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The Effect of Moisture Content on the Strength and Anisotropy Index of Tropically Weathered Shale

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ABSTRACT

Moisture content is one of the most important factors and a powerful mechanism manipulating the engineering properties of rock on its physical and mechanical properties. This issue becomes more significant in shale as it possesses fine lamination structures which tend to split unevenly, parallel to the weakness plane. It becomes more severe when the rock material is subjected to higher weathering process. This paper aims to investigate the effect of moisture on the strength, and anisotropy index, $Ia_{(50)}$ of fresh to highly weathered shale collected at Ayer Hitam, Johor, Malaysia. A total of 96 samples representing various weathering grades were tested for this purpose. The samples were tested at varying moisture by immersing them in water at different duration of time. The results revealed that there is a significant relationship among weathering grades, moisture absorption, strength and anisotropy index of shale. The moisture absorption is dependent on the clay minerals present in the rock material which indirectly affects the strength. However, the result shows a unique pattern on the range of anisotropy index for various weathering grades. Shale with higher moisture content and weathering grade exhibits higher range of anisotropy index.

KEYWORDS: Moisture content, tropically weathered shale, strength, anisotropy

INTRODUCTION

Rock weathering involves the release of compounds into solution, creation of new mineral products and breakdown of rock into smaller pieces (Nordberg and Turkington, 2004). Moisture content plays a major role in both physical and chemical weathering of rocks especially in the tropical region. This leads to significant changes in most of the engineering properties of rocks, particularly in terms of its strength.

The presence of moisture content in rock structure would affect the engineering properties of rock, such as porosity, degree of saturation, and strength. Kwasniewski et al., (2009) studied the effect of water on the deformability of rocks under uniaxial compression. In the study, he clearly indicated that moisture had a very significant, strong effect on both the strength and deformational properties of sandstone and shale. Meanwhile, Edy Tonnizam et. al.,(2008) conducted a study on the influence of moisture content to the strength of weathered sandstone. He 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 microfracturing and pores in the rock material.

Shale is one of the fine-grained sedimentary rocks that has fissility structures or fine lamination that are built parallel to the weakness plane. These cause shale rocks to be easily broken into flakes and tend to split unevenly under the loads or influence of weathering agents, especially water (Abhijit, 2010). Thus, it is critically important to understand the effect and influence of moisture content on the engineering properties of shale, particularly on the strength and anisotropy index.

SCOPE OF THE STUDY

This study focused on the effect of moisture content on the strength and strength anisotropy index of weathered shale, where samples were collected from Ayer Hitam, Johor (Figure 1). Point load test was conducted in order to determine the strength index of weathered shale. All tests were carried out in accordance to the International Society for Rock Mechanics Standard Procedures, ISRM (1981) and ISRM (1985). Meanwhile, two minor tests which are the X-Ray Fluorescence (XRF) and X-Ray Diffraction analysis (XRD) were also being conducted in order to clarify the mineralogy that exists in the rock material. All the laboratory tests were conducted at the Geological Laboratory, Universiti Tun Hussein Onn Malaysia, Johor.

