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BASIC AND MORPHOLOGICAL PROPERTIES OF GEBENG BAUXITE

SITI HAJAR BINTI AZIZ

Thesis submitted in fulfillment of the requirements for award of the degree of Bachelor Engineering (Hons) of Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2016

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor Engineering (Hons) of Civil Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :
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DEDICATION

Dedicated to my parents; Aziz Mohd Ali and Hamidah Othman

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ABSTRACT

Bauxite ore is a primary raw material required in aluminium production where its mining had been discovered at Gebeng in Kuantan district, Pahang. Bauxite collected will be export to manufacturing country, for example China to be process into aluminium. Basic properties of bauxite is determined for exporting purpose in which several international specifications need to be follow while handling bauxite in order to ensure those raw materials are passing the standard to be imported. IMSBC Code; an international standard for cargo transportation is referred and Geospec 3: Model Specification for Soil Testing is referred for laboratory testing. Laboratory test had been done to three bauxite samples taken from Gebeng mines and from stockpile to identify its basic properties; particle size distribution, moisture content, specific gravity and its morphological properties. Laboratory test involved are Hydrometer test, Small Pcyknometer test, Dry Sieve test and SEM test. From laboratory test done, the average value of moisture content is 22.65%, the value of specific gravity is not between the range of 1190 kg/m^3 to 1389 kg/m^3 and particle size distribution for lumps is less than 70% from total mass which means bauxite samples collected consists of fine particles more than lumps. Result from SEM test proves that there are bulky of fine particles attached to the bauxite. Referring to the IMSBC Code, it can be stated that bauxite sample collected from Gebeng mines does not qualify the standard as its basic properties is more than the standard value and therefore it is not suitable to be export. This is due to the presence of bulky fine particles which tend to absorb water more than granular particles that may lead to liquefaction to occur. Liquefaction during cargo transportation is high risk especially when there are strong current at the sea. In order to ensure the bauxite is passing the standard, beneficiation process may takes place where it include washing, wet screening and mechanical or manual sorting.

ABSTRAK

Bijih bauksit adalah bahan mentah utama yang diperlukan dalam pengeluaran aluminium di mana sumber bauksit telah ditemui di Gebeng yang terletak dalam daerah Kuantan, Pahang. Bauksit yang dikumpul akan dieksport ke negara pembuatan seperti Negara China untuk di proses menjadi aluminium. Ciri-ciri asas bauksit ini telah dikenalpasti untuk tujuan pengeksportan yang mana beberapa spesifikasi antarabangsa perlu dipatuhi semasa meggendali bauksit untuk memastikan bahan-bahan mentah tersebut melepasi piawaian untuk diimport. Kod IMSBC; piawaian antarabangsa untuk pengangkutan kargo diguna pakai dan Geospec 3: Model Spesifikasi untuk Ujian Tanah dirujuk untuk melakukan ujian makmal. Ujian makmal telah dilakukan keatas tiga sampel bauksit yang mana 2 sampel diambil dari lombong bauksit di Gebeng dan satu sampel dari simpanan untuk mengenal pasti ciri-ciri asas bauksit tersebut iaitu taburan saiz zarah, kandungan kelembapan, berat jenis dan sifat-sifat morfologi bauksit. Ujian makmal yang terlibat adalah Ujian Hydrometer, Ujian Pcyknometer Kecil, Ujian Kering Ayak dan Ujian SEM. Daripada ujian makmal yang dilakukan, nilai purata kandungan lembapan adalah 22.65%, nilai graviti tentu bukanlah antara lingkungan 1190 kg / m^3 hingga 1389 kg /m^3 dan taburan saiz zarah untuk ketulan adalah kurang daripada 70% daripada jumlah jisim yang bermakna sampel bauksit yang diambil terdiri daripada zarah halus lebih daripada ketulan. Keputusan daripada ujian SEM membuktikan bahawa terdapat besar zarah halus melekat bauksit. Merujuk kepada Kod IMSBC, sampel bauksit dikumpul dari lombong Gebeng tidak memenuhi piawaian kerana ciri asas melebihi nilai piawaian dan oleh itu ia tidak sesuai untuk dieksport. Hal ini adalah disebabkan oleh kehadiran zarah halus besar yang cenderung untuk menyerap air daripada zarah berbutir yang boleh membawa kepada pencairan berlaku. Pencairan semasa pengangkutan kargo berisiko tinggi terutamanya apabila terdapat ombak yang kuat di laut. Proses beneficiation boleh dilakukan di mana antara proses yg terlibat adalah termasuk membasuh, saringan basah dan pengasingan secara mekanikal atau manual.

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LIST OF SYMBOLS

w	Percentage of moisture content
m	Mass of soil sample
C_m	Meniscus correction
R_h’	Observed hydrometer reading
η	Dynamic viscosity of water at test temperature
ρ_s	Particle density

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation
Al	Aluminium
Fe	Iron
FMP	Flow Moisture Point
IMO	International Maritime Organization
IMSBC	International Maritime of Solid Bulk Cargoes
SEM	Scanning Electron Microscope
SOLAS	Safety of Life at Sea
TML	Transportable Moisture Limit

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Malaysia is well-known for its beautiful culture, richness in biodiversity a well as its natural and earth resources. Petroleum, copper, barite, cement, iron and steel are some of the natural resources that can be found in Malaysia, not to forget bauxite. Rapid growth in aluminium industry resulting in increasing demand of bauxite which is the primary ore in aluminium metal production. In our daily life, we can see a lot of aluminium product or the combination of aluminium and alloy to produce lightweight but strong product.

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. Most of cookware and kitchen utensils such as boilers and cookers are made of aluminium as it is a good conduction of heat.

Figure 1.1: Map of mineral distribution in Malaysia

Source: Map of world 2007

Due to high demand as well as its function in electricity generation, founding of aluminium will attract aluminium miners and create competitiveness among them. Therefore, founding of new bauxite deposition at Kuantan, Pahang had become an economically attractive and a major issue in Malaysia. There are several aluminium mines that had been identified all around Malaysia such as Bukit Batu and Bukit Gebong at Sarawak, Bukit Mengkabau at Sabah and Bungai Rengai at Johor (Tse, 2004). Since Malaysia itself did not have its own an aluminium smelter, international investors to name few; from Bahrain, China, United States and United Arab Emirates had submitted proposal to Malaysian Government to build and established aluminium smelters in Malaysia (The International Aluminium Institute, 2012).

This study is mainly about bauxite properties; basic properties and chemical properties for the bauxite sample taken at bauxite mine in Gebeng, Kuantan, Pahang. Bauxite mining at Kuantan had become a major issues for Pahang State Government. As the end-product of bauxite only being exposed, people tend to recognize aluminum rather than bauxite. Therefore, bauxite mining at the area contribute to anxiety of locals as the mines are located near to residential area.

The area of study is a residential area which now had turn into economically attractive to bauxite miners and company to establish their collected plant before it is transported to smelter plant. Thus, it is important to carry out the study on this area to determine whether the bauxite at this area is suitable for export and does bauxite properties may harmful to human.

1.2 PROBLEM STATEMENT

Exploration of earth resources contribute to national economic growth as it involve international market and demand. Therefore, potential mining location of earth resources is identified such for this study is at Gebeng, Kuantan. The collected area is at Port Kuantan; approximately 5.7 km from study area. Transportation of bauxite from mine to the 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.

Besides smelter and manufacturing its own aluminium, Malaysia also exported the bauxite to China which is Malaysia's largest export destination. Due to strong demand from this country, Malaysia had to double and tripled the production of bauxite in order to meet the demand. But, there are some standard and regulations that need to be follow for example mining companies in Kuantan are using International Maritime of Solid Bulk Cargoes (IMSBC) Code to determine the standard quality of bauxite. Thus, this study is carried out to determine does the bauxite production is achieved the IMSBC Standard or not for exporting.

Bauxite is composed of various element in which each of its element have its own effect and function. Some element in the bauxite is safe but in the other hand, some element may cause harm to the human or the environment if it is not in stable state. Morphological characteristic of Gebeng bauxite will be studied to determine the each element present and its effect. If the element is found to be harmful, prevention and safety measure should be applied and will be discuss.

1.3 OBJECTIVE

A large bauxite mine is identified at Gebeng,Kuantan where it had attract bauxite miners resulting in uncontrolled mining works. An issue arise questioning does bauxite collected from Gebeng mine are qualified to be exported or not. Therefore, this study is carried out based on problem arise and the objectives are as follows:

a. To determine basic properties of Gebeng, Kuantan bauxite
b. To determine morphological characteristics of Gebeng, Kuantan bauxite
c. To determine the suitability and quality of Gebeng, Kuantan bauxite according to IMSBC code.

1.4 SCOPE OF STUDY

This study is conducted at Gebeng, Kuantan where the samples were taken from the bauxite mine and also from the stock pile. Figure 1.1 shows the location of the bauxite mine in Peninsular Malaysia, while Figure 1.2 shows the location of the mine at Kuantan District. Only lab testing is involved in this study and all the testing are carried out based on Geospec 3: MODEL SPECIFICATION for SOIL TESTING. The required testing are Hydrometer Test, Small Pyknometer Test, Wet Sieving Analysis, Dry Sieve Analysis and Moisture Content determination.

Figure 1.2: Location of bauxite mine at Peninsular Malaysia

Source: Travel Reflectim 2016

Figure 1.3: Location of bauxite mine at Kuantan District

Source: Bast and Petronas (2013)

1.5 SIGNIFICANCE OF STUDY

Well growing in aluminium industry resulting in increasing of bauxite demand all over the world. World Manufacturing country like China and United Kingdom will always searching for new bauxite mine in order to ensure their targeted amount of manufacturing is achieved. Founding of bauxite at Kuantan will surely help to improve the State as well as the Federal economy in terms of export and import business. The study is carried out to evaluate Kuantan bauxite whether they are within the standard for international market or not which will be the benchmark for continuous demand from aluminium industry. Studies of bauxite morphologies and its chemical properties will give a clear understanding on how bauxite will affect human and environment as well as enhancing the knowledge of the society about the production of aluminium.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Formation of soil is basically from rocks where it can be divided into two factors which is physical weathering and chemical weathering. Bauxite deposition in the same hand also formed by weathering of aluminous rock which is the reason why bauxite are an aluminium ore for aluminium production (metallurgical bauxite) and some are uses for production of refractory materials, chemicals or cements (non-metallurgical bauxites). Generally, metallurgical bauxites are classified into three types based on how the bauxite deposition occur; low temperature Gibbsitic bauxite, high temperature Boehmitic bauxite and Mixed bauxite (Gow and Lozej, 1993).

Gibbsitic or gibbsite mineral is an alumina tri-hydrate and it is the most valuable of alumina ore due to its state which readily dissolves at low temperatures and pressures during Bayer process. Boehmite mineral in the other hand is alumina mono-hydrate that need to be processed at high pressure and high temperature. Extraction of pure alumina from bauxite is by Bayer process which will be discussed later.

2.1.1 Soil Structure

Made up of 25% water, 45% mineral matter, 23% air and 5% organic matter (USDA, 2016) soil structure is varies depending of type of soil, whether it is sand, silt or clay. (Punmia et al., 2005) defined soil structure as an arrangement and aggregate condition of soil particles in a soil mass where it largely influenced soil properties such as shear strength and permeability. Generally, soil structure can be recognized into 7 types which are single-grained, honeycomb, flocculent, dispersed, coarse-grained skeleton and cohesive matrix. Single-grained structure can be found in coarse-grained soil while honeycomb, flocculent and dispersed in fine-grained soil, cohesive skeleton and cohesive structure in composite soil.

2.1.2 Single-grained Structure

Single-grained structure is a soil that are not attach to each other or in other word, the soil is broken into individual particle (Fang, 2013). Sandy soil that consist of large grains are an example of single-grained soil structure. It will fall apart easily whenever come into contact with pressure eventhough the sandy soil with high content of colloids. Basically, the composition of this soil is dominated by coarse particles with no presence of aggregate resulting the grain structure become loose (Fang, 2013).

2.1.3 Honeycomb Structure

Honeycomb structure is an arrangement of soil particles where it can be found in silts deposits is a result of a settlement of particles at the lower region, leading to formation of arches, also known as honeycomb. Ability to resist vertical slope, this structure shows high bearing capacity when it is in dry state (Watson and Burnett, 1993). Due to high void ratio of deposits; the honeycomb, any disturbance to the structure will lead to reduction of total volume causing breakdown of the structure which the condition is also referred ad ‘collapse’ (Palanikumar, 2013).

2.1.4 Dispersed Structure

Dispersed structure is referred as parallel particles, having ’face-to-face’ orientation and tend to repel to each other (Lambe and Whitman,1969) can be found in clay soil, this structure will plug soil pores therefore blocking water infiltration and soil drainage. Due to it dispersion in structure, generally it has a low shear strength with high compressibility and low permeability. Application of pressure on the structure for example remoulding the soils may leads to structure slippage, where consolidation may occur.

2.1.5 Flocculent Structure

Although it is also found in clay soil, flocculated structures are edge to face and attract to each other. As a result of concentration of dissolved minerals in water due to salt water environment, flocculated structure with very high void ratio is formed. Unlike dispersed structure, flocculated structures are higher in strength and permeability with lower compressibility

2.1.6 Coarse-grained skeleton

Coarse-grained skeleton structure can be found in composite soils where the ratio of coarse-grained is greater than fine-grained ratio. It is known as coarse-grained skeleton because the coarse-grained particles will form a skeleton or more likely a shell with partly filled by a fine - grained particles. Designation for stabilization of this soils is known as ‘granular stabilization’ (Fang, 2013) and it able to transfer load without permanent deformation to the structure. According to Fang, designation for granular stabilization involve preparation of mixture of aggregate and compaction so that the soils will achieve high strength, stability and durable to restrain all weather condition.

