Uniaxial Compressive Strength of Composite Rock Material with respect to Shale Thickness Ratio and Moisture Content

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ABSTRACT

The strength of intact rock is one of the prime parameter used to classify the quality of rock mass. So far the study is mainly on the behaviour of uniaxial compressive strength of a homogenous rock. Unfortunately, for tropical Kenny Hill sedimentary rock formation, the rock mass constitutes of more than one type named as composite rock. An experimental study was carried out to determine the strength and behaviour of a composite rock specimen made of sandstone and shale (Kenny Hill formation) at different moisture content. Shale was used as an intermediate layer of sandstone rock sample and prepared to the standard size as composite rock material. The composite specimens were tested for uniaxial compressive strength to failure and the results were analysed accordingly. A series of graphs was plotted to determine the uniaxial compressive strength of composite rock with respect to change in the shale constituent and moisture content. The result shows that shale has a great influence on the strength behaviour of Kenny Hill which is known to be dominated by sandstone. The higher moisture susceptibility of shale comparative to sandstone denotes a significant impact to the overall strength of the rock mass.

KEYWORDS: Kenny Hill, composite rock, uniaxial compressive strength, sandstone, shale

INTRODUCTION

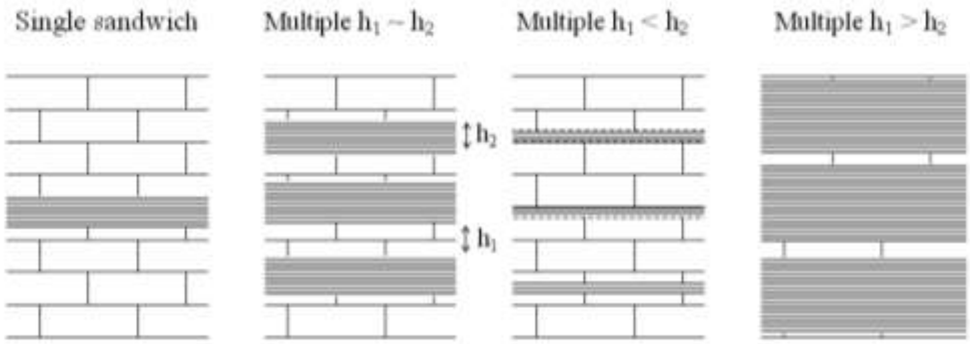
The determination of rock strength by the in-situ test is the most preferable and reliable method of testing. However, the technique is normally very tedious and expansive exercise to be performed.

Rock strength is the most important parameter representing the bearing capacity of rock mass (BS 8004, 1986) Hence, an alternative method by rock material strength index test has been commonly adopted. The uniaxial compressive strength of intact rock specimen of homogenous and isotropic rocks such as granite, sandstone, basalt and etc had been well published. Substantially, all the findings were based on the study conducted on a single rock type that ranges from hard to weak rocks. Unfortunately, little study has been conducted on anisotropic and non-homogenous rock to address the complexity of the tropically weathered sedimentary to metamorphic rock mass (Zainab *et al*, 2007)

Composite Rock

Composite rock is defined as rock mass which constitutes of more than one type of rock in a rock mass (Mohamed, 2004) Most of these rock masses are of sedimentary to meta-sedimentary formations and the geological sedimentation process produced an interbedded profile of different rocks, one being weaker than the other. To name a few are the Kenny Hill formation widely found in Kuala Lumpur and Klang Valley bedrock within the state of Selangor, Malaysia. It is of meta-sedimentary formation that consists of sandstone and siltstone interbedded with thin layer of clay-shale ranging from one centimetre to one meter thickness. The Jurong formation in Singapore constitutes of an alternation of mudrock, sandstone, shale and conglomerates. The study carried out by Liu *et al.* (1998) on this formation reported that on average the strength of highly weathered sandstone, mudstone and phyllite reduces to by more than 90% from unweathered state. Goodman, (1993) has earlier emphasized that any combination of more than one type of rock having different properties shall impose a complex geotechnical engineering problem.

