

Effects of Bauxite Tailings as Partial Replacement for Sand in Sandcrete Bricks Production

Yalley Peter Paa-Kofi[1*] Asiedu Emmanuel[2] Mpae Isaac[1]
1.Department of Design and Technology Education, University of Education, Winneba, PO Box 1277, Kumasi Ghana
2.Department of Building Technology, Takoradi Polytechnic, PO Box 256, Takoradi, Ghana
* E-mail of the corresponding author: easiedu47@yahoo.com

Abstract
This study was carried out on sand-cement bricks with bauxite tailings, a mining by-product partially replacing the sand varying percentage levels. The bauxite tailings varied from 0% to 50% against the sand at intervals of 10%. Using bricks with dimensions: 210mm × 105mm × 75mm, a total of 120 bricks were produced and tested for their compressive strength, abrasion loss and water absorption after 28-days curing age. Results from the study showed that composite bricks with the bauxite tailings replacing up to 20% of the sand content recorded the highest compressive strength, lowest abrasion loss with the least water permeability. Even though, there was a general decline in the properties of the composite bricks with bauxite tailings replacement beyond 20%, bricks produced satisfied the minimum requirements for bricks suitable for walling. A strong correlation exited between bricks produced from the different replacement levels and the properties of the bricks studied. The bricks performed satisfactorily as masonry units where bauxite tailings content did not exceed 20%.
Keywords: Bauxite tailings, sand, composite bricks, abrasion loss

1. Introduction

Regarded as having Africa's 3rd largest bauxite reserves, Ghana's bauxite production rose to 295,993 tonnes during the first half of 2012, up from 173,601 tonnes produced in the comparative period in 2011 (Biswas 2012). Major deposits in the country can be found in Kibi, and Mt. Ejuamena near Nkawkaw, Atewa Range in the Eastern Region and Nyinahin Ashanti Region, Asafo Asempanaiye and Awaso (the only deposit producing) in the Western Region of Ghana (Patterson 1967).

Bauxite tailings or red mud as popularly referred has been produced globally by the Aluminium industry since the late nineteenth century. According to Power *et al.* (2009) by the year 2000, the alumina industry had produced circa 2 billion tons of bauxite tailings. This production rate is expected to grow by approximately 120 million tonnes per annum (Aluminium Association 2013).

Basically, bauxite tailings or red mud is the insoluble product generated as a result of the Bayer process; an alkaline leaching process which extract alumina from the bauxite ore (Rai *et al.* 2012). It is generated in vast quantities as slurry having a high solid concentration of 30 - 60% which compose of iron oxides, titanium oxides, silicon oxides and un-dissolved alumina together with a wide range of other oxides. According to Snars *et al.* (2002), for every tonne of alumina produced, there is between 0.3 and 2.5 tonnes of bauxite tailings produced which depends on the type and grade of bauxite whiles the physical and chemical characteristics of the tailings depend mostly on the nature of the processing procedure and the bauxite ore. They further explained that the tailings consist of very fine grained particle sizes mostly less than 150µm in diameter.

In Ghana and other countries where bauxite is mined, the detrimental environmental footprint has vehemently been seen. Gräfe *et al.* (2010) stated that these tailings are strongly alkaline with pH > 11 and high electrical conductivity mostly dominated by sodium ions (Na^+) which has attributed to the residual caustic soda present making their disposal problematic. Studies have shown that improper disposal of these tailings poses enormous health risks via leaching into water bodies or direct intake by living organisms as a result of the high levels of thorium and uranium (notable heavy metals) they sometimes exhibit (Cooper *et al.* 1994). According to Gawu (1997) some of the effects of improper disposal of bauxite tailings include dust pollution, increase in turbidity whiles Anon (1995) pointed out that Lake Batata in Brazil has been inundated with these tailings.

