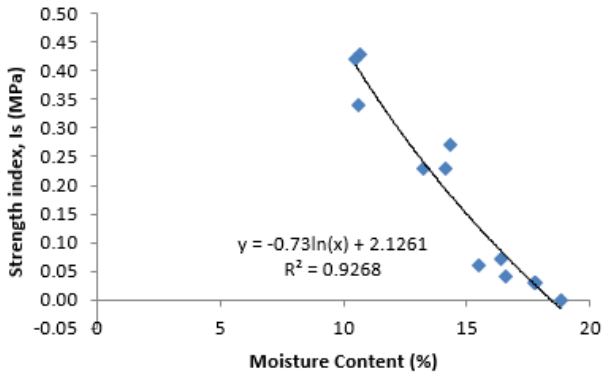


Figure 7 Reduction in strength index due to moisture content increase for grade IV sandstone

Figures 5, 6 and 7 represent a strong relationship between the strength and moisture content of weathered sandstone. The decrement in strength index of weathered sandstone relies on the increment of moisture content. On the strength index and moisture content issues, it can be mentioned categorically that the strength reduction is due to the increment of clay minerals in the weathered rock. The clay minerals assist in absorbing water and acts as lubricant, thereby reducing the strength of the rock material. This action is common in Grade III and IV.

In addition, Table 4 shows the percentage reduction in initial strength index of weathering grades. For weathered sandstone (Grade II, III and IV), the mean initial moisture content ranges from 0.65 % to 10.58 %, while the initial mean strength index has maximum values of 5.26 MPa, 3.28 MPa and 0.38 MPa for grade II, III and IV, respectively. Following the results shown, it is noticed that higher weathered sandstone has higher tendency to absorb more water, thus resulting in significant reduction of strength from their natural state. In Grade IV samples, a reduction of 92.77 % is noticeable when the samples were soaked in water, whereby, only 37.65% of strength reduction occurred in Grade III samples. The strength reduction becomes lesser when the weathering grade decreases.

Table 4 Percentage reduction in initial strength index of weathering grades

Weathering Grade	Mean value of Initial Moisture Content (%)	Mean value of Initial Strength (MPa)	Percentage of Initial Strength (%)	Percentage of Strength Reduction (%)
II	0.65	5.26	100	0
III	1.90	3.28	62.35	37.65
IV	10.58	0.38	7.23	92.77

5.0 CONCLUSION

This paper presents the effects of moisture content on the strength of wet tropical weathered sandstone. From the analysis of results and comparisons made, some conclusions were derived from this study. Increasing of weathering grade from lower grade to higher grade (Grade II to IV) would exhibit in the increasing of moisture absorption. Grade II to III samples, however, show relatively little variation as compared to grade IV samples, as the engineering properties of rock are furtherly changed when the rock material is subjected to higher weathering process. It was also found that the reduction in strength increases with increasing of weathering grade. The results show that higher grade sandstone absorbs more moisture as compared to lower grades sandstone, hence significantly reducing the strength indices, due to increase of clayey mineral from sandstone. Based on these results, moisture content can be described to have significant effects on the strength index of wet tropical weathered sandstone.

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