2.1.7 Cohesive Matrix Structure

Besides coarse-grained skeleton structure, cohesive-matrix is another structure that can be found in composite soil. In this structure, the ratio of fine-grained is greater than coarse-grained, therefore the coarse-grained will attach to the smaller particle; the fine-grained preventing them from having particle-to-particle contact. Compare to coarse-grained skeleton, this structure is more compressible

2.2 BAUXITE HORIZON

Natural geological formation of bauxite or also known as bauxitization process may resulting in different type of bauxite form affecting their geological characteristics. Hao et al., (2010) state that there are three types of bauxite named as Lateritic bauxite, Sedimentary bauxite and Karst bauxite. Formation of Lateritic bauxite is generally by the strong chemical weathering of aluminious rocks as for example lateritic deposits at Boke, Guinea is a result of long-term weathering and leaching of mafic volcanic rocks. The horizon for this type of bauxite is consist of three layers; an upper layer of laterite and massive bauxite, lateritic soil and earthy bauxite at the middle and the bottom part of ferruginous clay rock in which the ore body is located at the middle layer (Hao et al.,2010).

Sedimentary bauxite in the other way is formed by the accumulation of lateritic bauxite during mechanical transportation of surficial flow besides weathering factor. Transfer of Fe and Al play a vital roles in bauxitization process promoting the formation of bauxite from kaolin clays. Bauxite formation at Henan Province of China (Hao et. al, 2010) is an example of sedimentary bauxite which oppose from lateritic, the ferruginous clay is at the upper layer together with silty clay rocks and kaolin. The middle layer is where dark-gray and gray bauxites are deposited and the bottom part is a layer of variegated clay enriched in Fe.

Due to its confinement to karst zones with karstified or karstifying carbonate rocks, karst bauxites is named. Sedimentation of insoluble residue of limestones, other aluminosilicate material like volcanis ash and clay layers, erosion as well as transportation is where karst bauxite gained its Al. Bauxitization for bauxite of karst type is referred as Karstification where it is found at Zagros Mountain Belt located at the southern Iran (Hao, 2010). The three layers of bauxitic horizon for this type of bauxite are argillite-argillaccous bauxite located at the lower layer followed by bauxite zone at the middle layer and ferruginous lime stone as its upper layer. For karst bauxite, the thickness of the horizons are varies from 1 m to 25 m depending on the topography of the area.

2.3 BAUXITE MORPHOLOGY

According to Rajah (1986), bauxite found in the Kuantan area is from ferruginous type where it shows a variety of textures. Referring to the Figure 2.2 below, the soil profile shows the thickness of the upper layer; consists of light red to chocolate brown lateritic clayey material is commonly varies up to 1.6 m depth and rarely exceed a depth of 3 m**.** The lower part is granular to earthy while the middle layer is the basal part consists of reddish brown and in places grey to olive brown residual clay which also known as saprolite. Bauxite is usually found at the middle layer but it is not continuously present in the entire area but is generally known for its hill capping deposition (Rajah, 1986).

Study carried out Rajah (1986) also analyse the chemical composition of the collected bauxite samples which the result shows the wide range composition indicate low or medium grade bauxite. Most of the bauxite is identify to be have a commercial grade as the alumina content would be upgrade upon washing of raw bauxite material is done. Table 1 represent the analyses of chemical composition of Kuantan bauxite while Figure 2.3 shows the variation of chemical composition of the bauxitic materials with depth. Result of Area 1 in both Table 1 and Figure 2.3 is use as a reference as it represent area near to Kuantan Port which is the main location for this study.

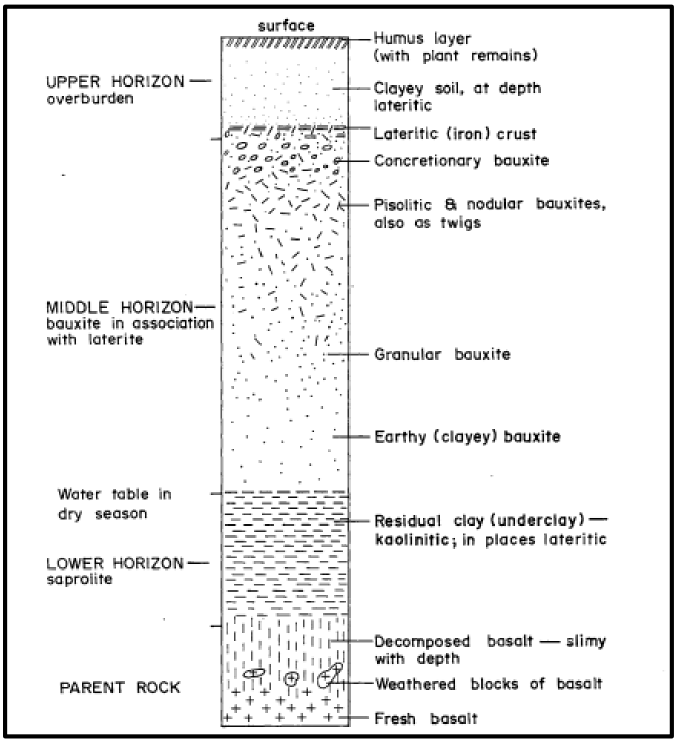

Figure 2.1: Soil profile of the bauxite area

Source: Rajah 1986

Table 2.1: Analyses of chemical composition of collected bauxite sample

COMPOSITE ANALYSES OF BAUXITIC MATERIAL FROM THE KUANTAN AREA

Sub-Area	Sample No.	Depth (ft)		Analyses (percent)				
		From	To	LOI	Al_2O_3	Fe_2O_3	SiO_2	TiO_2
Area 1	1K6a	7	17	23.8	39.9	30.7	0.90	3.72
Area 1	1K8a	7	14	23.8	41.1	14.4	17.9	2.56
Area 1	1K1a	10	15	26.4	44.4	21.2	4.52	3.38
Area 2	2K1a	2	10	25.7	41.3	19.3	9.30	2.92
Area 2	2K16a	10	15	20.0	31.8	23.9	20.3	3.92
Area 2	2K32b	15	30	26.5	43.7	23.0	2.96	3.84
Area 2	2K42d	20	25	25.8	46.3	20.1	5.28	2.80
Area 2	2K43a	6	10	28.4	44.1	20.8	3.12	2.48
Area 2	2K46a	8	15	26.2	43.5	19.2	7.56	3.20
Area 3	3K1a	9	15	26.3	39.8	25.9	3.20	4.00
Area 3	3K8a	10	16	23.1	23.6	40.6	6.28	5.12
Area 3	3K7c	15	30	22.8	38.4	23.6	11.0	4.00
Area 4	4K44a	5	10	28.3	48.6	18.2	2.40	2.62
Area 4	4K27a	10	15	29.2	48.2	15.6	3.84	3.60
Area 4	4K42b	10	15	26.7	46.3	21.1	1.48	4.08
Area 4	4K43c	15	20	25.6	42.5	19.7	9.20	2.94
Area 4	4K15c	20	25	25.0	40.4	28.1	1.68	4.24
Area 4	4K11d	25	30	24.6	40.1	20.8	11.3	3.28
Area 4	4K48a	5	10	21.2	35.2	15.3	25.2	2.43
Area 4	4K26b	10	20	25.6	41.9	26.7	1.40	4.32

Source: Rajah (1986)

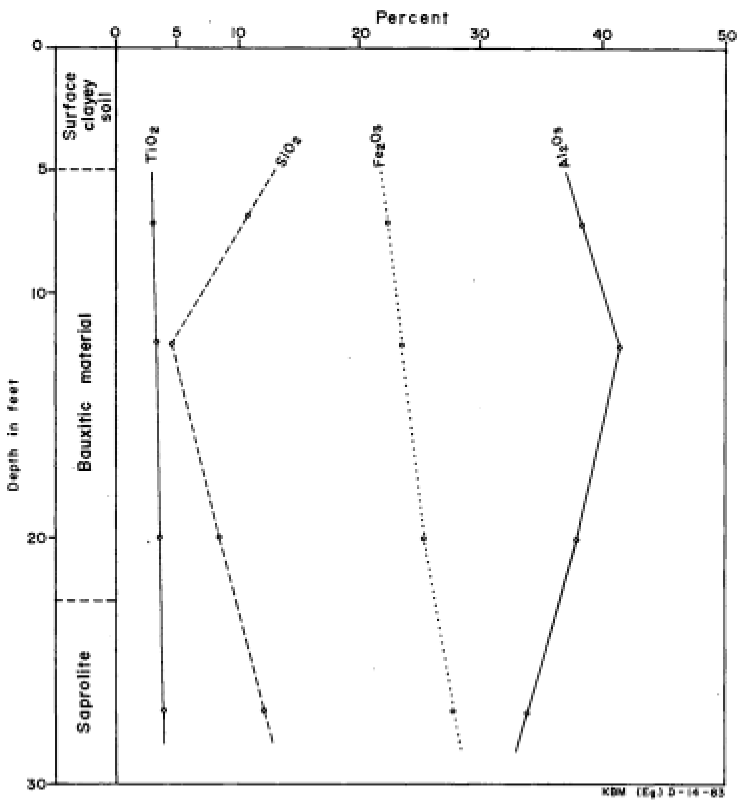

Fig. 4. Variation with depth in composition of bauxite material and underlying clay at Area 1 (Hole 1K4).

Figure 2.2: Variation of chemical composition of the bauxitic materials with depth of Kuantan Port bauxite sample

Source: Rajah 1986

Thus, from the table and figure above, it is found that the content of bauxite in Kuantan Port area including Gebeng is high with ferric oxide, therefore it can be termed as ferruginous bauxite. This type of bauxite will show a characteristic such as hard, porous masses with brick-red colour near to the surface of the ground. Down the depth near to the middle, it become soft and earthy clayey bauxite with yellow, red brown or buff in colour.

2.4 SOIL CLASSIFICATION AND SOIL DESCRIPTION

According to Craig (2004), soil is described as an uncemented or weakly cemented of mineral particles formed by the weathering of rocks (physical and chemical weathering) which the void space of the particles contained water and air. The soil formed by the disintegration of rocks may either remain at its original place or will be moved and transported to other place by various surrounding agents such as water, gravity and wind. ‘Transported soil’ is named for those transported soil while the remaining soil is called ‘Residual soil’ (Palanikumar, 2013). This formation of soil can be grouped as coarse-grained soil and fine-grained soil where they are identified and differentiate by soil description and soil classification.

Soil classification is defined as the identity of the material itself; composition of the soil and its mechanical properties. There are few classification systems for reference such as Casagrande system and AASHTO. Soil description is defined as the in-situ properties of the material; its undisturbed state. Descriptive system enable accurate analysis of the material in-situ whenever there are no undisturbed sample are available.

Buol et al., (2011) had identified and listed out the purpose of soil classification. The purposes are as follow:

a) Organizing knowledge of research subject
b) Maximize knowledge input of the subject by minimizing the cognitive effort.
c) Mapping about our world and nature for enhancing communication and information.
d) Provide an informative source for research and experimentation.
e) Subdivision or grouping of the subject according to their similarity in characterization or chemical properties.

2.5 BASIC ENGINEERING PROPERTIES OF BAUXITE

Basic properties that need to be determine are particle-size distribution, specific gravity and moisture content. The laboratory test conducted are based on Geospec 3: Model Specification for Laboratory Testing to ensure the prepared sample and the result is accurate and acceptable for the use in export and import business. Each of the test will show the properties of the soil which analysis can be done to check whether its properties are follow IMSBC Code specification or not.

2.5.1 Particle-size Distribution

Presence of various particles size in soil is known by identifying the proportion of the size in the sample which it is recognize as particle size distribution. By expressing the various particle size in percentage, soils can be broadly classified as coarse-grained soils and fine-grained soils. By conducting mechanical analysis or commonly known as grain-size analysis, particle size distribution will be determine. Grain-size analysis is divided into two parts which are sieve analysis for coarse-grained soil and sedimentation analysis for fine-grained soil.

Gravel and sand are categorized as coarse-grained soil due to its size which is coarser than 0.075 mm size. Reddy and Sastri, (2002) mentioned that the importance of classifying the distribution of different sizes is to enable identification of the soil whether it is well-graded or poorly-graded. Sand and gravel are further divided into two groups that are clean and dirty. Sands are labelled as clean sand if the percentage of fines is less than 5 while if the percent of fines is more than 12 percent, it is considered as dirty sand (Palanikumar, 2013)

Meanwhile, silt and clay are grouped under fine-grained soils or also known as cohesive material where the sizes are finer than 0.075 mm. In this study, it is important to identify the distribution of particles and clear separation between granular particles and fine particles should be done. This is because, in order to fulfill the IMSBC Code of Standard, the percentage of lump particles must be above 70% of its total mass and only small amount of fine particles is allowed. Besides that, behavior of fine-grained soil affected by moisture content of the soils which controls the shear strength and compressibility of the soil. Due to water- particle interaction and attraction forces of the particles, fine-grained soil tends to stick together, resulting sticky and plastic behavior of the soil.

The study by Wu and Sun (2008) also state that the diameter size of particles; coarse, fine and clay will have a different effect on liquefaction characteristics. The larger the diameter size of the particles, the higher the dynamic stability which will decrease the risk of liquefaction to occur. In the other way, the chances of liquefaction to occur will increase in terms of the following sequence: coarse particles, fine particles and powdery particles. Stability and ability in anti-liquefaction of granular particles is varies in terms of arrays and cementation depending on the characteristics of the granular structure. Due to influence of deposition age as well as the stress and strain history, granule particles with stable array sand and cementation have a better ability of anti-liquefaction.