It is worth noting that as the demand for alumina and aluminium products keeps surging, bauxite tailings are expected to reach 4 billion tonnes globally by 2015 (Power *et al.* 2009). In Ghana, substantial quantities of these by-products have unfortunately not been satisfactorily handled as they are disposed in mined pits, terrace dams and nearby damps (as shown in the Figure 1 below) without a reliable and long term disposal system which adheres to appropriate environmental regulations.

Figure 1: Disposal of the Bauxite Tailings (Source: Field study)

In light of this, immense efforts are being taken globally to find alternative options rather than storage, which is to recycle these bauxite tailings as a starting materials for engineering applications. Dodoo-Arhin *et al.* (2013) posited that, recycling such by-products can ensure environmental sustainability as it eliminates disposal cost and avoids pollution. Many researchers have enumerated the various applications of bauxite tailings as a construction material, geopolymers, coagulant, adsorbent and catalyst and in paints or pigments (Shing 1977; Singh *et al.* 1996; Cablik 2007; Kalkam 2006). Schwarz and Lalík (2012) also pointed out that bauxite tailings tends to hardens and form stable and durable compounds after mixing with lime in the presence of water when used in the production of ceramic materials. The use of bauxite tailings in cement products according to Liu *et al.* (2009) not only serves as an effective recycling mechanism, it also improves the engineering properties due to the pozzolanic properties it exhibits. Amritphale and Patel (1987) furthermore reiterated that, bauxite tailings pressed into blocks and calcined at high temperature (>1000ºC) have incredible compression strength suitable for high rise building construction with exceptional fire resistance, low water absorption and an appealing colour (Dimas *et al.* 2009).

Even though, bauxite tailings are generated in Ghana, information regarding its suitability as a replacing material for sand is limited. This study thus seeks to determine the suitability of sandcrete bricks using bauxite tailings as a partial replacing material for the sand.

2. Materials and Experimental Studies

2.1 Materials Used

Sand sourced from Kojokrom in the Western Region was used in this study. It was clean from all forms of organic matter and air dried.

The bauxite tailing was obtained from a terrace damp in Awaso in the Western Region of Ghana. No further treatment was done to the bauxite tailing as the study was to use raw materials which could be easily replicated by the indigenous people.

Portable drinking water supplied by Ghana Water Company was used whiles Ordinary Portland cement produced by Ghana cement (Ghacem) with Class 32.5R which conformed to BS EN 197 (2000) was used as the binding material. The sand and bauxite tailings used in the study were investigated to determine their basic properties and particles distribution as presented in Table 1 and Figure 2 respectively.

2.2 Preparation of Specimen

In all, 20 specimens were produced for each batch. The batches consisted of B_0, being the control, and those with bauxite tailings replacing the sand content were designated as B_{10}, B_{20}, B_{30}, B_{40}, and B_{50} which respectively represent specimen with 10%, 20%, 30%, 40% and 50% of the bauxite tailings. Using a motorised-operated brick machine, bricks were moulded to dimensions: 210mm × 105mm × 75mm. The moulded specimens were cured in the open at the laboratory under ambient temperature and 100% humidity for 28 days as recommended by ASTM C 192.

2.3 Testing of Specimen

2.3.1 Density

Five bricks from each batch were selected after 28 days curing age. These bricks were gently wiped with non-absorbent cloth in order to remove any dust or loose matter stuck to them. Their average dimensions were recorded before calculating their volumes. The bricks were then weighed before deducing the density.

2.3.2 Compressive strength

Five bricks which had no surface cracks visible to the naked eye were selected from each batch of moulded bricks. The bricks were gently wiped of any dust or loose dirt stuck to them. The bricks were then tested for their compressive strengths using an electronic ADR 2000 Compressive Strength Machine with a pace rate of 6.80kN/s.

