Earth Sciences Malaysia (ESMY)

DOI: http://doi.org/10.26480/esmy.01.2022.32.39

ISSN: 2521-5035 (Print)
ISSN: 2521-5043 (Online)
CODEN: ESMACU

RESEARCH ARTICLE

# COMPARATIVE STUDIES OF SOME OF THE ROCKS IN THE SEKONDIAN SERIES – IMPLICATIONS FOR PETRO-MECHANICAL STRENGTH OF THE ROCKS

**Matthew Coffie Wilson[a*], Theophilus Amo Asumah[b], Joshua Tetteh Emmaham[b], Kingsley Kwame Asante[b]**

[a]*Department of Geological Engineering, Kwame Nkrumah University of Science and Technology, University Post Office, Kumasi – Ghana.*
[b]*Department of Geological Engineering, National Service Personnel, Kwame Nkrumah University of Science and Technology, University Post Office, Kumasi – Ghana.*
[*]*Corresponding Author Email: regimatt2003@yahoo.co.uk; mcwilson.coe@knust.edu.gh*

## ARTICLE DETAILS

*Article History:*

Received 07 December 2021
Accepted 10 January 2022
Available online 17 January 2022

## ABSTRACT

This study petrologically and mechanically assesses and compares five of the seven stratigraphic units of the Sekondi Group comprising Elmina sandstone from Central region; Ajoa, Takoradi, Takoradi Harbour and Essipong shales from the Western region in Ghana. All the studied shales were detrital clastic sedimentary rocks observed to have angular, near rounded and elongated crystal habits which are randomly distributed within fine-grained clay minerals as cementing matrix. These characters were clearly observed in the Ajua shales than the others. Unlike the shales, no chlorite, organic materials or foliations were observed in the Elmina sandstone. Also, the most consisted minerals in the shales were the feldspars (K- and plagioclase) and quartz, whereby the K-feldspar dominated the other crystals in the sandstone. The finer texture of the shales may be inferred that the shales have undergone longer times and distances of transportation process. The UCS test carried out on the Elmina sandstone reveals it to be a weak rock with a strength value of 37.3 MPa whilst the Schmidt Hammer test carried out on the four shale rock samples define the shales to be delaminated with the average rebound value of zero (0) each. Both results confirm the megascopic and microscopic petrological results, since both revealed the occurrences of laminated sections within the rocks, and the fissile property of all the shales. It also proves megascopic observation of Elmina sandstone being the hardest of the rocks observed, although the sandstone is still relatively weak from the rock hardness classification.

## KEYWORDS

compressive strength, petrology, geological structures, shales, sandstone

## 1. INTRODUCTION

The West African Craton, as shown in Figure 1, is one of five cratons of the African plate which is made of two regions north and south of each other; the Reguibat and the Man Shield respectively. The Taoudeni, a pseudo shield, separates these two shields. Both of these regions (the Reguibat and Man Shield) are mainly made of rocks that are either Archean or Paleoproterozoic in age (Jessell and Liégeois, 2015). The Man Shield covers the countries Ivory Coast, Mali, Burkina Faso, Ghana, Sierra Leone, Liberia, and Guinea (Jessell and Liégeois, 2015). Eburnean trends within the Eglab shield were repeatedly reactivated from the Neoproterozoic to the Mesozoic. The Eburnean orogeny was characterized by the accretion of thick sedimentary materials. The accretion was accompanied by the deformation of an emplacement of syn-post orogenic granodiorite, tonalite, trondhjemite and granite plutons along fractures (Feybesse et al., 2006).

The Late Ordovician to Early Cretaceous Sekondian Group crops out along the western and central coasts of Ghana, as shown in Figure 2. It is a 1.2 km-thick sandstone and shale dominated succession, but also includes coarse breccias and conglomerates. The rocks are extensively faulted and virtually unmetamorphosed (Asiedu et al., 2010.). The type of sedimentary rocks which are most widely used in engineering are sandstones, limestones and shales. Compressive strength is one of the physical properties of rocks. Different types of rocks formation will have different compressive strength. Therefore, to give better understanding on rock behaviors, laboratory tests are conducted on the field data. Rocks compressive strength value is affected by rock type, locality and weathering (Brune, 1965).

According to properties such as porosity, density, mineralogy and degree of cementation are related to the rock strength (Franklin, 1979; McNeilly and Funkhouser, 2004). Furthermore, another rock property that affects rock strength is mineralogy. Mineralogy will also affect the rock type, strength, color and other properties. Strength of rock increase proportionally with the degree of cementation (Meehan et al., 1975; Tarrer and Wagh, 1991). The study of the mechanical properties of rocks and their respective mineralogy characteristics are important in determining the rocks strength and its capability from failure (Tugrul and Zarif, 1999). The properties of rock are influenced by the mineral composition, texture (grain size and shape), fabric (arrangement of minerals and voids) and the weathering state (Irfan, 1996).

| Quick Response Code | Access this article online | |
|---|---|---|
| | **Website:**<br>www.earthsciencesmalaysia.com | **DOI:**<br>10.26480/esmy.01.2022.32.39 |

Cite The Article: Matthew Coffie Wilson, Theophilus Amo Asumah, Joshua Tetteh Emmaham, Kingsley Kwame Asante (2022). Comparative Studies of Some of The Rocks in The Sekondian Series – Implications For Petro-Mechanical Strength of The Rocks. *Earth Sciences Malaysia, 6(1): 32-39.*