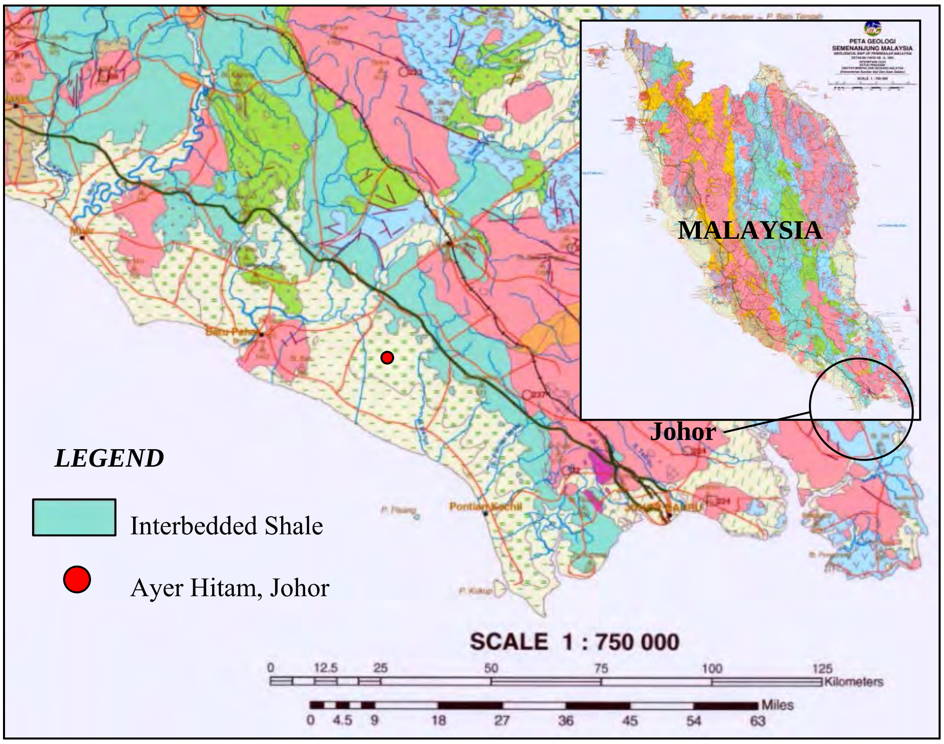

Figure 1: Location of study where rock samples were collected.

METHODOLOGY

Rock and Weathering Grade Determination

A systematic observation and examination on the rock samples were made prior to determination of weathering grade. The classification of the weathering grade was done in accordance to the system proposed by ISRM (1981) as shown in Table 1, and the results are shown in Table 2. Samples were identified as sedimentary shale according to the physical appearance (color, texture and grain surface). The shale samples taken from site in Ayer Hitam were identified to have fine to medium laminated structures and are grey in color.

Table 1: Weathering classification suggested by ISRM Working Party, 1981.

Grade	Grade	Diagnostic Features
Fresh	I	No visible sign of decomposition or discoloration. Rings under hammer impact.
Slightly Weathered	II	Slight discoloration inwards from open fractures. Otherwise similar to F.
Moderately Weathered	III	Discolored throughout. Weaker minerals such as feldspar discomposed. Strength somewhat less than fresh rock but cores cannot be broken by hand or scraped by knife. Texture preserved.
Highly Weathered	IV	Most minerals somewhat decomposed. Specimens can be broken by hand with effort or shaved with knife. Core stones present in rock mass. Texture becoming indistinct but fabric preserved.
Completely Weathered	V	Mineral decomposed to soil but fabric and structure preserved (Saprolite). Specimens easily crumbled or penetrated.
Residual Soil	VI	Advanced state of decomposition resulting in plastic soils. Rock fabric and structure completely destroyed. Large volume change.

Mineralogy Clarification

Mineral identification in the rock samples were carried out by using X-Ray Fluorescence (X-RF) and X-Ray Diffractions tests. The XRF test gives the results on chemical constituents of the samples while the XRD test aims to determine the mineralogy exists in the samples. All samples were classified as shale based on recommendation proposed by Kelvin et al., (2011) and Wenk et. al., (2008). They proposed shale should be composed of clay minerals (illite, montmorillonite, kaolinite, chlorite) and other minerals, mostly quartz or carbonate minerals (calcite, ankerite, siderite and dolomite) and some other minor forms of silica and feldspar. Table 3 shows the summaries of major minerals exist in the samples for each weathering grade. Kaolinite and montmorillonite exist abundantly, about 65% in grade IV samples. Their existence in grade III is about 40% while grade II and I has 20% and 5%, respectively. It is seen that the amount of clayey minerals increased with the increase of weathering grade. The presence of clayey minerals in the higher weathering grade materials caused the material weak, moisture sensitive, and likely to expand significantly (Edy Tonnizam., 2011).

Table 2: Typical characteristics and appearance of shale in this study.

