PROPERTIES AND LIQUEFACTION RISK ON BULK CARGOES CARRYING GEBENG, KUANTAN BAUXITE IN ACCORDANCE TO IMSBC CODE

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NORAISHAH BINTI LAMIN

Thesis submitted in fulfilment of the requirements
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To my beloved family.

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ABSTRACT

This research is to identify the differences between the geotechnical properties of raw and processed Gebeng bauxite. Raw bauxite deposits usually contain a higher percentage of clay and siliceous materials. The silica present in the bauxite usually are concentrated in the finer grained fraction of the bauxite deposit. The fine particles in bauxite will cause the bauxite to have higher moisture content and increases the risk of liquefaction to occur during the bauxite's transportation in cargo. The main objective of having beneficiation process before cargo transporting is to minimize the silica content which contributes to the finer fraction in bauxite, as well as to improve the geotechnical properties of bauxite so that it passes the specification of International Maritime Solid Bulk Cargoes Code (IMSBC) for cargo shipping purpose. In this research, a series of laboratory tests will be conducted and the results will reflect the geotechnical properties of Gebeng Bauxite and the correlation of the bauxite's properties can be done. Both the raw and processed Gebeng Bauxite samples will undergo moisture content test, specific gravity test, particle size distribution, Field Emission Scanning Electron Microscope (FESEM) and X-ray fluorescence (XRF) to obtain the desired data.

ABSTRAK

Penyelidikan ini bertujuan untuk mengenal pasti perbezaan antara bauksit Gebeng mentah dan bauksit Gebeng yang telah diproses dari segi sifat-sifat geoteknik. Bauksit mentah biasanya mempunyai peratus tanah liat dan bahan–bahan bersilika yang tinggi. Silika yang berada dalam bauksit biasanya menyumbang kepada zarah halus dalam bauksit. Zarah halus yang berada dalam bauksit akan menyebabkan bauksit mengandungi kandungan kelembapan yang tinggi dan meningkatkan risiko pencairan untuk berlaku ketika dalam pengangkutan kargo. Objektif utama untuk menjalankan proses pembasuhan bauksit sebelum pengangkutan kargo adalah untuk mengurangkan kandungan silika yang menyumbang kepada zarah halus dalam bauksit, dan untuk meningkatkan sifat-sifat geoteknik bauksit supaya ia memenuhi spesifikasi yang ditetapkan dalam Kod IMSBC (Intternational Maritime Solid Bulk Cargoes Code) untuk tujuan pengangkutan kargo. Dalam penyelidikan ini, berbagai ujian makmal akan dijalankan dan keputusan ujian makmal tersebut akan melambangkan sifat-sifat geoteknik untik bauksit Gebeng dan kolerasi untuk sifat-sifat bauksit boleh didapatkan. Kedua-dua bauksit Gebeng mentah dan bauksit Gebeng yang telah diproses akan menjalani ujian kandungan kelembapan, ujian graviti tentu, taburan saiz zarah, Field Emission Scanning Electron Microscope (FESEM) dan X-ray fluorescence (XRF) untuk mendapatkan data yang diingini.

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°C	Degree Celsius
%	Percentage
km	Kilometer
g	Gram
kg	Kilogram
mm	Milimeter
µm	Micrometer

ABBREVIATIONS

pH	Potential hydrogen
IMSBC	International Maritime Solid Bulk Cargoes
FESEM	Field Emission Scanning Electron Microscope
XRF	X-Ray Fluorescence
Al	Aluminium
Fe	Iron
Na	Sodium
O	Oxygen
Ti	Titanium
Si	Silicon

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF RESEARCH

The third most abundant element that exists in the earth's crust is Aluminium which is after silicon and oxygen. It makes up for about the earth's solid surface's weight by 8% (Schreiner, 2004). Aluminium remained so rare and was not segregated until 1825. It was said to be valued more highly compared to silver. Unlike silver and gold, Aluminium in its pure form is too reactive thus it did not occur in this pure state and that's is the reason that this element remained uncovered for so long. Aluminium can be described as a strong, malleable metal element that has low density and high resistant to corrosion. Besides it highly reflective surface properties, aluminium is a good conductor of heat and electricity. Its corrosion resistance and easy shaping characteristic become a reason to be choose in drink cans and roofing materials industry. Alternatively, Aluminium is found and discovered as bauxite, ore which its colour is reddish-brown. As the end-product of bauxite only being exposed, people tend to recognize aluminium rather than bauxite. Therefore, bauxite mining at the area contribute to anxiety of locals as the mines are located near to residential area.

Bauxite is a mixture of hydrous aluminium oxides, aluminium hydroxides, clay minerals and insoluble materials such as quartz, magnetite, hematite, siderite and goethite. In the industrial perspective point of view, Bauxite is considered as a natural material that which can extract alumina from it in a Bayer plant (Lozej, 1993). The alumina will be extracted from bauxite through the Bayer process, where the ore is mixed with sodium hydroxide and then heat up inside a pressure chamber with temperature of 150 °C to 200 °C until the alumina dissolved and then being filtered out. This process will create waste by-product which is known as bauxite residue or what we called red mud, a heavy metal laden slurry with high alkalinity which can, contain naturally occurring radionuclides at times (Gore, 2015). Nowadays, the bauxite's mining work had reached a number of 220 million tons per year, with Australia as the leading country that provides almost one-third of total production of Bauxite in the world (Gore, 2015). The world's biggest bauxite producing countries was shown in Figure 1.1

Figure 1.1: Bauxite Producing Countries

Source: Gore (2015)

Bauxite mining has become a contentious issue in Kuantan, Pahang. Since Indonesia stopped producing and exporting bauxite ores to China, Malaysia miners take over the labour and later become the world's top producer beating China itself for nearly half of its ore supply. In 2013, around 100,000 tonnes of bauxite are exported and increased to approximately 205 million tonnes in a year. The exports of bauxites hit a high mark of 20 million tonnes in 2015. The most famous excavation area is Gebeng and Bukit Goh Kuantan, Pahang. Unregulated mining bauxite gives crucial impact to the serving community. Out of 236 active mine sites, only 36 are legal. This means that, for one legal site excavated, another six are being dug up. Red cuts in the hills are seen behind the east coast town of Kuantan. Based on New Straits Times Online (2015), it was reported that Kuantan, Malaysia is facing severe hazard due to mining of bauxite at that area. A scientist team has sounded warning to public that the damage caused from this poorly and undirected regulated mining activity to our environment may be so intense that the ecosystem might not recover to what it was before. The harmful effect on health of Kuantan's public could be disastrous, and this might carry on for generations. They said, this was in inclusion to the problem of where certain points of water intake being at the downstream of most of the bauxite mines. They underrated the risk that all these hazards might be cause by heavy metals, which includes elements such as mercury, arsenic and aluminium, and also not ignoring other pollutants, which enters the rivers during rain.

1.2 PROBLEM STATEMENT

Exploration of earth resources contribute to national economic growth as it involves international market and demand. Therefore, potential mining location of earth resources is identified such for this study is at Gebeng, Kuantan Pahang. The collected area is at Port Kuantan; approximately 5.7 km from study area. Transportation of bauxite from mine to collective area had resulting a leakage of bauxite fine fraction on the road as well as the surrounding area. It can be said that the area had been polluted by the bauxite residue due to improper method of transport. Hence, the study is done to this area to identify the properties of bauxite due to long term exposure to human and surrounding.

Recently, the loss of Bulk Jupiter – a cargo that carries bauxite from Kuantan, Malaysia to China had risen up the concern of industry and public on bauxite liquefaction. The cargo sunk on a voyage from Kuantan to China which is fully loaded with bauxite and is said to be caused by bauxite liquefaction (Bahamas, 2015). Based on Bahamas Maritime Authority (BMA)'s report on Bulk Jupiter (2015), it highlights on the moisture content of the bauxite transported exceeds the IMSBC specification which is 10%. The testing on cargo loaded on Bulk Jupiter were made and the test revealed that the bauxite samples that were being transported has a moisture content of about 21.3% which is against the 10% as stated by IMSBC. Since then, bauxite liquefaction had become a great concern to public and these concerns include a lack of understanding of Bauxite's behaviour and uncertainty in geotechnical properties of Gebeng Bauxite. By comparing the results which is the differences between the basic properties and shear strength of raw and processed Gebeng Bauxite with International Maritime Solid Bulk Cargoes Code (IMSBC Code) then it will decide whether the bauxite is safer to be transported or not.

1.3 OBJECTIVES

This research focuses on the geotechnical properties of raw and processed bauxite of Gebeng, Kuantan. Through this research, the geotechnical of Gebeng Bauxite will be determined. In order to achieve the research aim, the following objectives had been established:

i) To determine the basic properties of raw and processed Gebeng Bauxite.
ii) To determine the suitability and quality of Gebeng, Kuantan bauxite according to IMSBC Code.
iii) To compare the raw and processed Gebeng bauxite with IMSBC Code.

1.4 SIGNIFICANCE OF RESEARCH

The significance of this research is to identify and obtain the basic properties and strength of raw and processed Gebeng Bauxite. The finding of this study, we can understand the bauxite basic properties with shear strength where it can be a proper guideline and references to ensure the safety of cargo vessel carrying any soil material, the soil properties must be mandatory to follow the International Maritime Solid Bulk Cargoes Code (IMSBC Code) for safe transportation that will lower risk of cargo liquefaction which is very dangerous. Besides that, processed bauxite will have less fine particles which result in much cleaner bauxite to be transported by lorries with less dust. It will reduce the air pollution in Kuantan mining area before exporting. It will make a significant contribution to the mining companies, maritime organization, geotechnical engineers, researchers and also society to understand more about bauxite properties at Gebeng, Kuantan.

1.5 SCOPE OF RESEARCH

The research is based on laboratory tests. In this research, a series of laboratory tests will be conducted to evaluate the basic properties of Gebeng Bauxite. Gebeng is located near Kuantan Port and approximately 39.5 km from Kuantan. Four (4) raw and four (4) processed bauxite samples will be collected at different stations at Gebeng. The processed bauxite sample will be provided by Aras Kuasa Sdn Bhd. Each of these samples will be tested in geotechnical laboratory and the results will reflect the geotechnical properties of Gebeng Bauxite. The bauxite sample is test in accordance with Geospec 3. The basic properties and strength of Gebeng Bauxite were determined from the tests below:

i) Moisture Content Test
ii) Specific Gravity Test
iii) Particle Size Distribution – Sieve Analysis
iv) Field Emission Scanning Electron Microscope (FESEM)
v) X-Ray Fluorescence (XRF)

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will provide a review of past research efforts which are related to bauxite in all aspect and gain idea to bring us more depth related to bauxite rock, bauxite mining activities, environmentally issues caused by the mining of bauxite and also some properties of bauxite. A review of other relevant research studies is also provided in this chapter in order to give a better view of bauxite in all aspect. Substantial literature has been studied on the history of bauxite rock and the bauxite's properties. The review is organized chronologically to offer insight in which how past research's efforts had laid the groundwork for subsequent studies, including the present researcher's effort. The review is written and described in detail so that the present research effort can be properly tailored to add to the present body of literature as well as to justify the scope and direction of the present researcher's effort.

2.2 ALUMINUM

In 1807, Sir Humphrey Davy proposed the name "aluminum" for a yet to be discovered metal that was positively known to exist as an oxide in 1787 by Antoine Lavosier who originally named it alumina (Hudson, 2012). Aluminum received its official elemental name when it was discovered as a solid by the Danish physicist and chemist Hans Christian Orsted in 1825. Two years later, it was isolated as an element by the German chemist, Friedrick Wohler. Despite not being discovered and isolated until the early 1800s, aluminum has been known to be used by humans since ancient Greek and Roman times. The ancients used aluminum salts to set dyes in fabrics and to stop bleeding wounds. Today, the Aluminum Association (of the United States) lists the top markets for aluminum in America as transportation, packaging, and building construction Aluminum is also used extensively in electrical systems, electronics, and the pharmaceuticals. Its desirable characteristics are its abundance and desirable properties: high strength, good conductivity, light weight, malleability, ductility, corrosion resistance, and easy recycling (Jones et al., 2011). Aluminum is the 13th element on the periodic table. It is a non-ferrous metal that rarely can be found in its elemental state due to its affinity to oxygen; therefore, it is found mainly in oxides and silicates. Although aluminum is the third most abundant element on earth behind oxygen and silica, it is difficult to extract from aluminum minerals. Instead, it is produced from alumina (chemically know as Aluminum Oxide (Al_2O_3)), a by-product produced primarily from the ore bauxite.

2.3 BAUXITE

First discovered in 1821 by the French geologist Pierre Berthier, bauxite was named after the town of Les Baux in France and was noted for having high levels of aluminum (Authier-Martin et al., 2001). It is an iron-rich tropical lateritic ore typically consisting of the minerals gibbsite, boehmite, and/or diaspore along with the iron oxides goethite and hematite, the clay mineral kaolinite, and trace levels of several metals that include cadmium and titanium. Table 2.1 provides an overview of the mineralogy of tropic bauxites. It can be found in abundance in Australia, Brazil, Guinea, and Jamaica. Today, mining of bauxite has reached 220 million tons annually, with Australia leading with almost one-third of the total production in the world.

Table 2.1: Mineralogy of Tropical Bauxites

Elements	Mineral
Major	
Aluminium	Gibbsite Boehmite
Silicon	Quartz Kaolinite/Halloysite
Iron	Hematite Aluminous Goethite
Titanium	Anatase Rutile
Minor	
Carbon	Organic carbon
Phosphorus	Wavellite Crandallite-H
Calcium	Calcite Crandallite-H
Potassium	Illite
Manganese	Lithiophorite
Magnesium	Magnesite Dolomite
Sodium	Dawsonite
Strontium	Celestite
Sulfur	Woodhouseite Pyrite
Zinc	Gahnite
Chromium	Chromite
Vanadium	Schubnelite
Zirconium	Zircon

Source: (Authier-Martin et al., 2001)

2.3.1 Bauxite Geology

Between latitudes 30° south and 30° north of the equator is where bauxite is primarily found on Earth, excluding the Chinese or Russian Tikhvin-type and also the Mediterranean lateritic bauxites. There are some countries with major reserves includes Vietnam, Brazil, Guinea, India, Jamaica, China and Australia, among others. Bauxite ore usually consists of the minerals diaspore, boehmite, and/or gibbsite together with the hematite and iron oxides goethite, the clay mineral kaolinite, and also some trace levels of some metals which includes titanium and cadmium.

Many varieties of choice of methods in classifying bauxite were developed by geologist over the past century. One well recognized system of classification has divided bauxites around the globe into three major categories which are lateritic (85%), karst (14%), and Tikhvin-type (1%) deposits (Bardossy, 1982).

While there were no perceptible or clear reason about why bauxite deposits might not be in of any age geologically, the ages of the most deposits will fall within a duration of specific era. Major times of bauxite formation include the Middle to Late Cretaceous, the late Paleozoic, and also the Middle to Late Tertiary. It is rather unfavourable to constrain and restrict the time of formation and the age of bauxite deposits and to put a date on the surface of land which they lie upon (Lozej, 1993).

2.3.2 Bauxite Ore to Aluminum

Once bauxite ore is mined from the ground, it is sent to refineries for processing. In terms of U.S. operations, bauxite ore is primarily received from mining operations in Jamaica, South America, and/or West Africa by ships at the refineries on or near the Gulf of Mexico. Approximately 60 refineries in the world transform bauxite ore into alumina. These refineries pulverize the ore into a fine powder and then process the ore using a century old technique called the Bayer Process. The entire process includes grinding, digestion, liquor clarification, precipitation of alumina hydrate, and calcination to alumina (Jones et al 2011). Bauxite residue is produced when the grinded ore is mixed with caustic soda (NaOH), heated and put under pressure, and transformed into sodium aluminate and insoluble solids (bauxite residue). The two materials are separated with sodium aluminate eventually producing alumina and residue being filtered out, washed, thickened, and discarded. The alumina is then transferred to a second system and converted into aluminum using the Hall-Heroult Process (a form of dissolution and electrolysis). At the end of this second process, the aluminum is manufactured into convenient transporting blocks and sent to production plants for various industries. The aluminum blocks can be used as pure aluminum or casted with other metals (including copper, magnesium, silicon, scandium, and zinc) into alloys.

2.3.3 Bauxite Production

As we know nowadays, bauxite is produced by mining process. The process of mining was existed since thousands of years ago and have been started in many areas. Usually, a type of mineral which is known as flint, were easily be made into weapons and equipment to be used in the mining of bauxite process. At the very beginning, the extraction process of minerals and the process of mining took places by using traditional methods. The method is then being improvise to get a higher yield. The mining process had become the very beginning stage of the supply chain for almost all products produced by bauxite and the minerals that are extracted through mining process are then be used in the production of everything from staplers to skyscrapers. Today, mining has grown drastically into a massive industry, and thus providing millions of people a job to feed themselves. This gives a huge advantage in promoting economic growth in countries rich in natural resources (Topstad & Karlsen, 2015).