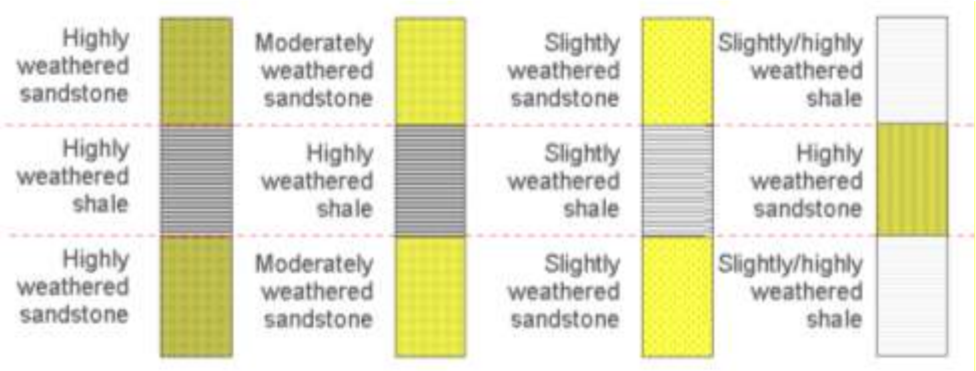
Duffault (1981) has first published his study to simulate and model the sandwich rock mass profile. Figure 1 shows the typical ideal profiles of such formation named as single sandwich and multiple sandwiches. The figure illustrates the four conditions of the sandwich profiles with the presence of weaker material (h_1) in various thicknesses.



(a) (b) (c) (d)

Figure 1: Heterogeneity of sedimentary formations (redrawn from Duffault, 1981)

Similarly the interbedded layer of sandstone, siltstone and clay-shale is very distinct in Kenny Hill tropically weathered meta-sedimentary formation in Malaysia. From the study, Zainab *et al*. (2007) had proposed four possible profiles of the composite models from Kenny Hill formation by grade of weathering. The schematic illustration of the profiles is as shown in Figure 2, representation of the matrix composite of sandstone and shale, each ranges from slightly weathered, moderately weathered to highly weathered state. The rock mineralogy, texture and structure vary respectively thus resulted to different rate of weathering. Figure 2 (a), (b) and (c), highlight the existence of weathered shale as an intermediate layer to weathered sandstone. Contrarily Figure 2(d) highlights the possible dominant layer of weathered shale as a unit rock mass. The significance of tropical rock weathering must be of utmost concerned for any study in tropical environment because it has great impact to the strength and behaviour of rock mass.



(a) **(b)** **(c)** **(d)**

Figure 2: The illustration of four possible profiles of composite rock (after Mohamed, 2004)

Figure 3 further illustrates the on-site outcrop profile of Kenny Hill formation showing the interbedding of thin layer of weathered shale to the thicker layer of weathered sandstone.

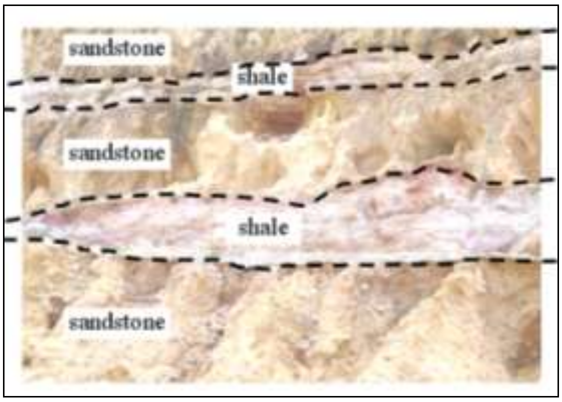


Figure 3: Typical composite profile of a tropically weathered Kenny Hill outcrop

MODELLING THE COMPOSITE ROCK

Less than a decade ago, many studies have been initiated to determine the strength and behaviour of composite rock. Greco (1994) conducted a study to observe the failure mode of stratified rock pillars in an underground excavation. He observed a distinct different in the failure mechanics of the stratified disk specimen from that of single rock. Vlasov and Merzlyakov (2004) had studied the deformability characteristics of composite rock by using the asymptotic method averaging differential equations. Within the same time, Lydzba *et al*. (2003) has also conducted the mathematical approach known as homogenization techniques to study the composite rock of sandstone and claystone. He reported that the strength of composite rock decreases with an increase in sandstone volume and confining pressure. The latest, Liang et al. (2007) found that the uniaxial compressive strength of bedded salt rocks (anhydrite–halite and mudstone–halite), are governed by the weakest material. The attempt made by Lee et al. (1998) and Carbone and Codegone (2004) had determined the effect of the mortar thickness on the orthotropic material like masonry wall. Generally all of these studies indicated that the strength of layered composite material is governed by the weaker constituent, their respective volume fraction and strength.