Weathering Grade	Description of Rock	Description of Weathering Grade	Physical Appearance on the rock materials
I Fresh	**Color:** Greyish black and slightly discoloration **Texture:** very fined-grained **Structure:** Fissile and embedded	No changes in texture and color in earth materials. Edge is unbroken by hand and remain as mass when slake in water. Slight iron stain in discontinuity spacing.	
II Slightly weathered	**Color:** Greyish and slightly discoloration on surface and along the joints **Texture:** very fined-grained **Structure:** Fissile and embedded	Slight changes of color on rock surface but most of the rock materials are still fresh. Edge is unbroken by hand and remain as mass when slake in water. Discontinuity spacing and surface covered by iron oxides.	
III Moderately weathered	**Color:** Whitish grey with some discolouration on surface and discontinuities. **Texture:** very fined-grained **Structure:** Fissile and embedded	Color changes in earth materials but texture and structure of rock mass remain unchanged. Edge of rock material is hard to broken by hand. Iron oxides covering discontinuity spacing and surfaces.	
IV Highly weathered	**Color:** Greyish brown and discoloration at surface and along the joints **Texture:** very fined-grained **Structure:** Fissile and embedded	Color changes in earth materials. Texture and structure remain unchanged. Rock breaks into fragments when crushed by hand or immersed in water. Iron oxides covering rock surface and discontinuity spacing.	

Table 3: Mineralogy in samples tested

Sample No.	Grade I	Grade II	Grade III	Grade IV
Kaolinite	√	√	√	√
Illite	√	√	√	√
Montmorillonite	√	√	√	√
Chlorite	√	√	√	√
Quartz	√	√	√	√
Calcite	√	√	√	√

Sample Preparation

In this study, irregular lump samples with dimension of 50 ± 35 mm have been used in accordance to ISRM, (1985) as shown in Figure 2. Samples were brought back to laboratory for trimming and lapping process. According to ISRM (1985), the ratio depth over width (D/W) should be between 0.3 and 1.0, preferably close to 1.0. The distance, L should be at least 0.5W. Therefore, the samples of weathering grade I, II and III were cut and trimmed into a particular size, approximately 40 mm in depth, 40 mm in width and 40 mm in length. However, samples from weathering grade IV is easily to break during cut and trimming process. Consequently, the sample was tested in original condition with size more less 50 ± 35 mm.

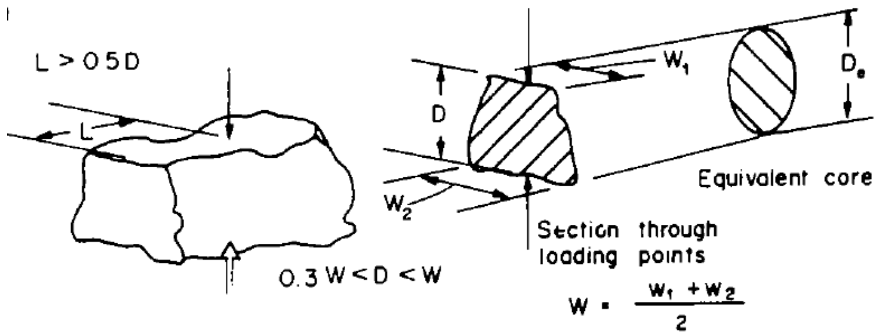

Figure 2: Specimens shape requirement for the irregular lump test in accordance to ISRM (1985).

Anisotropy Index

Ajalloeian et.al.(2000) reported that the point load strength anisotropy test is a good index of anisotropy for shaley and bedded rocks. ISRM (1981) defined the strength anisotropy index as the ratio of mean $Is_{(50)}$ values measured in the strongest and the weakest direction (perpendicular and parallel to the planes of weakness). In order to determine the strength anisotropy index of weathered shale under influence of moisture content, the determination of anisotropy index suggested by ISRM (1981) was closely followed and applied. Equation 6 has been used to determine the anisotropy index ratio of shale.

$$Ia_{(50)} = \frac{Is_{(50)\perp}}{I_{(50)//}} = \frac{\text{Perpendicular Point Load}}{\text{Parallel Point Load}} \qquad (6),$$

where $Is_{(50)\perp}$ and $I_{(50)//}$ is the point load strength of rock block or irregular lumps perpendicular and parallel to the planes of weakness at the axial of the samples. The methodology was graphically demonstrated as shown in Figure 3.