2.3.3 Abrasion resistance of composite bricks

Randomly selected bricks were initially weighed (as M_I) before being brushed using a stiff wire brush at a constant pressure in forth and back motion for 3 minutes. The wire brush made of 1.6mm flat 26 gauge wire bristles assemble in 50 groups of 14 and fixed to form 5 longitudinal and 10 transverse rows. After brushing, the debris on the face of the brick was cleaned and the weight recorded (as M_{Ab}) before deducing the loss in weight due to abrasion using the Equation 1.

$$\frac{M_{Ab}-M_I}{M_I} ?\ 00 \qquad (1)$$

2.3.4 Water absorption by Total Immersion

Water absorption was measured by the change in weight for specimen stored for 28 days in a laboratory environment. This test focused on the change in weight of the specimen since Omopariola (2014) stated that this test provides a useful measure of the durability of building bricks. Specimens for this test were randomly selected from each batch, cleaned and oven dried. They were then continually weighed for 2 hours interval until a constant weight was obtained indicating a fully dried specimen. The oven dried specimen were then weighed before taking the initial reading M_0. Specimens were then immersed in water before readings were taken as M_{72} after 72 hours later. The change in weight was deduced as shown in deduced through Equation 2.

$$\frac{M_{72}-M_0}{M_0} \times 100 \qquad (2)$$

3. Results and Discussion

The results of the various laboratory tests carried out have been presented in Table 1 and Figure 2 below.

3.1 Properties of Materials

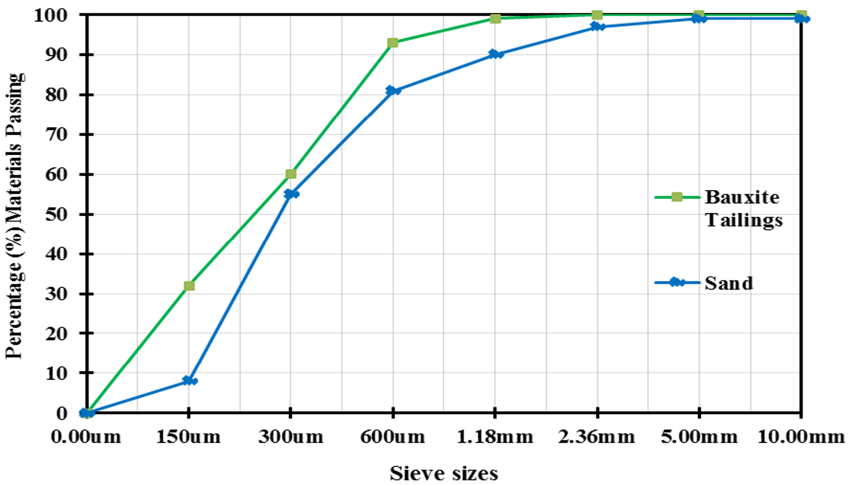

Figure 2 Particles size distribution curves of the Sand and Bauxite Tailings

Table 1. Properties of Sand and Bauxite Tailings

Properties	Sand	Bauxite tailings
Specific gravity	2.64	2.36
Bulk density	1863.91kg/m^3	1715.98kg/m^3
Silt content	26.5%	-

Table 2. Tests results of Sand-Bauxite Tailings bricks after 28 days curing age

Batch	Density(kg/m^3)	Compressive strength (N/mm^2)	Abrasion loss (%)	Water absorbed (%)
B_0	2200.1	12.775	3.820	10.11
B_{10}	2147.4.	13.750	1.750	8.03
B_{20}	2094.0	15.907	0.888	4.97
B_{30}	2049.1	11.910	4.930	5.11
B_{40}	2007.2	10.555	6.894	5.18
B_{50}	1888.6	8.427	9.120	5.23

3.2 Density of Composite Bricks

From the results presented in Table 2 and illustrated in Figure 3, there was a systematic fall in the average densities of the composite bricks as the bauxite tailings content increased. All the bricks used in the study had their densities within the range of 1500-2400kg/m^3 as specified by BS 6073 for dense aggregates masonry units. Significantly, the control bricks had the highest average density of 2200.1kg/m^3. Composite bricks with 10% bauxite tailings replacing the sand content recorded an average density of 2147.40kg/m^3 which was 2.4% less dense than bricks with no bauxite tailings. Furthermore, composite bricks with 20%, 30%, 40% and 50% of bauxite tailing replacing the sand had average dry densities of 2094.0kg/m^3, 2049.1kg/m^3, 2007.2kg/m^{3}and 1888.6kg/m^3 respectively which were found to be 4.82%, 6.86%, 8.77% and 14.16% less dense than the bricks with no bauxite tailings (control batch).