2.5.2 Moisture Content

Moisture content plays a vital role since porosity and void in soil may filled and absorbed water. Moisture content or also known as water content highly influenced the behavior of fine-grained soil where it may change from liquid state to plastic and solid state (Reddy and Sastri, 2002). The shear strength, compressibility as well as compaction is affected by the moisture content of the soil. Moisture content has a huge influence in liquefaction during cargoes transportation which this matter had been seriously look into and specified in IMSBC Code of transportation.

Percentage of moisture content is depend on the specific gravity of the soil where high value of specific gravity indicate the presence of fine particles which resulting more pores will absorb moisture. Meanwhile, Manzhou et al (2010) had carried out a study on water rock interaction in bottom bed of a bauxite deposit which shows the presence of the water or moisture content will reduces the clasticity of the rocks as well as the strength of the rock. In the presence of moisture content, it will affect the deformation of rocks by improving the mobility of the molecules. Water pressure from the inside of the pores will counteract the total stress inside the rocks, reducing the elastic yield limit and thus facilitate shear breakage. This condition will resulting in formation of fine and powdery particles which are the main cause in liquefaction.

Percentage of moisture content for each bauxite type is different as been mentioned by Jain (1995) where percentage of water content for Guyanese bauxite is more than the percentage of water content for rotary kiln bauxite. Bulk density and the porosity of the both bauxite sample eventually had influenced the percentage of water content.

2.5.3 Specific Gravity

Specific gravity, G consists of specific gravity of solid soil and specific gravity of soil. Specific gravity of solids is the ratio of unit weight of solid solids to that water while specific gravity of soil (include solids and voids) is the ratio of unit weight of soil to that water. Punmia et al. (2005) state that the soil solid has a void inside them that acts as permeable and impermeable where the permeable voids are able to be filled with water. In addition, the value of specific gravity is depending on mineral composition of the solids.

Specific gravity of a soil may lead to liquefaction to occur where a study done by Sumer (2014) stated that there is a relationship between initial soil specific gravity with the concentration of solid grains in liquefied soil. The relationship between this two factors can be explained as the force that keep the particles away in liquefied soil or also known as ‘suspension’ is an upward-directed pressure-gradient force. This pressure-gradient force is increasing as the value of the specific gravity increase, resulting in decreasing concentration of solid grains in the soil, thus liquefaction is easy to occur. For liquefied soil, the specific gravity may vary depending on several factors such as the soil category, soil class, initial soil specific gravity, specific gravity of soil grains and lastly the coefficient of lateral earth pressure (Sumer, 2014).

Bauxite sample collected are consist of agglomeration between fine particles and granular particles. IMSBC Code requires more than 70% lump particles or granular particles to be pack in the cargoes as a safety measures to prevent liquefaction from happen. The properties of this granular particles as anti-liquefaction is studied by Wu and Sun (2008) by doing an experiments in the laboratory by using uniform graded fine sand; represent fines particles. The results from the experiments indicate the anti-liquefaction ability for this type of soil is low where the sand tend to liquefy when it was applied with seism load as specific gravity is one of the main factor in liquefaction.

2.6 EXTRACTION OF ALUMINIUM FROM BAUXITE

Although aluminium are found abundance in Earth crust, it is usually bound to other elements such as oxygen and silicon (Davyson, 2014), forming a compound mineral known as bauxite. Bauxite need to be purified using Bayer process in order to extract aluminium in from its ore by electrolysis step. Bayer process or also known as Bayer cycle involves four major steps; digestion, clarification, precipitation and calcination where this four major steps are divided into a several minor steps, for example liquor flashing, sand separation and evaporation.

Raw materials; bauxite are collected from mine by drilling a series of hole with a depth 3.5 metres to 5 metres. The bauxite are loaded to the truck to be transported to the dump station where it is screened and washed to remove fine particles and soon to be placed in a stockpiles to be loaded onto ships to be export. Refining process or Bayer process of bauxite will produce alumina (aluminium oxide, Al_2O_3) which generally two tonnes of bauxite will produce one tonne of alumina. Bayer process start with digestion process where bauxite is ground in mills, followed by mixing of hot caustic soda into it at high pressure and temperature to dissolve alumina in the ore.

Second stage of Bayer process is clarification which the caustic soda and alumina solution will passes into thickener tanks where there will be a sediment of fine particles at the bottom of the tank. The sediment of fine particles is commonly known as red mud due to its colour and usually this sediment will affect environment if it is not dispose properly. At this stage, the impurities are washed with water for few times and being disposed in tailings dam on site while the remaining solution of alumina trihydrate is filtered to make it clearer.

Precipitation is the next stage in Bayer process where alumina trihydrate solution is cooled, concentrated and stirred in an open tanks until crystal is form (Yarwun refinery slices, 2016). Precipitation process may take up a several days, thus pure alumina is added to the mixture to enhance the formation of alumina trihydrate crystals. As crystallization is formed, calcination process will take place. This is the last stage of Bayer process where the crystals are washed, filtered and followed by heating in gas fired kilns at a temperature higher than 1100℃. The aim for this process is to remove water molecules present in the crystals therefore the final product of this process is a fine, dry, white powder known as alumina which then is cooled and stored.

Aluminium metal is obtained by separating aluminium and oxygen presence in alumina during smelting process. Smelting process uses an electrical energy to separate (electrolysis) the elements presence in alumina in order to produce aluminium metal. One tonne of aluminum produced requires two tonnes of alumina undergo smelting process. A large steel, carbon lined reduction cells is fed with alumina which then is dissolved in molten cryolite; a liquid that can dissolve alumina as well as conduct electricity at 970℃. In this process, continuous electrical current of 100 000 to 320 000 amps (Yarwun refinery slices, 2016) is introduced via carbon anodes passing through the alumina/cryolite mixture, to the carbon cell lining which will then flow to the anode of the next cell and so on, creating a cycle.

Strong current applied to the carbon cell resulting aluminium; in molten form sink at the bottom of the reduction cell whereas the carbon dioxide and other gaseous as the end products appear at the top of the cell. Before the gaseous are released to the atmosphere, the gaseous are cleaned to remove any contaminants that may harmful to human as well as to the environment (Davyson, 2014). Molten aluminium at the bottom of the cell is siphoned by a process called tapping before it is transported to a holding furnace to be cast into requested products under temperature of over 700℃. Casting of aluminium usually are in large blocks, t-bars or long-cylindrical logs shape which this form of shape are known as primary aluminium. Figure 2.5 below shows the summary of electrolysis process of producing aluminium.

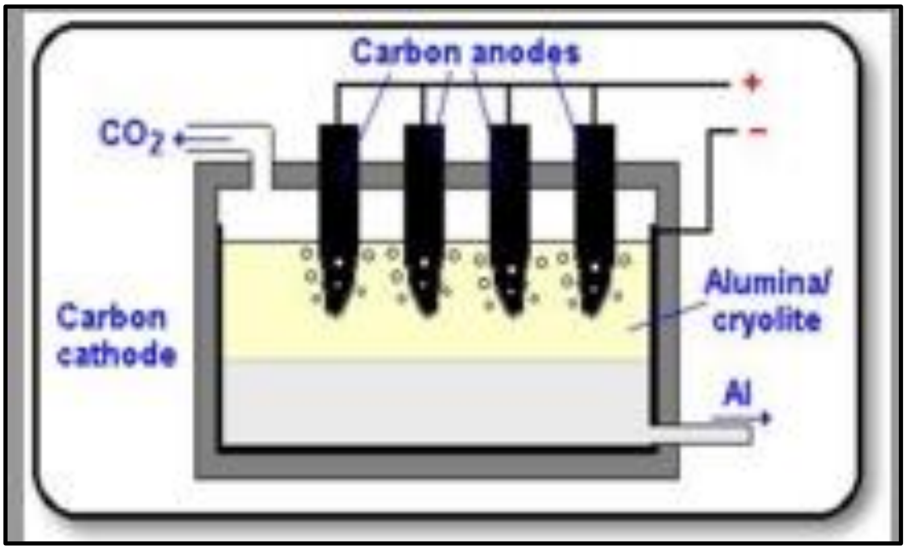

Figure 2.3: Electrolysis process for aluminium production

Source: Davyson, 2014

2.7 LIQUEFACTION

Liquefaction is defined by Environment Canterbury Regional Council (ECRC, 2012) is the process where the sand and silt grains in wet soil will rearranged themselves in the presence of shaking or continuous horizontal movement for example during earthquake or strong current at the ocean. As liquefaction occur, void water between the soil particles will squeezed out, creating a ‘floating’ condition for both sand and slit grains. As the water is forced up to the ground surface, it will find the easiest path; usually cracks and crevasses on the soil to go upwards, taking sand and silts grains together with it. Sand boils or also known as sand volcano will form at the top surface of the soil, resulting the surface to tilts and sinks. Any structures on top of this liquefied soil is often damages due to loss of stability at the foundation of the structure as the structure will tilting or sinking into the ground.

Rearrangement of soil particles is illustrated in Figure 2.4 below and Figure 3.5 shows the movement of pressurized water out to the surface of the soil, causing the soil to sink. As been stated before, there will be continuous horizontal movement during earthquake, causing liquefied soil to move sideways, usually the movement is towards river or streams if the surrounding land is lower than liquefied land. Movement of the land toward the streams is known as lateral spreading which it may cause cracking on the ground surface as the soil underneath it is moving sideways. Figure 2.6 shows the lateral spreading and its effect to the soil surface.

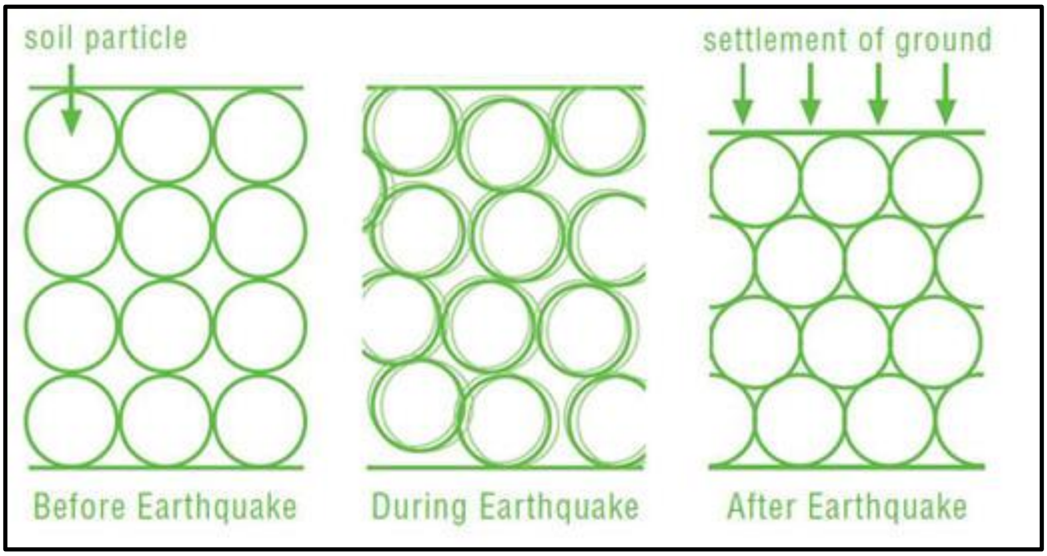

Figure 2.4: Rearrangement of soil particles as a results of shaking

Source: ECRC (2012)

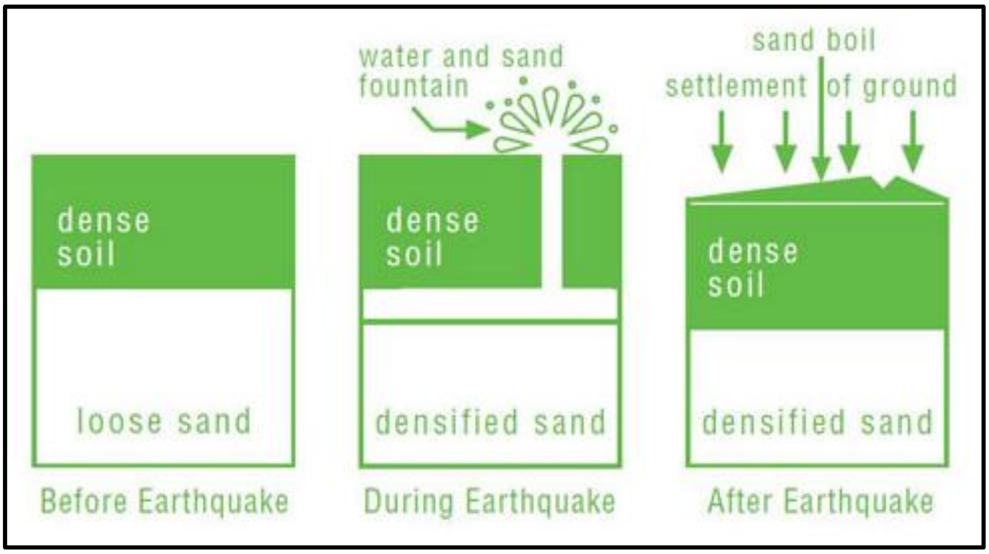

Figure 2.5: Movement of pressurized water out to the soil surface

Source: ECRC (2012)

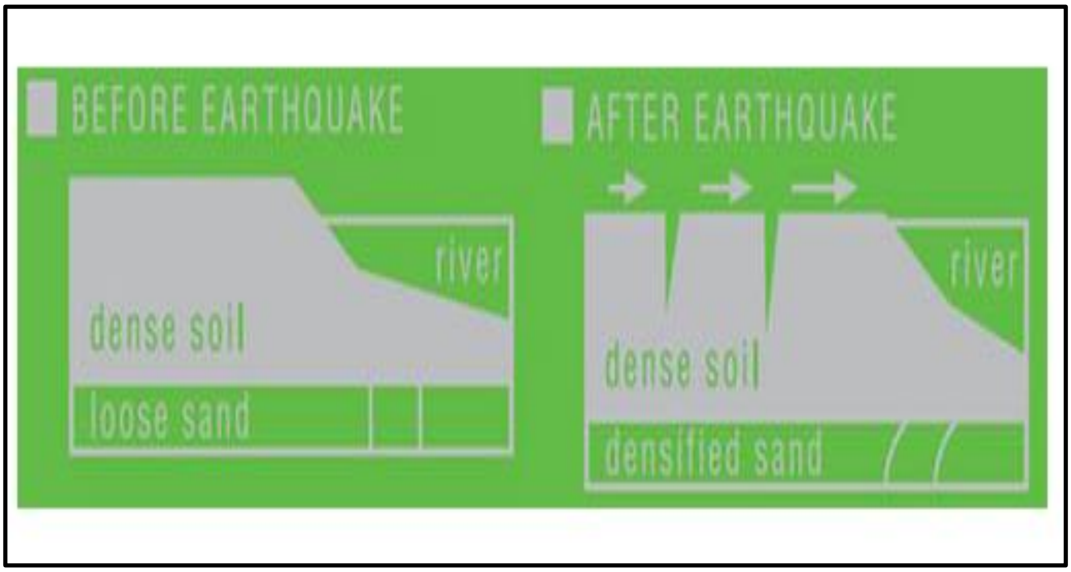

Figure 2.6: Lateral spreading of liquefied soil

Source: ECRC (2012)

2.7.1 Liquefaction of Mineral Ores

Besides occur in soil, liquefaction tend to occur in mineral ores especially when transporting the mineral ores in cargoes resulting in loss of stability and cargo shift. Since bauxite is one of the minerals ores and liquefaction in mineral ores had been a major cause for marine casualties, international certification compliance of mineral shipping had been stated to prevent any catastrophe from happen. Risk of liquefaction to occur increase if the minerals being transported contain at least some fine particles and some moisture although they are dry in appearance at the time of loading as it is stated by Cargo liquefaction (2016).