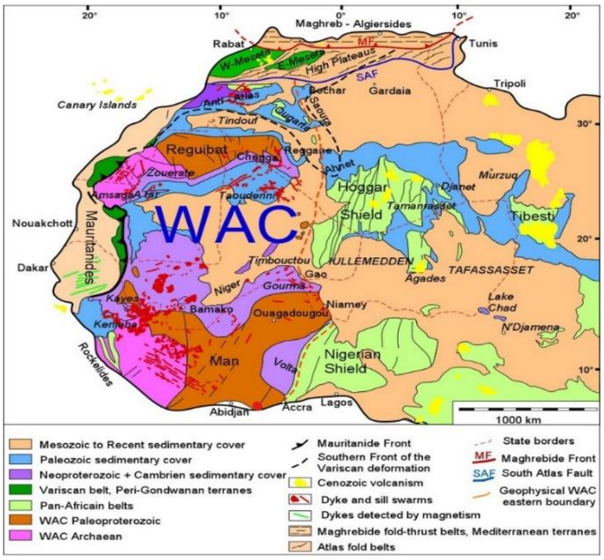


**Figure 1:** General geology of the West African Craton (Fabre, 2005; Ennih and Liégeois, 2008)

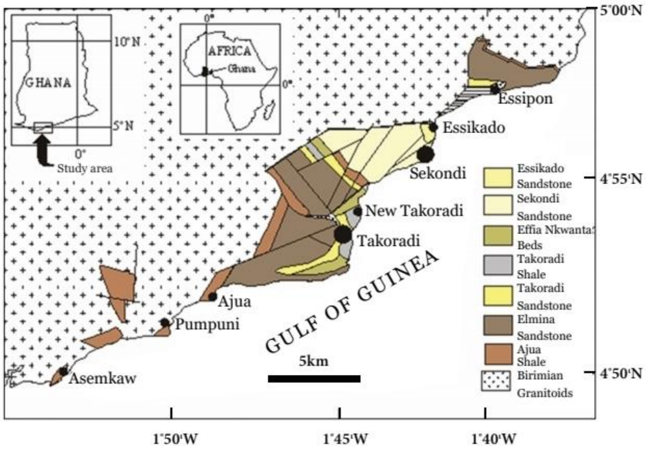


**Figure 2:** Geological map of the Sekondi Group in the Sekondi-Takoradi area, Ghana (Asiedu et al., 2005; inset showing the map of Ghana and Africa).

A group researchers established in their study about the relationship of sandstone's strength with mineral content and petrographic characteristics that, both petrographic characteristic and mineral content had a good correlation with the mechanical properties (Yasir et al., 2018). A group researchers investigated and clearly stated the relationship between the tensile strength and the percentage of quartz (Meriam et al., 1970). Higher percentage of quartz has higher strength of rocks. In contrast of presence of feldspar, the strength of rocks seems decreased. This study seeks to provide a comparative evaluation of some of the sedimentary rocks in the Sekondian series in terms of strength using their mineralogical compositions from petrographic analysis. The main objective of the research is to carry out a comparative analysis of the petrographic and the Unconfined Compressive Strength (U.C.S) properties of some of the rocks in the Sekondian series.

Engineering geologists, geological engineers, civil engineers, and mining engineers have many diverse and important encounters with rocks and soils. These materials are of geologic origin. In nature, rock formations and soil deposits of widely varying characteristics can be anticipated. This is due to the inherent nature and diversity of geological processes involved in such formations. As such, the engineer is confronted with a greater degree of uncertainty in the assessment of the engineering properties of those geological materials than of other processed and manufactured construction materials. It is therefore necessary to determine the various strengths of the rocks in the Sekondian group so that engineers, in doing their work, would know which rock in the group will best suit a particular work.

## 2. GEOLOGIC SETTING

The Sekondian Group rest with a profound unconformity on granitic rocks of the Paleoproterozoic Birimian Super group. Provenance studies suggest that the sedimentary rocks of the Sekondian Group were largely derived from the Birimian granitoids (Asiedu et al., 2005). On the basis of Paleontological evidence, sedimentary textures and sedimentary structures, the environment of deposition of the Group has been interpreted as non-marine to coastal marine (Crow, 1952; Atta-Peters, 1999, 2000; Asiedu et al., 2000). The Sekondian Group can be divided into seven formations on the basis of lithology and stratigraphy (Mensah, 1973). It is about 1200 m in thickness and consists of a predominantly fine-grained basal unit, Ajoa Shale, overlain by six predominantly arenaceous lithologic units: Elmina Sandstone, Takoradi Sandstone, Takoradi Shale, Effia Nkwanta Beds, Sekondi Sandstone, and Essikado Sandstone, in decreasing order of age (Mensah, 1973). The whole sequence overlies the Pre-Cambrian basement made up of hornblende, granite, biotite granite, schists and granulites which are probably metamorphosed or partly granitized Birimian rocks (Atta-Peters, 1999).

The Takoradi shale formation is dominantly black and grey carbonaceous shales with some sandy shales and shale sandstones. Also interbedded within these rocks are grits and fine-grained sandstones with nodules of siderite and pyrite. Recent sedimentological studies on the Takoradi Shale Formation, however, suggest that deposition took place in a deltaic environment (Agbetsoamedo, 2014). It is suggested that the Takoradi Shale Formation was deposited in a marginal marine to brackish environment, under early diagenetic processes (Agbetsoamedo et al., 2018). The Ordovician to Silurian lacustrine Ajoa Formation consists of laminated shales; it is overlain by the fluvial and lacustrine Elmina Formation, composed of feldspathic sandstone and minor conglomerate. Both formations are present only in the Saltpond Basins (Kjemperud et al., 1991).

## 3. METHODOLOGY

A total of five (5) samples with one (1) sample each from five of the seven stratigraphic units of the coastal Sekondian Series from Sekondi-Takoradi were hand-picked from the field. Each sample was given a unique sample ID and location coordinates. The samples include Ajoa shale, Essipon shale, Takoradi shale, Takoradi Harbour shale (all in Western region, Ghana) and Elmina sandstone (in Central region, Ghana).

### 3.1 Laboratory Work

Thin sections of the sampled rocks for petrographic analyses and Unconfined Compressive Strength were prepared at the Geological Engineering and Civil Engineering Laboratories respectively at the Kwame Nkrumah University of Science and Technology, Kumasi – Ghana.

### *3.1.1 Petrographic Thin Section Preparation*

This was performed to determine the mineralogical composition of the various samples of study. Thin sections were prepared from each sample for the petrographic analysis. The rock samples were cut into small slabs using the rock cutting machine. The samples were cut in three different orientations to provide three different dimensional planes for the petrographic analysis (x, y and z dimensions); thus, three cubes were cut from each rock sample. A face of each of the cube samples was selected at random and smoothened using abrasives. The surface of the glass slide was roughened using silicon powder. The slide was then thoroughly cleaned and made to dry. The epoxy was prepared using a hardener (the ratio of the epoxy to the hardener used was 15:2) and used to bond the smoothened face of each sample to the roughened surface of the glass slide. The setup was then left for 48 hours to cure completely. Upon hardening, the bonded sample was trimmed to a smaller size until a thickness of 30μm was obtained. The thin sections were then smoothened. This was done using the Hill Quist Cutting and Polishing machine.

