UNIVERSITY OF EDUCATION, WINNEBA

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THE USE OF BAUXITE MINING WASTE AS FINE AGGREGATE REPLACEMENT FOR CONCRETE PRODUCTION

JOSEPH KENT BOADI

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SEPTEMBER, 2018

DECLARATION

STUDENT'S DECLARATION

I, **JOSEPH KENT BOADI,** declare that this Thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE: ....

DATE: ....

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Thesis as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR: **DR. HUMPHREY DANSO**

SIGNATURE: ....

DATE: ....

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I would like to thank my family and friends for their encouragement, support and love throughout the completion of this research work.

DEDICATION

I dedicate this Thesis to my family.

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ABSTRACT

Conventional construction materials require the extraction of large quantities, causing depletion of natural resources and environmental damage. This work investigates the possibility of using bauxite mining waste as fine aggregate replacement for concrete production. The experimental works were conducted by varying sand and bauxite mining waste to mix ratio of 1:2:4 with five different replacement levels namely: 0%, 25%, 50%, 75% and 100% by weight and water cement ratio of 0.60. A total of sixty (60) cubes of size 150mm x 150mm x150mm, sixty (60) cylinders having diameter of 150mm and height of 300mm and sixty (60) beams of size 150 mm x 150 mm x 450 mm were cast and tested in 7days, 14 days, 21 days and 28 days respectively. Tests conducted include workability, density, compressive strength, tensile strength and flexural strength. It was found that the bauxite mining waste composite mix was less workable to control mix. It was found that the density of the bauxite mining waste produce achieved slightly higher results as the quantity of bauxite mining waste increased, there was no statistical significant difference among concrete produced. It was also found that the compressive strength, tensile strength and flexural strength achieved good results as the quantity of bauxite mining waste increased, there was statistical significant difference in the various mix proportions as the quantity of bauxite mining waste increased. It was also found that there was positive correlation between the density of the concrete produced and the compressive strength, tensile strength and flexural strength. It is recommended that bauxite mining wastes are suitable to use as fine aggregate replacement for concrete production in the areas where the bauxite residues are deposited.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The versatility of concrete and its relative economy in meeting wide range of needs in the construction industry has made it a very competitive and widely used building material (Adinkrah-Appiah, 2015). This has led to a high demand for concrete as a construction material, being the world's most consumed man-made material (Naik, 2008). One of the most significant constituent materials of concrete is fine aggregate (sand), which serves as economic filler for a concrete mix (Adinkrah-Appiah et al. 2015).

However, the availability of pit sand for the preparation of concrete is becoming scarce due to the excessive nonscientific methods of mining from the pit site, lowering of water table, sinking of bridge piers, etc. are becoming common treats (Mageswari & Vidivelli, 2010). Where conventional aggregates are scarce or cost of haulage is very high such that they are rendered uneconomical, other known hard materials have been successfully used to produce concrete instead (Poitevin 1999, Alduaij et al. 1999, Adom-Asamoah & Afrifa, 2015).

Therefore, using industrial waste as alternative sources in replacement for fine aggregates appears to be a subject that is gaining popularity all over the world. Industrial waste materials can be used as alternative sources in concrete as they can assist in solving some environmental concerns, as they decrease the problem of waste disposal and reduce the intensive use of energy and natural resources (Rkein, 2015).

Sustainability is a global concern and hence the goal of human kind should be to create a sustainable world (Danso, 2018a). In order to achieve sustainability, methods that are to be employed are effective utilization of currently available resources for a prolonged period of time, minimization of wastage of material / energy and controlling overuse, and ensuring that there are reserves kept for future generations without complete exhaustion (Sakthival et al. 2013). By 2050, humanity could consume an estimated 140 billion tons of minerals, ores, fossil fuels and biomass per year (three times its current amount) (Sakthival et al. 2013).

