PROPERTIES OF RAW AND PROCESSED BUKIT GOH BAUXITE IN KUANTAN, PAHANG IN ACCORDANCE WITH IMSBC CODE

Muzamir Hasan[1,2], Ahmad Amirul Faez[1,2], M. Azizul Moqsud[3], Tam Weng Long[2] and Phang Biao Yu[2]
[1]Centre for Earth Resources Research & Management, Universiti Malaysia Pahang, Malaysia;
[2]Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Malaysia;
[3]Department of Civil and Environmental Engineering, Yamaguchi University, Ube-Shi, Yamaguchi, Japan.

ABSTRACT

This study focus on the differences of geotechnical properties between raw and processed Bukit Goh bauxite. As bauxite material has high clay content which mostly composed of silicate minerals, it has high risk to cause cargo liquefaction which in turn causes catastrophic incident. This paper includes the analysis of raw and processed bauxite where its fine particle contents has been minimized using beneficiation method to reduce the risk of liquefaction by referring to the International Maritime Solid Bulk Cargoes Code (IMSBC Code) standard. To analyse these characteristics of the bauxite, five samples were selected at Bukit Goh, Kuantan; three of the samples from the Bukit Goh mine and two samples from stock pile were tested to identify the bauxite geotechnical properties by referring to GEOSPEC 3: Model Specification for Soil Testing; particle size distribution, moisture content, specific gravity, morphological properties as well as its elemental and oxide properties. Laboratory tests involved including Small Pycnometer test, Dry Sieve test, X-ray fluorescence test (XRF) and Field emission scanning electron microscopy test (FESEM). The results show that average moisture content of raw bauxite is 24.81% which exceeded the recommended value of maximum 10% while the average moisture content of processed bauxite is only 6.69%. The average fine material for raw bauxite is 38.40% which should not be greater than 30% per IMSBC standard while for processed bauxite is 21.40%. In conclusion, the quality and safety of processed bauxite is better than raw bauxite.

Keywords: Bauxite, Beneficiation, Geotechnical Properties, Soil Liquefaction

INTRODUCTION

Bauxite is the principal ore of alumina (Al_2O_3), which is used to produce aluminum. Hydrated aluminum oxides, hydrated aluminosilicates, iron oxides, hydrated iron oxides, titanium oxide, and silica are the main compound that made a bauxite [1]. Around the globe, approximately 165 million tonnes of bauxite are mined each year and they are usually transported to refineries by conveyor, ship, or rail [2]. Bauxite reserve has been found in Kuantan district and bauxite mining activity has started due to strong demand from China, Malaysia increases the production of bauxite. In 2015, a bulk carrier capsized about 150 nautical miles off the coast of Vietnam with 18 fatalities and only one survivors which were carrying 46 400 tonnes of bauxite. Investigation conducted by International Maritime Organization (IMO) concluded that the loss of the Bulk Jupiter has uncovered evidence to suggest liquefaction of cargo led to loss of stability [3][4]. Liquefaction is a phenomenon where soil experience a process by which water-saturated sediment temporarily loses strength and acts as a fluid [5]. There are some standard and regulation that need to be follow; in this case IMSBC Code to determine the safety of bulk cargoes carrying bauxite and to minimize the risk of the cargoes to capsize. Figure 1 shows the classification of Bauxite in Group C where it is neither liable to liquefy (Group A) nor to possess chemical hazards (Group B) [6]. If bauxite samples are complied with the specifications as stated in IMSBC Code, the samples are allowed be shipped and exported. Thus, this study is carried out to determine whether Kuantan bauxite samples are in accordance with the IMSBC Code or not; by comparing the parameters stated in the code.

BAUXITE

DESCRIPTION
A brownish, yellow claylike and earthy mineral. Moisture content: 0% to 10%. Insoluble in water.