In 2009, Australia becomes the top producer of bauxite with approximately one-third of the world's production. It was then being followed by China, Brazil, India, and Guinea. Most of the world's aluminium today is mined from lateritic bauxite deposits (Bell, 2001; Buultjens et al., 2010). Other countries with large reserves include Vietnam, Guinea, and Jamaica (Brown et al., 2010, 2015). Compared to other types of bauxite ore mentioned, the pisolitic bauxite ore is the most ideal ore for many reasons. This include its location which is located close to the surface. Thus, very little cover is needed to be removed to make the ore being exposed. Moreover, the bauxite particles is also loose and easily be mined with front-end loaders using simple strip-mining (Patterson, Kurtz, Olson, & Neeley, 1986). Strip mining mentioned here is a type of surface mining. In surface mining, it is mainly comprised of strip mining, open-pit mining and mountaintop removal mining. Surface mining is a broad category of mining in which the soil and rock overlying the mineral deposit (the overburden) are removed. Figure 2.1 shows the bauxite mining process.

The followings are the typical processes involved in the mining of surface deposits:

i. Firstly, all the vegetation must be cleared and collection of valuable topsoil will be carried out by using scrapers and bulldozers.
ii. It is then followed by the process of overburden removal.
iii. Then, the blasting or ripping of some parts of the ore that cannot be dug easily is carried out. This process involves drilling and placing the explosives or ripping it with large bulldozers.
iv. The resources were then being loaded onto trucks and being hauled to a crushing facility. Trucks ranging in size from 30 to 180 tonnes are used depending on the different in the size of mines.
v. It will be then being continued with the landscaping and rehabilitating back to the existing land used.
vi. The sorting and crushing of mined resources will be taken place.
vii. It will then be continued with the washing and beneficiation process if necessary. The mined resources were then delivered to be exported or to local refineries.

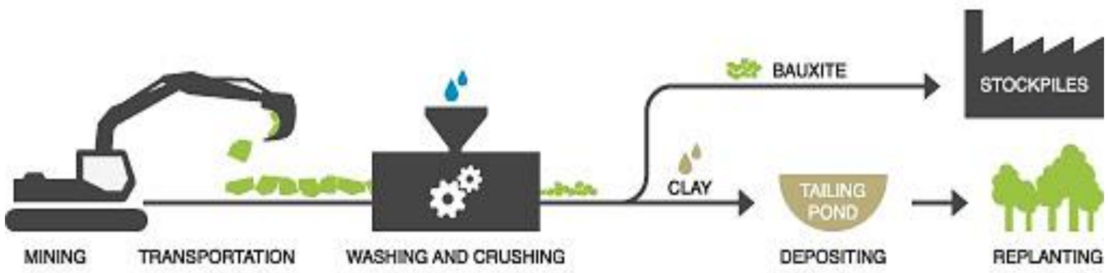

Figure 2.1: Bauxite Mining Process

Source: http://www.hydro.com/en/about-aluminium/Aluminium-life-cycle/Bauxite-mining/ (2016)

Bauxite is also can be mined mine by using the open-cast methods since it occurs typically in broad layers 3m to 10m thick with very little topsoil or other overburden (Greenwood et al., 2012). Open-pit mining mentioned here is the process of a digging out rock or minerals from the earth by their elimination from an open pit or borrow.

Table 2.2 are sourced from 2008 US Geological Survey "Mineral Commodities Summaries". It shows the summary of world bauxite production and reserves by country. The table shows the production figures of 2006 and 2007 and two indicators of bauxite reserves.

Table 2.2: World Bauxite Production and Reserves

Country	**Production**		**Reserve (10^6 T)**	**Reserve base (10^6 T)**
	2006 (10^6 T)	**2007 (10^6 T)**		
Australia	62.30	64.00	5800	7900
China	21.00	32.00	700	2300
Brazil	21.00	24.00	1900	2500
Guinea	14.50	14.00	7400	8700
Jamaica	14.90	14.00	2000	2500
India	12.70	13.00	770	1400
Russia	6.60	6.00	200	250
Venezuela	5.50	5.50	320	350
Suriname	4.92	5.00	580	600
Kazakhstan	4.80	4.90	360	450
Guyana	1.40	2.00	700	900
United States	–	–	20	40
Other countries	5.46	6.80	3400	4000
World total	178.00	190.00	25,000	32,000

N.B. sorted by 2007 production. Suspected to not include the "new" Paragominas deposit which could easily double this reserve, T = metric ton.

Source: Bray (2008)

From the USGS report, the "Reserve Base" mentioned above is the resource that passed the minimum chemical and also physical characteristic concerning to the depth, quality thickness and grade. The "Reserve" mentioned above are limited to the part that is economically recoverable with latest technologies (Bray, 2008). Others figures from the most recent report have minimal different compared to the one stated by Brays but cannot be reproduce due to its copyright issues (Roskill, 2008) .

Generally, this shows slight lower in Chinese and higher Guinea production in 2007, with production about 209 MT (Gu, 2008) . The Bray report estimates world bauxite resources with the total of approximately 55 to 75 billion tons. All the resources mentioned are being explained as the concentration of bauxite such that the economic extraction is feasible. Normally, the breakdown of world reserves by region and its reproduction as shown in Table 2.3 below are included in this report mentioned.

Table 2.3: World Bauxite Resources by Region (Total World Estimates 55–75 Billion Tons)

World region	% of world bauxite resource
Africa	33
Oceania	24
South America and Caribbean	22
Asia	15
Others	6

Source: Smith (2009)

As shown above, 55 to 66% of world resources that are not explained as being within the economic reserve prove that there is potential for new processes in the process of exploiting these holdings to be discover and bring them into the area of economic reserves (Smith, 2009).

Moreover, another claim has been made by the Bank Indonesia, which claims that Indonesia's top five export partners until January 2015 were; China, Japan, United States, India and Singapore. Through all these export partners, it was revealed that bauxite, copper and nickel were amongst the products that are being exported. However, in January 2014, Indonesia unfortunately imposed a heavy tax on export of raw minerals and halted the shipments of raw ore which includes the nickel, bauxite and copper from Indonesian mines. This were said to encourage domestic processing of the minerals (Topstad & Karlsen, 2015).

Meanwhile in Malaysia, it was first discovered there was bauxite under their feet which has approximately 600 Felda Kuantan settlers in Pahang, Malaysia. This contribute to the successfulness of billion-dollar industry in Malaysia in 2015. Thus, since then, the bauxite mining industry are then being increased rapidly in Malaysia since late of year 2014, especialy in Kuantan, Pahang. Kuantan is described here as a land along the east coast facing the South China Sea. All the mining processes carried out here in Kuantan, Pahang have been contributing in the process of shipping rises the amounts of bauxite of aluminium production exported to China. This certainly fills a gap formed when Indonesia banned the ore exports in January 2014 to encourage self-processing at home. According to a data from the Minerals and Geoscience Department in Kuala Lumpur, the bauxite production in Malaysia are more than quadrupled to 962,799 tons in 2014 from 208,770 tons last year 2013 (The Malay Mail, 2015)

However, as man began to extracts the minerals to further increase their profits and at the same time to boost up the economy of Malaysia, the natural deposits have slowly become decreased in concentration and quantity. Hence, this have been making the mineral wealth of the Earth decreases. Although the mining activities for bauxite ore was a source of income for many, it is sad to be said that this mining activities in turns have been causing dramatically environment issues such as air pollution and water pollution on that area due to uncontrolled and rampant bauxite mining in Kuantan, Pahang.

2.3.4 Bauxite Process

In the late 1888, Karl Josef Bayer had developed and patented a process, which has become the new discovery of the world aluminium production industry that we have nowadays. It is none other than the Bayer Process. Basically, the Bayer process usually be used for refining bauxite. Typically, around 1.9 to 3.6 tonnes of bauxite is required to yields 1 tonne of alumina depending on the quality of the ore itself.

The Bayer process was invented by the Austrian chemist Carl Josef Bayer in St. Petersburg, Russia in 1887 while trying to develop a method for using alumina in the textile industry as a substance for setting dyes in fabric (Power et al., 2011). Bayer discovered that, in a cold sodium aluminate solution (alkaline in nature), aluminium hydroxide precipitated into crystalline form if a seed of aluminium hydroxide was used. The aluminum hydroxide could be filtered, washed and the easily used later to make aluminium sheets. Bayer also discovered that the required sodium aluminate solution could be prepared by heating bauxite ore under pressure in concentrated caustic soda solution. Eventually, the potential of combining the two processes was brought to fruition, leading to the process of extracting alumina from bauxite and the manufacturing of aluminum. The Bayer Process led to the modern-day alumina industry and the accelerated use of aluminum. The Bayer Process was shown in Figure 2.2 below.

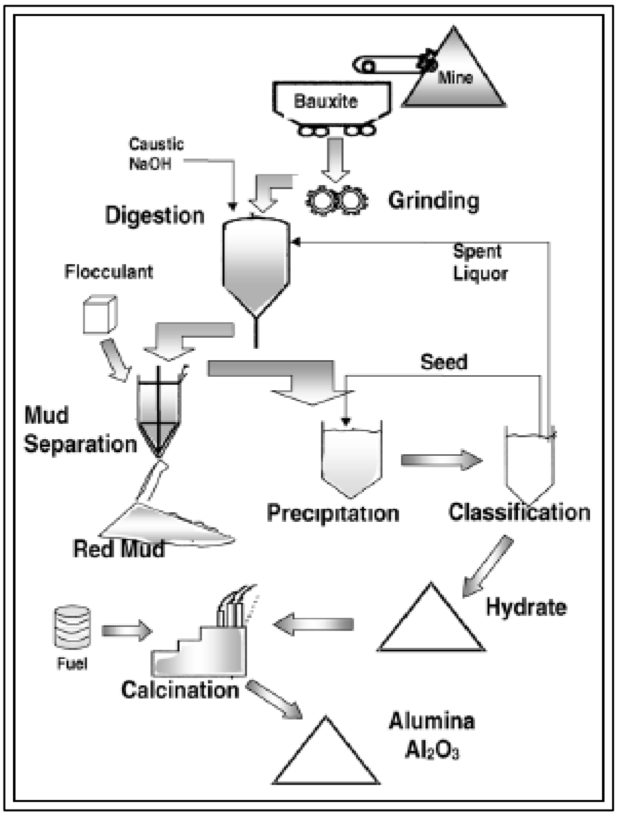

Figure 2.2: The Bayer Process

Sources: Martin (2001)

In Bayer process, the bauxite will be refined before being converted to smelting grade alumina (Al_2O_3) which is the precursor to aluminium (Hind et al., 1999). It will then be followed by the digestion process of crushed bauxite in concentrated sodium hydroxide (caustic) solution at temperatures up to 270°C. This allows most of the aluminium containing element in the ore will be then dissolved (1) and thus leaving an insoluble residue which is known as red mud as its end product. Basically, red mud is mainly composing of fine particles that includes the mixture of aluminium, calcium, silica, iron and titanium and hydroxides together with iron (Hudson, 1982). Red Mud will then be extracted by settling/filtration process. Gibbsite ($Al(OH)_3$) will be precipitated after the solids separation process by cooling the solution and seeding it with gibbsite (2). The gibbsite is then being removed and washed prior to the calcination process (3). The extraction process depends on the chemical processes that occurs at the solid/aqueous interface. All these processes mentioned above can be summarized as shown in Table 2.4 below:

Table 2.4: Summary of Bayer Process

Equation	Chemical Equation
Equation (1)	Extraction: $AlO(OH)_{3(s)}+NaOH_{(aq)} \rightarrow Na^{+}Al(OH)^{-}_{4(aq)}$ and, $AlO(OH)_{(s)}+NaOH_{(aq)}+H_2O \rightarrow Na^{+}Al(OH)^{-}_{4(aq)}$
Equation (2)	Precipitation: $Na^{+}Al(OH)^{-}_{4(aq)} \rightarrow AlO(OH)_{3(s)}+NaOH_{(aq)}$
Equation (3)	Calcination: $2AlO(OH)_{3(s)} \rightarrow Al_2O_{3(s)}+ 3H_2O$

Source: Hudson (1982)

2.3.5 Bauxite Residue

Bauxite residue (also called "red mud", "red clay", "alkaline clay", and "cajunite", among other names) is the waste product left from the filtering and washing of the aluminum hydroxide crystals. The residue can vary in color but is typically a reddish brown color and is high in iron (20-45%), aluminum (10-22%), and silica (5-30%) content (IAI 2013), with a specific gravity of 3.0 to 3.6. Bauxite residue is produced as a slurry that is highly alkaline (pH as high as 13), laden with heavy metals, fine grained (can exceed 95% finer than 0.075 mm) (Hind et al., 1999). The Basil Convention (a convention organization of the UN) designates the material as a contaminated waste, which does limit transportation for storage, disposal, or treatment applications and reuse options, with regards to transport between countries (Johnston, 2010). However, the major concern of the Basil Convention is the alkalinity and removing the restrictions simply requires neutralization of the residue down to a desired end-point pH of 7 to 9. In the Bayer Process, alumina to bauxite residue ratios by mass can range from 1:1 to 1:4, depending on the mineral composition of the bauxite used for production. Figure 2.3 shows the bauxite residue production has rapidly increased with time, with likely the fourth billion being reached by 2015. The accelerating production of waste has led to questions and discussions on methods of bauxite residue reduction, the proper method of disposal, and possible reuse alternatives for the waste by-product.

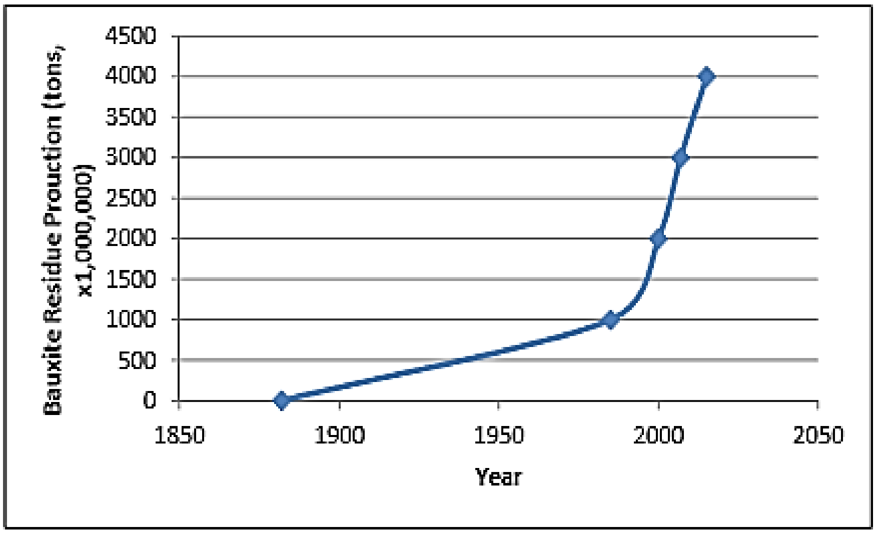

Figure 2.3: Worldwide Bauxite Residue Production

Source: Johnston (2010)

2.4 GEOTECHNICAL PROPERTIES

2.4.1 Grain Size Distribution

Based on U.S. Geological Survey Professional Paper, it mentioned that the grain size of bauxite depends on certain factors. The factors that might affect the grain size of bauxite are; the grain size will increase with the increasing mineral's age, techtonic stress, and overburden thickness (Patterson, 1986). It is common that a lot of bauxites are oolitic or pisolitic, and also compound pisolites were enclosed and inter-grown by bigger pisolites in size. Figure 2.4 shows the pisolitic bauxite from little Rock, Arkansas which are exhibiting a pisolotic structure and characteristic red iron staining and it specimen is approximately 4 inches or 10 centimetres across. Figure 2.5 shows the close-up view of the bauxite specimen and Figure 2.6 shows the bauxite from Demerara, Guyana which are some specimen of bauxite do not have the pisolotic structures.

