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Comparison study on the strength index of tropical shale and sandstone influenced by moisture content

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Abstract. The effects of variation of moisture content on the strength index are different depending on the type of rocks. Hence this paper compares effect of moisture content to the strength and anisotropy index of moderately weathered shale and sandstone of Jurong Formation. Both field and laboratory works had been carried out to in order to gain useful data such as the physical description, the strength index and also the anisotropy index of the rocks. Twenty-four samples of moderately weathered for each shale and sandstone (total 48 samples) were tested at a wide range of moisture content varying from original moisture content to saturated condition. The results revealed that the presence of water has affected the strength index of shale more than sandstone. The strength index of shale decreased up to 80% with just 7.4% increment of moisture content while the strength index of sandstone only decreased up to 46% by 6.94% increase in moisture content. The presence of water also affected the anisotropy index of the material. The results discovered that the presence of moisture content has affected the anisotropy index of shale more than sandstone. With original moisture content of 1.06% to moisture content of 8.45%, the shale is shifting from fairly-moderately anisotropic to highly anisotropic while sandstone that had not been affected much in term of anisotropy index still remain as fairly-moderately anisotropic material with 6.94% increase of moisture content. Field and experimental results shown the increment of moisture content has affected the strength and anisotropy index of shale more than sandstone of the same weathering grade. The impact of moisture content on tropical shale and sandstone strength index is required for the design and construction of foundations, tunneling and slope stability studies in rock mass.

1. Introduction

Moisture content of rock that represents the existence of water in rock as weathering agent will be able to change the engineering properties of rock physically and chemically. Since Malaysia has equatorial climate that is hot and humid throughout the year, heavy rainfall is expected. The rains are abundant and continuous throughout the year and can go up to 3000 mm during monsoon season with temperature can go from as low as 23 °C to as high as 33 °C. Hence, the presence of moisture content in rock mass is most likely impossible to be an issue that has to be explored for the effect of moisture content is different depending on type of rocks. Ergular and Ulusay [1] suggested that moisture content is one the most important factors that influencing the rock material strength where with small increase in moisture content may lead to remarkable reduction in strength of the rock mass.

Besides moisture content, an anisotropy is one of the important factors that affect the behaviour of rocks as the properties of the rocks vary with direction. Sedimentary rock such as shale and sandstone are commonly known as anisotropy rock. The anisotropy of shale and sandstone is giving a significant effect in designing geotechnical structures such as design of tunnels, underground space, dams and the stability of rock slopes. The presence of water makes the problem more critical as it will accelerate weathering process as well as it will affect the strength and anisotropy index of the rock. This paper is focusing to compare the level of effect on the strength index of tropical shale and sandstone when influenced by moisture content. At the end of this study, correlation among moisture absorption, strength and anisotropy index of different types of sedimentary rock were investigated and analysed in detail.

2. Background of study

Moisture content plays a dominant role in both physical and chemical weathering of rocks. This leads to significant changes in most of the engineering properties of rocks, particularly in terms of its strength [2][3]. Various research has been published on the effect of moisture content on the rock strength. For instance, Broch [3] explained that the reduction of strength with increase of moisture content is due to the reduction in the internal friction and their surface energy. Meanwhile, Moon [4] advised that the presence of water would soften the bonds or interact with mineral surfaces and alter their properties. The moisture within the grains acting as grease and reduce the strength of the material. Furthermore, Ergular and Ulusay [1] suggested that moisture content is one the most important factors that influencing the rock material strength where with small increase in moisture content may lead to remarkable reduction in strength. Kwasniewski and Oitaben [5] is agreeing with that and believed the presence of moisture content in rock structure would affect the engineering properties of rock, such as porosity, degree of saturation, and strength. He has studied the effect of water on the deformability of rocks under uniaxial compression and clearly indicated that moisture had a very significant, strong effect on both the strength and deformational properties of sandstone and shale.