**Figure 3:** Finished Thin-Sections of Samples

Cite The Article: Matthew Coffie Wilson, Theophilus Amo Asumah, Joshua Tetteh Emmaham, Kingsley Kwame Asante (2022). Comparative Studies of Some of The Rocks in The Sekondian Series – Implications For Petro-Mechanical Strength of The Rocks. *Earth Sciences Malaysia, 6(1): 32-39.*

Thin Section Examination: The thin sections were examined under an optical microscope for the petrographic studies. Leica DM 4 P petrographic microscope was used. The properties accounted for in each slide to identify the rock types were color, pleochroism, relief, cleavage, crystal habit, birefringence, interference colors and extinction. The thin section was first viewed in plane polarized light (PPL) to identify the color, pleochroism, relief, cleavage, and crystal habit. The birefringence, interference colors and extinction were viewed under crossed polarized light (XPL). The data obtained from the petrographic study under the microscope were compiled. The data was interpreted using the Michel-Levy chart and the Elsevier's Mineral and Rock table.

### *3.1.2 Unconfined Compressive Strength (UCS) Test*

This test was aimed at obtaining the maximum axial compressive stress the rock sample can bear under zero confining stresses. Only the Elmina Sandstone was tested using the UCS test. This was due to the inability to obtain rock cores from the flat and weak shale samples. The test was carried out in the Civil Engineering Laboratory (KNUST). The samples used were cylindrical rock cores obtained from the rocks under study. The cylindrical cores were obtained using the rock coring machine. The core length to diameter ratio of each sample was ensured to be 2.5-3.0 inches in accordance with the International Society of Rock Mechanics. The cylindrical surfaces of each core were prepared in order to be flat and smooth using the saw machine. The rock cores were placed between the two platens (one at the top and the other at the bottom). A load was continuously applied at a rate of 1.0Mpa/s. The stress and deformation was continuously recorded till failure occurred in the form of a crack. Different formulae were used to calculate for the different strengths such as: axial strain, diametric strain, compressive strain, uniaxial compressive strength, modulus of elasticity, Poisson's ratio, etc.

### *3.1.3 Schmidt Hammer Test*

This test was aimed at determining the compressive strength of the rock samples. Owing to the inability to perform the UCS test on the Shale samples, the compressive strength of the shale rock was determined using this method. The Schmidt hammer test was performed using the Schmidt Hammer or Rebound Hammer. The Rebound Hammer measures the elastic properties or strength of rocks or concretes, mainly their surface hardness and penetration resistance. The test was carried out at the Geological Engineering laboratory, KNUST.

Sampling: The Ajoa shale, the Essipong shale and the Takoradi and Takoradi harbour shales were the samples tested. The rocks were tested as they were when they were retrieved from the field.

Procedure: For testing, smooth, clean and dry surface sample was selected. The point of impact was set at least 20 mm away from any edge or shape discontinuity. For taking a measurement, the rebound hammer was held at right angles to the surface of the concrete member. The test was thus conducted horizontally on vertical surfaces or vertically upwards or downwards on horizontal surfaces. The Rebound hammer test was conducted around all the points of observation on all accessible faces of the structural element. Concrete surfaces were thoroughly cleaned before taking any measurement. Around each point of observation, six readings of rebound indices were taken and average of these readings after deleting outliers as per IS: 8900-1978 became the rebound index for the point of observation. The rebound value was read off along the graduated scale on the rebound hammer (IS-13311 (Part 2):1992).

## 4. RESULTS

### 4.1 Petrological Studies

### *4.1.1 Megascopic Description*

#### *4.1.1.1 The Ajoa Shale*

The rock is moss green in colour. It is well sorted, tightly packed and has silt sized particles with visible laminations. The laminations however, when compared to the other shales seem to have undergone some form of metamorphic processes and have begun to fuse together making it extremely difficult to separate the various layers (just as hard as if it was being broken in the vertical direction). Of all the shales being studied, it is the hardest to flake. The rock has an aphanitic texture.

(a)

(b)

(c)

(d)

(e)

**Figure 4:** Megascopic descriptions of rocks sampled at: (a) Ajoa Shale at Asemkaw, Takoradi, Ghana; (b) Essipong Shale at Essipong beach, Takoradi, Ghana; (c) Takoradi Shale at Takoradi, Ghana; (d) Takoradi Harbour Shale at Takoradi Harbor, Ghana; (e) Elmina Sandstone at Elmina beach, Ghana.

#### *4.1.1.2 The Essipong Shale*

The rock is characterized by a grey colouration. It consists of clay sized particles that are well sorted. The rock is aphanitic and has a smooth surface texture, but the particles have been cemented into a tightly packed unit, far more compact than both the Takoradi Shale and Takoradi Harbour Shale. The rock has thin dark grey to black laminations that run throughout the unit. These laminations are more visible as compared to that of the Takoradi Harbor Shale and the Ajoa Shale but not as visible as the laminations on the Takoradi Shale whilst being of a different colour. Although fractures can occur along the lamination zone, it is more difficult to separate two adjacent layers of this as compared to the Takoradi Shale and Takoradi Harbour Shale but much easier as compared to the Ajoa Shale.

#### *4.1.1.3 The Takoradi Shale*

This rock is characterized by a dark brown to black colouration. It is well sorted, tightly packed and has clay sized grains, a trait shared with the Takoradi Harbor Shale. It also has very visible thin yellowish laminations occurring throughout the rock. It is the only one of the Shales to have this. These laminations act as zones of weakness along which fracture can occur easily. It is the weakest of the shales and rocks in total being studied in this project. It fractures laterally, splitting into layers. The rock is aphanitic and has a smooth surface texture.

#### *4.1.1.4 The Takoradi Harbour Shale*

This rock is characterized by a dark brown to slightly grey colouration. It is well sorted and tightly packed with clay sized grains. It has thin, slightly visible laminations. These laminations share almost the same colour as the rest of the rock and are not as visible as the laminations of the Takoradi Shale. These laminations act as zones of weakness along which flaking may occur. More effort is needed to cause flaking in this rock as compared to the Takoradi Shale. The rock is aphanitic and has a smooth surface texture. It has a soft clay-like feel when crushed.