Figure 2.4: Bauxite from Little Rock, Arkansas

Sources: Hobart (2005)

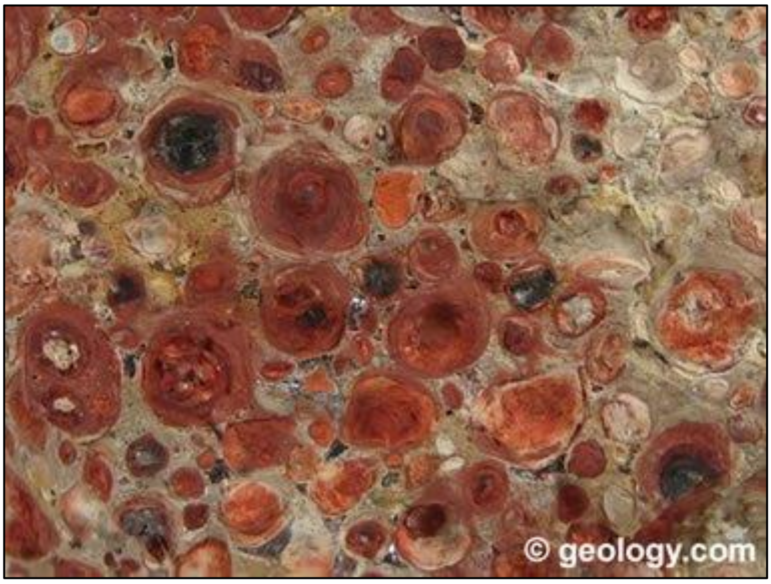

Figure 2.5: Pisolites In Bauxite

Sources: Hobart (2005)

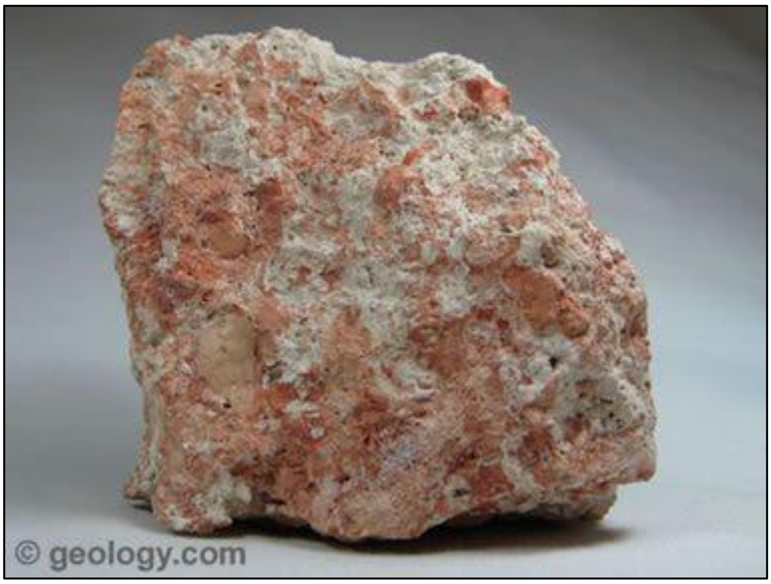

Figure 2.6: Bauxite Without Pisolites from Demerara, Guyana

Sources: Hobart (2005)

2.4.2 Specific Gravity

Specific Gravity is the ratio of the mass on dry particles to the mass of water displacement and it is a dimensionless quantity. Specific Gravity of bauxite can be said to be ranged from 2.5 to 3.0 (Donaldson, 2013) and is tabulated as shown in table 2.5.

Table 2.5: Specific Gravity of Typical Solid

Concentrate Type	Specific Gravity of Solids
Iron	4.5 – 5.0
Copper	4.2 – 4.8
Zinc	4.0 – 4.3
Nickel Laterite	3.3 – 4.0
Phosphate	2.8 – 2.9
Bauxite	2.5 – 3.0
Copper Tailings	2.5 – 3.0

Source: Donaldson (2013)

Bauxite is a type of rock that is composed primarily of Aluminium Hydroxide and Aluminium Oxide minerals. These rocks might include: Diaspore, Boehmite and Gibbsite. These rocks typically also include other materials for example clay, free Silica, Iron Hydroxide and silt. Bauxite most frequent occurs or presents as a residual soil material in subtropical and also tropical areas. Bauxite is considered as the main source of Aluminium. Bauxite mineral's specific gravity are summarized as shown in Table 2.6.

Table 2.6: Properties of Bauxite Mineral

Mineral	**Gibbsite**	**Boehmite**	**Diaspore**
Common Chemical Formula and Name	$Al_2O_3{\cdot}3H_2O$ Alumina Trihydrate	$Al_2O_2{\cdot}H_2O$ Alumina Monohydrate	AlO(OH) Aluminium Oxide Hydroxide
Crystal System	Monoclinic	Ortho-rhombie	Orthorhombic
Alumina Content (%)	65.35	84.97	84.98
Combined Water Content (%)	34.65	15.03	15.02
Specific Gravity	2.3 - 2.4	3.01 - 3.06	3.3 - 3.5
Hardness (Mohs Scale)	2.2 - 3.5	4 - 5	6.5 - 7
Reference	Bromfield, 1967	Bromfield, 1967	Palache, 1951

Based on Table 2.6, it was stated that specific gravity of Gibbsite ranges from 2.3 to 2.4; specific gravity of Boehmite ranges from 3.01 to 3.06; and specific gravity of Diaspore ranges from 3.3 to 3.5. All these are the specific gravity of bauxite mineral.

2.4.3 Moisture Content

The moisture is the ratio of the water mass in a sample to the mass of solids in the sample, expressed as a percentage and it indicate the water content of soil. Bauxite that is freshly mined will have moisture content that ranges from 5% up to 20% depending to the porosity of the bauxite itself. Bauxite that is freshly mined is known as raw or wet ore. Their moisture content is about 15% in average and the bauxites were in addition to the combined water in minerals which are hydrated that comprise the rock (Harbeck, 1958).

2.5 CHEMICAL PROPERTIES

2.5.1 Scanning Electron Microscope Study of Bauxite

A scanning electron microscope (SEM) is a type of electron microscope which uses a focused beam of high-energy electrons to produce a variety of signals on the surface of samples. From the signals that were derived from electron-sample, some information such as texture or external morphology of sample, crystalline structure, chemical composition and material orientation that makes up the sample can be revealed. SEM is critical and vital in every field that requires the characterization of solid materials, which concerns most in geological applications.

A scanning electron microscope (SEM) study of bauxites of different origins had been carried out by Bardossy (1978). The form and size of grain aggregates and individual crystals were studied. In this research, significant differences were found by making a comparison between lateritic and karstic bauxite samples. Based on Bardossy (1978), the grain size of bauxite mineral varies from 0.05µm to 1.00mm. Young, surface-deposits of karstic bauxite group will have the smallest grain size while the lateritic bauxite deposits show large grain sizes that goes up to 100µm, and bigger sigle crystals in cavities might reaches sizes of millimetre. Table 2.7 shows the location and age of the bauxite samples that were used in this SEM study. There were total of 3 types of bauxites being experimented which are Karstic Bauxite, Lateritic Bauxite and Tichvin-type Bauxite. Significant differences were found in bauxite of different ages and type having the same mineralogical composition but revealing different crystallinity, grain size and space filling. The SEM results were shown from Figure 2.7 to Figure 2.11 with different magnifications.

Table 2.7: Location and Age of Bauxite Samples for SEM Test

Locality, Country	Type of Bauxite	Age	Macro-texture	Figure
Samar Island, Philippine Island	Karstic	Pleist.	Pelitomorph	Figure 2.8
South Manchester 2, Jamaica	Karstic	U.Mioc.	Pelitomorph	Figure 2.9
Fria Mine, Guinean Republic	Lateritic	High-level	Relict	Figure 2.10
Bamako, Mali	Lateritic	High-level	Collomorph	Figure 2.11
Sinionskoe, Tichvin, USSR	Tichvin-type	L.Carb	Arenitic	Figure 2.12

Source: Bardossy (1978)

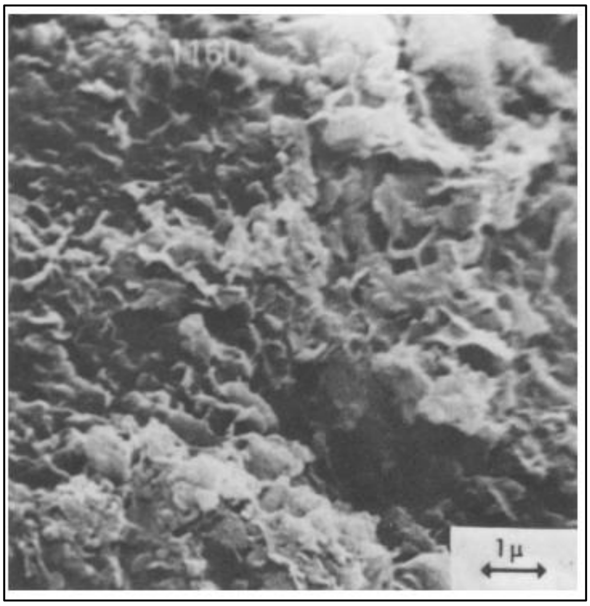

Figure 2.7: Pleistocene Karstic Bauxite, Samar-Island, Philippine Islands (3000 Magnification)

Source: Bardossy (1978)

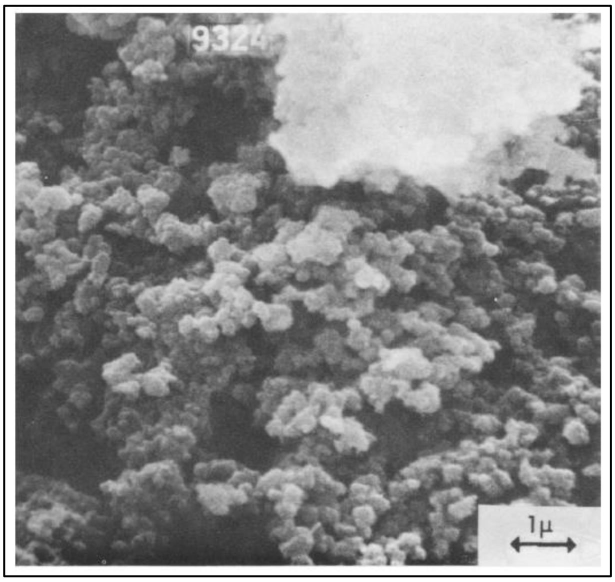

Figure 2.8: Miocene Karstic Bauxite, No 2, South Manchester Plateau, Jamaica (10000 Magnification)

Source: Bardossy (1978)

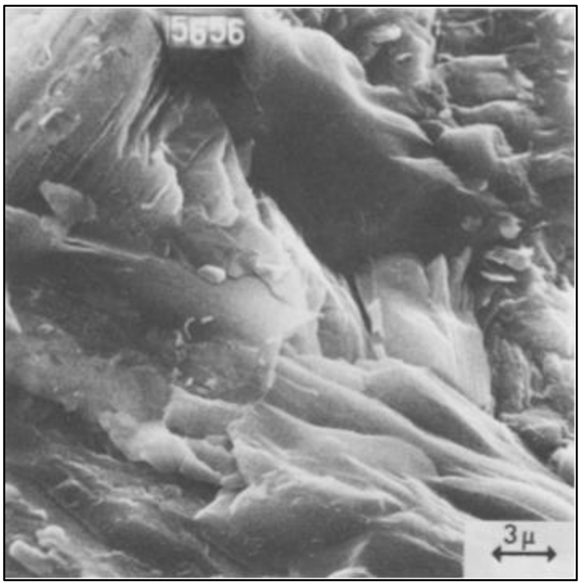

Figure 2.9: Lateritic Bauxite, Fria Mine, Guinean Republic (3000 Magnification)

Source: Bardossy (1978)

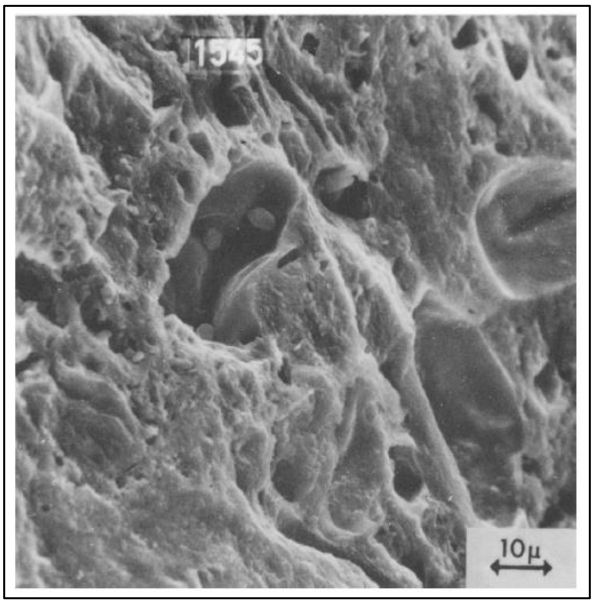

Figure 2.10: Lateritic Bauxite near Bamaco, Mali (1000 Magnification)

Source: Bardossy (1978)

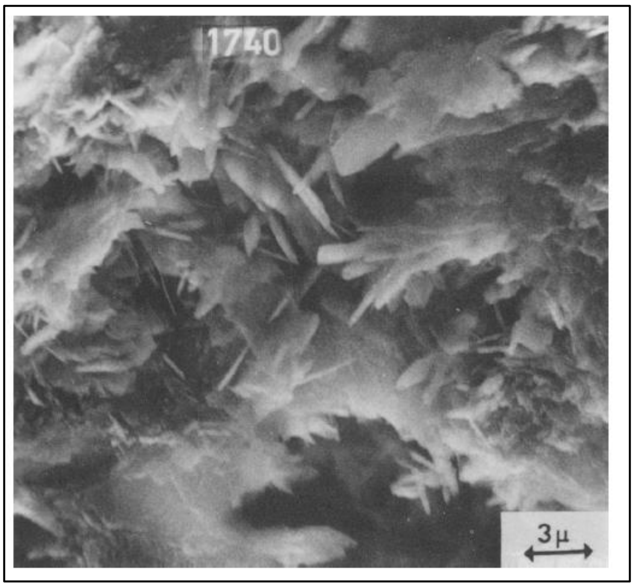

Figure 2.11: Tichvin-Type Bauxite, Sinionskoe Mine Near Tichvin, USSR (3000 Magnification)

Source: Bardossy (1978)

2.6 PHYSICAL PROPERTIES

Bauxite occurs and exists in a number of varieties and different forms; thus, bauxite's physical properties might vary considerably. Bauxites might be gigantic or earthy, oolitic, nodular, brecciated, cellular, pisolitic, botryoidal, vermicular or platy. Most of the pisolites will made up of concentric layers, and it is common to have banding in other structures. The colour of bauxite has a very broad range. Shades of brown or red are the most common ones among the colour of bauxite. Some of the highly graded bauxite will be nearly white or light grey in colour, but brown shades, red, yellow, purple and pink shades are common too; In certain cases, there are a few deposits which it's colour are green, while nearly black to those that are rich in organic matter (Bromfield, 1967).

About 14% of the production of bauxite comes from terra rossa bauxite, and about 85% of this production comes from lateritic bauxite, while the remaining 1% of production of bauxite comes from allochthonous (transported) bauxite (Bardossy, 1982). Deposits of bauxite have been categorized using several different criteria, which includes host rock type, mineralogy, geomorphology and chemical composition. The classification used in this matter will divide bauxite deposits based on the host rock into two rock types. The first type of this classification includes those that are developed in carbonate rock's karst, also called as the "terra rossa" deposits. Relatively, the second type of rock type will include those deposits that are developed on other rocks thus will be referred to or called as "lateritic" deposits. This kind of classification (by host rock) is validated by paleo and genetic geographical considerations (Lozej, 1993).

Based on (Patterson, 1986), it was said that bauxite which ranges from dense types which are three times the weight of water to lightweight porous varieties which are lesser than one and a half times as heavy as water. Most of the bauxite deposits are sufficiently unconsolidated and soft to be loaded and loosened by heavy machines, while others that made up of hard and dense bauxite will require blasting in mining (Patterson, 1986).

2.7 ENVIRONMENTAL CONCERNS

2.7.1 Metals

The Bayer Process cannot avoid the usage of caustic (corrosive) soda, high temperature and high pressure in order to drain out and leach alumina from the ferruginous residue slurry, what we refer to as red mud or bauxite residue. In this leaching process, it will produce the ratio of alumina to bauxite residue or ferruginous from 1:1 to 1:4 with the consequences that there will be bauxite residue waste quantity with billions of tons (4 billion tons by the year 2015 worldwide are recorded). The residue is corresponding and associated with the chemically basic which have an average of 12 in pH, heavy metals which are high, and had uncover the low-level NORMs (naturally occurring radioactive materials) which are synonymous to other materials used in household building such as gypsum, granite, and also marble (Gore, 2015). Research found out that in bauxite residue, it carries significant levels of trace metals which includes vanadium, cadmium, zinc, mercury, arsenic, chromium, and lead (Fuller, 1986).

2.7.2 pH

Bauxite residue is strongly alkaline and has high sodicity and electrical conductivity levels (dominated by Na+ in solution and in the solids phase with average concentration = 101.4 mmol/L, average EC = 7.4 ± 6.0 mS/cm with a range of 1.4 to 28.4 mS/cm (standard deviation was 6.0 and population size was 46) (Grafe, 2010). The pH values for bauxite residue in the containment facilities worldwide varies from 9.2 to 13.2 (Pincus, 1968; Rushing, 1973; Jenny, 1973; Somogyi, 1976; Srivastava, 2002; Zouboulis, 1993; Liu, 2006; Grafe, 2010; Kirkpatrick, 1996; Wagh, 1987; Newson, 1996). Based on the lagoons being open to the elements, there is a range of pH over the area and depth of the containment facility and this pH decreases with time (Liu, 2006). Over time, the bauxite residue would be exposed to increasing levels of rainfall that would dilute the residue mixture and decrease the pH of the residue in the lagoons.