2.1 Anisotropy Index in Sedimentary Rock

Sedimentary rocks can be categorized into three groups based on sediment type which are clastic, organic and chemical. Clastic as a basic sedimentary rocks are accumulations of discrete fragments or clasts of materials derived from other minerals such as sandstone and shale which have piled up and been lithified by compaction and cementation. Sandstone and shale also categorized as weak or loose rocks that has laminated structure. Sedimentary rocks exhibit anisotropic behaviour at all scales. Recent publications show very strong elastic and transport property anisotropy especially in shaly formations [6]. Anisotropy is one of the factors that affect the behaviour and strength of rocks. Zeng *et al.* [7] believed that the rock anisotropy can be one of the dominant factor in the development of fractures in sedimentary rock mass. Fractures, as comprehensively known as one of the rock discontinuities and it is generally recognized that rock discontinuities affect the strength properties of rock masses, and many examples can be cited from the relevant literature of rock failure due to the misjudgement of the effect of discontinuities on rock strength [8]. Palmstrom [9] suggested that anisotropy in rock material is mainly caused by schistosity, foliation or bedding and the different in properties is determined by the arrangement and amount of flaky and elongated mineral such as mica, chlorite and amphiboles. Ajalloeian and Lashkaripour [10] defined anisotropy index, Ia_{50} as the ratio of mean strength index values measured in the strongest and weakest direction (perpendicular and parallel to the planes of weakness). ISRM [11] in the meantime, defined anisotropy index as the ratio of mean anisotropy values measured perpendicular and parallel to planes of weakness.

2.1.1. Shale.
Shale is a fine-grained clastic sedimentary rock that composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite from the weathering of rocks which is deposited and accumulated in a sedimentary area. Shale is distinguished from other mudstones because it is fissile and laminated. The term laminated in shale means that the rock was made up of many thin layers meanwhile fissile means that the rock is ready to split into thin pieces along the laminations structure. Shale typically characterized by fine lamination that is parallel to the bedding plane and will break along the thin laminate which is known as fissility. Owing to their fissility, shale rock tends to split unevenly by parallel to the bedding plane and break up in flakes when subjected to immense weathering. Abhijit [12] believed that the structure of shale cause shale rocks to be easily broken into flakes and tend to split unevenly under the loads or influence of weathering agents, especially water. 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. Edy *et al.* [2] believed that shale with higher moisture content has the tendency to exhibit wider range of anisotropy index, Ia_{50} and lower strength in its respective weathering grade.

2.1.2. Sandstone.
Sandstones are clastic in origin. They are formed from cemented grains that may either be fragments of a pre-existing rock or be mono-minerallic crystals. The cements binding these grains together are typically calcite, clays, and silica. Sandstone's banding is due to layers of sand that are deposited with differing characteristics. Sandstone is formed in many deposits that are episodic in nature and the resulting layers can be very different from previous layers. Sometimes the sand is courser or finer than the previous layer and this difference causes the banding. In 2008, Edy *et al.* [13] has 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.

3. Methodology
In order to achieve the objectives of this study, it is important to explore the texture and the properties of the rock. Site observation and laboratory tests are being conducted in order to obtain the sample and to determine the rock properties and to assess the effect of moisture content and anisotropy of shale and sand stone. The study area is located at Gelang Patah, Johor Bahru where site observation has been conducted.

3.1 Field Works
The study site SilC Nusajaya is mainly underlain by shale and sandstone of Jurong Formation. The sample was collected and classified by types, colors and texture. The shale sample collected is moderately weathered which has whitish grey with slight discoloration on the surface and the edge is easily broken. The texture is very fined-grained but fissile and embedded the lamination is obvious. Meanwhile, the sandstone sample is coarse in texture and the lamination is not obvious. The sample consists of moderately weathered sandstone and shale. Weathering grade determination of material at site was carried out by referring to Table 1 and Table 2.

Table 1. Weathering profile classification of rock mass [14].