A laboratory study carried out by Zainab *et al.* (2007) to determine the strength of tropically weathered sandstone and weathered shale was reported to be a challenging task. The study was conducted on individual grade of weathering for sandstone and shale. The uniaxial compressive strength and point load strength of the respective weathered sandstone and weathered shale were used to formulate and predict the strength of the composite rock model as shown in Figure 2. The finding revealed that the presence of weathered shale has significant influence to the overall strength of the composite rock mass although it was dominated by harder material such as sandstone.

The influence of moisture content to the strength and deformability of individual sedimentary rocks has been reported by Inoue and Ohomi (1981) and later by Marinos and Hoek (2001) They highlighted that the strength of weak rock significantly decreases with an increase in water content. Vasarhelyi (2003) reported that the uniaxial compressive strength of saturated sandstone is 76% lower than dry state. A similar study on limestone reported that the strength reduces to 66% lower than dry sample. This was further supported by Weng *et al*. (2005) whereby it was also found that the strength of saturated Taiwan's sandstones is between 15 % to 80% of the dry specimens.

This study reported the preliminary results of the uniaxial compressive test on the designed models of composite rock material. The influence of the weathered shale thickness ratio to the uniaxial compressive strength of composite rock material at dry and wet state was observed.

MATERIAL AND METHODOLOGY

Block samples of weathered sandstone and shale were extracted from Kenny Hill sedimentary formation at Puncak Perdana's construction site in Shah Alam. The sandstone was classified based on the hardness of rebound hammer with an average value of R approximately 32 while shale rebound hardness was about 6, both were classified as moderately weathered rocks. Natural moisture content of weathered sandstone and shale were found to be within the range of 0.13 % to 0.67 % and 0.83 % to 1.71 % respectively. The dry density was in the range of 2.05 g/cm^3 to 2.14 g/cm^3 for sandstone and 1.77 g/cm^3 to 1.98 g/cm^3 for weathered shale. The broad range of values is common for tropically weathered rocks.

The cylindrically cored specimens for uniaxial compression test were prepared with the length to diameter ratio of 2.0. The two ends were then trimmed and further flattened to the desired size of disc to form the five categories of samples as depicted in Figure 4. Each composite material was designed by stacking the disc together using a thin slime of gypsum plaster as a bonding material. The individual sample of weathered sandstone and shale were also prepared as the control samples. The composite samples were designed into three different thickness ratio of shale to the total height of sample, *H*, each having 0.1*H*, 0.2*H* and 0.3*H* of shale. Each sample was then marked as composite 1, composite 2 and composite 3 respectively. These composite samples were designed to simulate the possible geometry profile of the constituents in the interbedded sedimentary formation.

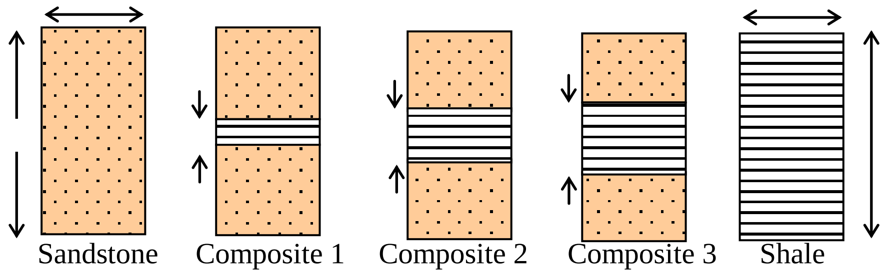


Figure 4: The five categories of samples

To achieve the objective of this study, the following testing programs were performed:

The first group of samples were tested in dry condition, and

The second group of samples were soaked in water for 24 hours under control room temperature and tested in wet condition.

