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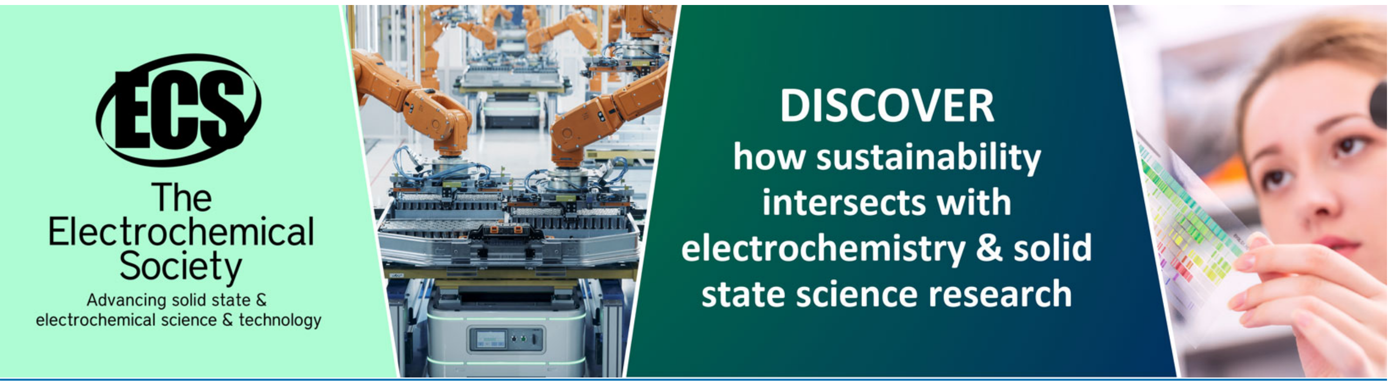

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Interaction of mineralogical content with engineering properties of selected weathered Semanggol formation mudrocks

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Abstract. A comprehensive study of rock properties is crucial to investigate and characterize the behavior of rock when it undergoes multiple loading and stresses. The properties of rocks are heavily influenced by weathering grade and the composition of minerals which indicates the hardness, swelling potential and abrasiveness, therefore give an effect on the strength and the durability of rocks. The interaction between mineralogy and engineering properties are significantly important for the engineer to fully understand the behavior of mudrock for further application especially in Malaysia. Selected weathered mudrocks from Bukit Kukus Kedah, a part of Semanggol formation were characterized for physical, mechanical and mineral properties. The result shows the degree of weathering influenced the physical and mechanical properties of mudrock. The sample with low porosity and high density possessed highest slake durability index of 91.43%. X-Ray diffraction revealed two of the sample tested were consists of goethite and quartz. The sample presence with goethite is higher in durability compare to sample consists of quartz only due to the cementation effect and denser minerals.

1. Introduction

The study of rocks is crucial for the design and construction purposes especially in geologically oriented project such as underground excavation, tunnel, dam etc. Soft rocks can be defined as medium to fine grained size sedimentary rocks such as mudstones, shale, sandstones, greywacke that classified as clay-bearing rocks and much softer than igneous rocks and metamorphic rocks. Soft rocks are generally classified as weak rock in engineering perspective due to its low resistance to disintegration, low shear and compressive strength, high swelling potential, crumbling, fast weathering and other characteristics [1][2]. Due to these unfavorable behaviors, soft rocks are hardly to be utilized in important engineering works. However, regions which dominated by soft rocks have challenged the civil engineers and construction companies to deal with them [2].

In Malaysia, numerous numbers of research been conducted on Semanggol formation mudrocks at Kedah comprising of stratigraphy, sedimentology, structural characteristics, geological, geotechnical properties and geophysical techniques [3][4] [5] [6] [7] [8]. Latest research conducted on Semanggol formation mudrock by [8] was on the correlation of the geotechnical properties of black shale and weathered interbedded chert-shale with its geological processes and depositional history. Despite of plenty research been conducted in Semanggol mudrocks in Kedah, least study focusing on interaction of weathering grades and mineralogical contents with engineering properties which potentially to be utilized in engineering works. Meanwhile studies by [9] [10] highlighted the effect of mineralogical content on the durability of mudrocks in Perak and Iran respectively. A study from [11] [12] revealed that the formation of clay minerals also indicates the rocks sample undergoes weathering process and sensitive to variation of moisture content which are affected mechanical properties such as the compressive strength of soft rocks. This study is aimed to give a good indication on the effect of mineralogical content with regards to the weathering grades and other geomechanical properties of weathered Semanggol formation mudrocks in Kedah.