Urban sprawl and building construction industry are the main causes of environmental pollution leading to severe sustainable issues. This environmental imbalance has created a situation for the people to focus on adoption of newer technologies and environmentally preferable materials, which will not only preserve the natural resources but also create a productive environment in which human and nature can exist in harmony (Danso, 2018b). To reach this endeavor, one way is to go green, i.e., produce green building materials for construction (Sakthival et al. 2013). From the wastes that are generated by manufacturing industries, as waste is certainly a good potential resource and lot of energy can be recovered from it; and the terminology 'green' in the present context refers to use of sustainable materials like stone dust or recycled stone, recycled blue metal/ gravel and other products that are non-toxic, reusable, renewable, and/or recyclable (Sakthival et al., 2013). However, bauxite mining waste is the industrial waste material that is discussed in- depth in this particular research.

1.2 Statement of the Problem

Rapid increase in construction activities has led to the acute shortage and high cost of conventional construction materials (Danso & Obeng-Ahenkora, 2018). The high and the increasing cost of these materials have greatly hindered the development of construction and other infrastructural facilities in developing countries (Obeng-Ahenkpra & Danso, 2018). Sustainable infrastructural growth demands the use of alternative materials. The market inflationary trend and the construction materials used for concrete have led to high cost of construction (Ndoke, 2006).

Researchers have documented the use of industrial waste as fine aggregate such as red sand, Sheet Glass Powder, copper slag, Quarry dust, Glass and fly ash, Red Mud-Clay, steel slag, Ground Granulated Blast Furnace Slag, (Davoodi, 2008; Mageswari & Vidivelli, 2010; Balarnurgan & Perumal, 2013; Dodoo-Arhin et al.2013; Kuttimarks & Shruthi, 2014; Kumar & Mahesh, 2015; Kumar et al. 2015; Kamalambigai, 2016). All these studies showed improvement in the use of industrial waste as fine aggregate replacement. However, bauxite mining waste is another potential industrial waste material that has not received much attention in terms of research. Therefore, this study seeks to investigate the possibility of using bauxite mining waste as fine aggregate replacement for concrete production, as bauxite mining waste is abundant in some parts of Ghana.

Bauxite mining waste is a by-product from the Bayer alumina production process. According to Snars et al. (2009), for every tonne of alumina produced there is between 0.3 and 2.5 tonnes of bauxite mining waste produced which depend on the type and grade of bauxite while the physical and chemical characteristics of the residue depend mostly on the nature of the processing procedure. It is worth noting that as the demand for alumina and aluminum products keeps surging, bauxite mining waste is expected to reach 4 billion tonnes globally by 2015 as reported by (Power et al., 2009). In Ghana, the Bauxite Company at Awaso has large quantities of this bauxite mining waste produced each year and it is not only of little use but actually requires a significant allocation of resources to enable proper disposal or storage. The use of bauxite mining waste in the concrete production has the potential to assist in alleviating the improper disposal of industrial waste and hence reduce environmental pollution. The potential success of the re-use method has the additional benefit of providing an alternative source of construction material (Wahyuni, 2005).

The bauxite residue produced retains some of the same characteristics of the mother bauxite, and also varies depending on the region of production (Chandra, 1997). That is, bauxite mining waste produced in Ghana Bauxite Company at Awaso is generally significantly different to a bauxite miming waste produced in the same process elsewhere in the world.

The chemical and physical treatments applied to it can bring about variances in the properties of the bauxite residue between refineries (Davoodi, 2008; Narayanaswamy et al. 2005). Paramguru et al. (2004) reported that, Australian bauxite mining waste tends to be comparatively high in Silica or Silicon Dioxide SiO_2. Dashmukh and Sarode (2014) also stated that, in India Hindulco, bauxite mining waste tends to have high Hematite, (Fe_2O_3). In Ghana Bauxite Company at Awaso bauxite mining waste tends to contain a higher proportion (75%) of hydrated alumina ($Al_2O_3 \cdot 3H_2O$ and $Al_2O_3 \cdot H_2O$) (Dodoo-Arhin et al.