CHARACTERISTICS

ANGLE OF REPOSE	BULK DENSITY (kg/m^3)	STOWAGE FACTOR (m^3/t)
Not applicable	1190 to 1389	0.72 to 0.84
SIZE	**CLASS**	**GROUP**
70% to 90% lumps: 2.5 mm to 500 mm 10% to 30% powder	Not applicable	C

Fig. 1 Bauxite's Group C Classification [6]

Percentages of moisture content of the sample do have a relationship with particle size distribution where the presence of fines particles will influence its water-holding properties [7].

Besides identifying the standard quality of Kuantan bauxite, its morphological characteristic also studied to determine the particles present and its effect. If the particles are found to be harmful, prevention and safety measure should be applied and discussed.

MATERIALS AND METHODS

All laboratory experiments were carried out based on Geospec 3: Model Specification for Soil Testing (as shown in Table 1). The beneficiation process is done in small scale with 100g of samples using a bottle dispenser on 4.25mm passing sieve.

Table 1 Laboratory tests and standard

Laboratory Tests	Standards
Moisture Content Test	Geospec 3: Part 2; 5 Clause 3.2
Specific Gravity Test	Geospec 3: Part 2; 7 Clause 3.4
Particle Size Distribution	Geospec 3: Part 2; 8 Clause 3.5
X-Ray Fluorescence (XRF)	Quantexpress (Full Analysis) by XRF S8 Tiger

RESULTS AND DISCUSSION

There are FIVE (5) samples selected from Bukit Goh in Kuantan; THREE (3) samples are in-situ samples (M2L1B1, M2L2B1 and M2L2B2) and TWO (2) samples are from stockpile (PTSTL1B1 AND PTSTL2B1).

Moisture Content

The result shows moisture content of Bukit Goh bauxite is higher compared to recommended percentage in the IMSBC Code (Table 2). Due to higher moisture content, it clearly shows that Bukit Goh bauxite have large amount of fine particle compared to coarse particle. Based on IMSBC Standard, the allowable moisture content for deposits to be on a cargo ship is 0%-10%. From the comparison in the histogram in Figure 2, it shows that the moisture content of raw Bukit Goh bauxite is higher compared to processed bauxite where it has the average of 24.81% over 6.69% only on the processed bauxite sample. Due to higher moisture content, it clearly demonstrates that raw Bukit Goh bauxite have large amount of fine particle compared to coarse particle. 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.

Table 2 Moisture content of raw and processed Bukit Goh Bauxite

	Moisture Content (%)	
Sample	Raw	Processed
M2L1B1	27.69	7.31
M2L2B1	22.96	6.12
M2L2B2	23.93	6.47
PTSTL1B1	23.51	6.62
PTSTL2B1	25.95	6.94

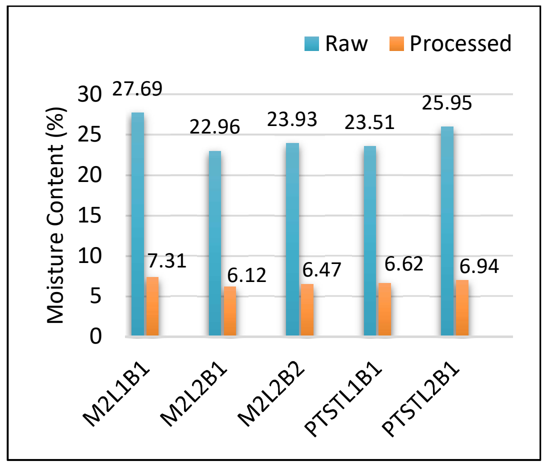

Fig. 2 Moisture content of raw and processed Bukit Goh Bauxite

Based on IMSBC Standard, the allowable moisture content for deposits to be on a cargo ship is 0%-10%. From the comparison in the bar chart, it shows that the moisture content of raw Bukit Goh bauxite is higher compared to processed bauxite where it has the average of 24.81% over 6.69% only on the processed bauxite sample. Due to higher moisture content, it clearly demonstrates that raw Bukit Goh bauxite have large amount of fine particle compared to coarse particle. 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.