2. Material and Methods

2.1. Sample Collection

The rock sample were collected at Bukit Kukus, Kuala Ketil, Kedah. The chert unit of Kulim – Baling area located at 5°35’27.6”N 100°41’44.5”E was specified as the site location. This location is part of Semanggol formation and comprising of four components of lithologies; laminated black mudstone, interbedded mudstone and sandstone, volcanic sediments and thinly bedded chert [6] as seen in Figure 1. Six (6) medium-sized of rock boulders as in Figure 1 was taken from natural ripping process and in-situ rebound hammertest was conducted to classify its weathering grade accordingly.

(a) (b)

Figure 1. (a) : Site location at Bukit Kukus, Kuala Ketil, Kedah (b) : Mudrock samples collected from site.

2.2. Physical Properties

The saturation and caliper technique were applied in determining the value of porosity and dry density as suggested by [13]. Twelve mini samples with dimension of 3 cm length x 3cm height or weighed at least 50g were produced by cutting and trimming processes from the six medium-sized samples. For cube samples, the bulk volume was determined by using Vernier caliper. While for irregular samples, the bulk volume was determined by using its average density due to the difficulty to produce a prism cube sample as it crumbled during cutting process. All samples were immersed in a water for at least 1hour in a desiccator and been wiped by using moist cloth without compromise the saturated sample. The sample then been weighed to determine its saturated mass. Next, the sample been oven-dried with the temperature of 105°C for at least 24 hours and been weighed afterwards to determine the dry mass of the sample.

2.2.1. Rebound Hammer Test

Twenty points on the rock sample were tested by using Schmidt Rebound Hammer and mean of ten higher value were used for analysis as suggested by [14] on revised version of suggested method in [13]. The rebound hammer test was executed on the horizontal and perpendicular to rock surface with different spacing of each point by one plunger diameter. The in-situ and laboratory testing were conducted for each sample to minimize the error in rebound number value because in-situ, the presence of microcrack on weak rock causing the inconsistency of R value according to [14]. The data then been used in classifying the weathering grade of mudrock by using mudrock classification summary by [15] and the rebound number values were converted into Uniaxial Compression Strength (UCS) values by referring to the conversion chart.

2.2.2. Ultrasonic Wave Velocity

Ultrasonic Wave Velocity test was conducted by providing a polished surface parallel to 0.1mm lateral dimension with every 20mm width for a good contact with transducer as highlighted by [16]. Grease gel been applied to smoothen the surface. P-wave velocities were measured on samples having a width of 50 mm and a minimum length of 100 mm, which would be acceptable as described by [16].

2.3. Mechanical Properties

2.3.1. Slake Durability Test

The Slake Durability Test procedures as outlined in [17] and [18] were referred and applied. 10 rocks samples weighed 450-550g were prepared. Then, the sample was divided into 6 sets with 10 lumps for each sample set. The weight of each rock lump should be in the range of 40g – 60g. The lump samples were slowly and carefully trimmed into a rounded shape before this test started.

Next, the sample been placed into a clean drum and oven-dried at temperature of 105ºC for 6 hours. The oven-dried sample was weighed and recorded as Mass 1. Immediately, the drum was set to the motor, and tap water was poured to a level of 20mm below the drum axis. The temperature of the water was recorded. The drum then been rotated at 20rpm. After 10 minutes, the oven-dried procedure was repeated, and Mass 2 was recorded. For rock durability classification, the classification table established by [18] was referred.