With high alkalinity, neutralization of bauxite residue to a safer pH level has been a principal research topic. Neutralization reduces the impact of bauxite residue on the environment and opens the door to using residue as a reuse product. Several methods of neutralization have been and continue to be studied for effectiveness. These methods include neutralization with strong acids, gypsum, seawater, carbon dioxide, and proprietary procedures.

The process of neutralization can affect the characteristics of the bauxite residue, including leachability, compatibility with other materials, and mechanical properties. Neutralization of bauxite residue to a pH around 8 or lower is optimal because the chemically adsorbed Na is released, alkaline buffer minerals are neutralized, and toxic metals are insoluble at this level (Rai, 2011).

2.8 BAUXITE LIQUEFACTION

2.8.1 Cargo Liquefaction

Liquefaction is a phenomenon where soil experience a process where water-saturated sediment temporarily loses its strength and acts as a fluid. The liquefaction process of saturated sands was studied by pulsating the loading triaxial tests on isotropically consolidated undrained laboratory samples. This analysis prove that this testing can be used to idealized the loading conditions on elements of soil in the field during earthquakes (Seed et al.,1966).

Table 2.8: Factors That Affects Soil Liquefactions

Factors	Hypothesis
Void ratio	Liquefaction will occur more easily when the void ratio is higher.
Confining pressure;	The liquefaction will occur more easily when the confining pressure is lower.
Magnitude of cycle stress or strain	The larger the cyclic stress or strain the fewer the number of cycles required to induce liquefaction.

Based on Dr. Jonas, a cargo can have the risk of liquefaction if the cargo contains at least some moisture and fine particles, even though they are not visibly wet in appearance**.** Despite their dry-looking appearance during the time of loading, there are still some moisture exists in between the particles inside the cargo. During voyage, cargoes will often be exposed to agitation caused by ship's rolling, engine vibration and wave impact, which will the results in the compaction of the cargo (Jonas, 2010). The compaction will result in the reduction of space between the particles inside the cargo where it will lead to increase in the water pressure inside the cargo and then force the particles to separate apart from each other. This will rapidly reduce the friction and shear strength of the cargo. As a result, the cargo will now behave like a fluid, which will cause huge stability problems for the vessel (GL, 2015).

Figure 2.12 illustrates the liquefaction that occurs as a result of cargo compaction. The left side of the picture shows that the cargo is in solid state, where the shear strength of the cargo is provided through the direct contact between the particles inside the cargo. As the ship agitates, cargo compaction will take place and the increase in water pressure will push the particles apart, which potentially leads them to lose direct contact and results in sudden loss of frictional force and shear strength. This will cause the cargo to behave like liquid as shown in the right picture of Figure 2.12.

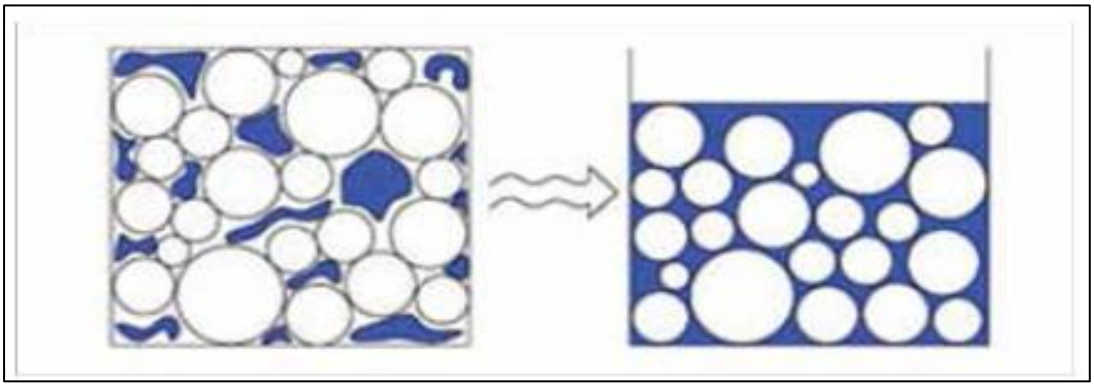

Figure 2.12: Liquefaction Due to Cargo Compaction

Source: Jonas, 2010

2.8.2 International Maritime Solid Bulk Cargoes (IMSBC) Code

International Maritime Solid Bulk Cargoes (IMSBC) Code is a code that is primarily used to facilitate safe shipment and stowage of solid bulk cargoes through providing guideline and information on hazards related with shipment of solid bulk cargoes. Other than that, IMSBC Code also aims to provide information and steps to be taken when the solid bulk cargoes shipment is contemplated.

Bauxite is listed within Appendix 1 of IMSBC Code where it is defined as a yellow claylike, earthy and brownish material. Table 2.9 shows the parameters for Bauxite under IMSBC Code. Based on the table, it is said that bauxite is listed under Group C cargo according to IMSBC Code, which means that it poses no liquefaction nor chemical risk. It is vital to understand that this parameter listing only includes the relatively coarse-grained and relatively dry bauxite. If the bauxite that were about to be transported has a moisture content above 10% or has a high proportion of fines, the cargo is said to be potentially unsafe and might have risk for the cargo to undergo liquefaction during voyage.

Table 2.9: Extract of Bauxite Schedule as Listed in Appendix 1 of IMSBC Code

Characteristic	Value
Angle of Repose	Not applicable
Size	10% to 30% powder 70% to 90% lumps: 2.5mm to 500mm
Bulk Density (kg/m^3)	1190 to 1389
Stowage Factor (m^3/t)	0.72 to 0.84
Moisture Content (%)	0 to 10
Class	Not applicable
Group	C
Hazard	No special hazards. This cargo has a low fire-risk and is non-combustible.

Source: Adoption of the International Maritime Solid Bulk Cargoes (IMSBC) Code, Annex 3 Resolution MSC.268 (85), (2008)

2.8.3 Accidents and Loss due to Cargo Liquefaction

Traditionally, liquefaction of dry bulk cargoes does not receive much attention from media. Nowadays, liquefaction had been seen as a major hazard especially for bulk carriers. For any accidents that were caused by liquefaction, there are some distinct and disturbing features. The time period for this accident to occur is fast as from the moment of detection of liquefaction occurs to the time of the vessel overturns might just happens in few minutes time. This leaves the crew to have very little time to evacuate and take remedial measures to encounter the situation (GL, 2015). There have been a series of serious incidents and total losses which were caused by cargo liquefaction. Table 2.10 shows the accidents and losses due to cargo liquefaction in the pass years.

Table 2.10: Liquefaction Accidents

Vessel	Built	Date of incident	Loss of Life	Cargo Type	Voyage	Source
Mega Taurus	1988	16/12/1988	20	Nickel Ore	Hinatuan Mine (Philippines) – Japan	(Tugsan C, 2014)
Asian Forest	2007	17/7/2009	0	Iron Ore Fines	Sank off New Mangalore Port	(GL, 2015)
Black Rose	1977	9/9/2009	1	Iron Ore Fines	Sank off Paradip Coast	(GL, 2015)
Jian Fu Star	1983	27/10/2010	12	Nickel Ore	Sank In The South China Sea 90 Miles Southwest Of Cape Eluanbi, Taiwan	(Tugsan C, 2014)
Nasco Diamond	2009	10/11/2010	20	Nickel Ore	Sank in the Pacific Ocean.	(Tugsan C, 2014)
Vinalines Queen	2005	25/12/2011	22	Nickel Ore	Sank In the Philippine Sea.	(GL, 2015)
Harita Bauxite	1983	16/2/2013	15	Nickel Ore	Sank off near Philippines	(GL, 2015)
Bulk Jupiter	2006	2/1/2015	18	Bauxite	Sank off the coast of Vung Tau, Vietnam	(Bahamas, 2015)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, all the laboratory tests that will be conducted in order to achieve the objectives of this research which is to determine the basic properties and liquefaction risk on bulk cargoes carrying Gebeng, Kuantan Bauxite in accordance to IMSBC code. All the experiments and laboratory testing will be in accordance to Geospec 3 – Model Specification for Soil Testing that are used to support the properties of the samples. Figure 3.1 shows the flowchart for the process for this research methodology.

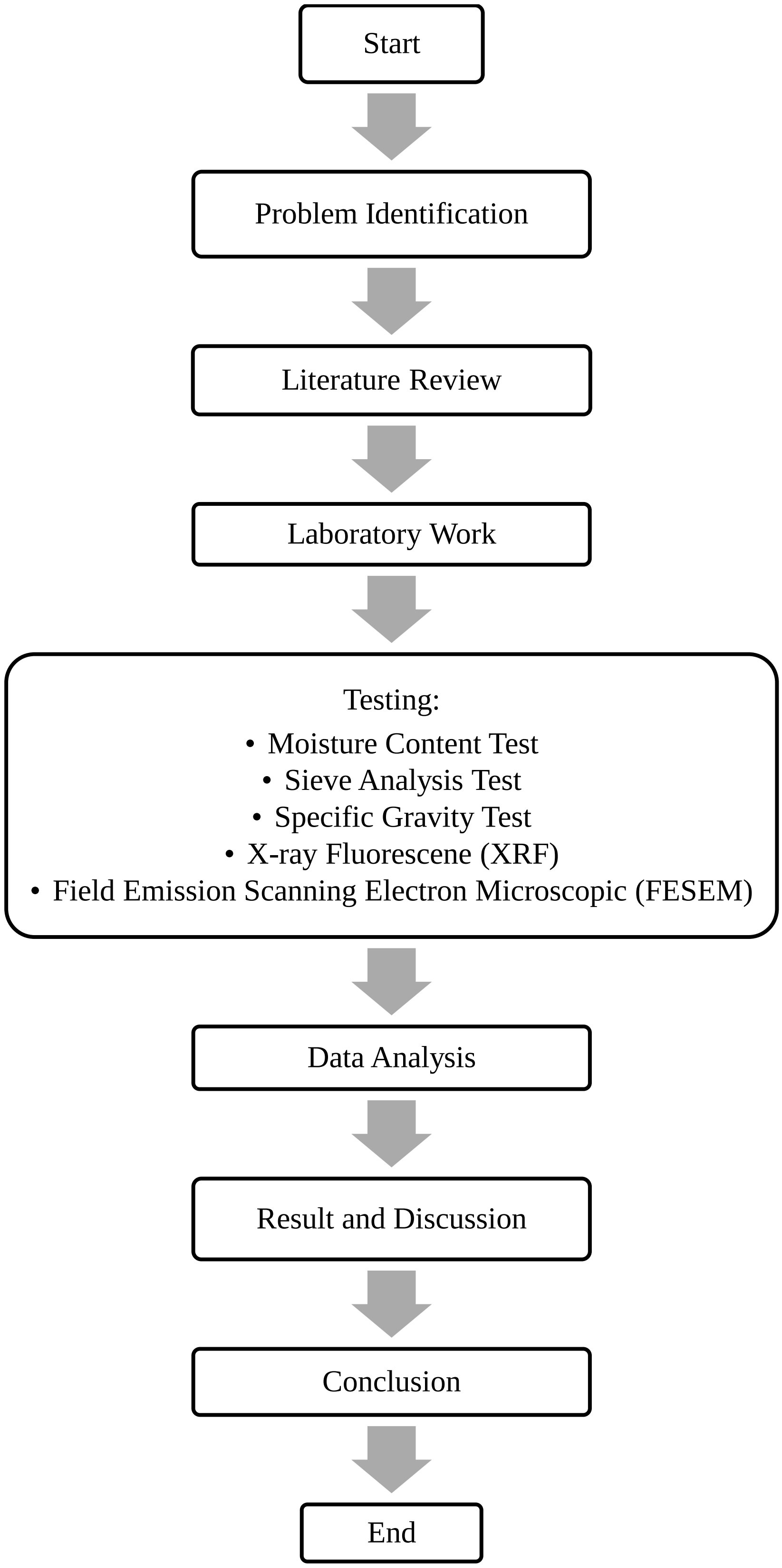

Figure 3.1: Flowchart for Project Methodology

3.2 SAMPLE COLLECTION

In order to achieve the objective of this study, Gebeng, Kuantan Bauxite will be used in this research. A series of laboratory tests will be carried out to indicate and obtain the basic properties, chemical properties and morphological properties of raw and processed Gebeng, Kuantan Bauxite. Gebeng is a small town and is Pahang state's main industrial area. The town is located near Kuantan Port. The phase one (1) of the East Coast Expressway leads to Gebeng. Four (4) raw and four (4) processed bauxite samples will be collected at different stations at Gebeng, Kuantan and all the experiments will be carried out on the four (4) raw and four (4) processed. The results obtained from these laboratory tests will represent the basic properties and strength of whole Gebeng, Kuantan Bauxite as there were four (4) raw and four (4) processed retrieved from different point of Gebeng, Kuantan. Each of these samples will be tested in geotechnical laboratory and the results will reflect the geotechnical properties of Gebeng, Kuantan Bauxite. The bauxite sample is test in accordance with Geospec 3 – Model Specification for Soil Testing. Table 3.1 shows the quantity that required for each experiment, and for this research, four (4) raw and four (4) processed samples are required in order to carry out the laboratory tests, which means eight (8) set of Bauxite samples from four (4) stations at Gebeng, Kuantan.

Table 3.1: Quantity Required for Each Laboratory Test

Test	Quantity per experiment (g)
Moisture Content Test	20
Particle Size Distribution	1000
Specific Gravity Test	10 (pass through 2mm sieve)
X-Ray Fluorescence (XRF)	10
Field Emission Scanning Electron Microscope (FESEM)	10
Total	**1050g ≈ 1100g or 1.1 kg**

3.3 DETERMINATION OF PROPERTIES OF GEBENG, KUANTAN BAUXITE

As all the experiments and laboratory testing will be carried out in accordance to Geospec 3 – Model Specification for Soil Testing, thus the results and data obtained from the laboratory work of this research is reliable and follows the standards. Table 3.2 shows the methods that will be used to determine the basic properties of raw and processed Gebeng, Kuantan Bauxite.

Table 3.2: Tests and Standards for The Research

Soil Sample	Laboratory Tests	Standard
Gebeng Bauxite	Moisture Content Test	Geospec 3: Part 2; 5 Clause 3.2:
	Particle Size Distribution - Sieve Analysis	Geospec 3: Part 2; 8 Clause 3.5
	Specific Gravity Test	Geospec 3: Part 2; 7 Clause 3.4
	X-Ray Fluorescence (XRF)	Quantexpress (Full Analysis) by XRF S8 Tiger
	Field Emission Scanning Electron Microscope (FESEM)	FESEM JEOL JSM-7800F

3.3.1 Moisture Content Test

Moisture content can be described as the ratio of mass of “pore” or “free” water in a soil with given mass to the mass of dry soil solids that are expressed in percentage. This test is carried out in order to obtain the water content of Gebeng, Kuantan Bauxite. This laboratory test will be carried out in accordance to Geospec 3: Part 2; 5, Clause 3.2. About 20g of Gebeng, Kuantan Bauxite sample is weighed and then left overnight in an oven to remove the moisture in the sample and the weight will be measured again after being taken out from oven. The moisture content of Gebeng, Kuantan Bauxite sample can then be calculated by dividing mass of pore water with mass of soil solids.

Figure 3.2: Oven dry method

3.3.2 Particle Size Distribution

Particle size distribution is a list of values that defines the relative amount by mass of soil particles according to size. In order to obtain the particle size distribution, two test which are fine analysis or hydrometer test and sieve analysis will be conducted. Fine analysis is carried out to determine the distribution of particle size that passes through sieve size of 63μm while sieve analysis is to obtain and carry out the distribution the particle size of Gebeng, Kuantan Bauxite up to size of 63μm.

Figure 3.3: Bauxite sample is put in the Sieve Shaker

Hydrometer method is conducted in accordance to Geospec 3: Part 2; 8.5, Clause 3.5 and it is used to determine the particle size distribution for a soil sample that passes through 63μm test sieve. In this experiment, the soil will mix with water and also a dispersing agent, then the mixture will be stirred vigorously and being left to settle to the bottom level of a measuring cylinder. As the particles of the soil sample settle out of suspension, the specific gravity of the mixture will be reduced. A hydrometer will be used in order to record the variation of specific gravity versus time. By application of Stoke's Law, where the law relates the free-falling sphere's velocity to its diameter, the test data is decreased to provide particle diameters and the percentage by weight of the sampler finer than a particular particle size. In this research, hydrometer test will be excluded if the mass of the particle retained at pan, or the percentage of mass passing 63 μm is less than 5% of the overall weight.

Figure 3.4: Hydrometer Jar

Sieve analysis is conducted in accordance to Geospec 3: Part 2; 8, Clause 3.5. The test is carried out to determine the particle size distribution in a cohesion less soil down to the fine-sand size. The sieve used in this experiment will have aperture sizes of 5.00mm, 3.35mm, 1.18mm, 600 μm, 300 μm, 150 μm, 63 μm and pan. The masses of samples retained on each sieve are recorded against the sieve aperture size on the particle size.