During loading of mineral in the cargoes, the minerals are usually in solid state in which the particles are in direct contact with each other as they are in dry state. As it been transported across the ocean, cargoes are exposed to agitation in the form of ship's movement, engine's vibration as well as the strong current, resulting in compaction of cargoes. Compaction in the cargoes is not mechanically done but the compaction occur due to surrounding factor. As a result of this compaction, the spaces between the particles is reduced, squeezing out water causing water level to rise. High water level will cause the particles to apart from each other, reducing the friction between particles and the shear strength of the cargo (Cargo liquefaction, 2016). The transition of the minerals in the cargoes from solid state into viscous fluid state will transform some or overall cargo surface into fluid form.

Preventive measure such that sufficiently low moisture content of the mineral and high interstitial air in the cargo can help to prevent and minimizing the risk of liquefaction to occur. This is because sufficient interstitial spaces will accommodate any increase in water pressure or water level, preventing the surface of the cargo to be flatten out into liquid. The lowest moisture content point known as the Flow Moisture Point (FMP) where liquefaction may occur is vary based on the size of cargo used and the FMP value must be determined by laboratory testing provided by the shipper. If the cargo is loaded with mineral exceeding the FMP value, liquefaction will unpredictably occur at any time during the voyage. As a result of liquefied cargo, some cargo shift as soon as it depart from the load port and some takes few weeks before liquefaction occur. Therefore, it is vital to strictly follow the IMSBC Code to ensure only cargo with allowable moisture content are loaded.

Another terms to describe moisture content is Transportable Moisture Limit (TML) which is defined as the maximum moisture content allowed that is proven safe for cargo carrying liquid solid bulk. According to Cargo liquefaction (2016), differ from FMP which can be determine from laboratory testing, TML is a calculated parameter by using the rule; 0.9 times the FMP value. Therefore, at the time of mineral loading, TML is lower than FMP, providing a safety margin to prevent variations of moisture in the cargo. If the TML value is exceed its safety margins value, the cargoes should never be accepted to be shipped.

2.8 INTERNATIONAL MARITIME OF SOLID BULK CARGOES (IMSBC) CODE

Due to series of cargo shift while shipping mineral ores as a result of liquefaction, The Maritime Safety Committee of International Maritime Organization (IMO) has adopted the IMSBC Code to facilitate the safety of the cargo while transporting solid bulk. The main purpose of IMSBC Code is to provide a better guidance while handling solid bulk shipping in the cargo in terms of stowage and shipment, Skibsteknisk Selskab (SS, 2009). On 1st January 2011, implementation of IMSBC Code has become mandatory on each cargo shipment in which the code had specify the requirements for the design, construction and equipment of the ships in order to carry solid bulk cargo, stressing on special fire protection as well as ventilation systems on board.

SS (2009) state that IMSBC Code had categorized solid bulk cargoes into three groups namely as Group A, Group B and Group C where each group consist of different characteristics of solid bulk to be shipped. Details of each group is specify below:

a) Group A: cargoes which may liquefy if moisture content during shipped is excessing their transportable moisture content limit.
b) Group B: cargoes which possess a chemical hazard and could cause a dangerous situation during shipment

c) Group C: cargoes which are act neither likely to liquefy as in Group A nor possess chemical hazard as in Group B

2.8.1 Certification Obligation by SOLAS

Any shipping of solid bulk cargo requires certificate of obligations under SOLAS which the requirement is stated in IMSBC Code. There are three procedures that need to be specify by the shippers in order to be certified by SOLAS that are Identification of hazard, Certification of moisture content an lastly Certification of TML. The procedure basically intended to ensure all shippers are following the standard especially when testing and sampling the mineral ores collected from the mines.

The first step to get certified by SOLAS is identification of hazard by the shipper to the Master through writing. Content of the writing is about declaration by the shipper whether the loaded cargo is a cargo that may liquefy or not. The declaration is one of the shipper’s obligation to provide sufficient information about the potential of the cargo to liquefy as sometimes the cargo name or from visual inspection the cargo is in a good condition. Due to this reasons, Master whom the certified person has the power to insist on moisture content and TML declaration before allowing the cargo to be loaded. In the presence of fine particles as well as some moisture in the loaded cargo, the cargo has the potential to liquefy, thus IMSBC Code has specify the needs of laboratory testing to identify the flow properties of the solid bulk before being loaded (Cargo liquefaction, 2016). Shippers must provide certification of moisture content and TML of the loading regardless of whether the cargo is specifically listed as a potential liquefy cargo in IMSBC Code or not.

Certification of moisture content is the next procedures requires by SOLAS prepared by the shippers. This declaration of moisture content is a statement from the shippers stated the average moisture content of the cargo at the time of declaration is hand on to the Master. Declaration of moisture content is hand over prior to start of loading as the entire cargo must be already available at the load port to be sampled for the purpose of moisture content determination. As the sample taken represent the whole cargo moisture content, it is crucial to have full access to the cargo as well as careful planning to ensure the average moisture content of the cargo is determined. Therefore, sampling for moisture content must be done within seven days from the loading start day to obtain the best percentage of moisture content of the cargo. If there is a rainfall between the loading and sampling day, additional test check should be done. For each cargoes hold of the vessel, shippers is required to prepare different moisture content declaration based on the cargo loading, unless the sampling has shown the moisture content is uniform throughout the entire consignment.

Last but not least, certification of TML is the last step in SOLAS certification reward. TML is calculated based on FMP value analyzed by an experience analyst who is used to identify and recognize the early signs of liquefaction in a sample test. This is because, ability to identify a flow state based on criteria stated in IMSBC Code is a critical part that is vary from each minerals as well as the origin of the minerals such as from Malaysia, Indonesia and Philippines which is affected by the weather and soil distribution. TML value most of the time is depend on technical details and usually does not really affected with shipments therefore it is usually been test once in six month time. If there is a difference in composition or characteristics of the cargo between shipments, TML test is required each time based on the requirement in IMSBC Code (Cargo liquefaction, 2016). Information statement with accurate information prepared by shippers is essential for approval by the Master which the burden of certification is places on the shippers. The reason for this matter is because of determination of TML by visual inspection is impossible as the appearance of the loading cargo may look the same although the TML value is different throughout the same loading cargo.

2.9 DESIGN GUIDELINES FOR CARGO VESSELS

Since transporting mineral ore can be classified as risky process as some of owner shippers had experienced cargo shifting due to liquefaction, cargo vessels that carry the mineral ore must be properly well designated. Well designated cargo vessel is important to ensure if there are any small movement from the mineral ore during transportation, risk of cargo shifting can be minimize. There are several criteria that had been taken into consideration while designing fitted cargo vessels such as certificate of fitness, stability evaluation, hull strength evaluation, specials considerations for bulk carriers and special considerations for ore carriers (Maritime bulk cargo, 2015).

2.9.1 Certificate of Fitness

Fitness in this study is referring to the ship capability to remain stable in the ocean during cargo transportation. If TML value for moisture content of the mineral is above allowable value, the mineral ore are not permitted to be loaded on board to be transport. However, as been mentioned in IMSBC Code, this situation may be fixed if specially fitted cargo is constructed, giving more stability to the ships to remain afloat although the cargo is shifting as a result of liquefaction. Usually, the specially constructed cargo vessels; also known as wet cargo have better operational efficiency since no moisture content test for TML determination is required.

In order to be certified as fitness, the specially constructed or fitted ships will have to ask an approval from the flag state on suitability and the ships conditions to be certify as wet cargo. Eventhough the specific requirement for wet cargo are not well specified in IMSBC Code, Maritime bulk cargo (2015) state that the specially constructed vessels must have a permanent structural boundaries or a specially designed portable compartment that will prevent any shift of cargo as a result of liquefaction from occur. While constructing the cargo vessels, structural strength is the important criteria to be taken into consideration where the applicable strength for the vessels will be discussed in the next sub-chapter.

2.9.2 Stability Evaluation

While designing strength stability for cargo vessels, there are two scenarios in which designer must take into consideration as those scenarios may resulting in different effect to the ship. The first scenario which has been mentioned Maritime bulk cargo (2015) is a situation where the cargo is shifted at an angle of 25 degree. As a result of this cargo shifting or sliding, fixed heeling moment is created and this condition is fulfils the criteria of grain stated in IMO Grain code. The condition of the mineral shifting is illustrated in Figure 2.7 below. The second scenario which is fully liquefied condition of the cargo vessels. At this condition, minerals inside cargo behaves as a liquid, therefore the cargo in all holds is assume to be liquefied and has a free surface effect. At this condition, the IMO Intact Stability Code is referred as the characteristics shown by the minerals in the cargo is satisfies the criteria stated in the code. If any damage occur, the conditions is checked independently without considering liquefaction as one of the factor.

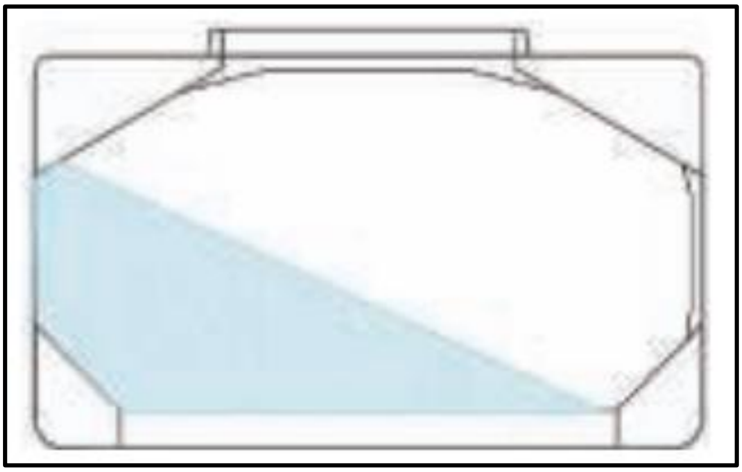

Figure 2.7: Mineral shifting in cargo vessel

Source: Maritime bulk cargo 2015

2.9.3 Hull Strength Evaluation

In this sub-chapter, evaluation of structural strength will be discussed in which only liquefaction condition will be investigated. Pressure on the vertical cargo is increasing significantly as the mineral in the cargo starts to liquefy. In this condition, the cargo is assumed to act as a heavy liquid for calculation purpose in design. Buckling strength as well as yield strength of the structure can be determine by finite element analysis. Maritime bulk cargo (2015) stated one of the guideline for designing cargo vessels is to identify operational cargo conditions; the possibility of liquefaction to occur in only one cargo or may be simultaneously occur to the other cargo. Identification of liquefaction intact conditions is crucial for design purpose because any deformation on ships structure is not allowed. There are some dispute on liquefaction whether it should be classify as an accidental load cases or not although liquefaction is an unwanted incident. In typical design procedure, there are certain value or indentations to allow buckling or deformation as a safety factor as long as the durability of the structure is remain the same. However, moisture content is a strictly factor in cargo vessel design where only cargo with allowable TML value will be permitted to be load into the ship. This procedure is one of the safety measure taken to prove that if liquefaction occur is due to extreme load cases instead of accidental load cases.

2.9.4 Special Considerations for Bulk Carriers

Study and investigation done by Maritime bulk cargo (2015) prove that the tendency for cargo shifting on conventional bulk carriers; carrier with no centerline bulkhead is higher than specially constructed cargo due to wide holds of the conventional carriers. Therefore, Maritime bulk cargo (2015) had determine method to overcome this matter which is by arranging bulkhead longitudinally to narrow the holds. By narrowing the holds, the cargo hold volumes is reduced resulting the cargo to have sufficient stability to withstand possibility of cargo liquefaction for conventional bulk carrier. In the other hand, reducing cargo hold volume will make the vessels less suitable for carrying low-density cargoes as the cost of construction will increase due to addition in steel weight.