Specific Gravity Test

The result from Small Pycnometer Test was collected where there is just a slight difference in specific gravity for both samples (Figure 3). Based on previous studies, the specific gravity values obtained for the bauxites are in the range from 2.70 to 2.87 and specific gravity of bauxite in India is higher compared to bauxite at Bukit Goh. The specific gravity of bauxite largely depends on the density of the mineral making up the individual soil particle.

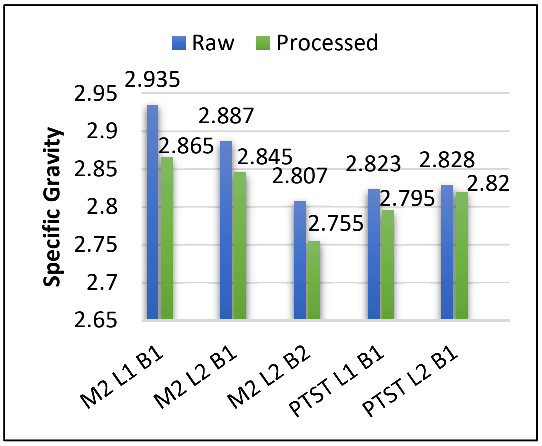

Fig. 3 Specific gravity of raw and processed Bukit Goh Bauxite

Particle Size Distribution

From Table 3, it clearly shows that bauxite sample that undergo beneficiation process have lesser fine particles compare to the raw bauxite sample. Particles that passed through 2.5mm sieve size is consider fine particles. The percentage passing 2.5mm for processed bauxite sample is 20% while for raw sample is 39%. Therefore, this prove that the particle size distribution of raw Bukit Goh bauxites is not in the range of less than 30% fine particle and coarse particle more than 70% as stated in IMSBC Code. Due to higher percentage of fine particle in the raw bauxite, it will cause the moisture content to increase as fine particles absorb more water. Meanwhile, 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.

Table 3 Percentage of fine particles between raw and processed Bukit Goh Bauxite

Samples	Raw (%)	Processed (%)
M2L1B1	39	20
M2L2B1	38	24
M2L2B2	47	18
PTSTL1B1	32	23
PTSTL1B2	36	22
Average fine particles	**38.40**	**21.40**

Morphological Properties of Bauxite

Field Emission Scanning Electron Microscopy (FESEM) Test is carried to determine the morphological properties of both raw and processed Bukit Goh bauxite. The results are shown in Figure 4, Figure 5, Figure 6 and Figure 7 where magnification for each figure is 1000x, 2000x 5000x and 10000x respectively; for both raw and processed bauxite samples. Closer inspection of the particles shows a layer of material coating most of the particle surfaces. The different sizes of particles can be observed with clear image of lump particles and powdery like-structure of fine particles under 2000x magnification. Clear image of particles started to be seen at 5000x magnification and under 10000x magnification, fine particles attached to the bauxite sample are clearly can be seen. Study on morphological properties of Bukit Goh bauxite above displays that the fine particles of raw bauxite is higher than the beneficiated bauxite. Clearly seen that the lesser fine particle attached to the processed bauxite ore. This proved the washing of bauxite can reduce the amount of fine particle in bauxite lump. Bauxite samples collected from Bukit Goh mine are disturbed sample, hence the tendency for this sample to liquefy is higher than undisturbed soil because of the shear force of anti-liquefaction of undisturbed soil is 1.5 to 2 times greater than disturbed soil.