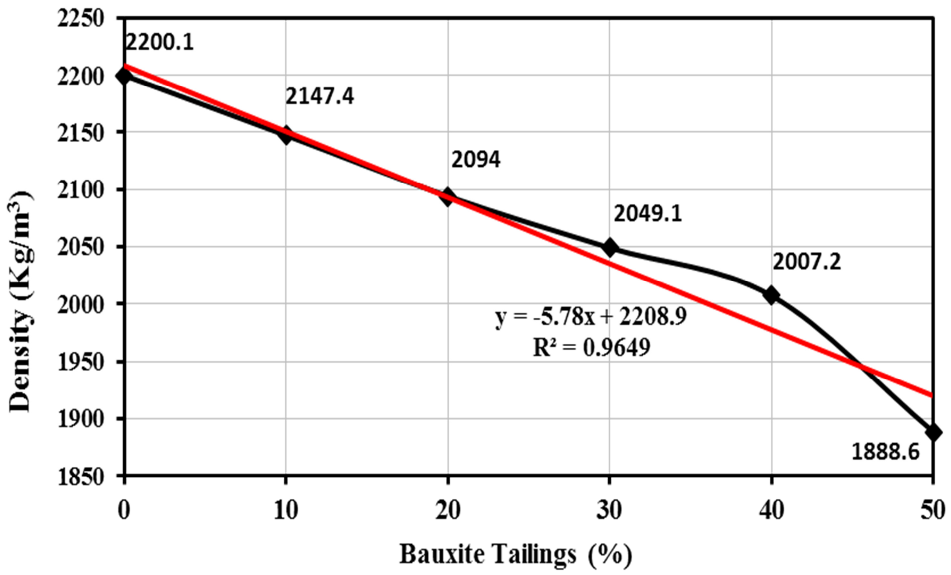

Figure 3 Relationship between Density and varying of the Bauxite tailings content

This declining densities as the bauxite tailings increases could be attributed to the relatively low specific gravity of the bauxite tailings, when tends to reduce the overall density of the batch as the quantity added increases.

Statistically, there was a relatively strong relationship between the densities and the batches (varying bauxite content) as the correlation coefficient of -0.98 was deduced. An equation of the model (Equation 3) which best describes the relationship between the density (y) and the bauxite tailings content (x) was given as:

$$y = 2208.9 - 5.78x \quad (3)$$

This equation of the model was able to explain 96.49% of the variability in the density of the various batches.

3.3 Compressive Strength of Composite Bricks

The compressive strengths determined after 28 days curing age has been presented in Table 2 and illustrated below in Figure 4. Data from the study showed a gradual increase in the compressive strength of the composite bricks until the bauxite tailings content was up to 20%. This pattern changed as there was a subsequent decline in the compressive strengths as the bauxite tailings content increased beyond 20%.

Composite bricks with 20% bauxite tailings had the highest compressive strength of 15.907N/mm^2 which was 24% higher than the control specimen. Whiles, composite bricks with 50% bauxite tailings had the least compressive strength of 8.427N/mm^2, this was found to be about 36% lower than the control specimen.

Composite bricks with 10% bauxite tailings were found to be 7.5% higher than the control, whiles bricks replacing sand with 30% and 40% bauxite tailings resulted in reduced compressive strengths of about 7% and 17% below the control specimen respectively. Nonetheless, none of the composite bricks had their average strength below the minimum 7.0N/mm^2 and 2.8N/mm^2 for bricks and blocks respectively as recommended by BS 6073.