2.4. X-Ray Diffraction Test

X-Ray Diffraction Test was conducted in Earth Material Characterization Laboratory (ECML) at the Centre of Global Archaeological Research (CGAR) in Universiti Sains Malaysia (USM). D8 Advance Brucker AXS was used for conducting the scientific analysis of material characterization. The instrument is able to identify phase materials in powder form through recognition of d-spacing values contained in any crystalline or non-crystalline material (amorphous). Geological hammer was used to breakdown the sample into smaller fragments. The rock sample are kept in a plastic wrap to ensure the sample is not contaminated. Then, the sample was oven-dried at the temperature of 105°C for 24 hours. After 24 hours, the sample were put into a high-speed milling machine to produce a sample in powder form. Next, the sample powder was put inside a tray of D8 Advance Bruker AXS. For a through scanning of diffraction, the tray was passed through an X-ray beam path androtated frequently. Lastly, the TOPAZ software was used for identification and quantification of minerals composition.

3. Results and Discussions

3.1. Degree of Weathering

From Table 1, the range of rebound hammervalue, R are recorded between 19 to 38. The classification of weathering degree was made by referring weak rock weathering grade classification tabulated by [15]. Weathering grades of mudrock obtained from this study are fresh weathered rock, slightly weathered, moderately weathered and highly weathered weak rock which inline with physical appearance of the samples.

During sample preparation, a plant root was found buried in the rock boulder as showed in Figure 2(a). From this observation, the root wedging indicates that living organism and microbial are parts of biological weathering process in marine environment. Nevertheless, the size of the root found are too small to cause a major disintegration. From the physical observation, even with the slight hammering, the rock sample is easily crumbled and disintegrated. For freshly and slightly weathered mudrock, the rock sample dominantly covered by dark brownish color and minor spots of yellow color. The color pattern is physically observed when breaking down the sample for X-Ray Diffraction Test.

For sample S6, it is categorized as highly weathered rock. From physical observation on the sample, it indicates that the sample experienced chemical and biological weathering processes. The red and violet color pattern as seen on Figure 2(b) confirmed that the iron sulfate been oxidized from the rock sample.

Table 1. Weathering Degree Classification of Mudrock

Sample no.	Mean of rebound hammer value	Uniaxial compressive strength (MPa)	Weak rock weathering grade	Description
S1	38	62	I	Fresh
S2	24	52	II	Slightly weathered
S3	23	44	III	Moderately weathered
S4	30	50	II	Slightly weathered
S5	25	33	III	Moderately weathered
S6	19	25	IV	Highly weathered

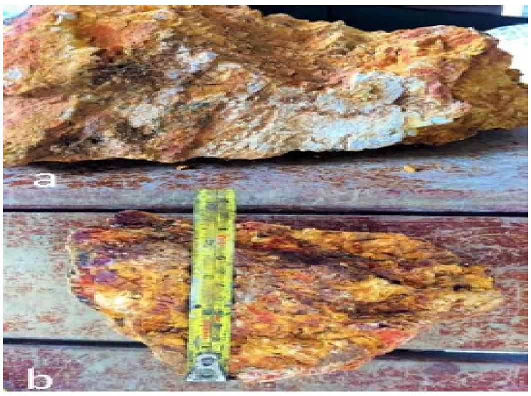


Figure 2. (a) Root wedges inside a rock (b) Red and violet as a sign of oxidation process occurred.

3.2. Physical Properties and Mechanical Properties

Table 2 represent average result of physical and mechanical properties of weathered mudrock. Generally, the dry density of sample ranged between 1.87 – 3.22 g/cm³, porosity (5-27%), moisture content (0.8-3.32%) and ultrasonicvelocity (1487.89-3759.40 m/s). For mechanical properties, the value of slake durability varied between 91.43-97.92 %.

The weathering characteristics influence in physical characteristics [19]. The relationship between index properties of mudrock and weathering degree are presented graphically in Figure 3. Generally, the dry density of sample is gradually decrease as the rock is weathered. For moisture content and porosity, the more weathered rock sample consist higher percentage of moisture content compare to fresh and slightly weathered rock [12][20]. The changes of dry density, porosity and moisture content in a rock are related to the alteration of rock composition by chemical weathering which resulted from the marine depositional environment of Semanggol Formation. Two factors that controlled the oxidation process, such as the composition of saltwater and the biological weathering by microbial during transportation and sedimentation process. The dissolution of sedimentary grains and minerals is accelerated by the sulfate condition of marine environment which lead to increment of porosity and eventually decreasing the value of bulk and dry density.