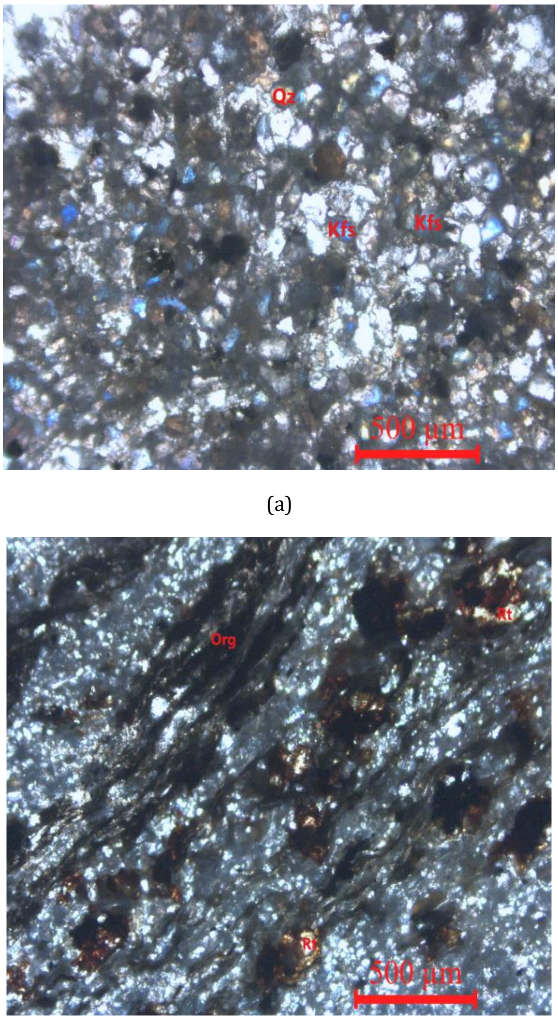
#### *4.1.1.5 The Elmina Sandstone*

The rock is seen to be a uniform, hard, feldspathic sandstone with a characteristic chocolate or chocolate-purple colour, which may be due to the pink feldspars and the dark brown limonitic cement present within the rock. In places where there is evidence of weathering, the rock is green or speckled with pink and green; possibly owing its colour to chlorite and ferrous iron. No laminations observed. Rock has sand sized particles, is poorly sorted and tightly packed. The rock is observed to be far more competent than the shales.

### *4.1.2 Microscopic*

#### *4.1.2.1 The Ajoa Shale*

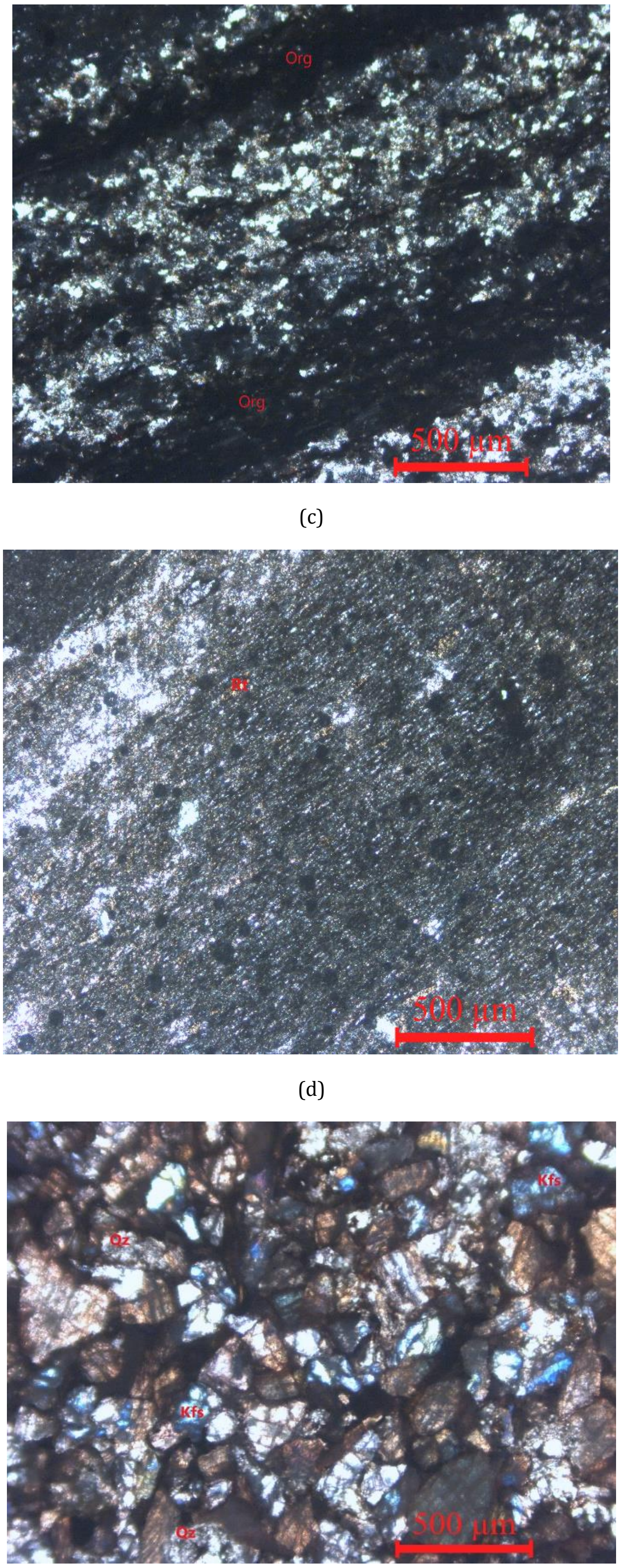
The Ajoa shale was observed to have 25 % quartz, 15 % feldspar, 5 % chlorite (Mg-Al), 5 % opaque and 50 % clay minerals (illite and kaolinite). Slide reveals that the rock is medium detrital clastic in texture with the most observed mineral grains within it being the K-Feldspar and quartz. The grains of quartz and feldspar are angular and well sorted. A minimal but random distribution of chlorite (Mg-Al) crystals and some opaque minerals can be observed. It is presumed that deformation occurs through the recrystallization of the feldspars. The major modal percentage for this rock falls under the clay minerals, which are found in the pore spaces between the grains forming the cementing matrix in which the crystals are embedded. These minerals cannot be well observed and studied using the polarizing microscope.



(a)

(b)

Cite The Article: Matthew Coffie Wilson, Theophilus Amo Asumah, Joshua Tetteh Emmaham, Kingsley Kwame Asante (2022). Comparative Studies of Some of The Rocks in The Sekondian Series – Implications For Petro-Mechanical Strength of The Rocks. *Earth Sciences Malaysia, 6(1): 32-39.*



(c)

(d)

**Figure 5:** Photomicrograph of Ajoa Shale under XPL at x5 magnification showing phenocrysts of quartz and K feldspar; (b) Photomicrograph of Essipong Shale under PPL at x5 magnification showing rutile crystals and foliation of opaque minerals (organic material); (c) Photomicrograph of Takoradi Shale under PPL at x5 magnification showing mafic bands (considered to be organic in origin) embedded in a matrix of opaque and felsic minerals; (d) Photomicrograph of Takoradi harbour shale under PPL with x5 magnification showing rutile crystals embedded within a mafic band; (e) Photomicrograph of Elmina Sandstone under XPL with x5 magnification showing the quartz and K-feldspar grains in the rock.