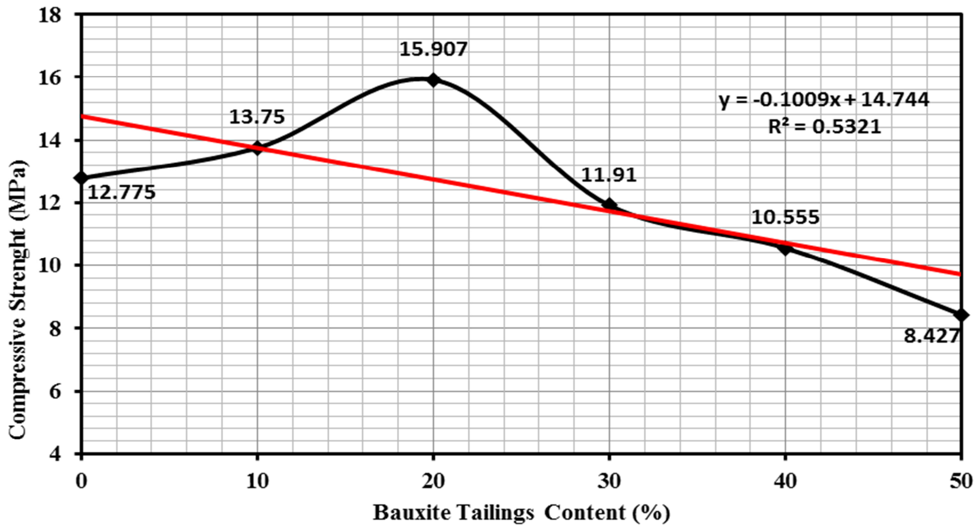

Figure 4 Relationship between Compressive strength and Bauxite tailings content

Data obtained showed quite a strong relationship between the compressive strengths (y) and the varying bauxite tailing contents (x) with a correlation coefficient of -0.729. This relationship was best described by the model equation (Equation 4) below:

$$y = 14.7437 - 0.10092x \quad (4)$$

The R^2 statistic of 0.5321 shows that the model equation explains 53.21% of the variability in the compressive strengths of the composite bricks and that the bauxite tailings used in the study was responsible for 53.21% of the variations in the compressive strengths of the composite bricks.

The declining compressive strength of the bricks as the bauxite tailings increased beyond 20%, could be attributed to the very fine grained particles of the bauxite tailings which were too numerous, to ensure an effectively bond in the cement matrix (Rai *et al.* 2012). Appukutty and Murugesan (2009) also attributed this phenomenon to the fine particles sizes below 150microns which requires high affinity to water thereby creating high water demand. The higher water demand might have hampered effective hydration process resulting in a reduction in strength of the composite bricks especially as the bauxite tailings increased. As a result, larger quantity of cement is needed to ensure a more effective and stronger bond or could be removed by vacuum de-dusting system as it is done with quarry dust.

3.4 Abrasion Resistance of Composite bricks

This property gives an idea of how masonry units disintegrate or degrade with time which can occur due to rubbing, scraping, skidding, or sliding on surfaces. In this study, the weight loss due to abrasion was the main parameter used in the analysis.

The loss in weight as a result of abrasion declined as the quantity of the bauxite tailings increased from 0% to 20%. Contrast to this observation, weight loss significantly increased as the quantity of bauxite tailings increased beyond 20% replacement in the composite bricks as shown in Table 3 and illustrated in Figure 5 below. This was evident as bricks with 30%, 40% and 50% bauxite tailings content had an average weight loss of 4.93%, 6.894%, and 9.12% respectively. Composite bricks with 10% and 20% bauxite tailings had respective average weight loss of 1.75% and 0.89%.