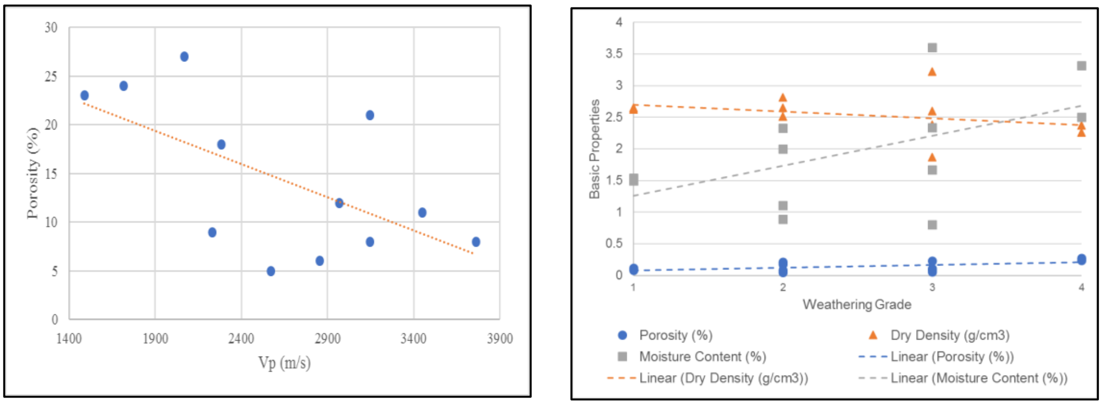
The wave velocity transmits in the rock is significantly decreases as responding to the increment of porosity and vice versa for bulk density. The travel time of the wave is delayed in a high porosity of high weathered rock due to a solid medium and porosity reduce the solid medium composition and the degradation particle grain size of the rock.

As for durability, all samples are categorized as extremely high and very high durability rock. The sample undergoes slaking processes are not profoundly affected due to the minimum cycle as suggested. The results obtained are inline with [21][22][23]. The dissolution of minerals has caused the increment in pore volume and the breaking down of rock's grain is allowing the water to infill the void and slowly breaking down the rock by continuously wetting and drying cycles.

Table 2. Summary of average index properties of mudrock

Sample no.	**WG**	ρ_d	**W**	**η**	V_p	I_{d3}	**Classification of Slake Durability (Franklin and Chandra, 1972)**
S1	I	2.63	1.52	10	3056.70	97.9	Extremely High Durability
S2	II	2.58	1.56	13	2857.79	97.1	Extremely High Durability
S3	III	2.12	2.97	17	1859.24	97.2	Extremely High Durability
S4	II	2.66	1.61	13	3021.83	97.1	Extremely High Durability
S5	III	2.91	1.24	8	3150.57	96.7	Extremely High Durability
S6	IV	2.32	2.91	26	1892.88	91.4	Very High Durability

WG: Weathering grade, ρ_d : Dry density (g/cm), W : Moisture content (%), η : Porosity, V_p : Ultrasonic wave velocity (m/s), I_{d3} : Slake durability index (%)



(a) (b)