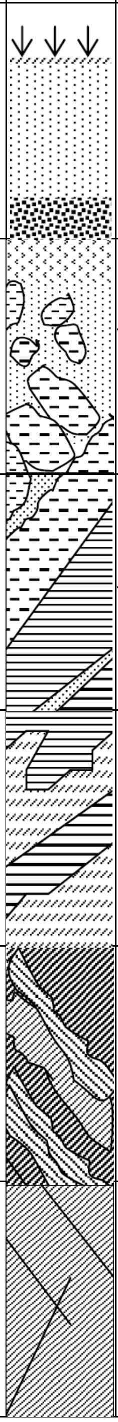
Classification	Weathering Zone	Log	Descriptive
Residual Soil	VI		Upper Soil
			All rock materials changed into soil. No texture or rock mass structure preserved. Homogenic.
Completely Weathered	V Vc		Zone is rich in Iron Concretion. Unclear texture, less than 25% preserved fabric. Preserved structure. Whole materials changed to soil. Stained.
	Vb Va		Whole materials changed into soil. Reddish color, Stained with original material 25-27% fabric are preserved. Materials disintegrate in water or crushable by hand.
Highly Weathered	IV IVb		Materials changed into soil preserving original color and textures. > 75% preserved texture, easy to disintegrate in water and crushable by hand. Slaking.
	IVa		Material is in transition to IVb condition. Texture & structure intact. Small fragments formed when cruch in hand or immerse in water. Geology Hammer does not rebound.
Moderately Weathered	III		Color changes in all earth materials (original color increases). Whole texture & structure of rock mass unchanged. Edge of rock material are hard to break by hand. Schmidt Hammer average value is less than 30. Geology Hammer rebounds by hit but does not rings, discontinuity filled with iron oxide.
Slightly Weathered	II		Sligthly changes of color in material. Most materials are still fresh. Changes of color on discontinuity clearly exceed 1cm.schmidt Hammer average value is more than 30. Geology Hammer rebound s and rings. Discontinuity spacing is filled with iron oxides.
Fresh Rocks	I		No changes of forms or color in earth materials. Slightly or no iron stains in discontinuity spacing. Geology hammer rebounds and rings on hit.

Table 2. Weathering classification used to describe the rock mass/material [15].

Description	W/G	MATERIAL				MASS			
		Colour	Texture	Slaking		Structure		Iron-rich layer	Strength (Schmidt hammer)
				In water	By Hand	Condition	Changes		
Residual soil	VI	Completely changed (homogeny)	Destroyed	Disintegrate	Disintegrate	100% destroyed	Completely changed	None	None
Completely weathered	V	Completely changed (homogeny or	Half remain unchanged			<25% remains		Normally exist	
Highly weathered	IV	Completely discoloured	Unchanged	Becomes flakes or small pieces	Becomes flakes or small pieces	>50-70% remains	Iron-rich filling in discontinuity	May exist	Less than 25
Moderately weathered	III	Slightly discoloured		Remain as Mass	Edge can be broken	100% intact			
Slightly weathered	II	No changes			Edge unbroken		Discolorations along discontinuity	None	Exceed 25
Unweathered	I						No changes		

Table 3. Classification of Rock Strength Using Schimdt N Type Hammer [16].

Strength	Low	Medium	High	Very High	Extremely High
Schmidt Hammer Rebound Value	< 10	10 - 25	25 - 40	40 – 60	> 60

Samples were tested in original moisture content, 15 minutes, 30 minutes and 60 minutes after soaked in water. For examples, six samples were tested in point load test at original moisture condition and another six samples were tested after 15 minutes soaked in water. Then another six samples were tested after 30 minutes soaked and the last six samples were tested after 60 minutes soaked in water. The duration of soaked and moisture content of each samples were taken before and after the test is carried out.

Point load test was conducted on the samples perpendicular and parallel to the weakness planes of the rock in order to determine strength and anisotropy index of shale and sandstone. The same results have been used to determine anisotropy index of the rock. Therefore, the prepared samples were not only used for strength index determination, but they were also used to determine the anisotropy using Table 4.

Table 4. Anisotropy classification according to anisotropy index [11].

Degree of point load strength anisotropy, $Ia_{(50)}$	Descriptive term
1	Isotropic
1 – 2	Faily-moderately anisotropic
2 – 4	Highly anisotropic
> 4	Very highly anisotropic

3.2 Point Load Test

This test can be classified as indirect measure of tensile strength. The technique is evaluating resistance load of the sample strength at which a compression load between two cone bits loads it. Photograph of point load apparatus is shown in Figure 3.6. One of the advantage of point load is it can be applied to either rock core or irregular lumps through points of standard dimension. The aim of this test is to determine the point load index Is_{50}.

The *Is* value has been transformed to a 50mm reference diameter, the strength that being known as the Is_{50} index which is expressed in MN/m^2 (MPa) as below.