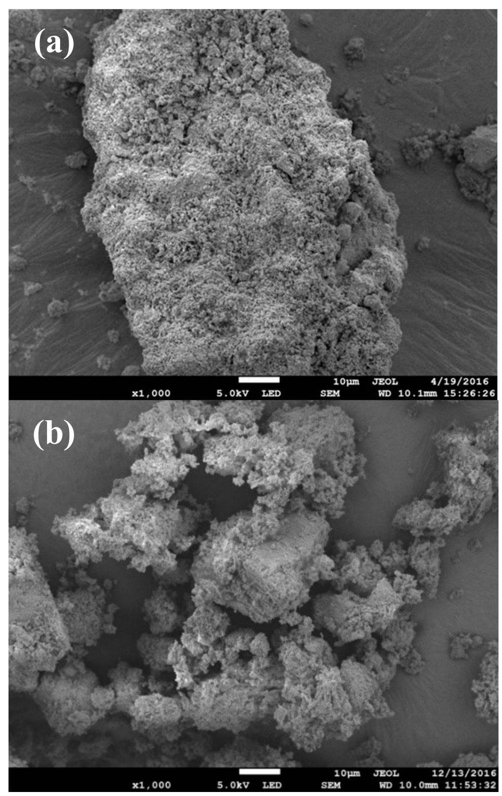

Fig. 4 Magnification of bauxite sample under 1000x magnification for (a) raw and (b) processed bauxite sample

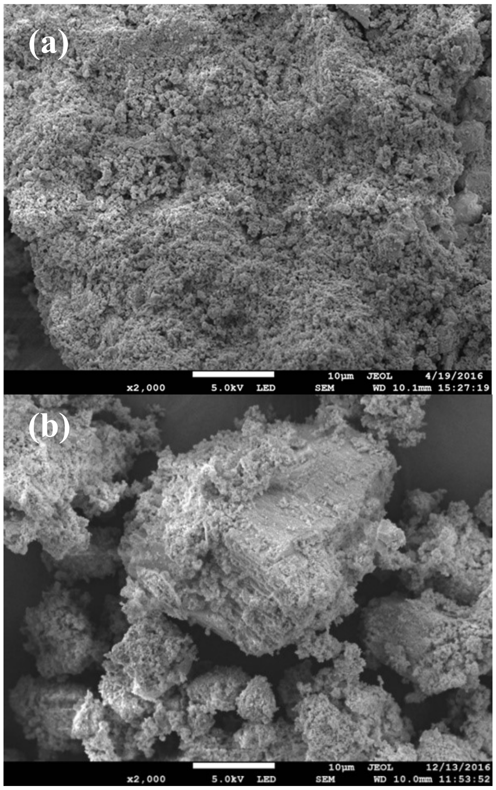

Fig. 5 Magnification of bauxite sample under 2000x magnification for (a) raw and (b) processed bauxite sample

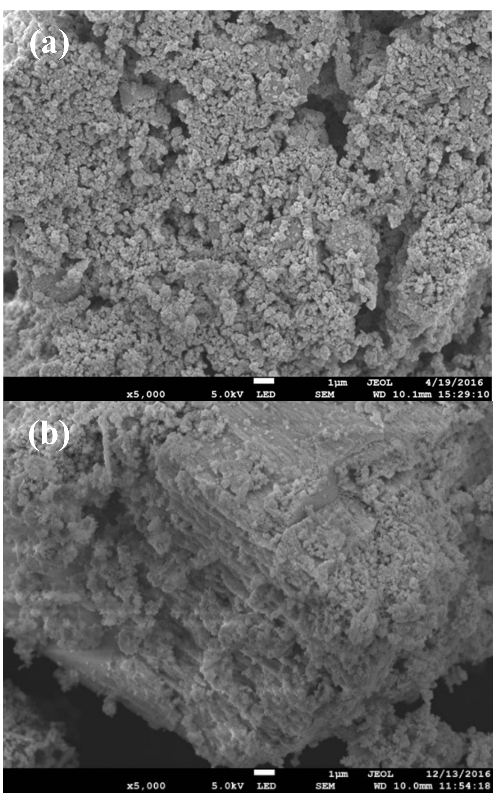

Fig. 6 Magnification of bauxite sample under 5000x magnification for (a) raw and (b) processed bauxite sample