2013). There is therefore the need to examine the possibility of using bauxite mining waste from Ghana Bauxite Company at Awaso as fine aggregate replacement for concrete production. A recent study by Mpae (2014) on "utilization of bauxite tailing/residue as partial replacement of sand in blocks" recommended that, future replication should look into the use of bauxite mining waste as replacement for concrete and mortar production. There is therefore the need also to examine the possibility of using bauxite mining waste from Ghana Bauxite Company at Awaso as fine aggregate replacement for concrete production.

1.3 Aim and Objectives

The aim of this research is to examine the possibility of using bauxite mining waste as fine aggregate replacement for concrete production.

To achieve this aim, the following specific objectives are pursued:

- To assess the workability of concrete made form bauxite mining waste as fine aggregate replacement.
- To ascertain the density of concrete made from bauxite mining waste as fine aggregate replacement.
- To ascertain the compressive strength of concrete made from bauxite mining waste as fine aggregate replacement.
- To ascertain the split tensile strength of concrete made from bauxite mining waste as fine aggregate replacement.
- To ascertain the flexural strength of concrete made from bauxite mining waste as fine aggregate replacement.

1.4 Research Questions

- What is the workability of concrete made from bauxite mining waste as fine aggregate replacement?
- What is the density of concrete made from bauxite mining waste as fine aggregate replacement?
- What is the compressive strength of concrete made from bauxite mining waste as fine aggregate replacement?
- What is the split tensile strength of concrete made from bauxite mining waste as fine aggregate replacement?
- What is the flexural strength of concrete made from bauxite mining waste as fine aggregate replacement?

1.5 Significance of the Study

This study will contribute to knowledge and provide significant benefits to the academics, government and the end users of bauxite mining waste. Also, the outcome of this study will have environmental, social and economic significance to the use of bauxite mining waste as fine aggregate for concrete production. The significances are discussed below;

1.5.1 Environmental Significance

Bauxite residue is not a particularly toxic material (Paramguru et al. 2004). Environmental issues surrounding bauxite mining waste is the increasing amount of land required for storing this by-product and due to its high causticity, this land cannot be used in the future, even if the by-product is removed. Therefore, environmental benefits of using Awaso bauxite mining waste for concrete production are to prevent land pollution, seepage into the ground water and the reduction of the mining of natural sand.

1.5.2 Social Significance

Communities surrounding Awaso have the preconceived idea that using bauxite mining waste in concrete is unsafe because of its high pH value and its caustic nature. In order to address this issue, testing is required to see if there are any long term environmental effects in using bauxite mining waste in concrete and to prove that it is a stable and non -toxic product. The results of the study will help promote sustainable development that could make bauxite mining waste concrete more attractive than using natural sand concrete in the Awaso communities.

1.5.3 Economic Significance

As the supply of natural sands is being greatly reduced due to excess consumption and price of this sand is set to increase. If bauxite mining waste can be proven to be an alternative source it will be an economically competitive alternative. This will make the price of bauxite mining waste very competitive with the prices that local suppliers have on their natural sand.

1.6 Structure of Thesis

The thesis consists of six chapters with references and appendices, as shows in the 1.1:

Table 1.1: Structure of Thesis

Chapter heading	Activities
Chapter One	Introduction
Chapter Two	Literature review
Chapter Three	Materials and methods
Chapter Four	Results finding
Chapter Five	Discussion
Chapter Six	Summary of findings, conclusions and recommendations
	References
	Appendices

The contents of this thesis are in six chapters.