In this study, a total number of 24 samples from each weathering grade (grade I, II, III and IV) were tested in different moisture conditions, which are the original moisture condition (OMC) , after 15, 30 and 60 minutes of immersion in water. For each condition, three samples were tested in perpendicular to the rock's foliation and another three samples were tested in parallel to the rock's foliation in order to determine the strength anisotropy index of weathered shale under influence of moisture content.

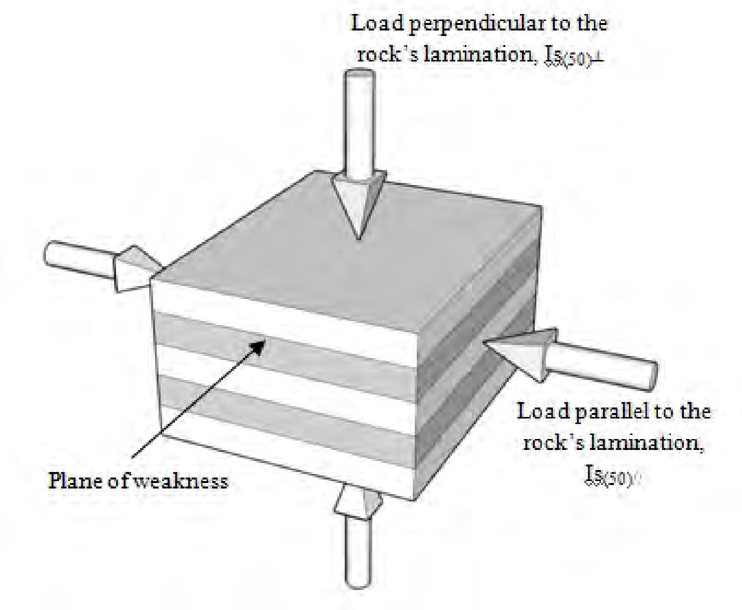

Figure 3: Load orientation perpendicular and parallel to the weakness plane of weathered shale.

RESULTS AND DISCUSSION

Rock samples of different moisture content have been tested for their point load strength. The main aim of this test was to identify the correlation among moisture content, strength and anisotropy index of the rock material. Sample preparation for testing was a little tough in this study, especially to standardize the size of shale samples of higher weathering grade (grade IV).

Many samples were broken during the cutting and trimming process due to disintegration of weak materials when samples are subjected to water and inherent weakness of laminated samples. This caused great difficulties to preparation of samples and two samples of weathering grade II and one sample of weathering grade III were damaged before being immersed in water.

The process of sample immersion required quite some time to be done, since the sample had to be immersed in water each at a time. Immersion of several samples in water at a same time causes the immersion time to be extended before samples are tested for point load test and this affects the moisture content of the samples, especially for samples of higher weathering grade (grade IV).

The results of point load test are summarized as shown in Table 4. As can be seen from the table, generally, the increment of moisture content reduces the strength index, while on the other hand, the range of anisotropy index is dependable on moisture content and strength index of the rock material.

Absorption of Moisture

In this study, rock samples representing four weathering grades were tested in order to determine the effect of weathering grade on the moisture content. The result from this correlation is presented graphically in Figure 4.

Generally, the result shows an increasing trend of moisture absorption with the increase of the weathering grade. Samples of weathering grade IV show significant increase in moisture content of more than 42% when the duration of immersion in water increases from original moisture content to 60 minutes. Shale sample of weathering III shows moderate increment in moisture content as the duration of immersion increases. Meanwhile, in samples of lower weathering grades (Grade I and II), slight increment of moisture absorption was noted less than 1% when the duration of immersion was increased. The increment of moisture content in the rock material is in accordance to the domination of clayey minerals (kaolinite and montmorillonite) as shown in Table 3. This result supports the finding of Edy Tonnizam et al. (2008) and Leelamanie (2010).