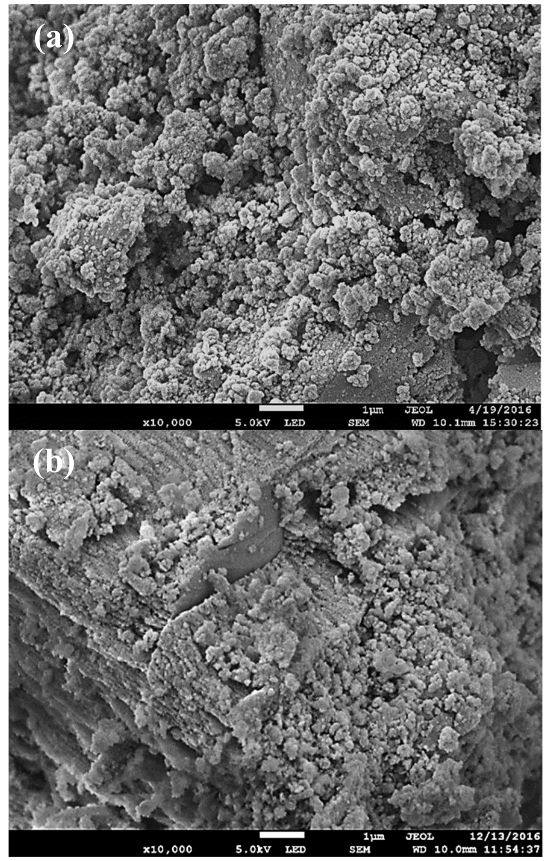

Fig. 7 Magnification of bauxite sample under 10000x magnification for (a) raw and (b) processed bauxite sample

Elemental and Oxide Properties Test

The test of both raw and processed bauxite elements and oxide properties is carried out by X-Ray Fluorescence XFF S8 Tiger machine from the UMP central Laboratory by bombarding a high-energy gamma ray on both M2L1B1 samples. The results are shown in Table 4 and 5.

From Table 4, it shows that the quantity of Silicon (Si) is reduced from 0.50% to 0.44% and from Table 3, the amount of Silicon Dioxide (SiO2) or also known as silica is minimized from 1.07% to 0.94% after beneficiation process. Unfortunately, the value of aluminium element also decreases slightly from 7.48% to 7.25% although it has not much effects on the bauxite products. As mentioned before, the core target of washing bauxite is to decrease the amount of silica and improve the amount of aluminium. In addition, along with silica, the insoluble iron and titanium oxides in red mud will also be removed that will abolish lower grade fines and enhance the quality of bauxite.

Table 4 Raw and processed Bukit Goh Bauxite elements

Parameters	Unit	Raw	Processed
Iron (FE)	%	31.38	26.49
Aluminium (AL)	%	7.48	7.25
Titanium (Ti)	%	3.96	3.33
Silicon (Si)	%	0.50	0.44
Phosphorus (P)	%	0.40	0.41
Calcium (Ca)	%	0.09	0.11
Sulphur (S)	%	0.09	0.07
Chromium (Cr)	%	0.08	0.09
Manganese (Mn)	%	0.06	0.05
Zirconium (Zr)	%	0.05	0.05
Strontium (Sr)	%	0.02	0.02
Niobium (Nb)	%	0.02	0.02
Zinc (Zn)	%	0.01	0.02
Gallium (Ga)	ppm	69	79
Yttrium (Y)	ppm	35	48

Table 5 Raw and processed Bukit Goh Bauxite oxides

Parameters	Unit	Raw	Processed
Iron (III) Oxide	%	44.86	37.88
Aluminium Oxide	%	14.13	13.69
Titanium Dioxide	%	6.60	5.55
Silicon Dioxide	%	1.07	0.94
Phosphorus Pentoxide	%	0.91	0.93
Sulphur Trioxide	%	0.22	0.18
Calcium Oxide	%	0.13	0.15
Chromium (III) Oxide	%	0.12	0.13
Manganese Oxide	%	0.08	0.06
Zirconium Dioxide	%	0.07	0.06
Niobium Pentoxide	%	0.03	0.02
Strontium Oxide	%	0.02	0.02
Zinc Oxide	%	0.01	0.02

Comparison with IMSBC Code

The comparison between raw and processed bauxite is shown in Table 6 shows that bauxite that went through beneficiation procedure pass all the requirements whether in particle size or moisture content.