For conventional bulk carriers, they are designed to have a wide cargoes with different characteristics especially in density value and angle of repose of the cargo. Meanwhile, modern bulk carriers is designed to withstand accidental flooding in the cargo and the filling height of the cargo is usually quite low compare to conventional carriers due to high relative density. Liquefaction on bulk carrier are generally has a minor impact to the structural consequences which means if liquefaction occur, hull strength of the structure is not a critical area to be assess.

2.9.5 Special Considerations for Ore Carriers

Carrier for ore is different from carrier for bulky material where the bulkheads is longitudinally arranged, usually meeting the criteria applied for cargo failure conditions. This is because the maximum breadth of the cargo vessel and ship breadth for ore carrier is lower than conventional bulk carrier which requires the hull to be strengthen to withstand cargo liquefaction purpose. Area in cargo vessel that require special attention is in Figure 2.8 below where the specialized area is focusing on three factor which are longitudinal bulkheads, lower stool and transverse corrugated bulkheads (Maritime bulk cargo, 2015).

Bulkheads in the cargo is arranged longitudinally resulting in increased of lateral pressure load on plates and stiffeners, thus the scantlings of the cargo need to be increased too. In the wing tank, the stiffeners which is supported by web frames as well as the increased loading will result in high shear stress to lower part of the web frames. Deformation may occur at this area thus prevention measures such as using thicker plating or using higher yield point of steel may be required. Increased in loading will resulting the cross ties to experienced higher compressive force which may cause buckling to the pillar of the ore carrier. Stress level act on the pillar may exceed yielding stress, require strength increase and therefore regular checked on the pillar is required.

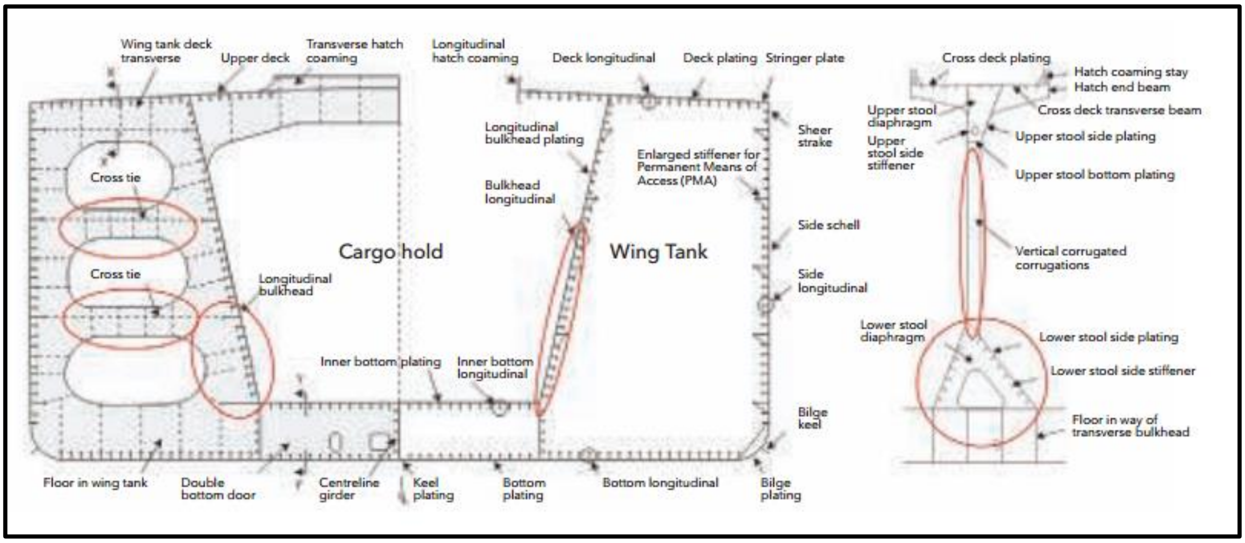

Figure 2.8: Area of special attention for ore cargo vessel

Source: Maritime bulk cargo 2015

Meanwhile, the lower part of the cargo; lower stool which consists of plates and stiffeners require a proper design to resist the load from transverse bulkhead as well as the load from longitudinal bulkheads. Down to the bottom part, the pressure is increasing causing the need of some reinforcement to the diaphragm of the inside stool as the scantlings need to be increased as well. Besides lower stool, the other part that requires special attention in designing is transverse corrugated bulkheads which it is depend on some loading conditions. If the vessels is designed to carry only homogenous loading, the structural check has to be on the worst condition it may occur. Homogenous loading will cause liquefaction to occur in one hold with no liquefaction on neighbouring vessels, resulting the neighbouring vessel to counteract the cargo pressure. If the vessels is designed to carry other conditions, this effect will not exist. Filling height of the cargo play a role in preventing liquefaction from occur as well as for corrugations purpose. Cargo carrying low-density loading require higher filling height to create larger total force on corrugations and vice versa. Figure 2.9 below shows the force from low-density loading and high-density loading acting on bulkhead.

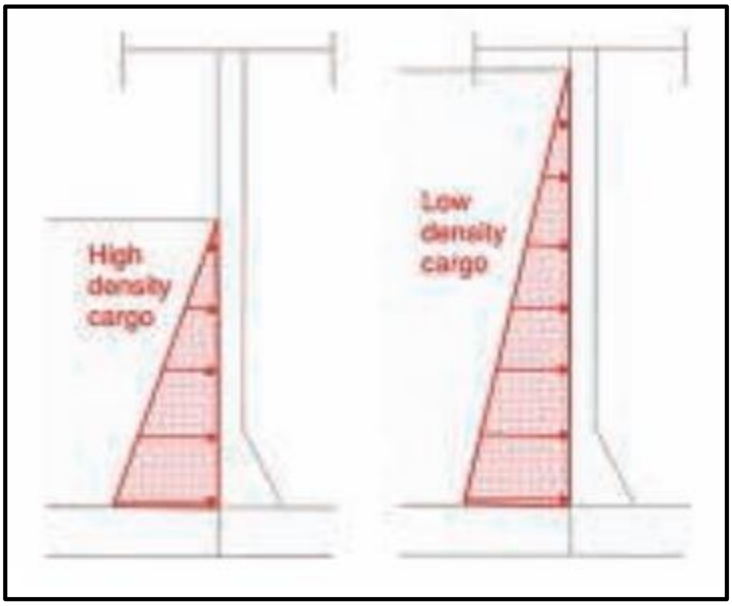

Figure 2.9: Force acting on bulkhead based on loading density

Source: Maritime bulk cargo 2015

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Work process and time constrain must be determine to ensure work flow smoothly and systematically. In addition, it helps to figure out backup plans and solutions if any problems occur. Before any work phase is done, few meeting and discussion with supervisor is held to identify problem arise at bauxite mining in Gebeng, Kuantan where the title of the study and the objectives can be determined. Next step in work process which is literature review is conducted to gather all the related information about the area as well as the title of the study. By conducting literature review, further understanding about the study is gained, thus scope of study is identified after some discussion and advice from supervisor.

Analysis phase started after collection of data related to this study where multiple of data had been collected such as map of study area, data from laboratory test and the equipment used for this study. Finally, conclusion of this study is made whether the objectives of this study set at the early phase is achieve or not and some recommendation is made for good. The flow chart of this study is shown in Figure 3.1 below.

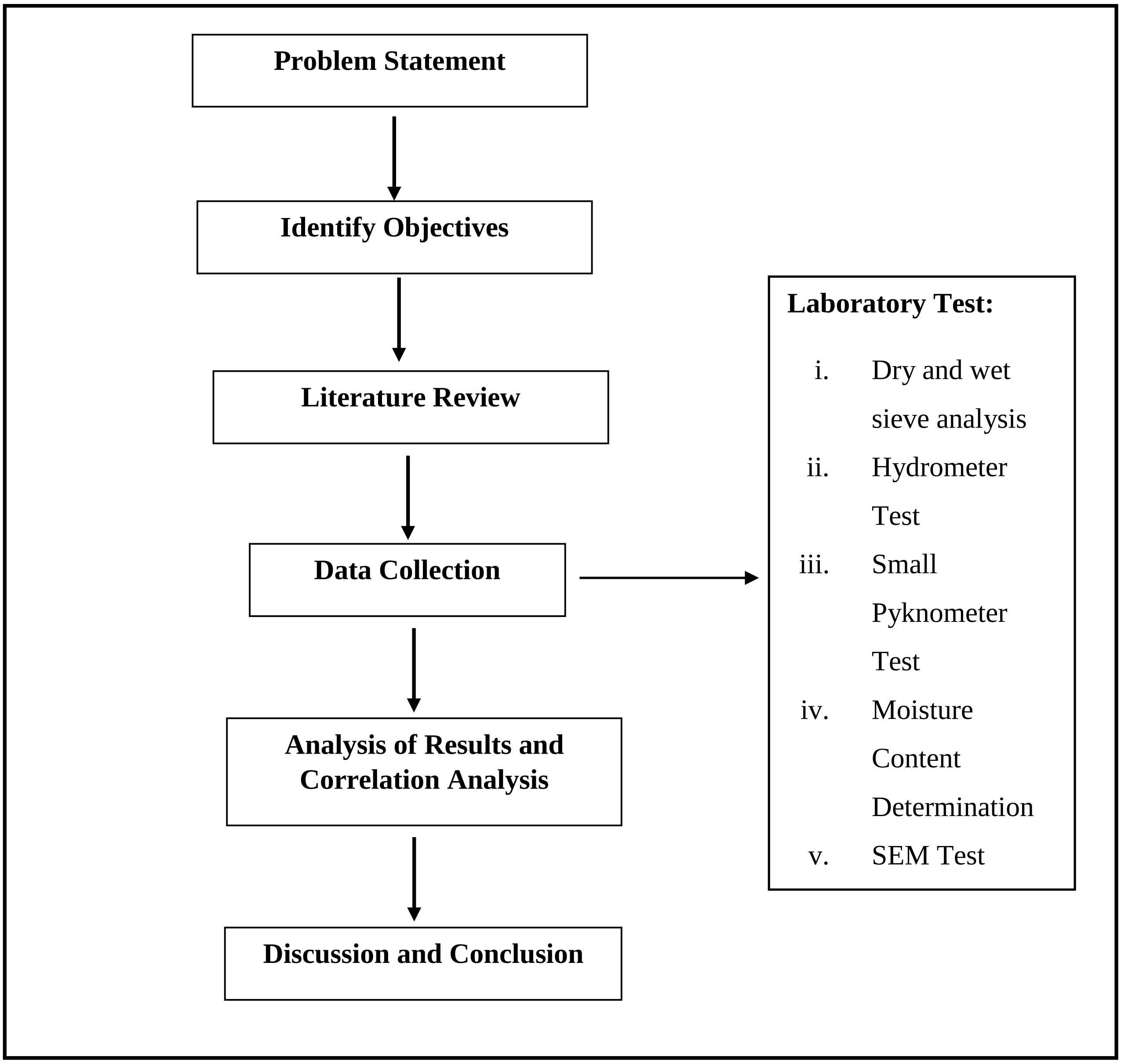

Figure 3.1: Flow chart of methodology

3.2 LITERATURE REVIEW

Before continue the investigation and analysis, information and knowledge must be gathered so that the result gained related to the study. Literature review is the process of searching, collecting and extracting the information from various sources related to the objective of the study. By collecting and comparing the information gained, further understanding and description of the topic is known. From conducting this phase, background of project as well as research techniques can be determine based on previous studies done by other party.

Source of literature review is not only limited from journal or books, but the information can also be gathered from technical paper, CD-ROM, internet, interview as well as from media. Development of technologies enhancing information finding, thus exposed user the new techniques in information searching. Information sharing is easier for the author and for user.

3.3 DATA COLLECTION

All the information collected from literature review is review and classify where the parameter to perform analysis is determined. This study require laboratory test in order to gain the data. The bauxite samples taken are tested at the laboratory for Moisture Content determination, Specific Gravity determination as well as Particle Size Distribution determination. Analysis of data is carried out before discussion and conclusion can be done.

3.3.1 Moisture Content

Moisture content is determined by oven-drying at 105 $\pm$ 5 where Clause 5.2 in Geospec 3 is referred to carry out this test. Minimum mass of soil require for sample preparation is 30 g for fine-grained soil, 300 g for medium-grained soil and 3 kg for coarse-grained soil. Moisture content of the soil sample, w, is determine by calculation by using equation below where w is a percentage of the dry soil mass to the nearest 0.1%.

$$w = \left(\frac{m_2 - m_3}{m_3 - m_1}\right) \times 100 \tag{3.1}$$

where m_1 is the mass of container (g)

m_2 is the mass of container and wet soil (g)

m_3 is the mass of container and dry soil (g)

3.3.2 Wet Sieving Analysis

Determination of particle size distribution by wet sieving method can be separated into two methods which are wet sieving with dispersant and wet sieving without dispersant. Wet Sieving with dispersant is referring to the sample had been pretreated with dispersant first before sieve. According to Geospec 3, soil sample should be treated according to its type, but if the soil origin is uncertain, by default it should be treated as saprolitic, residual or colluvial soil.