The purpose of carrying out the uniaxial compressive strength test on weathered sandstone and shale were meant to establish the reference control points. Following that, the uniaxial strength test on each composite sample shall record and analyse the role and influence of weathered shale to their respective global strength. The second set of test shall study the effect of moisture content to the strength of the composite samples. The uniaxial compressive tests were performed in accordance with the ISRM suggested method (ISRM, 1981). The findings were then analysed and concluded as follows.

RESULTS AND DISCUSSION

For each set of test, ten specimens were prepared. However, due to the fragile properties of weathered shale, a few of them were not successfully tested for its uniaxial compressive strength. Table 1 and Table 2 show the results of uniaxial compressive strength of the dry and the wet specimens respectively.

Table 1: The uniaxial compressive strength of dry specimens, σ_c (MPa)

Strength of dry specimens, σ_c (MPa)				
Weathered Sandstone	Composite 1	Composite 2	Composite 3	Weathered Shale
40.10	13.24	8.96	7.90	8.63
33.76	9.96	10.64	9.39	5.95
38.79	7.74	13.58	10.46	8.27
35.18	7.85	10.29	7.54	6.29
35.34	11.84	10.65	7.53	6.64
-	12.45	8.97	8.66	9.87
-	10.26	10.30	-	-
-	15.86	-	-	-
Mean=33.63 Std dev=2.68	Mean=11.15 Std Dev=2.76	Mean=10.48 Std dev=1.55	Mean=8.58 Std dev=1.17	Mean=7.6 Std dev=1.55

Table 2: The uniaxial compressive strength of wet specimens, σ_{cw} (MPa)

Strength of wet specimens, σ_{cw} (MPa)				
Weathered Sandstone	Composite 1	Composite 2	Composite 3	Weathered Shale
19.42	10.61	6.10	5.21	6.66
26.83	8.41	6.06	6.76	3.87
21.35	7.24	8.54	7.03	6.61
20.34	6.52	8.17	6.79	4.78
26.47	5.28	8.09	4.64	-
18.90	8.36	5.89	5.69	-
-	7.57	8.55	7.44	-
-	7.29	5.87	5.00	-
-	-	-	8.82	-
Mean=22.22	Mean=7.66	Mean=7.16	Mean=6.38	Mean=5.48
Std dev=3.53	Std dev=1.56	Std dev=1.27	Std dev=1.35	Std dev=1.38

From the results, the uniaxial compressive strengths with respect to each category of sample in the dry and wet condition were then plotted. For each data set, the arithmetic mean was calculated to illustrate strength profile in graphical format. The mean value was used in the analysis to represent on average properties and behaviour of the sample under each condition.

Strength of Dry Composite Material

Figure 5 shows the graphical plot of uniaxial compressive strength with respect to their own specimens in dry condition, σ_c. As shown in Figure 5(a), five specimens of sandstone exhibit the strength between 33.76 MPa to 40.1 MPa with linear average of 36.63 MPa and standard deviation of 2.68.The strength of weathered shale specimens (Figure 5 (e)) ranged between 5.95 MPa to 9.87 MPa, having the mean value of 7.6 MPa and standard deviation of 1.55. The standard deviations described the variability of weathered sandstone is about 1.7 times higher than weathered shale. This is explained by the type of texture matrices of the weathered sandstone and weathered shale that are influenced by the percentage ratio of quartz grains to cement matrix and deteriorates with the degree of weathering. This was justified through texture study published by Zainab et al. 2007. Sandstone is classified as moderately weathered and shale is slightly weathered by their respective uniaxial compressive strength.

Figures 5(b), 5(c) and 5(d) show the presence of weathered shale as an intermediate layer in term of thickness ratio of the composite specimen. The mean strength values of composite 1, composite 2, and composite 3 are 11.15 MPa, 10.48 MPa and 8.58 MPa respectively. Relative comparison to sandstone, the strength of composite 1 is reduced by 70 % for shale thickness ratio of 0.1H, followed by 71 %, and 77 % for the composite 2 (0.2H) and composite 3 (0.3H) samples. In other words, 10% of shale reduces the strength of composite sandstone drastically by 70% and as the thickness ratio increases by 10% the strength further reduces by additional 1 % and 6 % consecutively. The results explained the needs to critically identify the presence of shale in the sandstone dominated sedimentary rock mass.