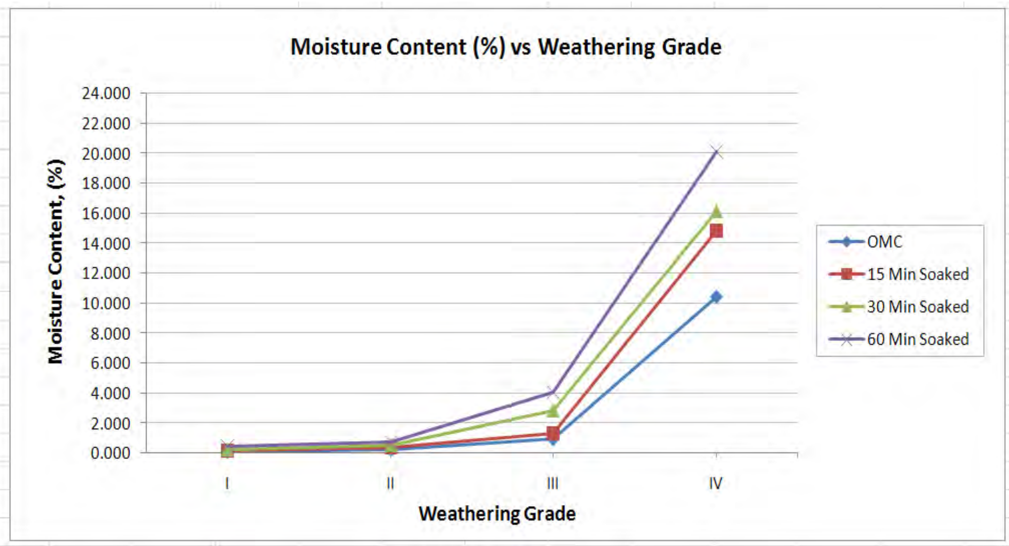

Figure 4: Absorption of moisture content with respective weathering grade.

Table 4: Results of the point load index with various moisture content.

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W/Grade	Soaked Duration (min)	Moisture Content, W (%)	Direction of Point Load Test (with foliation) MPa		Anisotropy Index, $Ia_{(50)}$
			$Is_{(50)}\perp$	$Is_{(50)//}$	
I	OMC	0.066	13.963	11.830	1.180
		0.105	13.495	11.701	1.153
		0.089	13.391	13.008	1.029
	15	0.164	10.576	10.431	1.014
		0.157	11.473	9.531	1.204
		0.159	11.274	11.204	1.006
	30	0.215	9.880	7.567	1.306
		0.279	9.172	7.385	1.242
		0.177	10.065	8.578	1.173
	60	0.473	5.867	5.233	1.121
		0.430	7.098	4.482	1.584
		0.475	5.894	4.146	1.422
II	OMC	0.230	11.352	8.126	1.397
		0.250	10.018	9.804	1.022
		0.230	11.071	9.579	1.156
	15	0.406	7.108	5.685	1.25
		0.435	5.925	5.091	1.164
		-	-	-	-
	30	0.518	5.239	4.698	1.115
		0.493	5.839	4.844	1.205
		-	-	-	-
	60	0.659	4.154	3.284	1.265
		0.724	4.513	2.244	2.012
		2.054	3.904	1.818	2.147
III	OMC	0.959	4.311	2.674	1.612
		0.894	4.599	2.023	2.273
		0.947	4.495	3.263	1.378
	15	1.507	1.963	1.896	1.035
		1.208	2.404	1.718	1.399
		1.366	2.128	1.550	1.373
	30	2.481	1.500	1.371	1.094
		3.126	1.383	1.214	1.139
		3.018	1.502	1.308	1.148
	60	3.932	1.254	0.611	2.052
		4.063	0.993	0.719	1.380
		-	-	-	-
IV	OMC	10.020	0.130	0.089	1.461
		10.746	0.119	0.101	1.174
		10.574	0.168	0.088	1.907
	15	14.720	0.071	0.064	1.11
		14.818	0.076	0.049	1.555
		14.938	0.073	0.056	1.288
	30	15.781	0.059	0.042	1.401
		15.895	0.050	0.037	1.350
		16.847	0.051	0.033	1.547
	60	21.361	0.036	0.115	0.312
		19.235	0.041	0.014	2.969
		19.852	0.029	0.095	0.305

OMC : original moisture content

Strength and Variation of Moisture Content

The correlation between strength index, $I_{s(50)}$ and moisture content for all weathering grades of samples is graphically illustrated in Figure 5.