Table 6 Comparison table with IMSBC code

PSD (IMSBC: 30% < 2.5mm passing)		
Sample	Passing (%)	Remarks
M2L1B1 (R)	39	Fail
M2L1B1 (P)	20	Pass
M2L2B1 (R)	38	Fail
M2L2B1 (P)	24	Pass
M2L2B2 (R)	47	Fail
M2L2B2 (P)	18	Pass
PTSTL1B1 (R)	32	Fail
PTSTL1B1 (P)	23	Pass
PTSTL2B1 (R)	36	Fail
PTSTL2B1 (P)	22	Pass
Moisture Content (IMSBC: 0% to 10%)		
M2L1B1 (R)	27.69	Fail
M2L1B1 (P)	7.31	Pass
M2L2B1 (R)	22.96	Fail
M2L2B1 (P)	6.12	Pass
M2L2B2 (R)	23.93	Fail
M2L2B2 (P)	6.47	Pass
PTSTL1B1 (R)	23.51	Fail
PTSTL1B1 (P)	6.62	Pass
PTSTL2B1 (R)	25.95	Fail
PTSTL2B1 (P)	6.94	Pass

*Raw = (R), Processed = (P)

CONCLUSION

The basic geotechnical properties, chemical properties and morphological properties of Bukit Goh bauxite had been determine based on criteria needed in IMSBC Code that focuses on three basic properties which are particle size distribution, moisture content and specific gravity.

The analysis and result from laboratory test shows that the average fine particle size of Bukit Goh bauxite is 38.40% while the average percentage of moisture content is 24.81%. The results obtained was compared with IMSBC Code where each of these basic properties are exceeding the specified value stated in the code. After comparing the results to IMSBC Code, Bukit Goh bauxite cannot be categorized as Group C because the basic properties obtained are not fulfilling the requirement in the standard IMSBC Code. Therefore, it is not suitable to be exported and there will be higher risk in the transportation of bauxite due to the waves of the ocean. Meanwhile, for the processed bauxite, the average fine particle size is 21.40% which is below the limit of 30% while the average percentage of moisture content is 6.69% which does not exceed the 10% limitation.

In conclusion, the quality of processed bauxite is better than raw bauxite. Bukit Goh bauxite must go through beneficiation process at the site to reduce and eliminate fine particle. The bauxite properties should follow IMSBC Code requirement to prevent liquefaction from occurring.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Universiti Malaysia Pahang (UMP) for financing this research through the Research University Grant Scheme, Project Number RDU1603122. The cooperation given by all parties involved in this research is greatly acknowledged.

REFERENCES

[1] Shakhashiri, BZ, “Chemical of The Week”: Aluminium. University of Wisconsin: SciFun.org, 2012.

[2] Donoghue, AM, “Bauxite Mining and Alumina Refining: Process Description and Occupational Health Risks”, Journal of Occupational and Environmental Medicine, Vol. 56, No. 5, 2014.

[3] International Maritime Organization. Retrieved from http://www.imo.org/en/MediaCentre/PressBriefings/Pages/38-bauxite-CCC.aspx, 2015.

[4] World Maritime News. Retrieved from http://worldmaritimenews.com/archives/172059/imo-bauxite-liquefaction-sank-bulk-jupiter/, 2015.

[5] Seed, HB, “Liquefaction of Saturated Sands During Cyclic Loading”, Journal of the Soil Mechanics and Foundations Division, pp. 105-134, 1966.

[6] IMSBC Code. International Maritime Solid Bulk Cargoes Code and Supplement. International Maritime Organization, 2013.

[7] Freyssinet, P. “Ore forming processes related to lateritic weathering”, Economic Geology One Hundredth Anniversary, Vol. 1, 2005, pp. 681-722.