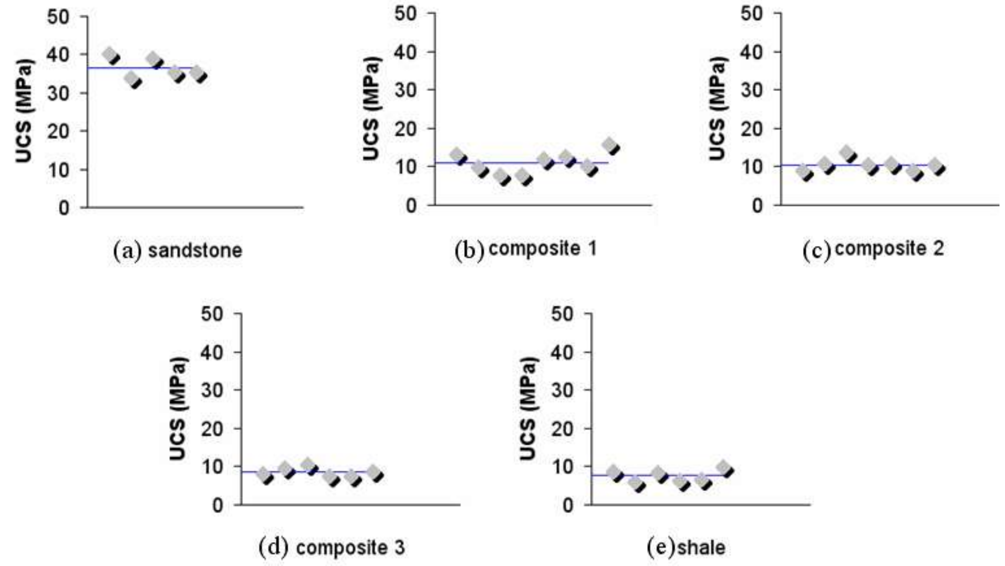


Figure 5: The uniaxial compressive strength of the dry specimens

When the same result was benchmarked to the strength of shale, the presence of sandstone in composite 3, composite 2 and composite 1 has increased the strength of the respective samples by 13 %, 38 % and 47 %. It is shown that the presence of sandstone also has implication on the strength of shale dominated sedimentary rock mass.

Strength of Wet Composite Material

Similar graphical plot was done as shown by Figure 6 for wet specimens. The average moisture content of sandstone was 2.7% and shale was 1.8% at a control 24 hour soaking time. For this initial study, these moisture content was assumed to represent moisture content of the composite specimen. The reason was due to the sensitiveness of shale to moisture. The uniaxial compressive strength of wet sandstones was in the range of 18.90 MPa to 26.83 MPa (Figure 6a) and wet shale between 3.87 MPa to 6.66 MPa, as shown in Figure 6e. The mean strength of sandstone and shale are 22.22 MPa and 5.48 MPa while their respective standard deviation is 3.53 and 1.38. As for the composite samples, the mean strength is 7.66 MPa, 7.16 MPa and 6.38 MPa respectively. Taking sandstone as reference, the strength of composite 1, has plunged by 66 %, followed by 68 %, and 71 % for the respective models of wet composite samples. Vice versa, the increase in the ratio of wet sandstone in the shale dominated material tends to increase the strength of wet shale by 16 % for composite model 3, 31 % for composite 2 and 40% for composite 1.