Calculations is done next to identify the actual mass of the sample being tested. For samples containing larger particles; larger than 20 mm, calculate the sum of masses of sample retained on each sieve including soil m_2. If the sum of masses is differ by more than 1% of the initial dry mass,m_1 the test shall be repeated. Then calculate proportion by mass of soil retained on each sieve as a percentage of m_1 as for example:

$$\text{Percentage retained on 28 mm sieve} = \left\{\frac{m_{(28\ mm)}}{m_1}\right\}\ 100 \qquad (3.2)$$

Next, the sum of masses retained on each sieve is calculated together with the mass m_5 passing 6.3 mm sieve. If the calculated value is differ by more than 1% from the dried riffled mass, m_4, the test shall be repeated. Then, calculate the corrected mass of soil retained on each sieve between 20 mm to 6.3 mm by using the equation as for example:

$$\text{Percentage retained on 10 mm sieve} = m_{(10\ mm)} \left(\frac{m_2}{m_3}\right)\left(\frac{100}{m_1}\right) \qquad (3.3)$$

Corrected mass of soil retained on each sieve is calculated after sum of masses retained on each sieve together with mass m_F or m_E passing 63 μm is calculated. Corrected masses on each sieve is determined by using equation as for example:

$$\text{Percentage retained on 300 } \mu\text{m sieve} = m_{(300\mu m)} \left(\frac{m_5}{m_6}\right)\left(\frac{m_2}{m_3}\right)\left(\frac{100}{m_1}\right) \tag{3.4}$$

Cumulative percentage by mass of soil passing each of sieves is calculated by using equation:

(% passing this sieve) = (% passing previous sieve) – (% retained on this sieve)

Lastly, calculate the fraction passing 63 μm test sieve by difference. Mass of fines lost during washing is equal to (m_3 – m_4) in which if mass of dry fines particle is added, the equation used to calculate percentage finer than 63 μm is:

$$\left\{\frac{(m_3 - m_4) + m_F}{m_3}\right\}\left(\frac{m_2}{m_1}\right) 100 \tag{3.5}$$

If the sample was subdivided the mass of fines m_E, the percentage finer than 63 μm is calculated by using equation:

$$\left\{\frac{(m_3 - m_4) + \left(\frac{m_E m_5}{m_6}\right)}{m_3}\right\}\left(\frac{m_2}{m_1}\right) 100 \tag{3.6}$$

3.3.3 Hydrometer Test

Main objective of carried out Hydrometer Test is for analysis of particle size which there are different sizes of grain size presence within a soil. Basically, Hydrometer Test is used to determine the distribution of fine particles in the soil and it can be divided into two method which are hydrometer test with dispersant and hydrometer test without dispersant. Usually, if material passing 63μm is less than 10%, the test will not be performed. This test is interrelated with wet sieving analysis discussed in Chapter 3.32 in terms of sample preparation as well as to identify particle size distribution.

Calculation fine sieving and for sedimentation is done after carried out the test. Following are the calculation for sedimentation:

i. Calculate true hydrometer reading, R_h (in mm) by using equation:

$$R_h = R_h' + C_m \tag{3.7}$$

where C_m is the meniscus correction derived and

R_h' is the observed hydrometer reading.

ii. Obtain effective depth, H_T (in mm) which the density of the suspension is measured, corresponding to R_h reading from hydrometer calibration done.

iii. Calculate the value of equivalent particle diameter, D (in mm) by using equation:

$$D = 0.005531\sqrt{\frac{\eta H_T}{t(\rho_s - 1)}} \tag{3.8}$$

Where η is the dynamic viscosity of water at test temperature (in mPa.s)

H_T is the effective depth at which the density of is measured (in mm)

ρ_s is the particle density (in Mg/m^3)

t is the elapsed time (in min)

0.005531 is constant

iv. Calculate modified hydrometer reading, R_d by suing equation:

$$R_d = R_h' - R_0' \tag{3.9}$$

where R_0' is the upper rim of the meniscus of hydrometer reading in dispersant solution

v. Calculate the percentage by mass, K, of smaller particles by using equation:

$$\mathrm{K} = \left\{\frac{100\rho_s}{m(\rho_s - 1)}\right\} R_d \tag{3.10}$$

where m is the mass of dry soil used (in g)

3.3.4 Small Pyknometer Test

Specific gravity bottle or pyknometer is a close-fitting ground glass stopper with fine hole through it which enables the density of a fluid to be measured accurately. Therefore, pyknometer test will determine particle density for soils consisting particles finer than 2 mm. A pyknometer consists of two parts; a bottom part which are a small bottle and the stopper which has capillary tube with a ground glass. A 100 g soil sample is prepared where large particles shall be ground to pass 2 mm sieve test. The average results obtained from the two sample is calculated which the values obtained is expressed to the nearest 0.01 Mg/m^3. Particle density, ρ_s (Mg/m^3) is calculated from the equation:

$$\rho_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \tag{3.11}$$

Where m_1 is the mass of density bottle (g)

m_2 is the mass of bottle and dry soil (g)

m_3 is the mass of bottle, soil and water (g)

m_4 is the mass of bottle when full of water only (g)

3.4 DISCUSSION AND CONCLUSION

To ensure the study is carried out correctly and uncertainty is solved, discussion with supervisor is important as a guidance and reference if any problem occur. Knowledge as well as experience of the supervisor will help to brainstorm the best solution and techniques to conduct the study especially when come into laboratory issues. Besides supervisors, discussion with research officers is also important to as they have involved in many projects with different experiences.

Correlation generates was compared with the other correlation had been made from previous studies. The similarities and difference is discussed within the context of soil properties. At the end of the study, conclusions are made based on the objectives together with all the results and analysis performed.

CHAPTER 4

DISCUSSIONS

4.1 INTRODUCTION

Raw data of basic properties of the samples collected from laboratory test were analyzed by referring to the formula and method stated in Geospec 3: MODEL SPECIFICATION for SOIL TESTING. Results obtained from laboratory tests were present in the form of graph as well as in the form of table and figure to make it understandable to read. Later, results gained was compared with standard stated in IMSBC Code where each of studied properties is compared before any conclusions is made.

4.2 PARTICLE SIZE DISTRIBUTION ANALYSIS

For particles size determination, there are few test that had been done as the bauxite samples consist of coarse particles, lump particles as well as fine particles. 6.30 mm to pan sieve is used to identify distribution of fine particles. For Wet Sieving Analysis method, the percentage passing 6.30 mm sieve for fine particles determination for the samples was tabulated in Table 4.1. There are about 70% particles that passing 6.30 mm sieve for sample M1L1B1, M1L2B1 and M1L3B1 for sample OPST the percentage passing is 63.24%.

Table 4.1: Percentage passing 6.3 mm sieve for fine particles determination (Wet Sieving Method)

	Percentage passing 6.3 mm sieve			
Sieve Size (mm)	**M1L1B1**	**M1L2B1**	**M1L3B1**	**OPST**
6.30	76.59	75.48	78.47	63.24
5.00	60.25	55.39	65.19	47.90
3.35	45.71	40.54	47.08	31.77
1.18	28.67	15.62	22.98	13.35
0.60	24.85	12.90	18.81	9.96
0.30	21.59	10.82	15.85	7.14
0.15	14.13	7.41	11.60	4.22
0.0063	0.35	0.15	0.70	0.17
Pan	0.00	0.00	0.00	0.00

Results from Hydrometer Test and Wet Sieving Analysis were analyzed and it is presented in Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4 where each figure shows percentage particle passing for M1L1BI, M1L2B1, M1L3B1 and OPST respectively. IMSBC Code standard was referred during analyzing data where for particle size, the allowable size for exportation is 2.5 mm to 500 mm with percentage passing for 2.5 mm is 70% to 90%.

M1L1B1 sample show percentage passing 2.5 mm particle size is 42% while for M1L2B1, M1L3B1 and OPST are 33%, 42% and 23% respectively. Approximately 70% from the total mass of each sample consists of fine particles where the presence of this fine particles will effect liquefaction to occur during transportation of bauxite in cargoes.