The figure shows a strong correlation of an exponential relationship between point load strength index, $I_{s(50)}$ of weathered shale and moisture content. Generally, it is shown that the strength index, $I_{s(50)}$ of weathered shale decreases as the moisture content in rock increases. Grade I and II samples do not exhibit significant increment of the moisture absorption, which range from 0.006% to 0.475% for grade I, and from 0.230% to 2.054% for grade II with range of strength index between 13.963MPa and 5.867MPa for grade I and between 11.352MPa and 3.904MPa for grade II. On the other hand, absorption of moisture significantly increase in samples of grade III and IV, where the moisture content ranges from 0.894% to 4.063% for grade III and from 10.746% to 21.361% for grade IV, and the strength ranges between 4.599MPa and 0.993MPa for grade III and between 0.168MPa and 0.029MPa for grade IV. The strength reduction is due to the increment of clayey minerals in weathered rock. This behavior may be explained by the presence of loosely bonded interlayer water in the montmorillonite, which is squeezed out at higher pressures, changing the frictional characteristics of the clay (C. Morrow et al, 2000).

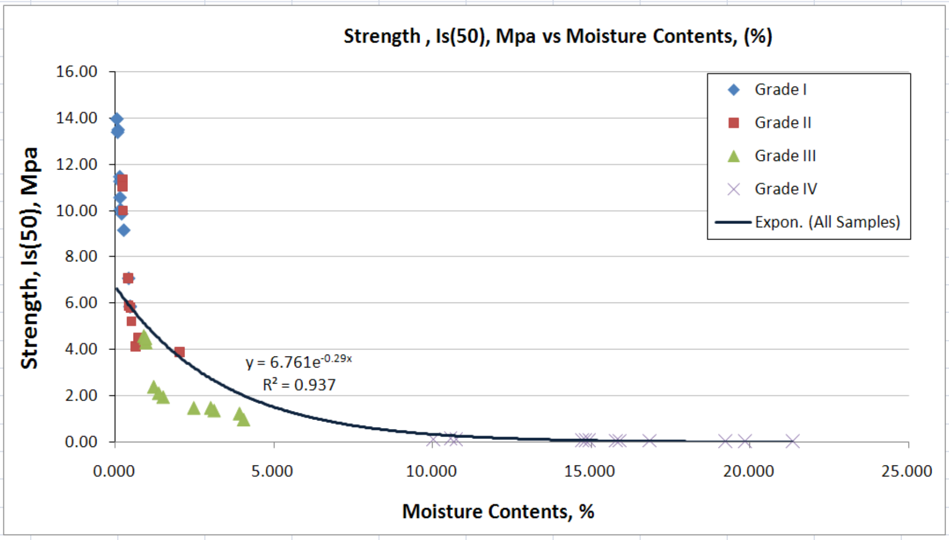

Figure 5: Trend of decreasing strength index, $I_{s(50)}$ with increasing moisture content for weathered shale.

Effect of Moisture Content on Anisotropy Index

The relationship between the anisotropy index of shale with weathering grades of I, II, III and IV in different moisture content is shown graphically in Figure 6. The correlation between moisture content and anisotropy index, $I_{a(50)}$ of weathered shale is summarized in Table 5. It can be seen that there is a significant change in anisotropy index, $I_{a(50)}$, corresponding to the moisture content changes.

The figure and table show that the increment of moisture content increases the range of anisotropy index of weathered shale. It was found that higher moisture content tend to exhibit higher range of anisotropy index, especially in shale of higher weathering grade (grade IV).