### *4.2.1.2 The Essipong Shale*

The rock was observed to have 20% quartz, 15% K feldspar, 15% rutile, 5% chlorite (Mg-Al), 10% opaque (organic materials) and 35% clay minerals (illite and kaolinite). The rock consists of rounded mineral grains, mostly quartz and K feldspar, and is medium detrital clastic in texture. However, it also has very visible dark and orange crystal network of rutile foliations and one comprising of opaque materials considered to be organic materials running diagonally through the cemented background. These foliations are observed as wavy (Crenulation), a trait observed only in this rock. This crenulation would imply that some sort of deformation process had begun within the rock before it was picked from the field. The rock also contains significant amount of quartz, and even lesser amounts of K-feldspar and chlorite (Mg-Al) and is heavily dominated by clay minerals.

### *4.2.1.3 The Takoradi Shale*

Rock is seen to have 20% quartz, 15% K feldspar, 10% rutile, 5% chlorite (Mg-Al), 20 % opaque (organic material) and 30% clay minerals (illite and kaolinite). The slide reveals that the presence of foliated bands alternating between mafic bands consisting of organic materials, from the depositional environment, embedded with rutile crystals and bands consisting of quartz and K-feldspar and a relatively small amount of chlorite (Mg-Al). Unlike in the Essipong Shale, the rutile and dark organic material bands are not wavy but are more abundant. Both the Ajoa and the Essipong Shales revealed that the grains were embedded in a matrix of clay minerals. The mafic bands are the foliations and refer to as microlithons, whilst the felsic minerals (quartz and feldspar) as well as some of the opaque and organic minerals form the domain of the rock.

### *4.2.1.4 The Takoradi Harbour Shale*

The rock was found to contain 20% quartz, 15% K feldspar, 10% rutile, 10 % chlorite (Mg- Al), 15 % opaque (organic materials) and 40% clay minerals. The slide reveals a domain of ultrafine grained dark greenish material with larger particles of chlorite, rutile and with K-Feldspar and quartz occurring as a layer located between adjacent greenish foliations. It is also noticed that the dark greenish foliations are wider than those of the quartz and K-feldspar. These mafic bands are observed to be wider, as compared to those observed in the Essipong shale and Takoradi shale, with crystals of chlorite and rutile embedded within them. The bands observed are also not crenulated as compared to those in the Essipong shale. These crystals have euhedral habits (elongated) and are oriented in the same direction as the foliations. There is indication of a greater amount of chlorite (Mg-Al) than in the Takoradi Shale. However, due to the fact that both the crystals and the background are almost indistinguishable from each other, it was rather more challenging to ascertain the modal percentage of each mineral in the matrix and the percentages were only given after a very thorough investigation using the polarizing microscope.

### *4.2.1.5 The Elmina Sandstone*

The rock was observed to contain 40% K feldspar, 20% Plagioclase, 20% Quartz, 5% opaque minerals and 5% clay minerals. The grains are far larger and more visible than those of the shales. The slide reveals that the rock has a crystalline texture. Mineral grains are angular and moderately packed with visible spaces between them, a trait not found in any of the shales. Unlike the shales, K-feldspar and plagioclase are more abundant than quartz.

## 4.3 Mechanical Strength

### *4.3.1 Uniaxial Compressive Strength Test (UCS test)*

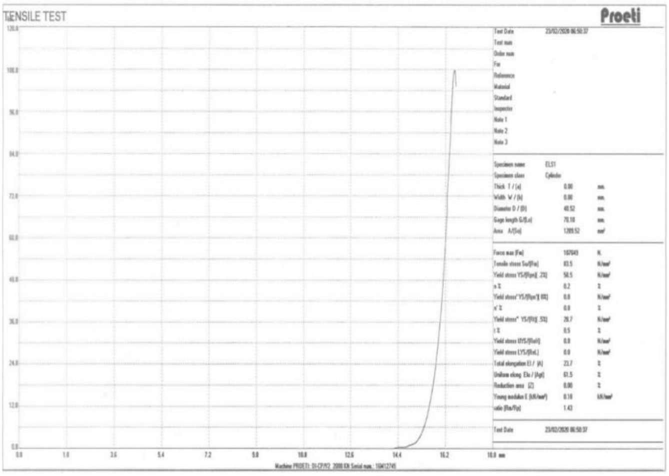


**Figure 6:** Graph of Load against Strain for Elmina Sandstone Core 1 (ELS1)

Cite The Article: Matthew Coffie Wilson, Theophilus Amo Asumah, Joshua Tetteh Emmaham, Kingsley Kwame Asante (2022). Comparative Studies of Some of The Rocks in The Sekondian Series – Implications For Petro-Mechanical Strength of The Rocks. *Earth Sciences Malaysia, 6(1): 32-39.*

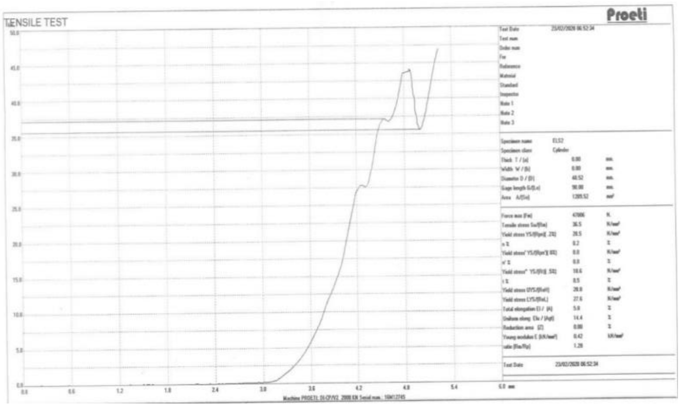


**Figure 7:** A Graph of Load against Strain for Elmina Sandstone Core 2 (ELS2)

**Table 1:** Classification of rock hardness (from Attewell and Farmer, 1976)

| **Strength Classification** | **Strength range (MPa)** | **Typical rock types** |
|---|---|---|
| Very weak | 10-20 | Weathered and weakly-compacted sedimentary rocks |
| Weak | 20-40 | Weakly-cemented sedimentary rocks, schists |
| Medium | 40-80 | Competent sedimentary rocks; some low-density coarse-grained igneous rocks |
| Strong | 80-160 | Competent igneous rocks; some metamorphic rocks and fine-grained sandstones |