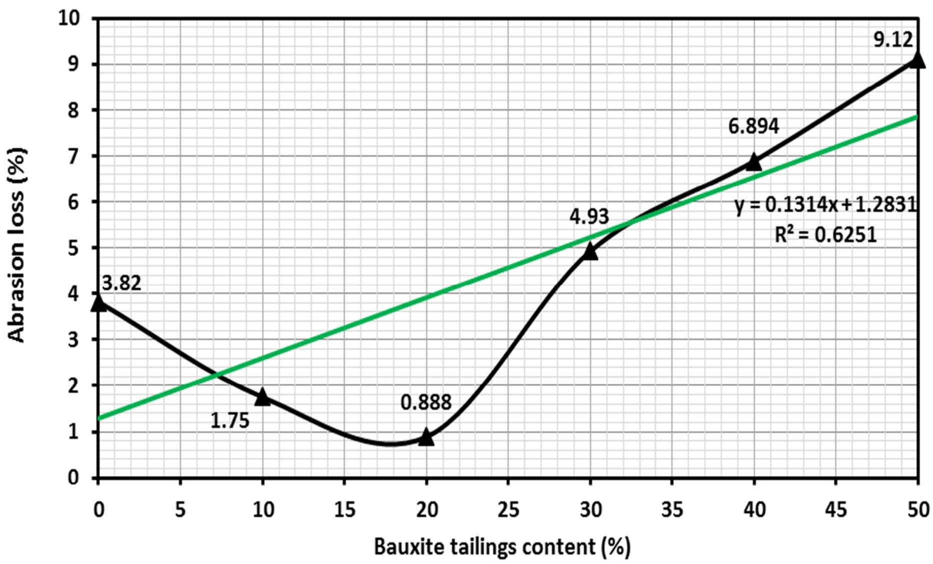

Figure 5 Relationship between bauxite tailing content and Abrasion resistance

A relatively strong correlation coefficient (0.791) was found between the quantity abraded (in percentage) and the varying bauxite tailings replacing the sand. The relationship between the abrasion loss (y) and the varying bauxite tailings (x) is given by:

$$y = 1.283 + 0.1314x \quad (5)$$

The R^2 statistics of 0.6251 indicates that 62.51% of the variability in the abrasion loss is explained by the bauxite tailings. In other words, the bauxite tailings used as a replacement for sand in the study accounted for 62.51% of the variations in the abrasion loss of composite bricks.

3.5 Water absorption by Total Immersion

It was observed that the composite bricks showed a steady decline in the total quantity of water absorbed as the bauxite tailings increases in the batch. The presence of bauxite tailings replacement reduced substantially the absorptivity of the bricks from 10.11% for 0% bauxite content to 8.03% for 10% bauxite tailings. Composite bricks with 20% bauxite tailings recorded the lowest quantity of water absorbed with only 4.97% increase in weight. As the bauxite tailings content increased to 30%, the water absorbed slightly increased to 5.11% whiles 40% and 50% increase in the bauxite tailings content also increased the absorptivity of the bricks to 5.18% and 5.23% respectively as illustrated in Figure 5 below.