Uncorrected strength, $$I_S = \frac{P}{D^2} \tag{1}$$

Corrected strength, $$I_{s50} = F\frac{P}{D^2} \tag{2}$$

Where, $$F = \frac{D^{0.45}}{50} \tag{3}$$

For the other than cores an 'equivalent core diameter', De is calculated such that the minimum cross sectional area is

$$A = WD = \frac{\prod De^2}{4} \tag{4}$$

Or

$$De^2 = \frac{4WD}{\prod} \tag{5}$$

The strength computation can be performed using De instead of D, which is

$$I_{s50} = F\frac{P}{D^2} \tag{6}$$

And

$$F = \frac{D^{0.45}}{50} = \frac{(De^2)^{0.225}}{2500} \tag{7}$$

For other core sizes the $\frac{P}{D^2}$ is retained and can be multiplied by a size correction factor, F.

3.3 Moisture Content

The moisture content or water content was adopted in this study because to measure the mass of water contained in a rock sample as a percentage of the oven dry sample mass. The controlling factors lie in the sample storage and pre-treatment (temperature), and duration of the test (time). According to [13], high water content will decrease the strength of the material. This is due to the fact that; water would soften the bonds or interacts with mineral surface, water can decrease of frictional shearing resistance will cause instability of weakness plane and alter their surface properties

Another samples have been soaked in water within 15 minutes, 30 minutes and 60 minutes before they are tested in point load test. Moisture content of each sample has been calculated and recorded before and after the test is conducted by using this formula.

Water content, $$w = \frac{B-C}{C-A}x100\% \tag{8}$$

3.4 Determination of Anisotropy Index, Ia_{50}

In order to investigate the effluence of moisture content to the anisotropy index of weathered shale, the anisotropy index was determined from the strength index perpendicular and parallel to the weakness planes of the weathered shale. Figure 1 illustrates the orientation of perpendicular and parallel load to the plane of weakness. Determination of anisotropy index that was suggested by [11] was closely followed and applied. The equation that was used to determine anisotropy index is as follow:

$$Ia_{50} = \frac{Is_{(50)\perp}}{Is_{(50)//}} = \frac{\text{Perpendicular Point Load}}{\text{Parallel Point Load}} \quad (9)$$

where $Is_{(50)\perp}$ and $Is_{(50)//}$ is the point load strength of rock block or irregular lumps perpendicular and parallel to the weakness planes at the axial of the samples.

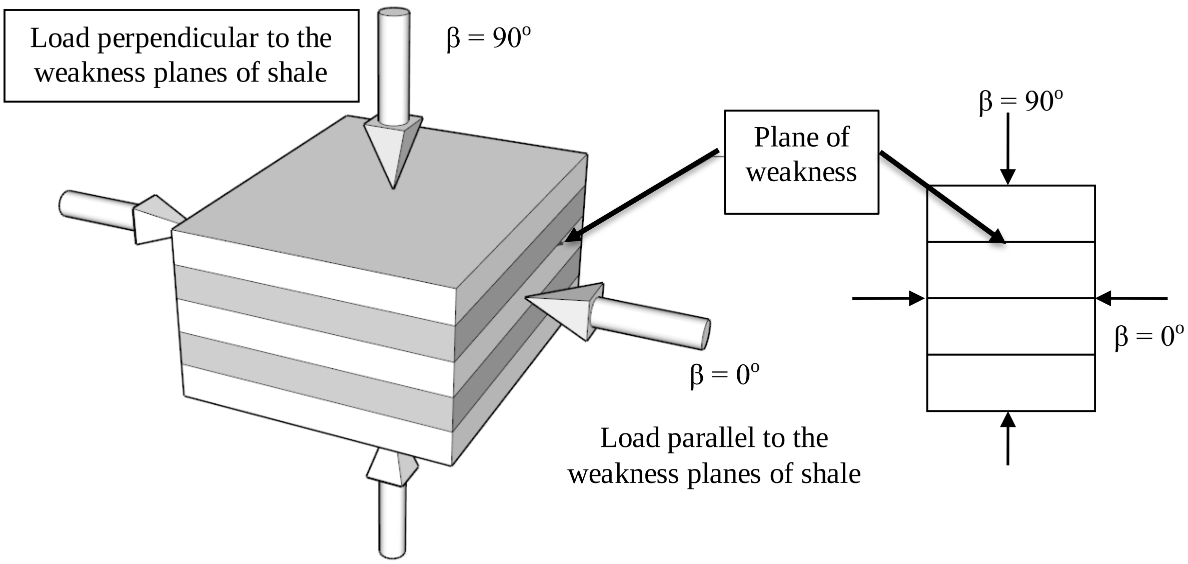


Figure 1. Orientation of perpendicular and parallel load to the plane of weakness.