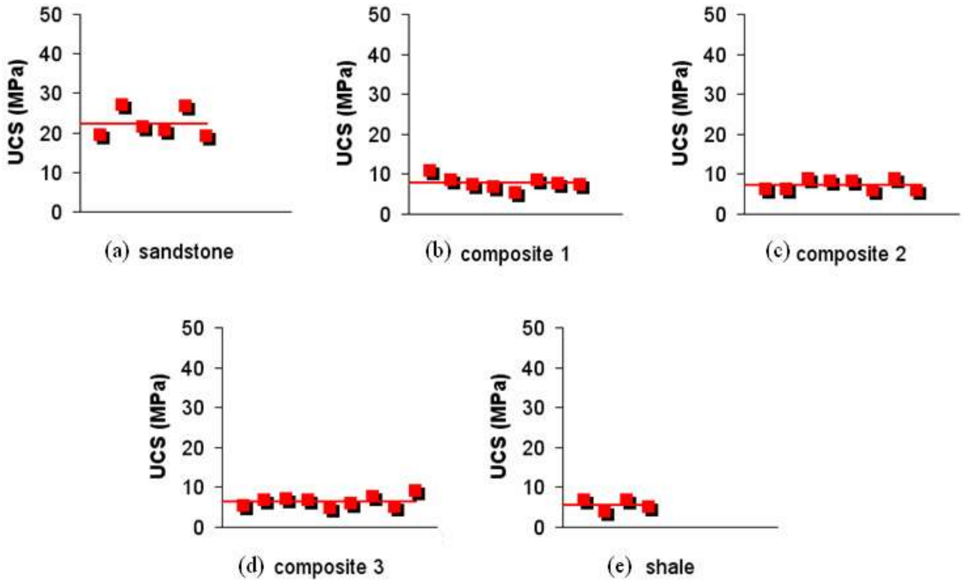


Figure 6: The uniaxial compressive strength of the wet specimens

Thickness Ratio and Moisture Content

To determine the significant role of very weak rock layer such as shale in tropically weathered Kenny Hill, a graphical profile was drawn to correlate uniaxial compressive strength of composite rock to the shale's thickness ratio and moisture content, as shown in Figure 7. Curvilinear lines were plotted to demarcate the strength boundaries of dry and wet samples. These bands represent the strength envelope with respect to moisture content. It can be seen that as an individual material, the strength of sandstone and shale are at the two extreme ends and on average, the strength of sandstone is about 4.5 times higher than shale at dry state. However, in wet condition, the respective strength of sandstone and shale were reduced by 34% and 27% each despite that, physically, shale tends to soften and is less brittle than sandstone at failure.

Geologically, Kenny Hill rock mass is dominated by sandstone which is considered as competent rock. The presence of relatively thin layer of shale should not be taken for granted. The result showed that an increase of less than 0.1H of shale has drastically dropped the strength of sandstone composite as the first failure in the load bearing of any of the constituent concluded as the global failure of composite rock. Subsequently, additional increase in the thickness ratio of shale does not shows much change to the global strength of composite sandstone as obviously seen by the uniform bandwidth between the upper and lower boundaries. For every test conducted, the probability of factures being first triggered by shale was greater than sandstone, thus demonstrated the critical role of shale material in stronger sandstone composites.

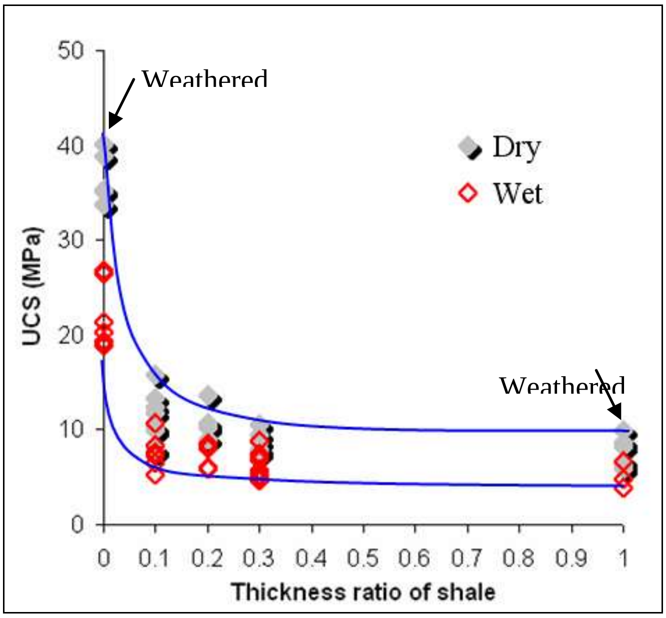


Figure 7: The strength envelope of dry and wet composite rock

CONCLUSION

This study has successfully demonstrated the influence of shale weak rock to the strength of sandstone composite, simulating the engineering properties of Kenny Hill interbedded sedimentary rock in tropical environment. Most of the time, shale dictates the load bearing capacity of the composite sandstone. These studies are limited to the proposed model of composite rocks and specified constituent materials that conclude the findings. It can be expected that underestimation of the presence of relatively thin layer of weak rock in the hard rock mass may introduce future geotechnical catastrophe.

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