3.3.3 Specific Gravity Test

Specific gravity is defined as the ratio of density of soil at a specific temperature to the density of gas-free distilled water with the same volume. Small pycnometer, also known as density bottle test which uses a working liquid with well-known density like water and it is very accurate method. This method will be used in this research due to its suitability for soil samples which consist of particles finer than 2 mm in accordance to Geospec 3: Part 2; 7, Clause 3.4. In this experiment, the sample will be weighted and placed inside a small pycnometer, which had already been half-filled with distilled water. After that, to remove the air existed in the sample, the small pycnometer was place in a vacuum chamber.

Figure 3.5: Pycnometer

3.3.4 X-Ray Fluorescence (XRF)

To obtain the composition of elements of Gebeng, Kuantan Bauxite X-Ray Fluorescene (XRF) test is carried out in this research. This analysing method indicates the chemistry of the sample by measuring the fluorescent X-ray emitted from the sample when the sample is stimulated by a primary X-ray source. For this research, the X-Ray Fluorescene (XRF) method used QUANT-EXPRESS (full analysis) where the qualitative and quantitative screening of samples is done in less than two (2) minutes. This method will be carried out using equipment XRF S8 Tiger. The chemical composition of both raw and processed Gebeng, Kuantan Bauxite can be obtained through this test and the quality of the bauxite can also be determined by comparing the quantity of Aluminium (Al) contents in both bauxite samples.

Figure 3.6: XRF S8 Tiger

3.3.5 Field Emission Scanning Electron Microscope (FESEM)

Morphological properties of bauxite are studied by Field Emission Scanning Electron Microscope (FESEM) test where the fine particles as well as the bauxite ore can be observed clearly. FESEM is used to visualize small topographic details of a fractioned or surface of an object. This test can be used to determine the morphological properties of raw and processed Gebeng, Kuantan Bauxite. JSM 7800F will be used to carry out FESEM test on both raw and processed bauxite for this research.

Figure 3.7: JSM 7800F

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The methodology described in the previous chapter provided the baseline for data-gathering. In this chapter, all the results of the research are discussed and presented here evidently which determining the basic properties of both raw and processed Gebeng bauxite. Laboratory test were carried out in accordance to Geospec 3: Model Specification for Soil Testing and results obtained from laboratory tests were tabulated. Both the results obtained from laboratory testing will be used to check and compare with the standards as stated in IMSBC Code for bauxite. There were total of three (3) test that had been carried out which are moisture content, particle size distribution and specific gravity test. Besides that, chemical properties and morphological properties for bauxite were investigated as well. To compare the differences of the properties between raw and processed bauxite all the results obtained from the laboratory tests were presented in table and graph form for ease of understanding.

4.2 PARTICLE SIZE DISTRIBUTION (PSD)

Particle size distribution is a measurement designed to determine and report information about the size and range of Gebeng bauxite. It is also to determine whether it is safe to be exported undisturbed or otherwise. Referring to IMSBC Code, allowable size for cargo transportation is between 2.5 mm to 500 mm with total percentage of 70% to 90% lumps and only 10% to 30% powder. For this research, four (4) raw and four (4) processed bauxite were being experimented to get the average data for Gebeng bauxite. The result from the test are shown in Appendix A.

4.2.1 Comparison Between Raw and Processed of Gebeng Bauxite

Comparison between raw and processed of Gebeng bauxite had been made and shown in Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4 for four (4) of the bauxite samples experimented. For easier comparison, Figure 4.5 was illustrated. The results show that after being processed, the bauxites will have lesser fine particles compared to raw bauxites. This is due to the removal of fines during the washing process of bauxite. Based on IMSBC Code, the allowable size for safe exportation is passing 2.5 mm with percentage below 30%.

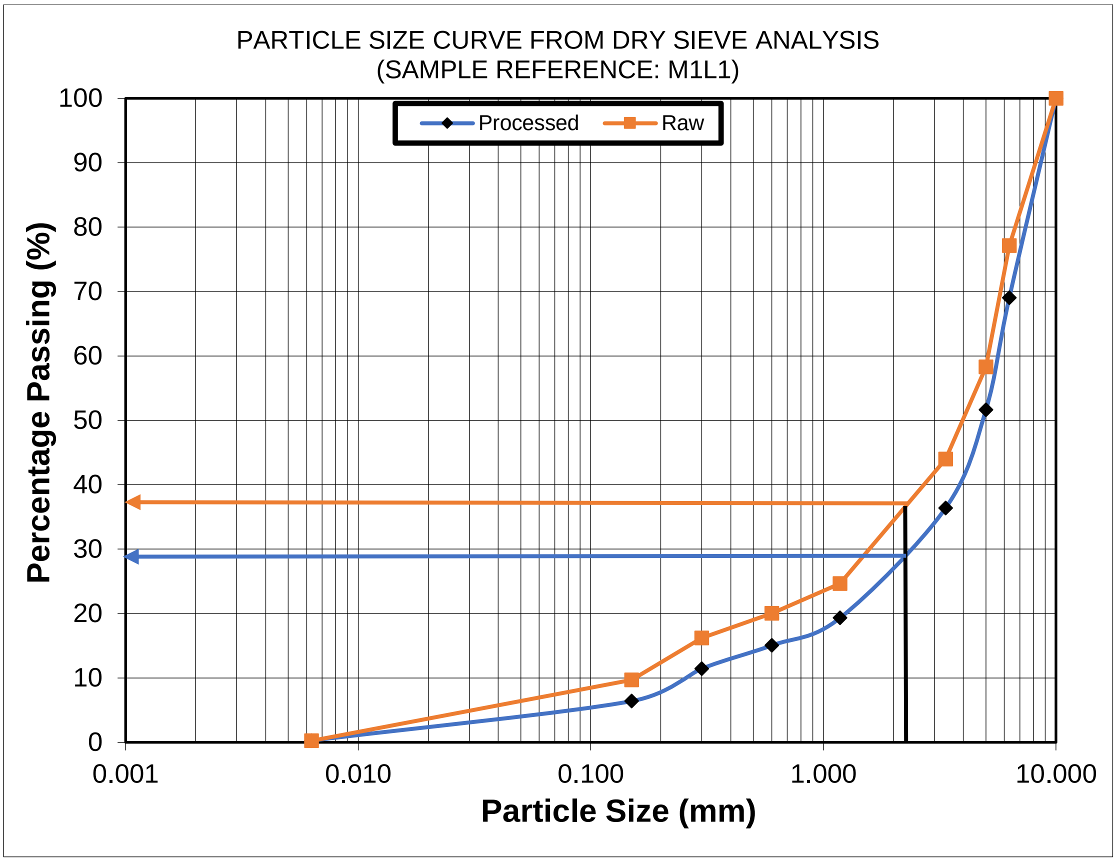

Figure 4.1: Particle size distribution for M1L1 sample

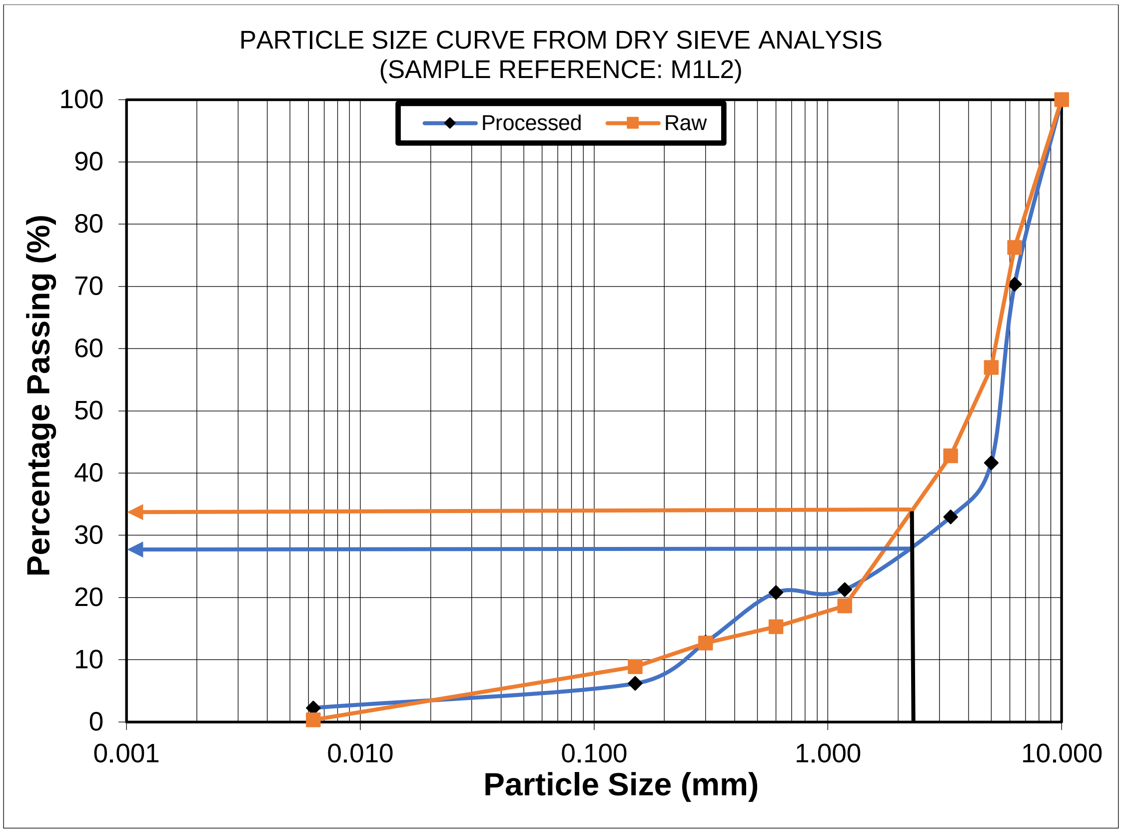

Figure 4.2: Particle size distribution for M1L2 sample

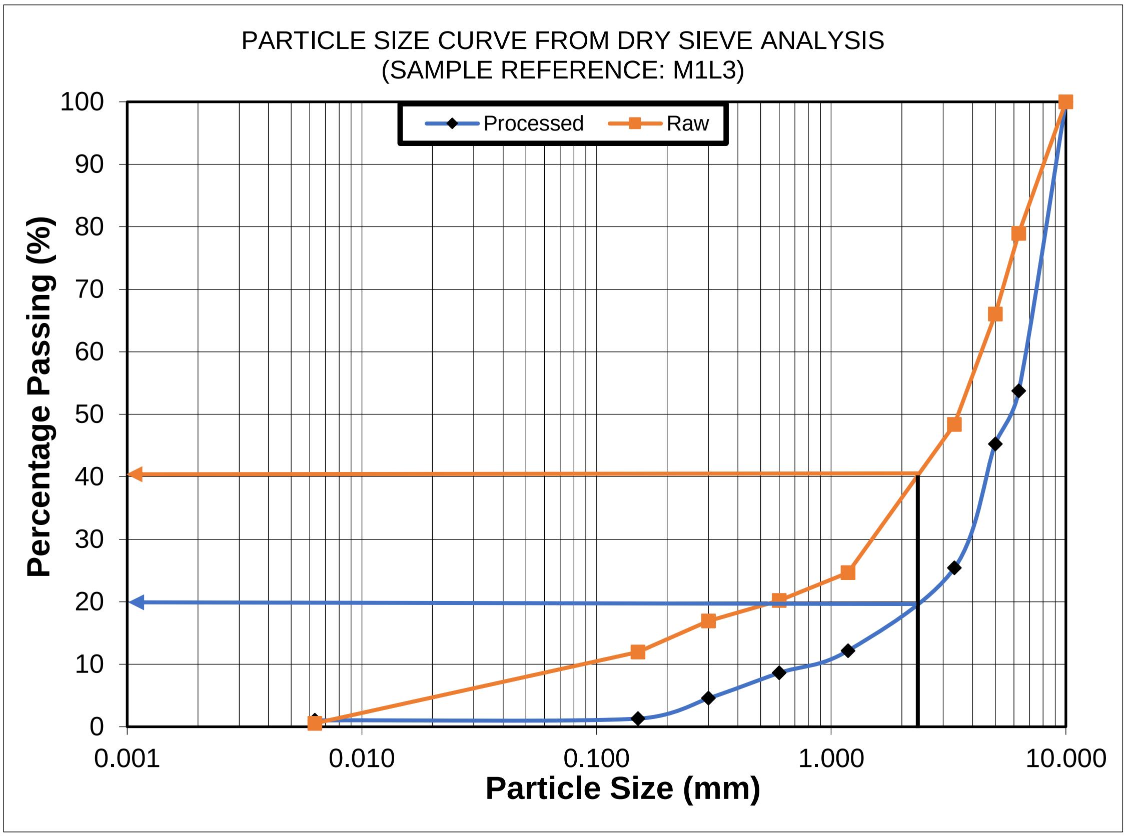

Figure 4.3: Particle size distribution for M1L3 sample

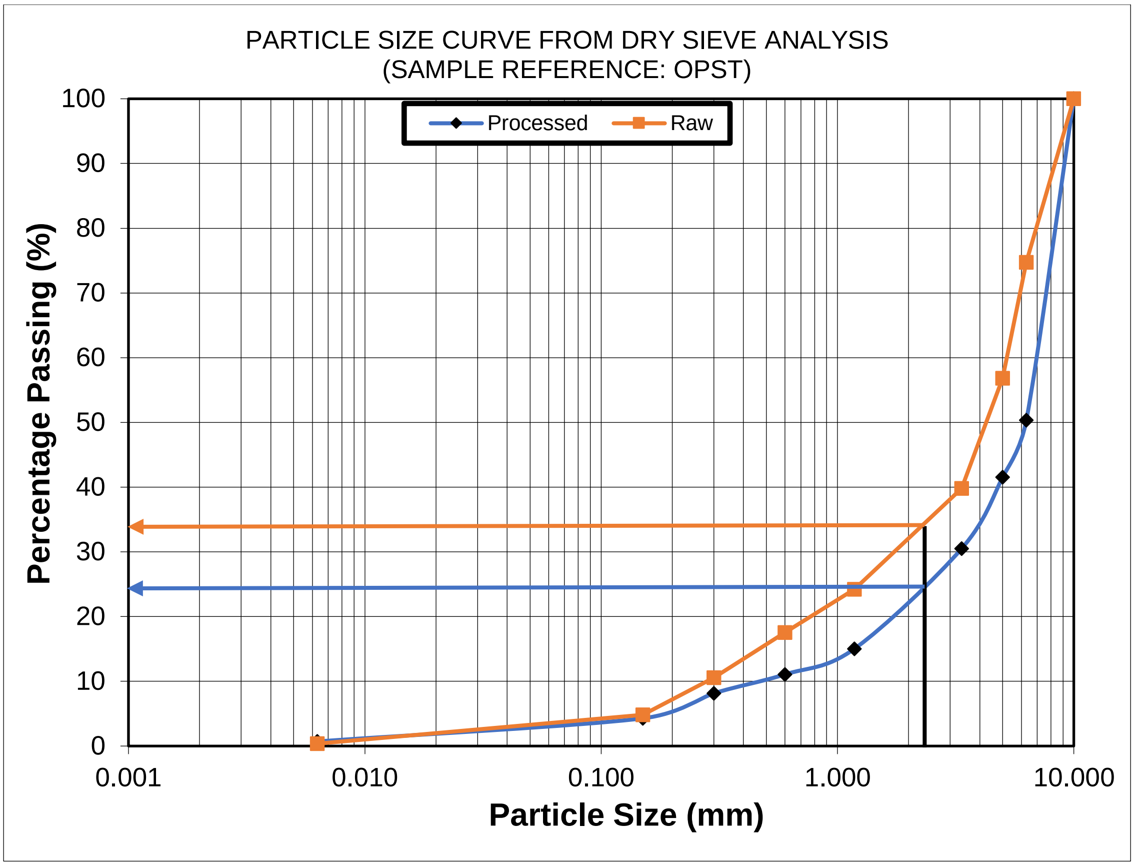

Figure 4.4: Particle size distribution for OPST sample

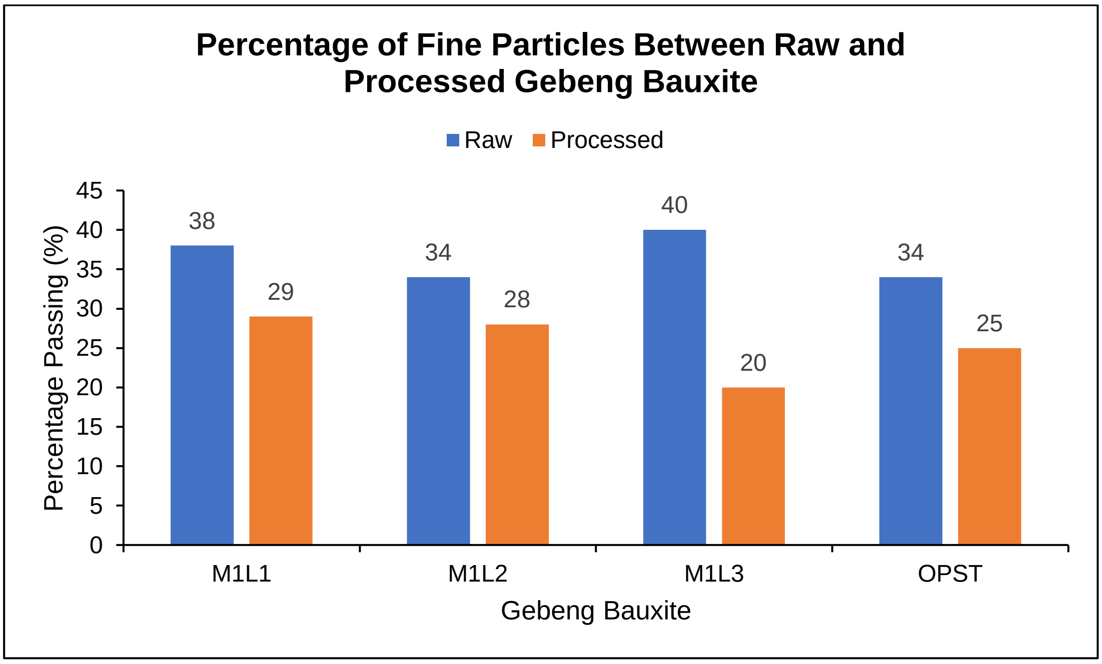

Figure 4.5: Tabulated of percentage fine particles between raw and processed Gebeng bauxite passing 2.5mm

Table 4.1 Comparison of percentage fine particles between raw and processed Gebeng bauxite from previous research

Researchers	Samples	Raw (%)	Processed (%)
Phang (2016)	M1L1	40	30
	M1L2	33	13
	M1L3	40	36
	OPST	25	12
Average fine particles		**34.50**	**22.75**
Current Research (2018)	M1L1	38	29
	M1L2	34	28
	M1L3	40	20
	OPST	34	25
Average fine particles		**36.50**	**25.50**

From Table 4.1, it shows that the processed bauxite samples have less fine particle compared to raw bauxite samples with the average of 25.50% compared to raw with 36.50%. Based on the result analysis prove that the particle size distribution Gebeng bauxite's not in range for requirement in IMSBC Code. Compared to previous researcher done by (Phang, 2016) from Department of Civil Engineering, University Malaysia Pahang, the result proved that raw Gebeng bauxite's in average consist more than 30% fine particle and less than 70% coarse particle. Due to this situation, the moisture content of the raw bauxite will increase and it will increase the risk of liquefaction to occur during transportation of bauxite in bulk cargoes. In the meantime, bauxite of the same sample that has been beneficiated has fine particle less than 30% which prove that beneficiation method can reduce the number of fine particles in bauxite.