**Table 2:** Classifications and Parameters of rock hardness of the Elmina sandstones 1 and 2

| | **ELS1 (Elmina sandstone 1)** | **ELS2 (Elmina sandstone 2)** |
|---|---|---|
| Diameter (D) | 40.52 mm | 40.52 mm |
| Length ($L_o$) | 70.10 mm | 90.00 mm |
| Area (A) | 1289.52 mm | 1289.52 mm |
| Maximum Force ($F_{max}$) | 107649 N | 47006 N |
| $\delta_{UCS}$ | $= F_{max}/A$ | $= F_{max} \div A$ |
| $\delta_{UCS}$ | 83.5 N/mm² | 36.5 N/mm² |
| $\delta_{UCS}$ | 83.5 MPa | 36.5 MPa |

According to ASTM, the samples' length to diameter ratio (L/D) must be between 2.0 and 2.5. For ELS1, $L_o/D = 70.10/40.52 = 1.73$. $1.73 < 2.0$

According to ASTM, the preferable sample L/D ratio is 2.0. Therefore, a correction formula is applied for larger ratios (smaller ratios are unacceptable). The UCS is recalculated as:

$\delta_c = \delta_{UCS} / (0.88 + 0.22\times (D/L)$

Since the $L_o/D$ ratio of ELS1 is less than 2.0, the UCS value of 83.5 MPa is not acceptable.

For ELS2, $L_o/D = 90.00/40.52 = 2.22$ $2.22 > 2.0$

Since the sample size ratio > 2, size correction needs to be applied.

$\delta_c = 36.5 / (0.88 + 0.22\times(40.52/90.00))$

$\delta_c = 37.3$ MPa

### *4.3.2 Schmidt Hammer Test*

**Table 3:** Rebound Hammer test values of the shales in the stratigraphic units of the Sekondian Series and the average Rebound values and quality of concrete by Spectro (2017)

| **Sekondian Series** | **Average Rebound Number (Sekondian Series)** | **Average Rebound Number** | **Quality of concrete (Spectro, 2017)** |
|---|---|---|---|
| Takoradi Shale | 0 | >40 | Very good layer |
| Takoradi Harbor Shale | 0 | 30 - 40 | Good layer |
| Essipong Shale | 0 | 20 - 30 | Fair layer |
| Ajoa Shale | 0 | <20 | Poor layer |
| | | 0 | Delaminated |

An average Rebound number of zero (0) was obtained for all the shale samples tested using the Rebound Hammer. Comparison with Table 3 indicates that the shale samples are delaminated.

## 5. DISCUSSIONS AND CONCLUSION

Among the 5 samples studied for petrographic details, 4 were Shales and 1 was a Sandstone. The shales mostly consisted of clay minerals (illite and kaolinite), quartz, K feldspar and chlorite (Mg-Al) crystals, opaque minerals and organic materials. All the shales were detrital clastic in nature with their quartz, feldspar and chlorite (Mg-Al) mineral grains having angular, near rounded and elongated crystal habits. The grains were also observed to be distributed randomly within a cementing matrix of fine-grained materials considered to be clay minerals. This was best observed in the Ajoa shales. Rutile crystals were also observed in the Essipong, Takoradi and Takoradi Harbour shales being most visible and abundant in the Essipong shale. The rutile crystals were observed to be fragmented and always appeared alongside foliation bands of mafic materials that were considered to be organic materials originating from the depositional environment.

The rutile crystals appeared embedded within the organic material bands in the Takoradi and Takoradi Harbour Shales (which might imply that deposition of both occurred simultaneously) whilst they appeared to form a highly fractured foliated band separated from the mafic material in the Essipong Shale. All the bands observed in the Essipong Shale were also crenulated. Both occurrences of rutile showed orientation in the same directions as the organic materials. The modal percentages of quartz and K feldspar remained relatively the same for all the shales with quartz dominating at approximately 20% followed by the K feldspar at approximately 15% as observed whilst the percentages for the chlorite and rutile crystals and the opaque material fluctuated for the Essipong, Takoradi and Takoradi Harbour Shales.

The Elmina Sandstone was the only sandstone studied in this project. Grains observed for this rock were far larger and more visible than that of the Shales revealing their crystalline texture. The grains also had very angular and anhedral crystal habits. The rock mostly consisted of quartz, K feldspar and plagioclase feldspar and was far more abundant in K feldspar (approximately 40%) than quartz unlike the shales. Again unlike the shales, no chlorite, organic materials or foliations were observed. The quartz and feldspar crystals were also distributed randomly within the rock. The mafic rutile index mineral in the shales at the Essipong, Takoradi and Takoradi Harbour stratigraphic units define them to be more matured than the stratigraphic units of Ajoa shale and Elmina sandstone.

Since most sedimentary rocks are derived by process of weathering, transportation and diagenesis, the texture we find in sedimentary rocks are dependent on the process that occur during each stage. These include the nature of the source rock, the strength of water currents that carry and deposit the sediments, the distance transported or time of transportation process, biological activity with sediment prior to diagenesis and chemical environment under which diagenesis occurs. The finer texture of the shales compared to the sandstone may suggest that the shales have undergone longer times and distances of transportation process. It also suggests that the source rocks of the shales may have been easier to weather compared to the sandstone. It also suggests that the sediments that formed the shales may have been transported by stronger winds or water currents. Also, it may suggest that there was higher rate of biological activity and higher rate of chemical weathering compared to the sandstone. Results of Uniaxial Compressive Strength tests on 2 specimens of the Elmina Sandstone are listed in Table 2. The graphs in Figures 6 and 7 also show the behaviour of the specimens (cores) under increasing load (strain on the specimens increase with increasing load). The highest UCS value is about 83.5 MPa for ELS1 (the first specimen of Elmina Sandstone), whereas the lowest UCS value is about 36.5 MPa for the ELS2 (the second specimen of Elmina Sandstone).