Important changes were also observed in the anisotropy index, $I_{a(50)}$ of weathered shale as the moisture content changes, especially in grade IV. When the perpendicular strength is less than 0.036MPa, the parallel strength could not be recorded because samples were broken without showing any load values. The anisotropy index was reduced to be 0.00, which is less than 1. The increment of moisture of shale grade IV of more than 19% increases the range of anisotropy index, $I_{a(50)}$ from 0.00 to 3.00. Based on Table 5, it can be summarized as follows:

1. Shale with higher weathering grade (IV) tends to show no value of strength as the samples were easily broken when tested in parallel direction.
2. Shale in higher weathering grade (grade IV) is able to register high value of anisotropy index of 3.00 because the strength measured in parallel direction is very much lower than the perpendicular strength.
3. Grade III samples show higher anisotropy index and moisture content as compared to grade II and I samples.
4. Grade I samples show the least moisture absorption and also has the smallest range of anisotropy index.

Table 5: Effect of moisture content on anisotropy index

Weathering Grade	Moisture Content (%)	Anisotropy Index $I_{a(50)}$
I	0.05 - 0.40	1.01-1.60
II	0.20 – 0.90	1.02-2.00
III	0.90 - 4.10	1.04-2.30
IV	10.0 - 22.0	0.00-3.00

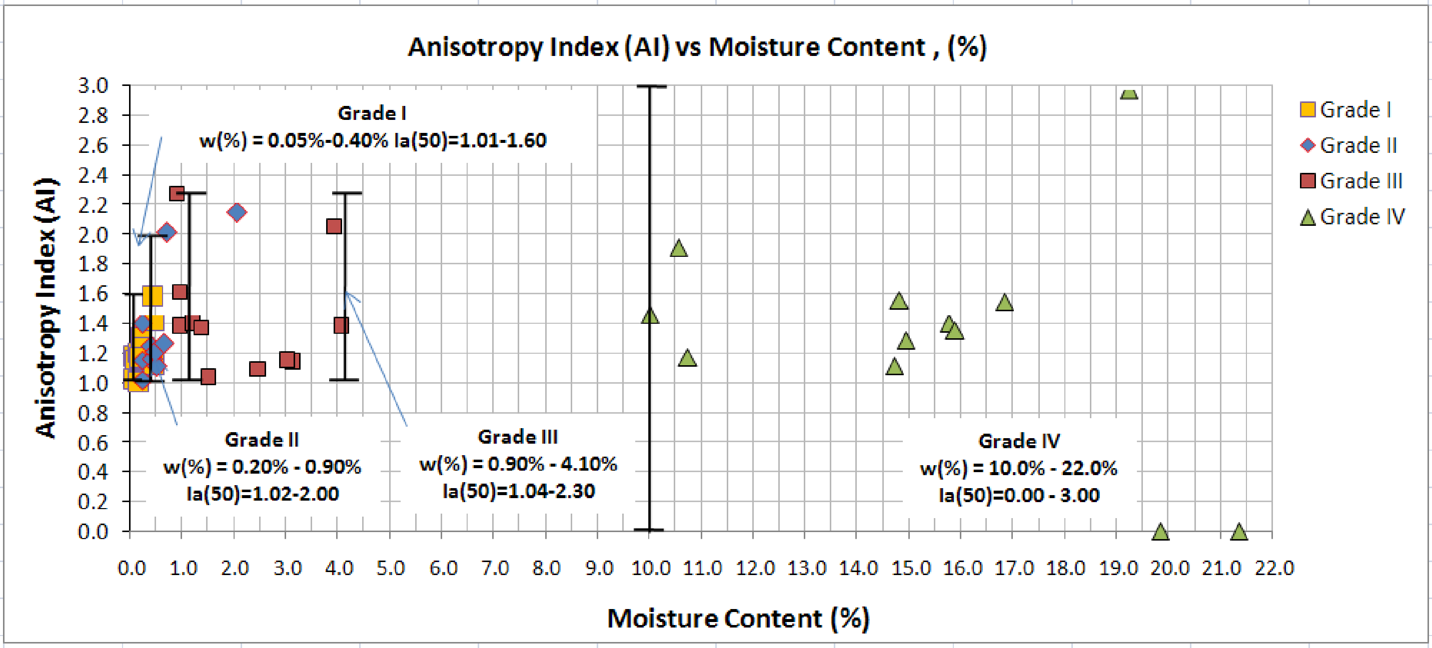

Figure 6: Effect of moisture content on anisotropy index

Strength and Anisotropy Index

The correlation between strength and strength anisotropy index of weathered shale is graphically presented in Figure 7. This study revealed that the range of anisotropy index, $I_{a(50)}$ becomes wider when the strength of the rock material is lower. The results are summarized in Table 6.