4.3 MOISTURE CONTENT

Moisture content of both raw and processed Gebeng bauxite sample are determined by oven-dry method. The difference between both data obtained from the tests was compared. Bauxite will have moisture content that ranges from 5% up to 20% depending to the porosity of the bauxite itself (Harbeck G.E., 1958). The allowable average moisture content according to IMSBC Code is 0%-10% to make sure the bauxite is save to be exported. The result from the test are shown in Appendix B.

Table 4.2: Average moisture content of raw and processed Gebeng bauxite

Samples	Raw (%)	Processed (%)
M1L1	21.03	5.28
M1L2	25.99	6.67
M1L3	23.16	4.67
OPST	25.48	5.68
Average moisture content	**23.92**	**5.58**

From the Table 4.2, it shows that the moisture content of raw Gebeng bauxite is higher compared to processed bauxite where it has the average of 23.92% over 5.58% only on the processed bauxite sample. To get easier comparison, a chart has been drawn and shown in Figure 4.6. From the results obtained, it shows that the presence of larger number of fine particles on the bauxite ore will contribute to higher moisture content percent and will give the bauxite sample more water absorption. High level of moisture content causes the liquefaction of mineral ores to be occurs and this making the cargo loss of stability during the voyage. If cargoes loaded with too high a moisture content, liquefaction may occur without warning at any time during the voyage.

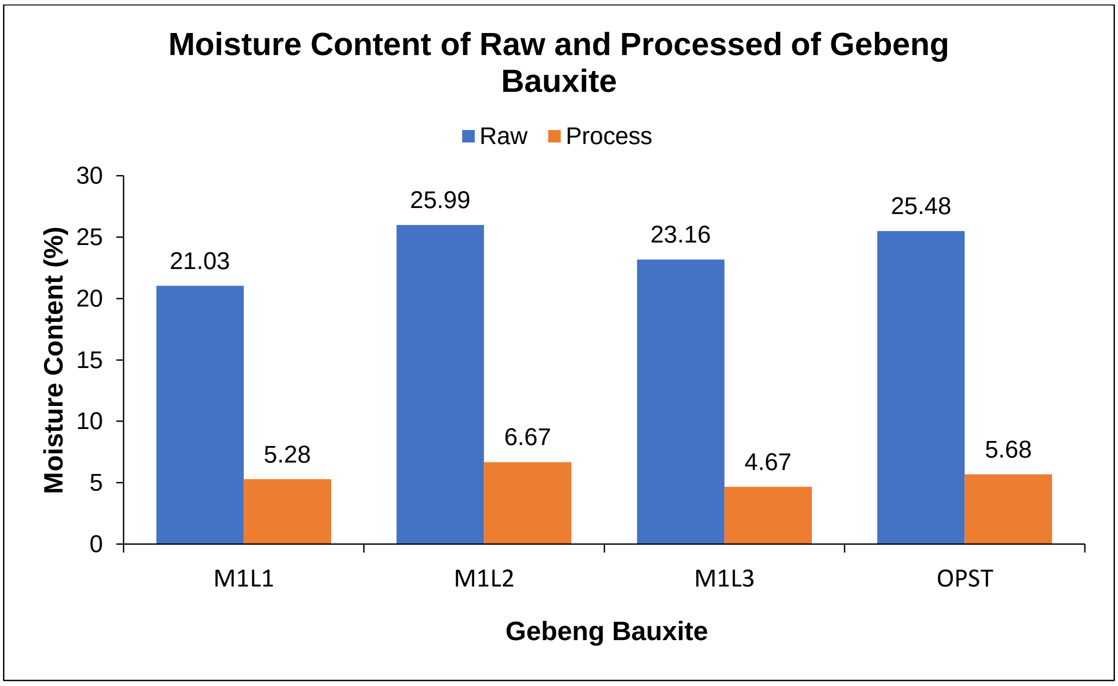

Figure 4.6: Moisture content of raw and processed Gebeng bauxite

4.4 SPECIFIC GRAVITY

To determine the specific gravity for all raw and processed Gebeng bauxite samples, Small Pycnometer Test was carried out. Based on research, it was said that the specific gravity for bauxite is between 2.5 to 3.0 (Donaldson D., 2013). The result from the test are shown in Appendix C. From the results, it was shown that the average specific gravity of processed bauxite samples is slightly lower than raw bauxite samples, which falls within the range of the study same as stated by previous research work. Table 4.3 shown the comparison on the average specific gravity of raw and processed Gebeng bauxite from previous research works.

Table 4.3: Comparison on the average specific gravity of raw and processed Gebeng bauxite from previous research work

Researchers	**Average Specific Gravity (Mg/m^3)**	
	Raw	**Processed**
Phang (2016)	2.82	2.66
Current Research (2018)	2.91	2.30

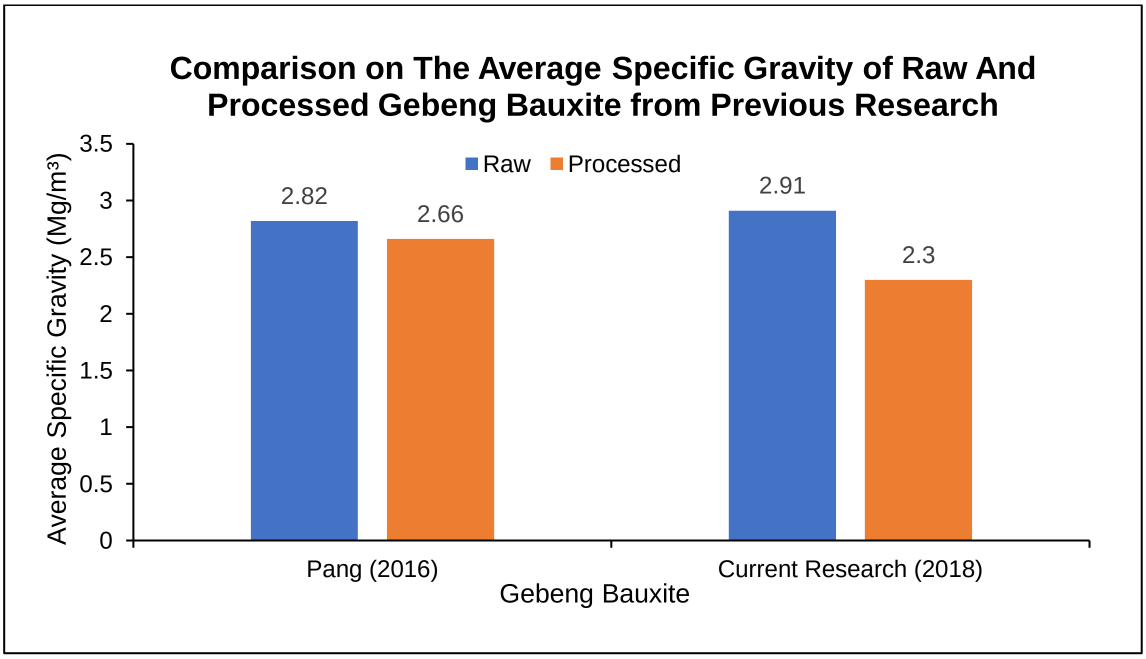

Figure 4.7: Tabulated of average specific gravity of raw and processed Gebeng bauxite from previous research work

4.5 FIELD EMISSION SCANNING ELECTRON MICROSCOPE (FESEM)

Morphological properties of both raw and processed Gebeng bauxite is studied by Field Emission Scanning Electron Microscope (FESEM) test where the fine particles as well as the bauxite ore can be observed clearly. The results are shown in Figure 4.8, Figure 4.9, Figure 4.10, Figure 4.11 and Figure 4.12 where magnification for each figure is 1000x, 2500x 5000x, 10 000x and 500 000x respectively for both samples.

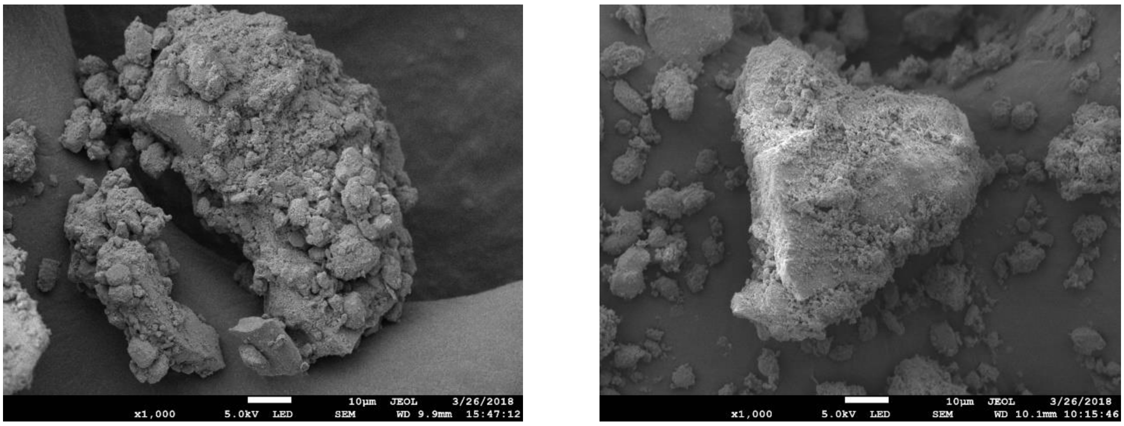

Figure 4.8: Magnification of Gebeng bauxite sample under 1000x magnification. Raw sample (left) and processed sample (right)

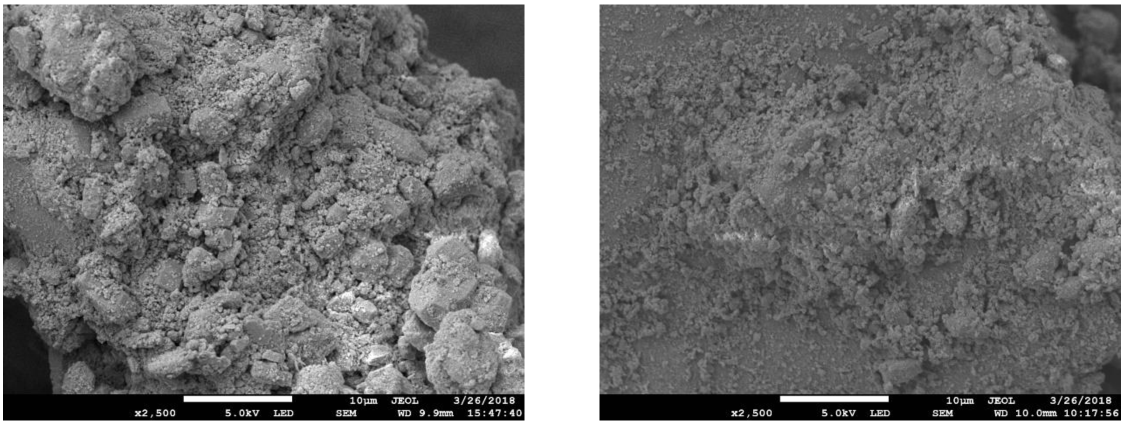

Figure 4.9: Magnification of Gebeng bauxite sample under 2500x magnification. Raw sample (left) and processed sample (right)

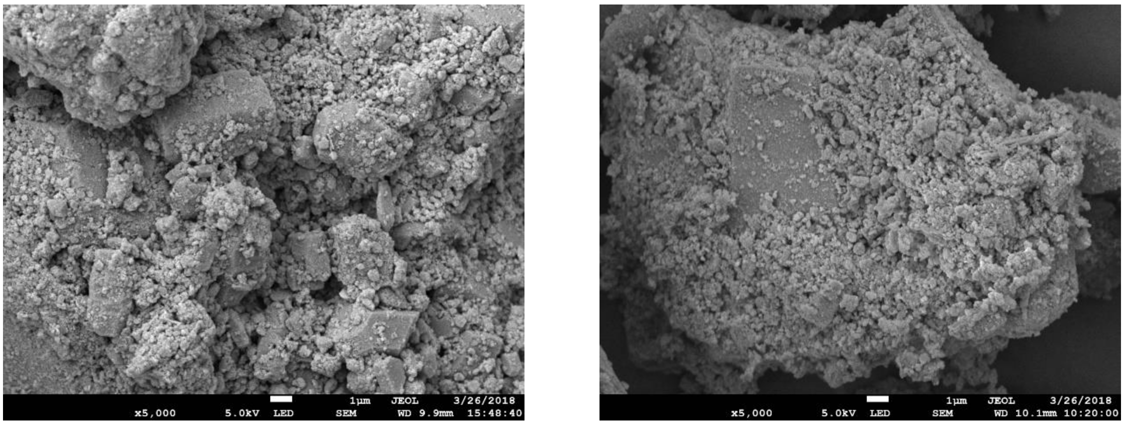

Figure 4.10: Magnification of Gebeng bauxite sample under 5000x magnification. Raw sample (left) and processed sample (right)

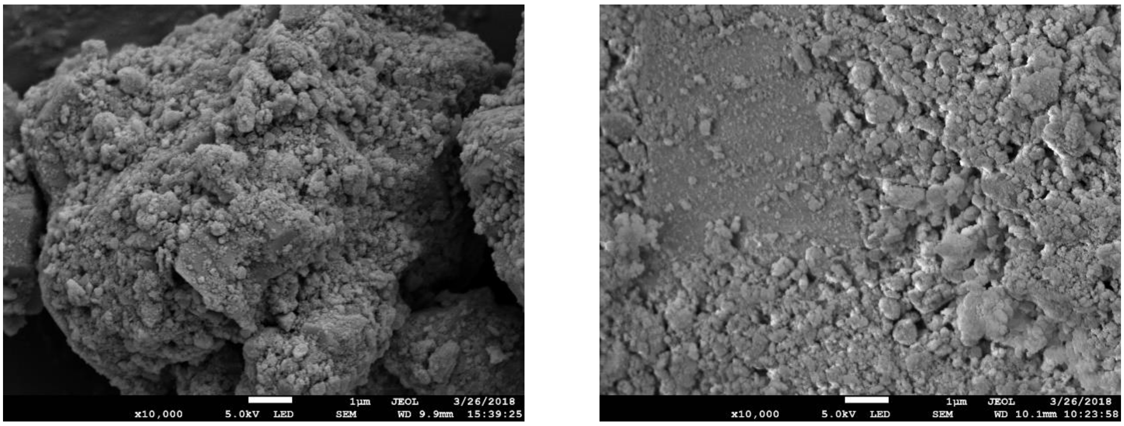

Figure 4.11: Magnification of Gebeng bauxite sample under 10 000x magnification. Raw sample (left) and processed sample (right)