In this study, samples were tested at different moisture contents. For example, shale sample in original moisture content, six samples were tested. The three samples were tested for perpendicular load to the foliation weakness planes and the other three samples were tested parallel load to the weakness planes in the same condition. These tests gave result on three data of anisotropy index. Then, another six samples were tested after 15 minutes, 30 minutes and 60 minutes soaked. Anisotropy index of weathered shale and sandstone then were classified based on the degree of point load strength anisotropy as shown is Table 1. This classification is to identify the type of anisotropy of weathered shale whether they are isotropy, faily-moderately anisotropy, highly anisotropy or very highly anisotropy. This classification was correlated to the strength of the weathered shale in order to identify the relationship between strength and anisotropy index of weathered shale.

4. Result and Analysis

The study site at SiLC Nusajaya is mainly underlain by massive shale and sandstone of Jurong Formation. During sample collection, moderately weathered shale and sandstone were collected and careful observation on the color, texture, friability and surface hardness were made for every sample. Then, the samples were taken to laboratory for further action. In laboratory, Point Load test was conducted to determine strength index and anisotropy index. Each type of rock was tested in original moisture content, 15 minutes immersion, 30 minutes immersion and 60 minutes immersion. Moisture content for every sample was determined before the testing.

4.1. Field Study

Table 5. Summary of Physical Appearance of Sample

Rock Type	Color & Texture	Description	Friability	Lamination
Shale 	Whitish grey with some discolouration on surface and discontinuities. Colour changes in earth materials but texture and structure of rock mass is unchanged. The texture is very fine. Moderately weathered shale.	Iron oxides cover discontituities spacing and surfaces. Schmidt Hammer Rebound Value is from 20 to 28. Point load index were recorded from 3.24 to 5.2 MPa with original moisture content between 1.03% to 1.1%	By hammer or by hand	Very obvious
Sandstone 	Yellowish colour changes in earth materials but texture and structure of rock mass is unchanged.Material has coarse grained. Moderately weathered sandstone.	Schmidt Hammer Rebound Value is from 30 to 48. Point load index were recorded from 6.5 MPa to 7.3 MPa with original moisture content between 0.98% to 1.03%.	By hammer	Not so obvious

4.2. Laboratory Assessment

4.2.1 Effect of Moisture Content on the Strength Index.

Twenty-four samples of each type of rock were tested by using Point Load Test to determine the strength index and anisotropy index. The samples were tested in original moisture content, after 15 minutes immersion, 30 minutes immersion and 60 minutes immersion. Figure 2 presents the reduction in strength index of shale and sandstone under various percentage of moisture content.