The data of strength are grouped into five classifications from very strong to very weak rock. This classification is modified from Broch and Franklin (1972). Very strong rock with values of $I_{s(50)}$ more than 12.4 MPa shows anisotropy index of 1.01 to 1.20, where the difference of interval is only 0.19. In contrast, moderately strong rock has interval of 0.50 with anisotropy value of 1.10 to 1.60. The result becomes more obvious in very weak rock, where the interval is 3.00. This result disagrees with Saroglou et. al.,(2007) finding, which they reported that there is no relating trend between the anisotropy index, $Ia_{(50)}$ and strength index of rocks.

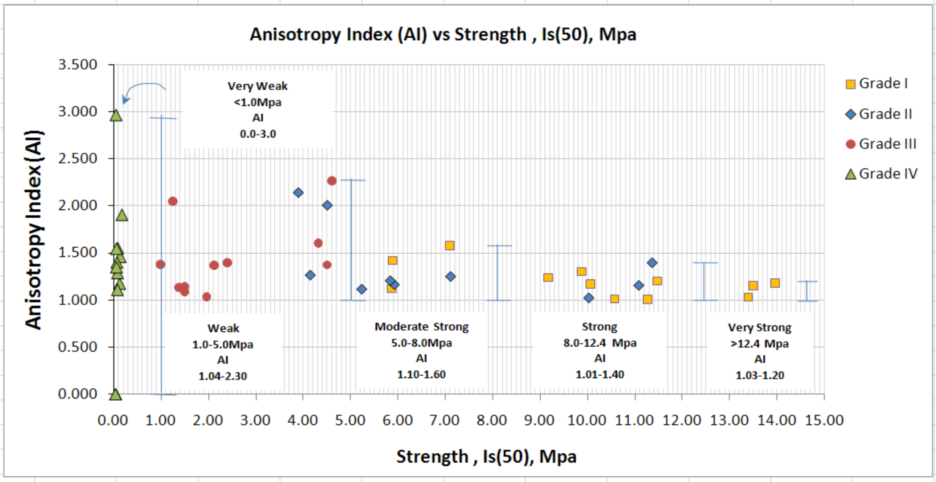

Figure 7: Effect of strength on the anisotropy index of shale in different weathering grades.

Table 6: Test result of strength and anisotropy index

Strength Classification	Strength (MPa)	Anisotropy Index $I_{a(50)}$
Very Strong	> 12.4	1.01 - 1.20
Strong	8.1 - 12.4	1.01 - 1.40
Moderately Strong	5.0 - 8.1	1.10 - 1.60
Weak	0.04 - 5.0	1.04 - 2.30
Very Weak	< 0.04	0.00 - 3.00

CONCLUSION

Conclusions that can be derived from this study are listed below:

1. Increasing of weathering grade from lower grade to higher grade (grade I to IV) would exhibit in the increasing of moisture absorption. The plots showing the results of testing are heavily influenced by the results on Grade IV samples, while the results from Grade I to III show relatively little variation as the engineering properties of rock are manipulated and changed when the rock material is subjected to higher weathering process,

especially on grade IV weathered materials, due to an increasing degree of microfracturing and pores in the rock material.

2. Generally, the low strength rock has the tendency to have higher anisotropy index, while very strong rock exhibits lowest range of anisotropy index, $I_{a(50)}$.
3. Shale with higher moisture content has the tendency to exhibit wider range of anisotropy index, $I_{a(50)}$ and lower strength in its respective weathering grade, Very weak rock which has strength less than 0.04MPa has the widest interval and is able to show significant changes in anisotropy index.

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