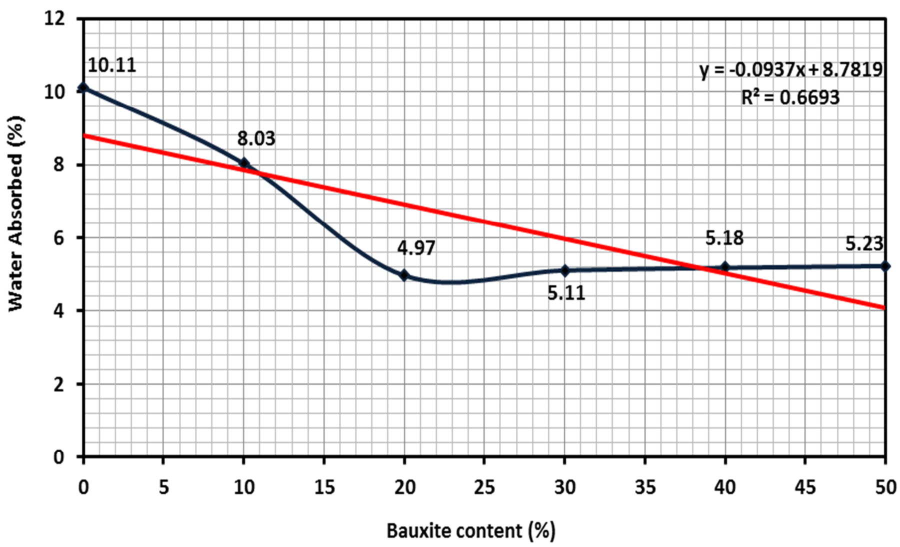

Figure 5 Water absorption characteristics of Sand-bauxite tailings composite cubes

Statistically, there was a significantly strong relationship between the water absorbed (%) and the composite bricks with varying amount of bauxite tailings at the 95% confidence level indicated by a correlation coefficient of -0.818.

From the regression analysis conducted, a linear model was used to describe the relationship between the water absorbed (%) and the bauxite tailings content. The equation of the model which explains 66.93% of the variability in the total water absorbed (%) was best described as:

$$y = 8.782 - 0.0937x \quad (5)$$

Generally, the addition of bauxite tailing resulted in lower migration of water into the brick (i.e. less permeable). This could be explained that the presence of the bauxite tailing eventually led to higher hydrated bauxite tailing and higher mortar content. The finer particles of the bauxite tailings makes bricks less porous and more impermeable than the control bricks (with only natural sand) probably by infilling the voids (filler effects) thereby reducing paths for water ingress. It was observed that increasing the bauxite tailing above 20% did not significantly improve the permeability of the brick.

5. Conclusions

From the experimental investigations conducted, the following conclusions were made.

1. The bauxite tailings significantly influenced the properties of the bricks considered in this study.
2. It was found that the densities declined as the quantity of bauxite tailings increased.
3. The compressive strength characteristics of the bricks gradually increased but saw a decline when the bauxite tailings content exceeded 20% replacement.
4. Other properties studied like abrasion loss and water permeability both significantly declined as the quantity of bauxite tailings increased to 20%. Further increase in the bauxite tailings quantity beyond 20% replacement marginally affected these properties.
5. Sand-bauxite tailings composite bricks give aesthetically pleasant appearances and are recommended for decorative or ornamental works.
6. Based on the results, the bauxite tailings used performed satisfactorily as a replacing material up to 20% for sand in the production of bricks for structural applications.

Acknowledgement

The authors would like to give their sincere thanks to staff of the Civil and Building Technology Laboratory for their enormous support towards this research.

References

Aluminuim Association (2013), "Bauxite Tailing Management: Best Practice", *International Aluminium Institute (IAI)*, London (UK).

Amritphale, S. S. & Patel, M. (1987), "Utilization of red mud, fly ash for manufacturing bricks with pyrophyllite", *Silicates Industriels*. **52**(3-4) pp.31-35.

Anon, (1995), "Environmental aspect of bauxite, alumina and aluminium production in Brazil", *United Nations Conference on Trade and Development (UNCTAD secretariat)*.

Appukutty, P. & Murugesan, R., (2009), "Substitution of quarry dust to sand for mortar in brick masonry works", *International Journal on Design and Manufacturing Technologies*. **3**(1).

Biswas, B. (2012), "The Untapped Bauxite Potential in Africa: Ghana, Nigeria, Cameroon and Sierra Leone", Retrieved from: http://blog.alcircle.com/?p=131.

British Standard Institution (1981), "Specification for Precast Concrete Masonry Units", British Standards Institute, BS 6073: Part 1. UK.

British Standard Institution (1992), "Specification for aggregates from natural sources for concrete", British Standards Institute, BS 882, UK.

British Standard Institution, (2000), "Cement composition, specifications and conformity criteria for common cements", BS EN 197: Part 1, 2000, London.

Cablik V. (2007), "Characterization and applications of red mud from Bauxite processing", *Gospodarka Surowcami Mineralnymi,* **23**(4).