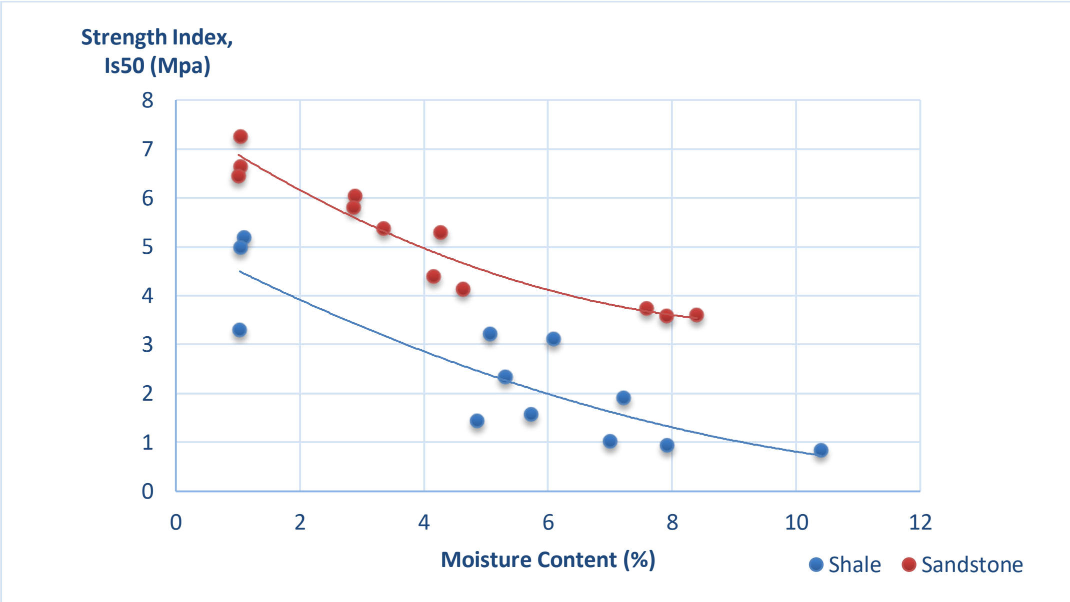


Figure 2. Variation of Strength Index, Is50 and moisture content

Table 6. Average Increment of Strength Reduction (%)

Types of Rock	**Average Increment of Strength Reduction (%)**		
	0 - 15 mins	**0 - 30 mins**	**0 - 60 mins**
Shale	36%	64%	80%
Sandstone	16%	32%	46%

Table 6 shows the average increment of strength after 15 minutes, 30 minutes and 60 minutes of immersion. After 15 minutes of immersion, the strength of shale reduced 36% while sandstone reduced only 16%. By soaking the sample for 30 minutes, the strength of shale was reducing 64% while sandstone reduce up to 32%. And after 60 minutes immersion, the strength of shale reduced 80% while sandstone reduced 46%. From here can be concluded that, the presence of moisture content reduced shale strength tremendously than sandstone. From here can be said that, moisture content affect the strength properties of shale more than sandstone for it reduced 80% of shale strength compared to 46% of sandstone strength based on the Table 3.

Table 6 also shows that shale has high strength at original moisture content. When the moisture content is been introduced the sample has a low strength. Meanwhile, sandstone has a very high strength although when is tested under different moisture content. This shows that, moisture content does not have a significant effect on sandstone compared to shale. The classification of rock strength is using a table of evaluation of rock strength proposed by [16] as attached in Appendix.