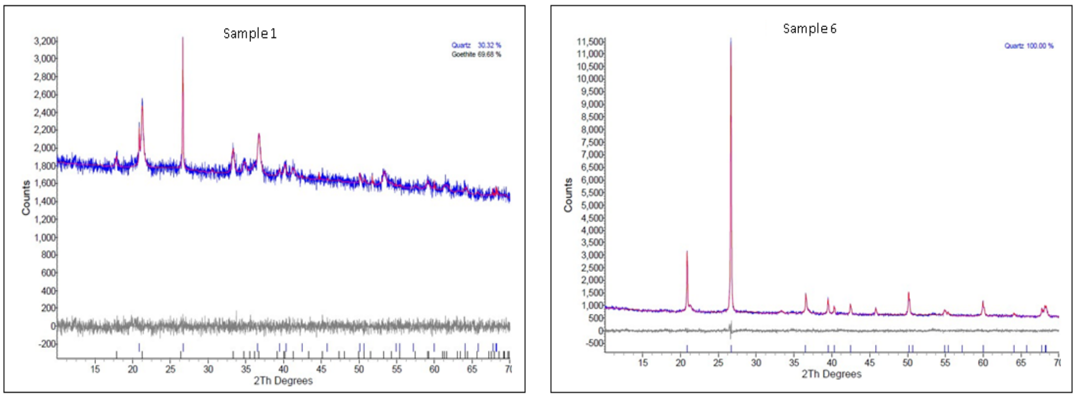
Figure 3. (a) Relationship of weathering grade and index properties of mudrock. (b) Relationship of wave velocity and porosity

3.3. Mineralogical Content Analysis by X-Ray Diffraction Test

The mineral composition of Sample 1 and Sample 6 are tabulated in Table 3. The existence of goethite minerals in sample 1 indicates that the rock is a pyritic mudrock. The oxidation of pyrite leads to the formation of goethite minerals, which is one the iron-based oxide minerals. This process might occur during the release of air during sediments deposition and the sulphate environment from saltwater. As the oxidation process occur continuously, the rock samples experienced different cycle of tidal. Moreover, the formation of goethite also governs by the presence of microbial as biological weathering agent. The stability of the minerals is decreasing due to the dissolution of minerals as found in XRD analysis on sample 6 which consists only quartz in Figure 4.

Table 3. Mineral composition of S1 and S6

Sample no.	Quartz content (%)	Goethite content (%)	Weathering grade and classification
S1	69.68	30.32	I - Fresh
S6	100	0	IV – Highly weathered



(a) (b)

Figure 4. Mineral Analysis of XRD for (a) S1 (b) S6

3.4. Interaction of Mineralogical Content with Engineering Properties

The results of engineering properties and mineralogical content as in Table 2 and Table 3 indicate that the mudrock sample 6 which comprises of quartz only is higher in porosity compared to sample 1 which comprises of 69.68% of quartz and 30.32% of goethite. This condition happens due to the presence of goethite as a coating to another mineral. The effect of cementation due to this coating minerals to quartz has resulted in formation of a skeletal bond between the minerals. During oxidation process of transforming iron minerals such as pyrite or magnetite into goethite, the cementation effect of the minerals filled up the voids in a rock sample. Hence, the porosity is reducing during compaction process of mudrock.

The porosity value of sample 1 which is 10% justified the presence of goethite. As the oxidation and compaction processes occur continuously, goethite minerals might chemically alter into more weak and expansive minerals and the porosity of the rock is increasing as the chemical or biological continuously occur. In addition, the sulfate condition of marine depositional environment is the key factor accelerating the dissolution of fine grain sediments and minerals during transportation and compacted of the rocks lead to the decrement of bulk density while the pore volume is increasing. Furthermore, goethite is a denser mineral compare to quartz, hence justified the bulk and dry density value for sample 6 is lower than sample 1.

For slake durability, there are no significant differences for both samples. No clay contents in both samples resulted in high slake durability. The result obtained by [9][10] are aligned with this study.

4. Conclusions

It can be concluded that the engineering properties of Semanggol formation mudrocks are governed by its mineralogical content. The following conclusions are highlighted from this study:

1) Data sets for weathering grades, index properties, mechanical properties and mineralogical data of Semanggol formation mudrocks have been tabulated.
2) The relationship between weathering grade and engineering properties been established.
3) Interaction between mineralogical content and engineering properties been studied. Low in void volume and high durability are resulted from mudrock with low degree of weathering and the presence of denser mineral. The physical and engineering properties of mudrock are governed by factors such as strength of inter-granular bonding, transformation of minerals due to dissolution, pressure release during compaction and sedimentation, cementation effect and oxidation of iron minerals.

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