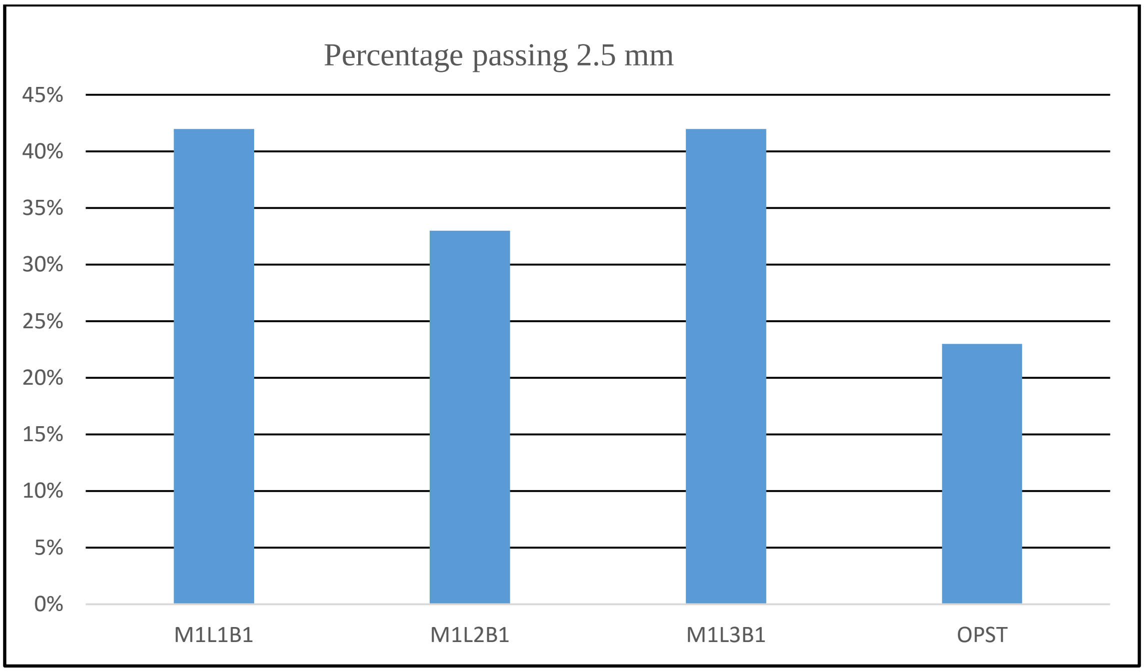

Figure 4.1: Tabulation of percentage passing 2.5 mm for each sample

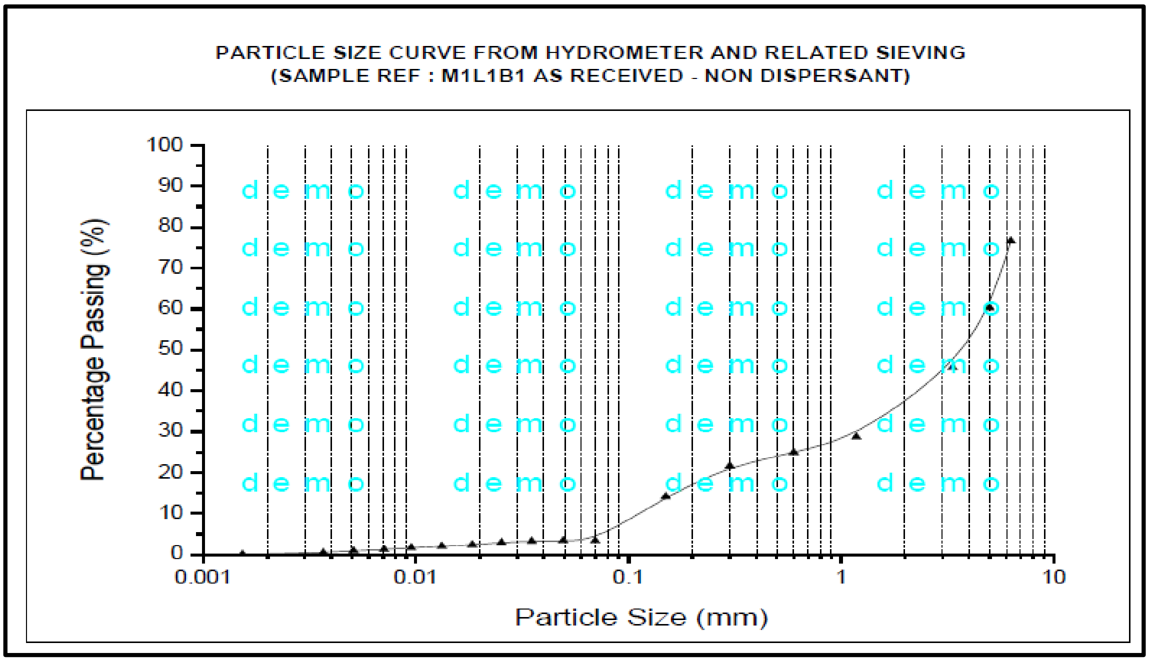

Figure 4.2: Particle size distribution of M1L1B1

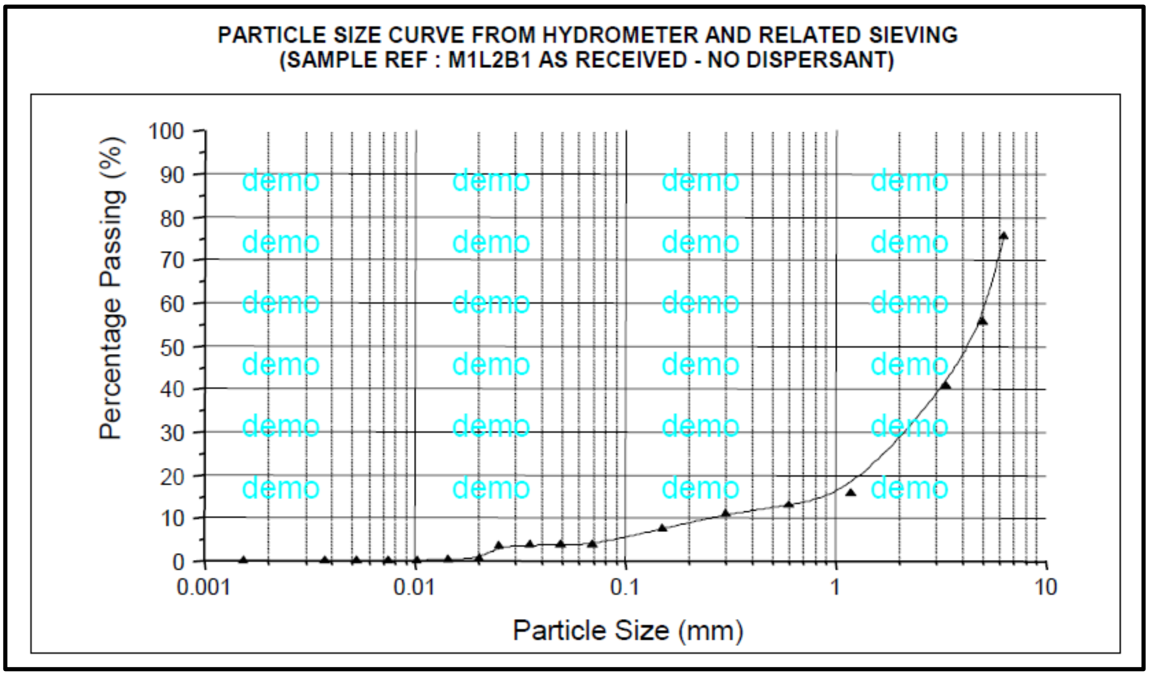

Figure 4.3: Particle size distribution of M1L2B1

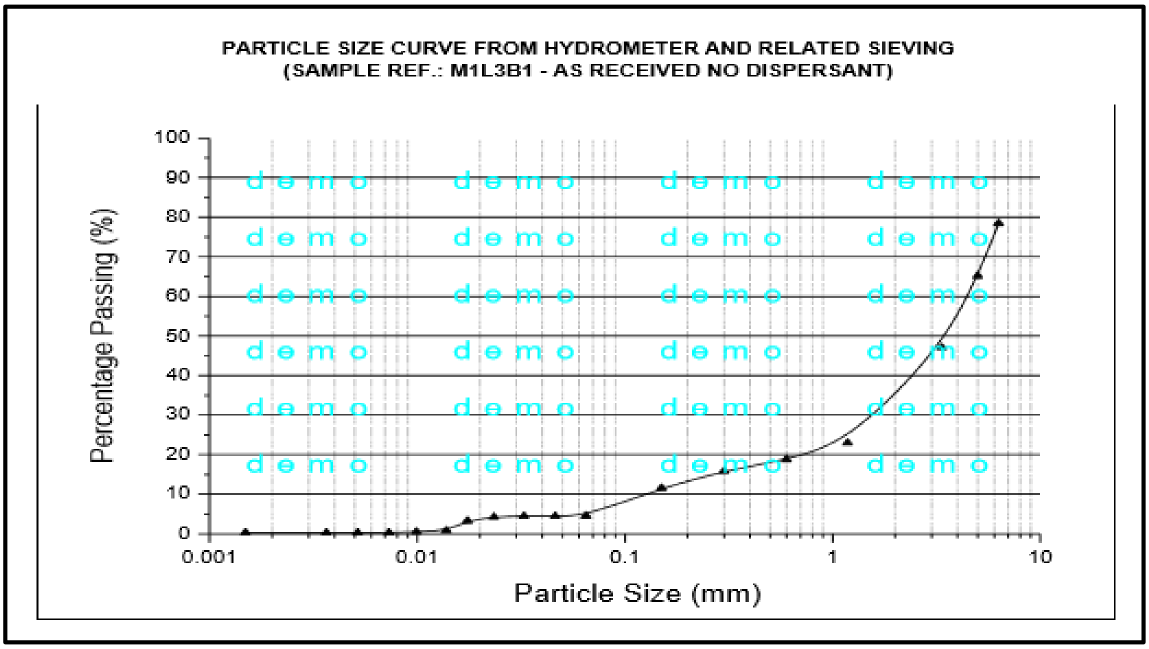

Figure 4.4: Particle size distribution of M1L3B1

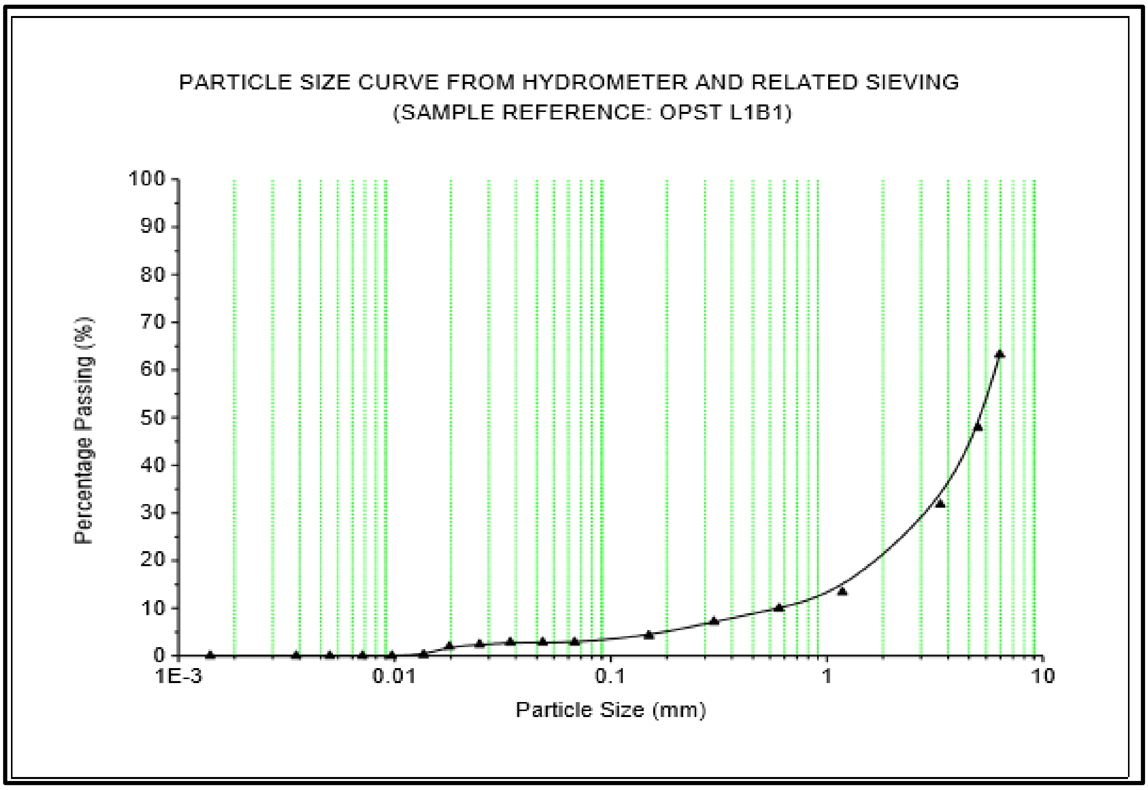

Figure 4.5: Particle size distribution of OPST

4.3 MOISTURE CONTENT

Moisture content of the sample is determined by both oven-dry and air-dry method where the difference between the data obtained from the tests was compared. Results from air-dry method shows less moisture content in the samples compared with the results from oven-dry method. The results from this two moisture content determination is difference as the study by Pantazidou (2005) state that the moisture content of bauxite is affected by the drying method and the drying method used. Besides the drying technique been used, the results of high moisture content percent is influence by the presence of large number of fine particles surround the bauxite ore. This fine particle will create large surface area for water absorption and storage resulting high moisture content.

Table 4.2: Average moisture content (Air-dry Method)

Sample	% Moisture Content Container 1	% Moisture Content Container 2	Average % Moisture Content
M1L1B1	17.77	18.68	18.23
M1L2B1	25.26	23.13	24.20
M1L3B1	23.34	23.76	23.55
OPST	16.60	15.06	15.83

Table 4.3: Average moisture content (Oven-dry Method)

Sample	% Moisture Content Container 1	%Moisture Content Container 2	% Average Moisture Content
M1L1B1	20.58	20.53	20.55
M1L2B1	26.20	26.62	26.41
M1L3B1	25.38	25.30	25.34
OPST	20.91	21.09	21.00

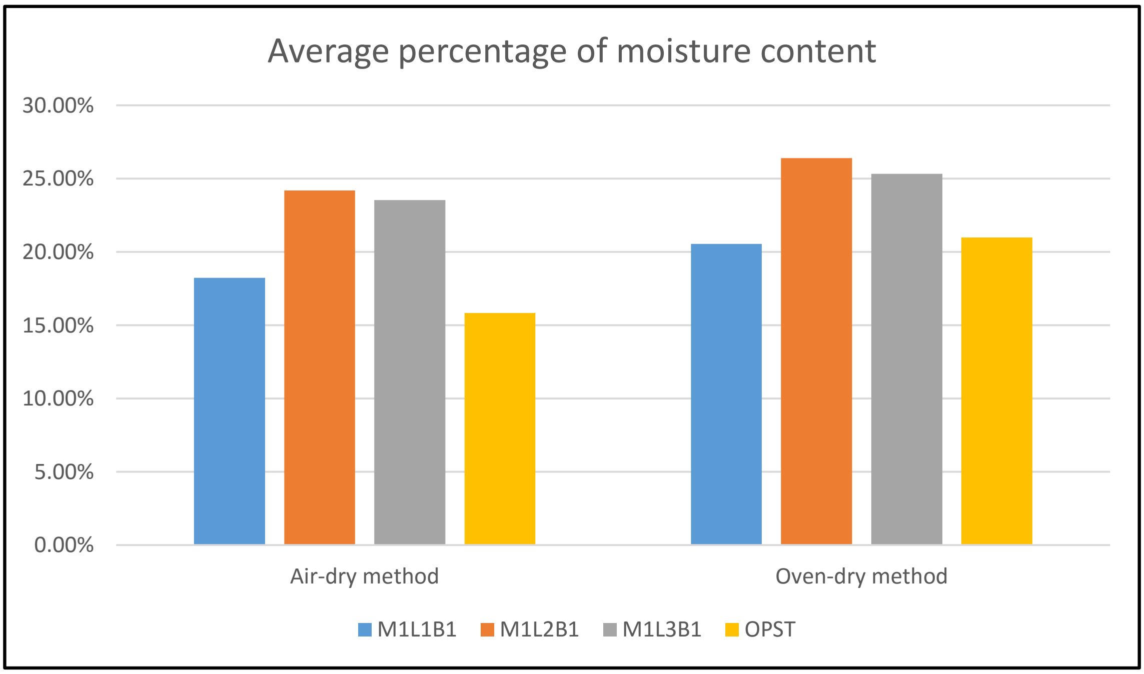

Figure 4.6: Tabulation average percentage of moisture content

4.3 SPECIFIC GRAVITY

From Small Pycknometer Test, the results collected was tabulated in Table 4.4 where the specific gravity for M1L1B1 and M1L2B1 is the same. Meanwhile, there is slight difference in specific gravity value for M1L3B1 as well as OPST sample. Based on studied carried out by Gandhi et al. (2013), specific gravity for bauxite is between 2.5 – 3.0, thus the bauxite samples collected from Gebeng mine are still between the range of the study. In order to compare the result from specific gravity test with requirement in IMSBC Code, this value was converted to bulk density value where 1kg/m^3 of bulk density is equal to 0.001 specific gravity. The bulk density results of the samples is in Table 4.5 below.

Table 4.4: Results of specific gravity

Sample	Specific Gravity of Container 1	Specific Gravity of Container 2	Average Specific Gravity
M1L1B1	2.77	2.74	2.75
M1L2B1	2.75	2.76	2.75
M1L3B1	2.88	2.85	2.87
OPST	2.88	2.89	2.88