Some researchers have conducted compression tests on soft rocks with an L/D ratio of 2.0. a group researchers conducted drained triaxial tests on Melbourne mudstone with L/D ratios from 0.5 to 3.0, and found that the trend of peak deviator stresses and secant Young's modulus tend to be constant when the ratio is at least 2.0 (Chiu et al., 1983). They pointed out that increased strength with a shorter specimen is due to lateral restraint at the ends of the specimen (Chiu et al., 1983). This explains the higher UCS value of 83.5 in ELS1. It is understood that this lateral restraint is caused by the platens, which may cause non-uniform stress distributions under compression (Matthews and Clayton, 1993). The volume of the specimen may also influence the results of the test.

However, it is the material properties that seem to cause the major effects on the mechanical behavior of soft rocks. Some researchers found that samples with ratios of 2.0 and 2.5 both displayed similar behavior under uniaxial compression stresses (Matthews and Clayton, 1993). They noted that the uniaxial compressive strength of chalk was more likely to be influenced by the dry density and porosity, rather than by the ratio of the sample dimensions. Some researchers pointed out that the sensitivity of sandstone to change in moisture content is controlled mainly by the mineralogy and to a lesser extent by texture and microstructure (Hawkins and McConnel, 1992). However, some researchers found that the weaker the sandstone, the more sensitive its strength to moisture content variation (Dobereiner and DeFreitas, 1986; Dyke and Dobereiner, 1991).

According to ASTM, the preferable sample L/D ratio is 2.0. Therefore, a correction formula is applied for larger ratios. The UCS is recalculated as: $\delta_c = \delta_{UCS} / (0.88 + 0.22\times (D/L))$. For ELS1, L/D is 1.73 while for ELS2, L/D is 2.22. Since the L/D ratio of ELS1 is not in the range suggested by ASTM, the UCS value of 83.5 MPa cannot be accepted. The L/D ratio of ELS2 which satisfies the condition is accepted and hence the corrected UCS value obtained is 37.3 MPa. For the classification, the rock is weak in terms of hardness (weakly-cemented sedimentary rock) (from Attewell and Farmer, 1976). And since the sandstone is classified as weak, it will be very sensitive to moisture content variation according (Dobereiner and DeFreitas, 1986; Dyke and Dobereiner, 1991). Since the other rocks (Ajoa, Essipong, and Takoradi and Takoradi Harbor shales) were not competent enough to be cored, the Rebound Hammer Test was performed to obtain their hardness. An average Rebound number of zero (0) was obtained for all the shale samples tested using the Rebound Hammer. With reference to Table 3, the shale samples are indicated to be delaminated. Delamination involves cracking parallel to the cleavage surfaces that starts the exposed dressed edge and moves inwards, towards the center of the layers of the shales. Since the shales are stratified and easily delaminated, they tend to be weaker than the sandstone.

The important phenomenon observed during the current investigations on the rocks are that weathering, is a complex factor that may involve not only one process, but also other processes which can occur simultaneously. Since the shales contain far more clay content than the sandstone, this indicates that the shales are more weathered compared to the sandstone. As products of weathering, it may be difficult to quantify clay minerals that may dominate over dry density and porosity in controlling the mechanical behavior of weathered rocks. Thus, both mineralogy and texture demonstrate, to some extent, an equal contribution to the mechanical characteristics of rocks, particularly the uniaxial compressive strength, depending on the degree of weathering (Agustawijaya, 2007). In terms of mineralogical composition, the shales studied were made up primarily of quartz and feldspar with small percentages of chlorites and very high percentages of ultrafine grained clay minerals. The Takoradi shales, the Takoradi Harbour shales and the Essipong shales have moderate percentages of rutile present within them, while the Ajoa shale has no rutile present. The Ajoa shale has a small percentage of recrystallized feldspar present, with a higher chlorite percentage than the rest of the shales. The Elmina sandstone studied was predominantly made up of feldspar with quartz as the next dominant mineral present. The feldspar percentage in the Elmina sandstone is significantly higher than in the shales and the quartz percentage is significantly lower than in the shales studied.

UCS test carried out on the Elmina sandstone reveals it to be a weak rock in terms of rock hardness as seen in Table 4.1.3.1 with a strength value of 37.3 MPa whilst Rebound hammer tests carried out on the Ajoa, Essipong, Takoradi and Takoradi Harbour Shales reveal them to be delaminated rocks with the average rebound number of zero (0) each (Attewell and Farmer, 1976). This implies that the shale rocks have been delaminated or that the rocks fracture in layers. Both results are in confirmation with observations and assessment made from the megascopic and microscopic results, since both revealed the occurrences of laminated sections within the rocks, and the fissile property of all the shales. It also proves megascopic observation of Elmina sandstone being the hardest of the rocks observed (although still being relatively weak from the rock hardness classification). Higher percentage of quartz mineral generally defines it to have higher strength of rock. However, the presence of higher feldspar has lower strength of rocks. With an average modal percentage of (<40%) for quartz in the samples studies, the low UCS values for the sandstones and the zero rebound values recorded for the shales are justified. However, the sandstones are comparatively stronger than the shales studied due to the existence of laminations, which are prominent planes of weakness and failure, in the shale rocks.

## Acknowledgement

I hereby acknowledge the tireless effort and effective contribution of my co-authors towards the production of this article.

## References

Agbetsoamedo, J.E., 2014. Depositional environment of the Takoradi Shale Formation, southwestern Ghana. Master's Thesis, University of Ghana, Accra, Ghana.

Agbetsoamedo, J.E., Asiedu, D.K., Atta-Peters, D., and Anani, C.Y., 2018. Isotopic compositional characterization of siderite nodules: Implications for the reconstruction of the depositional paleoenvironment of the Takoradi Shale Formation, around Essipong. Ghana. Science and Development, 2, Pp. 28 – 37.

Agustawijaya, D.S., 2001. The Development of Design Criteria for Underground Excavations in Coober Pedy Arid Soft Rocks. Ph.D. Dissertation, University of South Australia.

Agustawijaya, D.S., 2007. The Uniaxial Compressive Strength of Soft Rock. Civil Engineering Dimension, 9 (1), Pp. 9–14.

Asiedu, D.K., Atta-Peters, D. and Peprah, R., 2000. Depositional Environment of the Takoradi Sandstone Formation of the Sekondian Group, Western Ghana, as revealed by textural analysis. Ghana Mining Journal, 6, Pp. 53–58.

Asiedu, D.K., Atta-Peters, D., Hegner, E., Rocholl, A., Shibata, T., 2010. Palaeoclimatic Control on the Composition of Palaeozoic Shales from Southern Ghana, West Africa. Ghana Mining Journal, 12, Pp. 7 - 16.