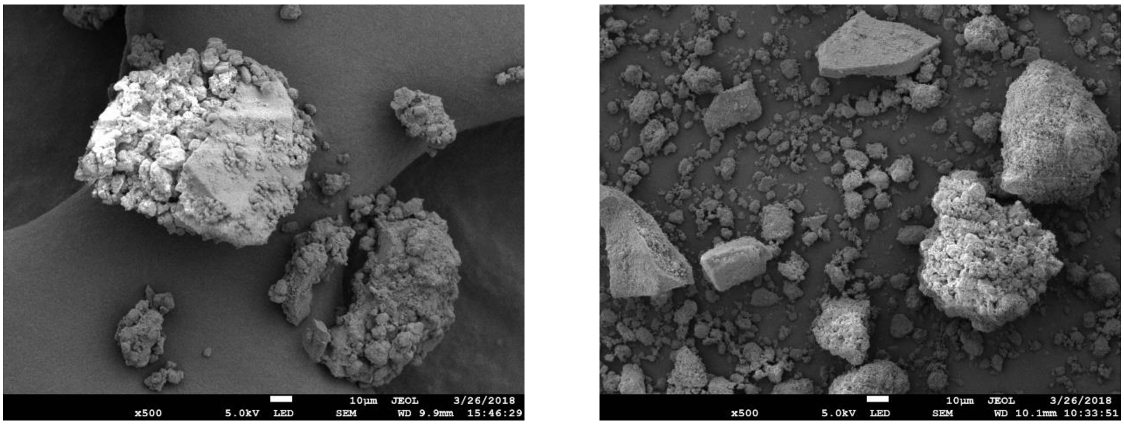

Figure 4.12: Magnification of Gebeng bauxite sample under 500 000x magnification. Raw sample (left) and processed sample (right)

Under 2500x magnification the different sizes of particles can be observed with clear image of lump particles and powdery like-structure of fine particles. Clear image of particles started to be seen at 5000x magnification and under 10 000x up until 500 000x magnification, fine particles attached to the bauxite sample are clearly can be seen. Morphological properties of Gebeng bauxite proved that the fine particles of raw bauxite are higher than the beneficiated bauxite. Clearly seen that the lesser fine particle attached to the processed bauxite ore. This proved that the washing of bauxite can reduce the amount of fine particle in bauxite lump. Large amount of fine particle at the bauxite ore may result liquefaction to take place due to fine particles that have low anti-liquefaction characteristics compared with lump particles and granular particles. Bauxite samples collected from Gebeng mine are disturbed samples, thus the tendency for this sample to liquefy is higher than undisturbed soil because shear-force of anti-liquefaction of undisturbed soil is 1.5 to 2 times greater than disturbed soil.

4.6 X-RAY FLUORESCENCE (XRF)

XRF is carried out in this research in order to obtain the composition of elements and oxide properties of Gebeng bauxite by direct a high-energy gamma ray on both raw and processed Gebeng bauxite samples using XFR S8 Tiger machine. The results of elemental and oxides properties are shown on Table 4.4 and Table 4.5 below.

Table 4.4: Elements of raw and processed Gebeng bauxite

Parameters	Unit	Raw	Processed
Iron (Fe)	%	67.02	64.34
Aluminium (Al)	%	23.06	25.36
Titanium (Ti)	%	7.42	7.79
Silicon (Si)	%	0.86	1.23
Phosphorus (P)	%	0.68	0.46
Calcium (Ca)	%	0.22	0.17
Zirconium (Zr)	%	0.19	0.13
Chromium (Cr)	%	0.17	0.16
Manganese (Mn)	%	0.11	0.10
Copper (Cu)	%	0.05	0.05
Zinc (Zn)	%	0.05	0.04
Nickel (Ni)	%	0.04	0.03
Gallium (Ga)	%	0.03	0.02
Niobium (Nb)	%	0.03	0.02

Table 4.5: Oxides of raw and processed Gebeng bauxite

Parameters	Unit	Raw	Processed
Iron (III) Oxide (Fe_2O_3)	%	57.31	53.12
Aluminium Oxide (Al_2O_3)	%	31.39	35.15
Titanium Dioxide (TiO_2)	%	8.27	8.24
Silicon Dioxide (SiO_2)	%	1.31	1.87
Phosphorus Pentoxide (P_2O_5)	%	0.97	0.75
Calcium Oxide (CaO)	%	0.21	0.13
Zirconium Dioxide (ZrO_2)	%	0.14	0.09
Chromium (III) Oxide (Cr_2O_3)	%	0.14	0.13
Sulphur Trioxide (SO_3)	%	0.14	0.18
Vanadium Pentoxide (V_2O_5)	%	0.10	0.13
Manganese (II) Oxide (MnO)	%	0.08	0.08
Nickel Monoxide (NiO)	%	0.03	0.02
Copper Oxide (CuO)	%	0.03	0.03
Niobium Pentoxide (Nb_2O_5)	%	0.03	0.02
Zinc Oxide (ZnO)	%	0.03	0.02
Gallium Trioxide (Ga_2O_3)	%	0.02	0.01

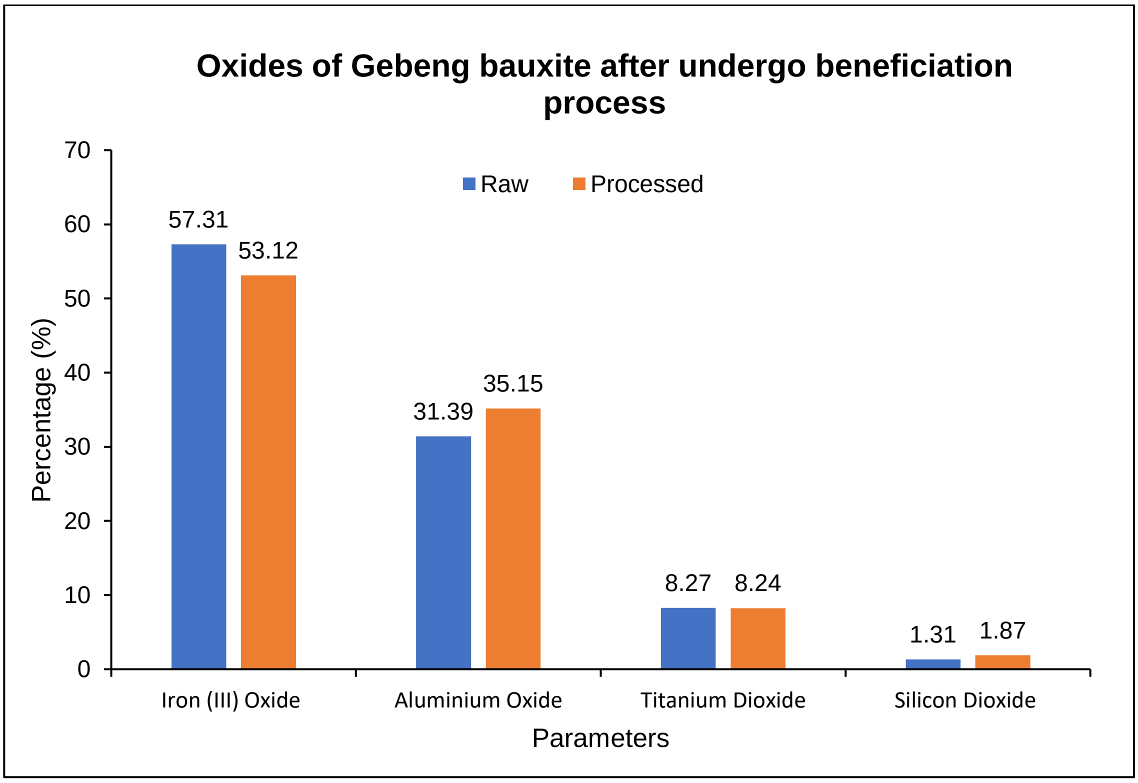

Figure 4.13: Tabulated of oxides of Gebeng bauxite after undergo beneficiation process

Based on Table 4.4 and Table 4.5, the elements and oxide of bauxite has slightly decreased after undergo beneficiation process. The main purpose of having beneficiation process is to minimize the silica content in bauxite and improve the amount of aluminium. In addition, along with silica, the insoluble iron and titanium oxides in red mud will also be eliminated that will lead to the removal of the lower grade of fines and improve the quality of the bauxite. Based on Figure 4.13, the content of Aluminium Oxide (Al_2O_3) has increased after undergo beneficiation process from 31.39% to 35.15% which same as expected. Unfortunately, the quantity of Silicon Dioxide (SiO_2) or also known as silica is slightly increased from 1.31% to 1.87% which is not achieve the main purpose. Although the increasing of Silicon Dioxide (TiO_2) not same as expected, it is not much effect on the bauxite products because the amount of Iron (III) Oxide (Fe_2O_3) and Titanium Dioxide (TiO_2) reduced from 57.31% to 53.12% and 8.27% to 8.24% same as expected. This will lead to the removal of the lower grade of fines and improve the quality of the bauxite.

A comparison of Gebeng bauxite has been made to have a further look into qualities of Gebeng bauxite. Table 4.6 shown the result on oxides of raw and processed Gebeng bauxite from previous research work. As we can see from the table, the result for Aluminium Oxide (Al_2O_3) decreased after undergo beneficiation process which does not same as expected (Phang, 2016). That might be some mistake during the beneficiation process which is the Al_2O_3 content has been washed away along with other finer grains during the process that can lead to the result.

Table 4.6: Comparison on oxides of raw and processed Gebeng bauxite from previous research work

Researchers	Parameters	Unit	Raw	Processed
Phang (2016)	Iron (III) Oxide (Fe_2O_3)	%	38.03	35.96
	Aluminium Oxide (Al_2O_3)	%	20.67	17.59
	Titanium Dioxide (TiO_2)	%	6.06	4.72
	Silicon Dioxide (SiO_2)	%	0.98	0.64
Current Research (2018)	Iron (III) Oxide (Fe_2O_3)	%	57.31	53.12
	Aluminium Oxide (Al_2O_3)	%	31.39	35.15
	Titanium Dioxide (TiO_2)	%	8.27	8.24
	Silicon Dioxide (SiO_2)	%	1.31	1.87

A comparison of Gebeng bauxite with bauxites from other regions also has been made to have a further look into the qualities of Gebeng bauxite compared to other region's bauxites. Table 4.7 shows the comparison between Gebeng bauxite with bauxite from other regions in term of chemical composition and moisture content.

Table 4.7: Comparison between Gebeng Bauxite with Bauxite from Other Regions

Country	**Chemical Composition**				**Moisture**	**Source**
	Al_2O_3	**SiO_2**	**Fe_2O_3**	**TiO_2**		
Australia, Weipa	54.8	5.3	5.20	-	-	(Roberts, 1977)
Australia, Jarrahdale	50	3.4-4.2	17.1	3.4	-	(Murray, 1979)
Brazil, Trombetas	55.9	4.8	9.4	1.3	-	(Greig., 1977)
Jamaica	49.1-50.6	0.7-6.1	18.9-20.5	2.5-2.7	15	(Bracewell, 1962)
Suriname	59	5	1.5	2.75	3-6	(Aleva, 1965)
Guyana	60	4.5	1	2.7	3-5	(Lachmansingh S.V., 1977)
Malaysia, Gebeng (Raw)	20.67	0.98	38.03	6.06	23.33	(Phang, 2016)
Malaysia, Gebeng (Processed)	17.59	0.64	35.96	4.72	5.98	(Phang, 2016)
Malaysia, Gebeng (Raw)	31.39	1.31	57.31	8.27		Current Research
Malaysia, Gebeng (Processed)	35.15	1.87	53.12	8.24		Current Research

4.7 COMPARISION WITH IMSBC CODE

There are some standard and regulation that need to be follow in IMSBC Code to determine the safety of bulk cargoes carrying bauxite and to minimize the risk of the cargoes capsize. Table 4.8 shows the parameters for bauxite under IMSBC Code. Based on the table, it is state that bauxite is listed under Group C where it is neither liable to liquefy nor to possess chemical hazard. If bauxite samples are complied with the specification as stated in IMSBC Code, the samples are allowed to be exported.

Table 4.8: IMSBC Code

Characteristic	Value
Angle of Repose	Not applicable
Size	10% to 30% powder 70% to 90% lumps: 2.5mm to 500mm
Bulk Density (kg/m^3)	1190 to 1389
Stowage Factor (m^3/t)	0.72 to 0.84
Moisture Content (%)	0 to 10
Class	Not applicable
Group	C
Hazard	No special hazards. This cargo has a low fire-risk and is non-combustible.

Source: Adoption of The International Maritime Solid Bulk Cargoes (IMSBC) Code, Annex 3 Resolution MSC.268 (85), 2008

The comparison between raw and processed of Gebeng bauxite with IMSBC Code are shown in Table 4.9. From the table, most of the processed of Gebeng bauxite samples passes the criteria according to IMSBC (Code International Maritime Solid Bulk Cargoes). The results show that processed bauxite have lesser fine particles compared to raw bauxite which is 30% of maximum lump is allowed. Hence, for moisture content, all the four (4) samples of raw bauxite fails the requirement which is more than 10% while another four (4) samples of processed bauxite, fulfil the criteria of IMSBC Code.

Table 4.9: Comparison Table Between Raw and Processed of Gebeng Bauxite with IMSBC Code

Characteristic	IMSBC Code	Sample	Raw Bauxite		Processed Bauxite	
Size (%)	At least 30% < 2.5mm	M1L1	38%	FAIL	29%	PASS
		M1L2	34%	FAIL	28%	PASS
		M1L3	40%	FAIL	20%	PASS
		OPST	34%	FAIL	25%	PASS
Moisture Content (%)	0 - 10	M1L1	21.03%	FAIL	5.28%	PASS
		M1L2	25.99%	FAIL	6.67%	PASS
		M1L3	23.16%	FAIL	4.67%	PASS
		OPST	25.48%	FAIL	5.68%	PASS

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study has successfully achieved the objective where it is focus on the properties of raw and processed Gebeng, Kuantan bauxite. The objectives of this research are to determine the basic properties of raw and processed Gebeng Bauxite, to correlate the basic properties of raw and processed Gebeng Bauxite, and to compare the raw and processed Gebeng Bauxite with IMSBC Code. The differences between the basic properties and shear strength of raw and processed Gebeng Bauxite will decide whether the bauxite is safer to be transported after beneficiation process or without the process by comparing the results with International Maritime Solid Bulk Cargoes Code (IMSBC).

Based on the results and data obtained from the previous chapter, several conclusions can be made:

1. Result from the average of particle size for raw Gebeng bauxite that are lesser than 2.5mm is 36.5%. The average percentage for moisture content for raw Gebeng bauxite is 23.92% and the average specific gravity for raw Gebeng bauxite is 2.91. While for processed Gebeng bauxite, the average of particle size that are lesser than 2.5mm is slightly decrease to 25.5%, the average percentage for moisture content is highly drop to 5.58% and the average specific gravity is decrease to 2.295. All these basic properties are influence factor for liquefaction to occur during bauxite cargoes transportation. Hence, it is important to identify the properties before it is being exported. It is obvious that processed bauxite has lower fine particles, lower moisture content and specific gravity value compared to raw bauxite. Thus, it has lower chance

for liquefaction to occur during bauxite cargoes transportation compared to raw bauxite.

2. Thus, by comparing to IMSBC Code, it can be concluded that raw Gebeng bauxite are not suitable to be transported as it exceeded all the limitations stated in IMSBC Code. The particle size for raw Gebeng bauxite that are lesser than 2.5mm is 36.5% exceeds the limitation which is 30%, the average percentage of moisture content is 23.92% doubles the allowable value which is between 0% to 10% only. Meanwhile, the particle size for processed Gebeng bauxite that are lesser than 2.5mm is 25.5% which is below 30% of the limitation. The average percentage of moisture content is well within the allowable range which is 5.58%. Hence, to reduce the risk of cargo liquefaction, it is preferable if the bauxite from Gebeng mine undergoes the beneficiation process before being transported.

3. The study on morphological properties of Gebeng bauxite shows the abundance of fine particle attached to the bauxite ore compared to the beneficiated bauxite. It will result in higher percentage of moisture content, low percentage of lump particles distribution as well as high value of bulk density. Thus, by undergoing beneficiation process, the fine particles will be washed away and this will reduce the percentage of moisture content as water absorption and also will reduce the value of its bulk density.

4. X-Ray Fluorescence (XRF) results shows that there was minor drop in the elements and oxides in Gebeng bauxite after beneficiation. From this, it is obvious that beneficiation can lead to the removal of the lower grade of fines such as Silicon Dioxide (SiO_2) and Titanium Dioxide (TiO_2), thus improve the quality of the bauxite.

5. Raw Gebeng bauxite cannot be classified under Class C of IMSBC Code and it is not suitable to be exported while Gebeng bauxite that undergo beneficiation process has better properties and is well within the limitation as specified in IMSBC Code. Thus, it can be classified under Class C which is safer to be transported.