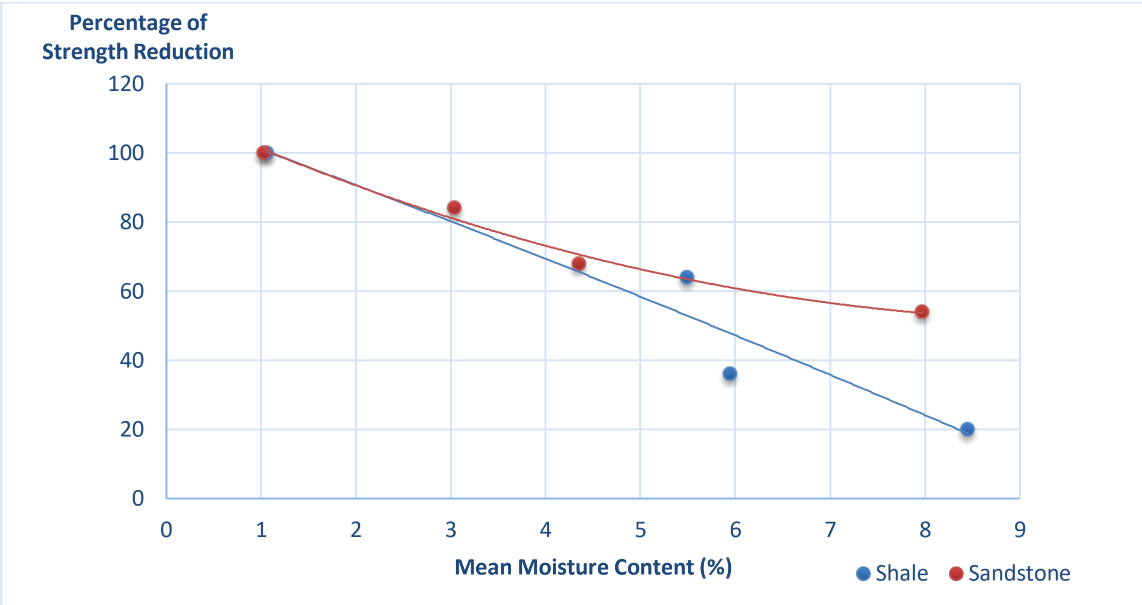


Figure 3. Percentage of Strength Reduction vs Moisture Content

4.2.2. Effect of Moisture Content on Anisotropy Index.
Table 7 shows that shale that has anisotropy index ranging from 1.16 to 2.3 is described as fairly to moderately anisotropic. The moisture content has great influence on anisotropy index of shale as it able to change the condition on shale in original moisture content that fairly-moderately anisotropic to highly anisotropic after the sample was immersed. However the sandstone remain in the same category which is fairly-moderately anisotropic although it have been immersed in the water. This shows that moisture content does not have significant influence on the anisotropy of sandstone. The classification of anisotropy description is done by using anisotropy classification proposed by [11].

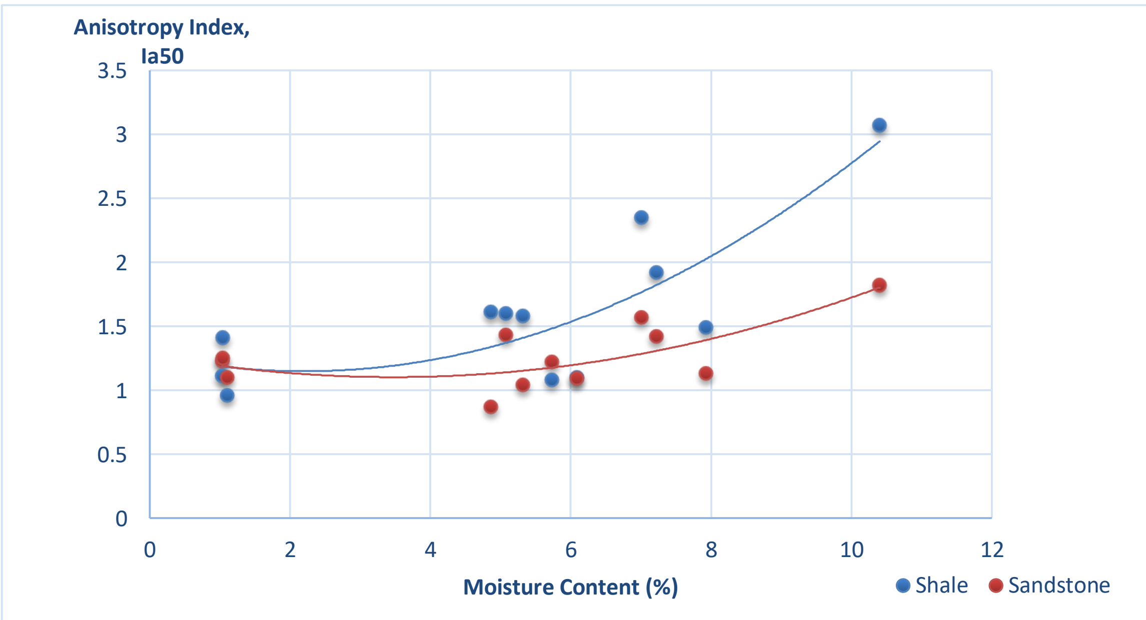


Figure 4. Variation of anisotropy index, Ia_{50} and moisture content.

Table 7. Anisotropy classification according to anisotropy index.

Types of Rock	Anisotropy Index, $Ia_{(50)}$	Descriptive Term
Shale	1.16 – 2.3	Fairly-moderately to Highly
Sandstone	1.07 – 1.51	Fairly-moderately

5. Conclusion

The results can be summarized as follows:

a) The presence of water has affected shale more than sandstone in term of strength and anisotropy index.
b) The presence of water has reduced 80% of shale strength under 8.45% moisture content and 40% of sandstone strength under 7.97% moisture content
c) With the presence of water, anisotropy index of shale is increasing from 1.16 to 2.3 (fairly moderately anisotropic to highly anisotropic) while sandstone has slight increment from 1.19 to 1.51 (remain as fairly moderately anisotropic).

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