Asiedu, D.K., Hegner, E., Rocholl, A. and Atta-Peters, D., 2005. Provenance of Late Ordovician to Early Cretaceous Sedimentary Rocks from Southern Ghana, as inferred from Nd Isotopes and Trace Elements. Journal African Earth Science, 41, Pp. 316–328.

ASTM D7012-14e1, 2014. Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures, ASTM. International, West Conshohocken, PA.

Atta-Peters, D., 1999. Upper Devonian Acritarchs from the Lower Takoradi Shales of the Sekondian Group. Ghana Mining Journal, 5, Pp. 1–10.

Atta-Peters, D., 2000. Early Cretaceous Miospores from the Essikado Sandstone Formation of the Sekondian Group of Ghana. Revista Espanola De Micropaleontologia, 32, Pp. 245-257.

Attewell, P.B., and Farmer, I.W., 1976. Principles of engineering geology. Chapman and Hall, London.

Brune, G., 1965. Anhydrite and gypsum problems in engineering geology. Engineering Geology, 2 (1), Pp. 26-38.

Chiu, H.K., Johnston, I.W. and Donald, I.B., 1983. Appropriate techniques for triaxial testing of saturated soft rock. International Journal of Rock Mechanics and Mining Science and Geomechanics Abstract, Pp. 107-120.

Crow, A.T., 1952. The Rocks of the Sekondi Series of the Gold Coast. Gold Coast Geological Survey Bulletin No. 18, William Lewis Ltd., Cardiff., Pp. 40.

Dobereiner, L., and DeFreitas, M.H., 1986. Geotechnical properties of weak sandstones. Gêotechnique, 36 (1), Pp. 79-94.

Dyke, C.G., and Dobereiner, L., 1991. Evaluating the strength and deformability of sandstone. Quarterly Journal of Engineering Geology, 24, Pp. 123-134.

Ennih, N., and Liégeois, J.P., 2008. The Boundaries of the West African Craton. Geological Society, London, Special Publications, 297, Pp. 1-17.

Fabre, J., 2005. Géologie du Sahara occidental et central. Série/Reeks. Tervuren African Geosciences Collection, MRAC Tervuren, Belgique, Pp. 572.

Feybesse, J.L., Billa, M., Guerrot, C., Duguey, E., Lescuyer, J.L., Milési, J.P., and Bouchot, V., 2006. The Paleoproterozoic Ghanaian Province: Geodynamic Model and Ore Controls, including Regional Stress Modelling. Precambrian Research, 149 (3), Pp. 149-196.

Franklin, J., 1979. Suggest methods for determining water content, porosity, density, absorption, and related properties and swelling and slake-durability index properties. Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., 16, Pp. 141-156.

Hawkins, A.B., and McConnell, B.J., 1992. Sensitivity of sandstone strength and deformability to changes in moisture content. Quarterly Journal of Engineering Geology, 25. Pp. 115-130.

Irfan, T.Y, 1996. Mineralogy, fabric properties and classification of weathered granites in Hong Kong. Quarterly Journal of Engineering Geology and Hydrogeology, 29 (1), Pp. 5-35. https://doi.org/10.1144/GSL.QJEGH.1996.029.P1.02.

Jessell, M.W., and Liégeois, J.P., 2015. 100 Years of Research on the West African Craton. Journal of African Earth Sciences, 112 (B), Pp. 377-381.

Kjemperud, A., Agbesinyale, W., Agdestein, T., Gustafsson, C., and Yükler, A. 1991. Tectono-stratigraphy of the Keta Basin, Ghana, with emphasis on late erosional episodes. Geologie Africaine. Proceedings of the 1st Conference on the Stratigraphy and Paleogeography of West African Sedimentary Basins, Libreville, 6- 8 May 1991, Bulletin des Recherche's Exploration-Production Elf Aquitaine, 13, Pp. 55-69.

Matthews, M.C., and Clayton, C.R.I., 1993. Influence of intact porosity on the engineering properties of a weak rock, Geotechnical Engineering of Hard Soils – Soft Rocks, Anagnostopoulos et al. (Eds.). Balkema, Rotterdam, Pp. 693-701.

McNeilly, M.F., and Funkhouser, M., 2004. Ground support design and analysis: Exchange place station improvements. Proceedings of the North American Tunneling Conference 2004, 17-22 April 2004, Atlanta, Georgia, and USA.

Meehan, R.L., Dukes, M. and Shires, P.O., 1975. A case history of expansive claystone damage. Journal of Geotechnical and Geo-Environmental Engineering, 101(ASCE# 11590 Proceeding).

Mensah, M., 1973. On the Question of the Age of the Sekondi Series, Upper Devonian or Lower Carboniferous Rocks of Ghana. Ghana Journal of Science, 13, Pp. 134–139.

Meriam, R., Herman, H.R. III. and Kim, Y.C., 1970. Tensile strength related to mineralogy and texture of some granitic rocks. Geology, Pp. 155-160, 108

Schmidt, E., 1950. Rebound hammer for concrete testing. Schweiz Baufachzeitung, 68 (28), Pp. 378-379.

Schmidt, E., 1951. Quality control of concrete by rebound hammer testing" (Versuche mit dem neuen Beton-Prüfhammer zur Qualitätsbestimmung des Betons). Schweiz Arch angew Wiss Tech, 17, Pp. 139–143.

Spectro, 2017. Average rebound number and quality of concrete. Spectro Analytical Labs Limited. IS: 13311 (Part 2) – 1992. CIN No – U74220DL1998PLC092698

Tarrer, A., and Wagh, V., 1991. The effect of the physical and chemical characteristics of the aggregate on bonding. National Research Council. Strategic Highway Research Program. Washington D.C.

Tugrul, A., and Zarif, I.H., 1999. Correlation of mineralogical and textural characteristics with engineering properties of selected granitic rocks from Turkey. Engineering Geology, 51, Pp. 303-317.

Yasir, S.F., Awang, H. and Ayub, M.I.H., 2018. The relationship of sandstone's strength with mineral content and petrographic characteristics in Sungai Tekai, Jerantut, Pahang. American Institute of Physics (AIP) Conf. Proc. 2020.020010-1–020010-7

Cite The Article: Matthew Coffie Wilson, Theophilus Amo Asumah, Joshua Tetteh Emmaham, Kingsley Kwame Asante (2022). Comparative Studies of Some of The Rocks in The Sekondian Series – Implications For Petro-Mechanical Strength of The Rocks. *Earth Sciences Malaysia, 6(1): 32-39.*