5.2 RECOMMENDATION

To reduce the liquefaction incident from occur, not all bauxite can be beneficiated. Thus, further study should be carried out in the future under a larger scale with real case scenario testing to test and analysis on the real performance and outcomes. Some recommendation is suggested so that Gebeng bauxites and this research can be improved:

1. Re-evaluated if the moisture content of the cargo is more than 10% before being transport.
2. To obtain more accurate results the beneficiation method must be uniformed throughout the research.
3. The study might be expanded to other bauxite mining site to prove this methodology can be applied to all the bauxites in the world.

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APPENDIX A

SIEVE ANALYSIS TEST

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

Sample ref: M1L1 Raw

Sieve Size	Mass Retained On Sieve + Sieve	Mass Of Sieve	Mass Of Soil Retained On Each Sieve, Wn	Percent Retained Rn	Cummulative Percent Retained, ∑Rn	Percent Finer, 100-∑Rn
	(g)	(g)	(g)	(%)	(%)	(%)
6.30mm	767.74	539.28	228.46	22.85	22.85	77.15
5.00mm	712.76	524.49	188.27	18.83	41.68	58.32
3.35mm	685.67	542.49	143.18	14.32	56.00	44.00
1.18mm	679.75	486.38	193.37	19.33	75.34	24.66
600µm	437.60	391.30	46.30	4.63	79.97	20.03
300µm	469.35	431.25	38.10	3.81	83.78	16.22
150µm	493.97	428.57	65.40	6.54	90.32	9.68
63µm	352.50	258.08	94.42	9.44	99.76	0.24
pan	370.04	367.54	2.50	0.25	100	0
			1000	100		

APPENDIX A

SIEVE ANALYSIS TEST

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

Sample ref: M1L2 Raw

Sieve Size	Mass Retained On Sieve + Sieve	Mass Of Sieve	Mass Of Soil Retained On Each Sieve, Wn	Percent Retained Rn	Cummulative Percent Retained, ∑Rn	Percent Finer, 100-∑Rn
	(g)	**(g)**	**(g)**	**(%)**	**(%)**	**(%)**
6.30mm	776.55	539.28	237.27	23.73	23.73	76.27
5.00mm	717.35	524.49	192.86	19.29	43.02	56.98
3.35mm	684.42	542.49	141.93	14.19	57.21	42.79
1.18mm	727.58	486.38	241.2	24.12	81.33	18.67
600µm	424.90	391.30	33.60	3.36	84.69	15.31
300µm	457.55	431.25	26.30	2.63	87.32	12.68
150µm	466.67	428.57	38.10	3.81	91.13	8.87
63µm	343.32	258.08	85.24	8.52	99.65	0.35
pan	371.04	367.54	3.50	0.35	100.00	0
			1000	100		

APPENDIX A

SIEVE ANALYSIS TEST

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

Sample ref: M1L3 Raw

Sieve Size	Mass Retained On Sieve + Sieve	Mass Of Sieve	Mass Of Soil Retained On Each Sieve, Wn	Percent Retained Rn	Cummulative Percent Retained, ∑Rn	Percent Finer, 100-∑Rn
	(g)	(g)	(g)	(%)	(%)	(%)
6.30mm	750.10	539.28	210.82	21.08	21.08	78.92
5.00mm	653.16	524.49	128.67	12.87	33.95	66.05
3.35mm	719.40	542.49	176.91	17.70	51.65	48.35
1.18mm	723.26	486.38	236.88	23.69	75.34	24.66
600µm	435.94	391.30	44.64	4.46	79.80	20.20
300µm	464.06	431.25	32.81	3.28	83.08	16.92
150µm	478.20	428.57	49.63	4.96	88.04	11.96
63µm	372.20	258.08	114.12	11.41	99.45	0.55
pan	373.06	367.54	5.52	0.55	100.00	0
			1000	100		

APPENDIX A

SIEVE ANALYSIS TEST

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

Sample ref: OPST Raw

Sieve Size	Mass Retained On Sieve + Sieve	Mass Of Sieve	Mass Of Soil Retained On Each Sieve, Wn	Percent Retained Rn	Cummulative Percent Retained, ∑Rn	Percent Finer, 100-∑Rn
	(g)	(g)	(g)	(%)	(%)	(%)
6.30mm	791.95	539.28	252.67	25.27	25.27	74.73
5.00mm	703.80	524.49	179.31	17.93	43.2	56.8
3.35mm	712.71	542.49	170.22	17.02	60.22	39.78
1.18mm	642.05	486.38	155.67	15.57	75.79	24.21
600µm	457.88	391.30	66.58	6.65	82.44	17.56
300µm	501.46	431.25	70.21	7.02	89.46	10.54
150µm	485.88	428.57	57.31	5.73	95.19	4.81
63µm	302.46	258.08	44.38	4.44	99.63	0.37
pan	371.19	367.54	3.65	0.37	100.00	0
			1000	100		

APPENDIX A

SIEVE ANALYSIS TEST

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

Sample ref: M1L1 Processed

Sieve Size	Mass Retained On Sieve + Sieve	Mass Of Sieve	Mass Of Soil Retained On Each Sieve, Wn	Percent Retained Rn	Cummulative Percent Retained, ∑Rn	Percent Finer, 100-∑Rn
	(g)	(g)	(g)	(%)	(%)	(%)
6.30mm	719.72	409.93	309.79	30.98	30.98	69.02
5.00mm	698.33	524.57	173.76	17.38	48.36	51.64
3.35mm	695.26	542.44	152.82	15.28	63.64	36.36
1.18mm	656.00	485.56	170.44	17.04	80.68	19.32
600µm	526.95	484.24	42.71	4.27	84.95	15.05
300µm	468.65	432.61	36.04	3.60	88.56	11.44
150µm	476.66	426.24	50.42	5.04	93.60	6.40
63µm	466.11	404.85	61.26	6.13	99.73	0.27
pan	374.74	371.98	2.76	0.28	100.00	0.00
			1000	100.00		

APPENDIX A

SIEVE ANALYSIS TEST

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

Sample ref: M1L2 Processed

Sieve Size	Mass Retained On Sieve + Sieve	Mass Of Sieve	Mass Of Soil Retained On Each Sieve, Wn	Percent Retained Rn	Cummulative Percent Retained, ∑Rn	Percent Finer, 100-∑Rn
	(g)	(g)	(g)	(%)	(%)	(%)
6.30mm	933.71	409.93	523.78	52.38	52.38	70.33
5.00mm	584.30	524.57	59.73	5.97	58.35	41.65
3.35mm	629.50	542.44	87.06	8.71	67.06	32.94
1.18mm	602.33	485.56	116.77	11.68	78.74	21.26
600µm	488.82	484.24	4.58	0.46	79.19	20.81
300µm	512.40	432.61	79.79	7.98	87.17	12.83
150µm	492.57	426.24	66.33	6.63	93.81	6.19
63µm	444.14	404.85	39.29	3.93	97.74	2.27
pan	394.65	371.98	22.67	2.27	100.00	0.00
			1000.00	100.00		

APPENDIX A

SIEVE ANALYSIS TEST

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

Sample ref: M1L3 Processed

Sieve Size	Mass Retained On Sieve + Sieve	Mass Of Sieve	Mass Of Soil Retained On Each Sieve, Wn	Percent Retained Rn	Cummulative Percent Retained, ∑Rn	Percent Finer, 100-∑Rn
	(g)	(g)	(g)	(%)	(%)	(%)
6.30mm	872.68	409.93	462.75	46.28	46.28	53.72
5.00mm	609.16	524.57	84.59	8.46	54.74	45.26
3.35mm	741.07	542.44	198.63	19.86	74.60	25.40
1.18mm	617.76	485.56	132.20	13.22	87.82	12.18
600µm	519.89	484.24	35.65	3.57	91.39	8.61
300µm	473.18	432.61	40.57	4.06	95.44	4.56
150µm	458.81	426.24	32.57	3.26	98.70	1.30
63µm	407.62	404.85	2.77	0.28	98.98	1.02
pan	382.25	371.98	10.27	1.03	100.00	0.00
			1000.00	100.00		

APPENDIX A

SIEVE ANALYSIS TEST

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

Sample ref: OPST Processed

Sieve Size	**Mass Retained On Sieve + Sieve**	**Mass Of Sieve**	**Mass Of Soil Retained On Each Sieve, Wn**	**Percent Retained Rn**	**Cummulative Percent Retained, ∑Rn**	**Percent Finer, 100-∑Rn**
	(g)	**(g)**	**(g)**	**(%)**	**(%)**	**(%)**
6.30mm	906.32	409.93	496.39	49.64	49.64	50.36
5.00mm	612.71	524.57	88.14	8.81	58.45	41.55
3.35mm	653.03	542.44	110.59	11.06	69.51	30.49
1.18mm	640.10	485.56	154.54	15.45	84.97	15.03
600µm	523.90	484.24	39.66	3.97	88.93	11.07
300µm	461.80	432.61	29.19	2.92	91.85	8.15
150µm	464.95	426.24	38.71	3.87	95.72	4.28
63µm	440.48	404.85	35.63	3.56	99.29	0.71
pan	379.13	371.98	7.15	0.71	100.00	0.00
			1000.00	100.00		

APPENDIX B

DETERMINATION OF MOISTURE CONTENT TEST RESULT

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 5
Clause 3.2

Sample ref: RAW

TEST NUMBER		**M1L1**	
Container No.		1	2
Container weight	gm	14.90	13.83
Wet soil + container	gm	34.90	33.83
Wet soil, W_w	gm	20.00	20.00
Dry soil + container	gm	31.47	30.31
Dry soil, W_d	gm	16.57	16.48
Moisture loss, $(W_w - W_d)$	gm	3.43	3.52
Moisture content, $(W_w - W_d)/W_d$	%	20.70	21.36
AVERAGE MOISTURE CONTENT	**%**	**21.03**	

TEST NUMBER		**M1L2**	
Container No.		1	2
Container weight	gm	14.29	10.58
Wet soil + container	gm	34.29	30.58
Wet soil, W_w	gm	20.00	20.00
Dry soil + container	gm	30.12	26.50
Dry soil, W_d	gm	15.83	15.92
Moisture loss, $(W_w - W_d)$	gm	4.17	4.08
Moisture content, $(W_w - W_d)/W_d$	%	26.34	25.63
AVERAGE MOISTURE CONTENT	**%**	**25.99**	

APPENDIX B

DETERMINATION OF MOISTURE CONTENT TEST RESULT

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 5
Clause 3.2

Sample ref: RAW

TEST NUMBER		**M1L3**	
Container No.		1	2
Container weight	gm	14.63	12.76
Wet soil + container	gm	34.63	32.76
Wet soil, W_w	gm	20.00	20.00
Dry soil + container	gm	30.80	29.07
Dry soil, W_d	gm	16.17	16.31
Moisture loss, $(W_w - W_d)$	gm	3.83	3.69
Moisture content, $(W_w - W_d)/W_d$	%	23.69	22.62
AVERAGE MOISTURE CONTENT	**%**	**23.16**	

TEST NUMBER		**OPST**	
Container No.		1	2
Container weight	gm	14.62	14.23
Wet soil + container	gm	34.62	34.23
Wet soil, W_w	gm	20.00	20.00
Dry soil + container	gm	30.68	30.05
Dry soil, W_d	gm	16.06	15.82
Moisture loss, $(W_w - W_d)$	gm	3.94	4.18
Moisture content, $(W_w - W_d)/W_d$	%	24.53	26.42
AVERAGE MOISTURE CONTENT	**%**	**25.48**	

APPENDIX B

DETERMINATION OF MOISTURE CONTENT TEST RESULT

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 5
Clause 3.2

Sample ref: PROCESSED

TEST NUMBER		**M1L1**	
Container No.		1	2
Container weight	gm	9.93	10.26
Wet soil + container	gm	29.93	30.26
Wet soil, W_w	gm	20.00	20.00
Dry soil + container	gm	29.11	29.08
Dry soil, W_d	gm	19.18	18.82
Moisture loss, $(W_w - W_d)$	gm	0.82	1.18
Moisture content, $(W_w - W_d)/W_d$	%	4.28	6.27
AVERAGE MOISTURE CONTENT	**%**	**5.28**	

TEST NUMBER		**M1L2**	
Container No.		1	2
Container weight	gm	10.10	10.22
Wet soil + container	gm	30.10	30.22
Wet soil, W_w	gm	20.00	20.00
Dry soil + container	gm	28.69	29.13
Dry soil, W_d	gm	18.59	18.91
Moisture loss, $(W_w - W_d)$	gm	1.41	1.09
Moisture content, $(W_w - W_d)/W_d$	%	7.58	5.76
AVERAGE MOISTURE CONTENT	**%**	**6.67**	

APPENDIX B

DETERMINATION OF MOISTURE CONTENT TEST RESULT

Client: AA14238

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 5
Clause 3.2

Sample ref: PROCESSED

TEST NUMBER		**M1L3**	
Container No.		1	2
Container weight	gm	10.10	12.04
Wet soil + container	gm	30.10	32.04
Wet soil, W_w	gm	20.00	20.00
Dry soil + container	gm	29.44	30.92
Dry soil, W_d	gm	19.34	18.88
Moisture loss, $(W_w - W_d)$	gm	0.66	1.12
Moisture content, $(W_w - W_d)/W_d$	%	3.41	5.93
AVERAGE MOISTURE CONTENT	**%**	**4.67**	

TEST NUMBER		**OPST**	
Container No.		1	2
Container weight	gm	10.64	12.17
Wet soil + container	gm	30.64	32.17
Wet soil, W_w	gm	20.00	20.00
Dry soil + container	gm	29.47	31.19
Dry soil, W_d	gm	18.83	19.02
Moisture loss, $(W_w - W_d)$	gm	1.17	0.98
Moisture content, $(W_w - W_d)/W_d$	%	6.21	5.15
AVERAGE MOISTURE CONTENT	**%**	**5.68**	

APPENDIX C

RESULT OF DETERMINATION OF PARTICLE DENSITY

(SMALL PYKNOMETER METHOD)

Client: AA14238 Sample ref: Raw

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

SAMPLE		**M1L1**		**M1L2**		**M1L3**		**OPST**	
Density Bottle No.		1	2	1	2	1	2	1	2
Mass of Bottle		32.95	29.28	31.84	30.34	28.46	32.04	31.26	30.44
Mass of Bottle + Stopper, m_1		38.02	34.21	37.17	35.75	33.50	37.62	36.33	36.10
Mass of Bottle + Stopper + Dry Soil, m_2		48.02	44.21	47.17	45.75	43.50	47.62	46.33	46.10
Mass of Bottle + Stooper + Soil + Water, m_3		144.75	143.54	142.78	141.69	140.14	143.03	141.77	142.09
Mass of Bottle + Stopper + Water, m_4		138.37	137.62	136.65	135.17	134.18	136.78	135.60	134.15
Mass of Dry Soil, $(m_2 - m_1)$		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Mass of Water In Full Bottle, $(m_4 - m_1)$		100.35	103.41	99.48	99.42	100.68	99.16	99.27	98.05
Mass of Water Used, $(m_3 - m_2)$		96.73	99.33	95.61	95.94	96.64	95.41	95.44	95.99
Particle Density, ρ_s		2.76	2.45	2.58	2.87	2.45	2.67	2.61	4.85
AVERAGE PARTICLE DENSITY, ρ_s		**2.61**		**2.73**		**2.56**		**3.73**	

APPENDIX C

RESULT OF DETERMINATION OF PARTICLE DENSITY

(SMALL PYKNOMETER METHOD)

Client: AA14238 Sample ref: Processed

Project: Properties and Liquefaction Risk on Bulk Cargoes
Carrying Gebeng, Kuantan Bauxite
in Accordance to IMSBC Code

Test Method: Geospec 3: Part 2; 7
Clause 3.4

SAMPLE		**M1L1**		**M1L2**		**M1L3**		**OPST**	
Density Bottle No.		1	2	1	2	1	2	1	2
Mass of Bottle		26.78	30.12	27.16	29.63	27.94	28.94	27.40	30.06
Mass of Bottle + Stopper, m_1		31.24	34.67	31.53	33.76	32.31	32.82	31.85	35.29
Mass of Bottle + Stopper + Dry Soil, m_2		41.24	44.67	41.53	43.76	42.31	42.82	41.85	45.29
Mass of Bottle + Stooper + Soil + Water, m_3		137.44	138.21	137.65	138.43	138.29	137.68	138.06	137.73
Mass of Bottle + Stopper + Water, m_4		131.77	132.54	132.34	132.94	133.18	131.40	132.80	131.68
Mass of Dry Soil, $(m_2 - m_1)$		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Mass of Water In Full Bottle, $(m_4 - m_1)$		100.53	97.87	100.81	99.18	100.87	98.58	100.95	96.39
Mass of Water Used, $(m_3 - m_2)$		96.20	93.54	96.11	94.67	95.98	94.86	96.21	92.44
Particle Density, ρ_s		2.31	2.31	2.13	2.22	2.04	2.69	2.11	2.53
AVERAGE PARTICLE DENSITY, ρ_s		**2.31**		**2.18**		**2.37**		**3.32**	