Cooper, M. B., Clarke, P. C., Robertson, W. J., McPharlin, W. J. & Jeffery, R. C. (1994), "An investigation of radionuclide uptake into food crops grown in soils treated with bauxite tailings", *Journal of Radiological and Nuclear Chemistry,* **194,** 379–387.

Dimas, D. D.; Giannopoulou, I. P. & Panias D. (2009), "Utilization of alumina red mud for synthesis of inorganic polymeric materials", *Mineral processing and Extractive Metallurgy. Review*, **30**(3), 211-239.

Dodoo-Arhin, D., D. S Konadu, E. Annan, F. P Buabeng, A. Yaya, Agyei-Tuffour, B. (2013), "Fabrication and characterisation of Ghanaian bauxite red mud-clay composite bricks for construction applications", *American Journal of Materials Science.* **3**(5), 110-119.

Ekrem, K. (2006), "Utilization of red mud as a stabilization material for the preparation of clay liners", *Engineering Geology*, **87**(3-4), 220-229.

Gawu, S. K. Y. Amissah, E. E., & Kuma, J. S. (2012), "The proposed alumina industry and how to mitigate against the red mud footprint in Ghana", *Journal of Urban and Environmental Engineering*. **6**(2), 48-56. ISSN 1982-3932.

Gräfe, M., Landers, M., Tappero, R., Klauber, C., Hutomo, G., Gan, B., Grabsch, A., Asutin, P. & Davies, I. (2010), "Chemistry of trace and heavy metals in bauxite tailings (red mud) from Western Australia", *19th World Congress of Soil Science, Soil Solutions for a Changing World*.

Liu W., Jiakuan Y. & Bo X. (2009), "Application of bayer red mud for iron recovery and building material from alumosilicate tailings", *Journal of Hazardous Materials,* **161**, 474-478.

Naik T. R., Singh S. S. & Ramme B. W. (2002), "Effect of Source of Fly Ash on Abrasion Resistance of Concrete", *Journal of Materials in Civil Engineering*, 417-426.

Omopariola, S. S. (2014), "A Study of the Hygroscopic Properties of Hollow Sandcrete Blocks", *American Journal of Engineering Research*, **3** (5), 93-97. e-ISSN: 2320-0847 p-ISSN : 2320-0936.

Patterson, S. H. (1967), "Bauxite reserves and potential aluminium resources of the world", *Geological Survey Bulletin*. 1228

Power G., Gräfe M. & Klauber, C. (2009), "Review of Current Bauxite Tailing Management, Disposal and Storage: Practices", *Engineering and Science*, DMR-3608, pp. 44. CSIRO-Minerals, Waterford.

Rai, S., Waswar, K. L., Mukhopadhayay, J., Yoo, C. K. & Uslu, H. (2013), "Neutralization and Utilization of red mud for its better waste management", *Architectural and Environmental Science*, **6,** 13-33

Shing, J. S. (1977), "Method of activation of red mud", US Patent 4017425.

Singh M., Upadhayay S. N. & Prasad, P. M. (1996), "Preparation of special cements from red mud", *Waste Management,* **16**(8): 665-670.

Snars K., Gilkes R. & Hughes, J. (2002), "Effect of bauxite tailing (red mud) on the availability of phosphorus in very sandy soils", *17th World Congress of Soil Science, Soil Solutions for a Changing World*, Thailand.

Schwarz, M. & Lalík, V. (2012), "Possibilities of Exploitation of Bauxite Tailing from Alumina Production, Recent Researches in Metallurgical Engineering - From Extraction to Forming", Dr Mohammad Nusheh (Ed.), ISBN: 978-953-51-0356-1, InTech, Available from: http://www.intechopen.com/books/recentresearches-

Wu, H., Huang, B., Shu, X. & Dong Q. (2011), "Laboratory evaluation of abrasion resistance of Portland cement pervious concrete", *Journal of Materials in Civil Engineering*, **23**(5), 697-702. Retrieved from http://www.ascelibrary.org