Table 4.5: Results of bulk density

Sample	Bulk Density (kg/m^3)
M1L1B1	2750
M1L2B1	2750
M1L3B1	2870
OPST	2880

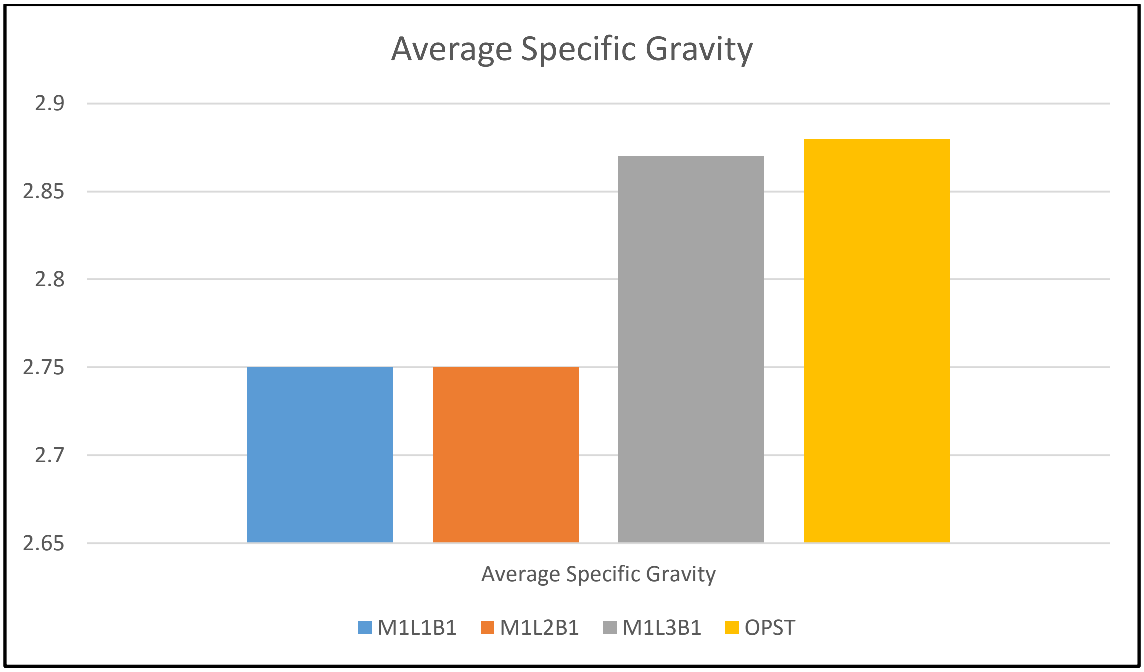

Figure 4.7: Tabulation of average specific gravity

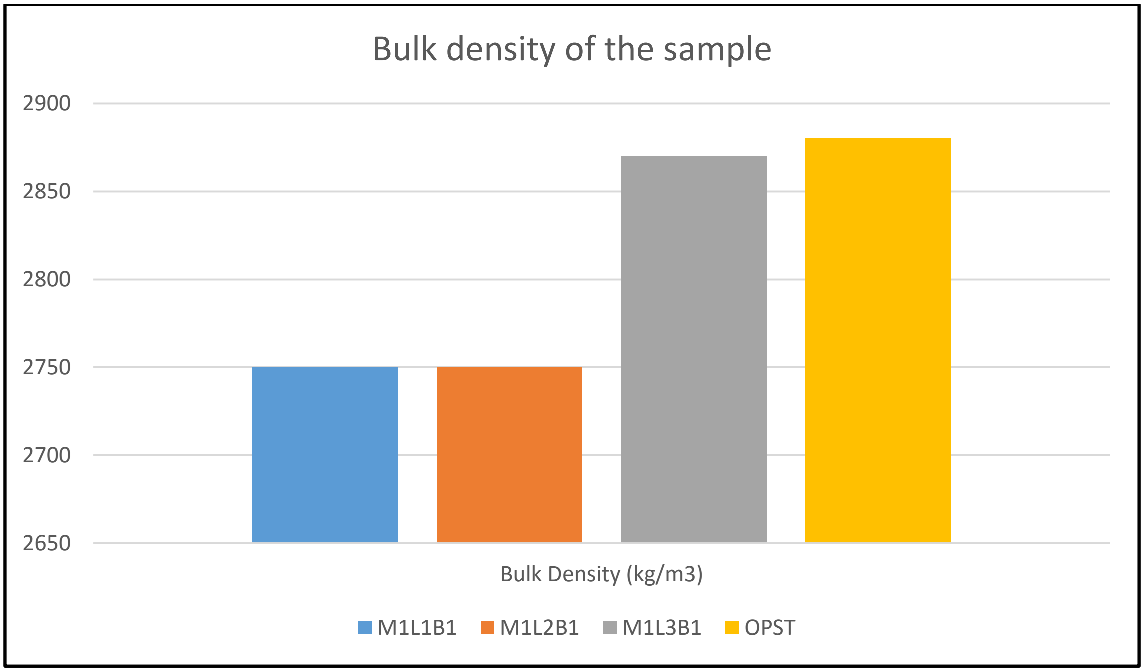

Figure 4.8: Tabulation of bulk density

IMSBC Code of standard stated that the allowable bulk density for cargo transportation is between 1190 to 1389 kg/m^3 indicating granular or lump particles. In the other ways, the bulk density results of the samples shows the value of bulk density is doubling the allowable bulk density value where presence of fine particles is more than lump particles. The presence of granular particles, lump particles as well as fine particles will effect liquefaction to occur, as it had been stated by Wu and Sun (2008), the chances of liquefaction to occur is increase in terms of particle size where the sequence are: coarse granules, middle granules, fine granules and lastly powdery granules. Thus the bauxite samples are not qualified to be exported.

4.4 MORPHOLOGICAL PROPERTIES OF BAUXITE

Morphological properties if bauxite is studied by SEM test where the fine particles as well as the bauxite ore can be observed clearly. Results of SEM test is in Figure 4.5, Figure 4.6, Figure 4.7 and Figure 4.8 where magnification for each figure is 1000x, 2000x 5000x and 10 000x respectively. With 1000x magnification, rough image of bauxite ore and other particle can be seen where it is uncertain to differentiate between lump particles of bauxite or the native soil from the mine. As the sample was collected from the mine and did not undergo any washing process, there is a possibility of the image shown is combination of soil and also the bauxite ore.

Meanwhile, under 2000x 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 magnification, fine particles attached to the bauxite sample are clearly can be seen. This figure explained the main cause of high percentage of moisture content as well as the big number of bulk density of the bauxite sample.

Large amount of fine particles at the bauxite ore may resulting liquefaction to take place due to fine particles that have low anti-liquefaction characteristics compared with lump particles and granular particles. This anti-liquefaction characteristics had been discuss by Wu and Sun (2008) where the granular or lump sizes of bauxite is a stable array sand with better cementation resulting in ability to prevent liquefy of soil to occur. Besides that, as the bauxite samples collected from Gebeng mine are disturbed sample, the tendency for this sample to liquefy is higher than undisturbed soil because of shear force of anti-liquefaction of undisturbed soil is 1.5 to 2 times greater than disturbed soil (Wu and Sun, 2008).

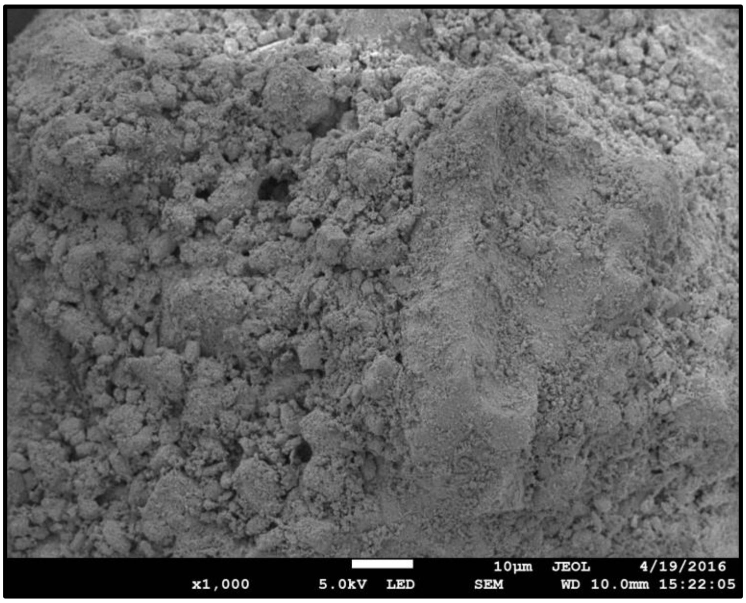

Figure 4.9: Magnification of bauxite sample under 1000x magnification

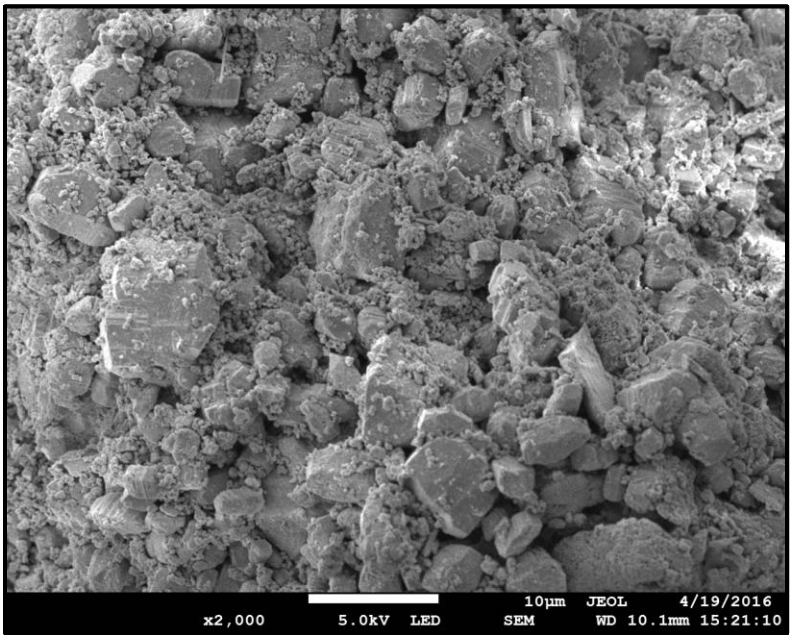

Figure 4.10: Magnification of bauxite sample under 2000x magnification

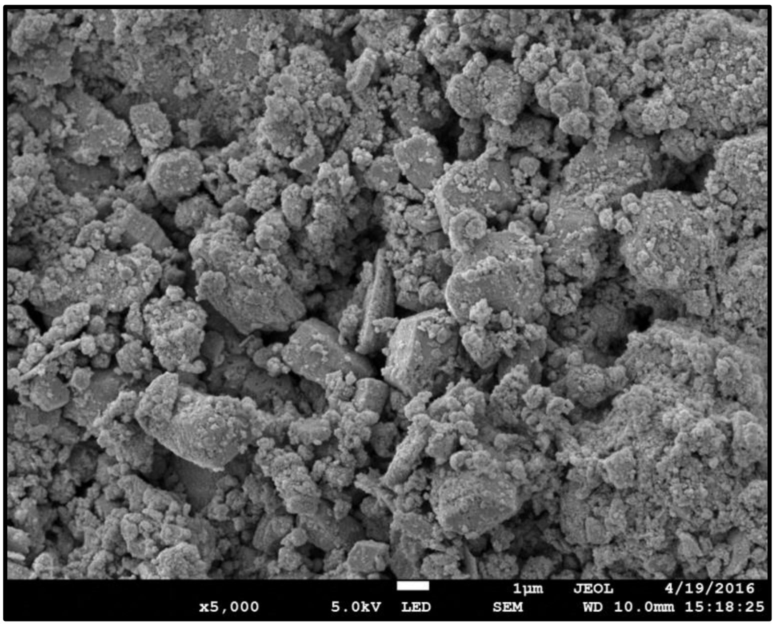

Figure 4.11: Magnification of bauxite sample under 5000x magnification

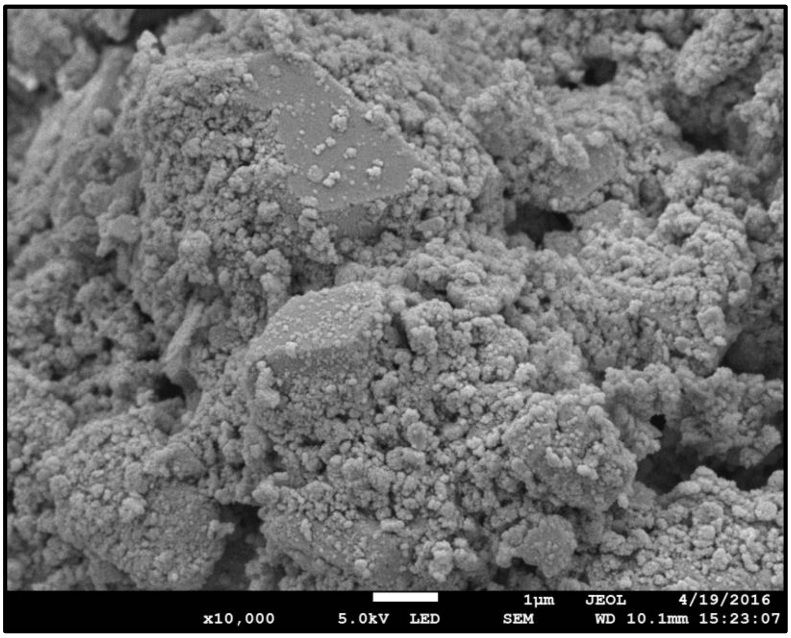

Figure 4.12: Magnification of bauxite sample under 10 000x magnification

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

Based on the objectives set at the early stage of the study, there are some conclusion can be made. Basic properties of bauxite collected from Gebeng mine had determine which the basic properties being studied is based on requirement been stated in IMSBC Code. Basic properties that had been studied are the distribution of particle size of the samples, moisture content and lastly specific gravity which later it is converted to bulk density.

Results from the basic properties study is simplified and summarize where the average particle size distribution for lump particles; particles sizes are 2.5 mm to 500 mm for the samples is 39%. The average percentage of moisture content of the samples is 22.65% and the average specific gravity for the samples is 27280 kg/m3. The results obtained was compared with IMSBC Code where each of this basic properties are exceeding the specified value stated in the code. All this basic properties are influence factor for liquefaction to occur during bauxite cargoes transportation, hence it is important to meticulously identify the properties before it is being exported. As the results is doubling the required value, it can be conclude that the bauxite collected from Gebeng mine are not suitable to be transported.

Study on morphological properties of Gebeng bauxite shows the abundance of fine particle attached to the bauxite ore, resulting in higher percentage of moisture content, low percentage of lump particles distribution as well as high value of bulk density. This is because, the presence of fine particles will absorb more water, increasing moisture content of the samples in which the presence of this fine particles have been proven by bulk density value as well as percentage of particle size distribution.

Gebeng bauxite cannot be classified under Group C of IMSBC Code and it is not suitable to be exported as none of the basic properties are fulfilling the requirement stated in the code. If there is a will of transporting the bauxite, it will be a high risk cargoes transportation due to string current from the waves at the ocean.

5.2 RECOMMENDATION

In order to ensure the bauxite collected from Gebeng mine are fulfilling the IMSBC Cod of standard, some recommendation is suggested so that the bauxite are approved to be exported. Beneficiation process of bauxite ore is one of recommendation where it is defined as the process to removes the gangue minerals from ore to produce a concentrated product. Beneficiation process involve several stages in which the end product is separation of fine particle and lump particle: removing fine particles and the concentration of bauxite ore is determined.

For exporting purpose, basic properties of bauxite ore must be determine to ensure zero catastrophic occur while it being transported. Basic properties of bauxite ore determined must fulfill the IMSBC Code of transportation standard as it is been widely used due to its safety factor.

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