Chapter one introduces the background to the study, problem statement, aim and objectives, significance of the study and the structure the thesis. Chapter two presents a review of the related literature on Bauxite mining waste and rationalizes the relevance of using Bauxite mining waste as fine aggregate for concrete production. Chapter three gives an overview of the research programme and procedures for experimental investigation and highlights on concrete mix design as per different constituent materials applied in the study. Chapter four presents the results findings on workability, split tensile strength, flexural strength and compressive strength tests on Bauxite mining waste as fine aggregates concrete. In chapter five, the results are presented and discussed. Finally, Chapter six presents the summary of findings and conclusions for the study and proffers recommendations for future studies in the content area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Concrete is a material used in construction, consisting of a hard, chemically inert particulate substance, known as the aggregate that is bonded together by cement and water (Adinkrah-Appiah, 2015). Concrete is the most consumed man-made material (Naik, 2008) in the world and due to its great versatility and relative economy in satisfying a wide range of needs, it has become a very competitive building material (Sashidar & Rao, 2010). The production of concrete is not only a valuable source of societal development, but it is also a significant source of employment to many people in the construction industry (Naik, 2008).

One major component of concrete, which accessibility may influence the extent of concrete usage, is the aggregate. Over the years, the most widely used fine aggregate for the production of concrete is the natural sand mined from the pit. In recent times, the high and the increasing cost of these materials have greatly hindered the development of construction and other infrastructural facilities in developing countries.

Such materials should be cheap and readily available. In view of this, the use of cost-effective building materials without loss of performance is very crucial to the growth of developing countries (Zemke & Woods, 2009).

The use of such replacement materials does not only contribute to construction cost saving and drive infrastructural development, but also contributes to the reduction of stress on the environment (Adinkrah-Appiah, 2015). This chapter reviews previous research on bauxite residue as fine aggregate replacement for concrete production.

2.2 Concrete

Concrete is a mixture of fine aggregate, coarse aggregate, cement and water in specific proportions that hardens to a strong element over varying length of time. Concrete is a widely used construction material in civil engineering projects throughout the world for the following reasons: it has excellent resistance to water, structural concrete elements can be formed into a variety of shapes and sizes and it is usually the cheapest and most readily available material for the job (Mehta & Mon teiro, 2006).

2.2.1 Materials for Concrete

The materials for concrete comprise the constituent material of:

- Cement + water = cement paste
- Cement paste + fne aggregate = mortar
- Mortar + coarse aggregate = concrete.

The chemical reactions that take place when different constituent materials are combined can vary depending on the properties of the individual materials. The materials can vary in their chemical makeup and performance characteristics, depending on where they were mined or quarried and according to the manufacturing methods used and conditions in the manufacturing plant.

2.3 Bauxite Mining Waste as Fine Aggregate

Bauxite mining waste is a by-product from the Bayer alumina production process. Borra, at el. (2016) describe bauxite mining waste (red mud) as reddish-brown solid waste generated during the production of purified aluminum (oxy) hydroxides from bauxite. Davoodi (2008) described the Bayer process refines bauxite ore to obtain aluminium oxide or alumina (Al_2O_3). The smelting step uses a process named the Hall - Heroult process to release pure aluminium from the aluminium oxide (Davoodi, 2008). Bayer (1889) process used by alumina refineries involves four main steps - digestion, clarification, precipitation and calcination as follows (Queensland Alumina Limited 2006).

Step 1: Digestion – Dissolving bauxite's alumina content

To turn bauxite into alumina, firstly the ore is ground and mixed with lime and caustic soda, then this slurry is pumped into high-pressure autoclaves or reactors and heated to form sodium aluminate solution. The reactions are:

$$2NaOH + AI_2O_3.3H_2O \rightarrow 2NaAlO_2 + 4H_2O$$

Equation 2-1: Bauxite Digestion- 1st Stage

$$2NaOH + AI_2O_3.H_2O \rightarrow 2NaAlO_2 + 2H_2O$$

Equation 2-2: Bauxite Digestion-2nd Stage

Step 2: Clarification and caustification – Settling out undissolved impurities

Settling allows the removal of waste tailings. Flocculants can be added to improve the rate of mud settling. This is then washed with slacked lime to allow the removal of insoluble carbonate with the mud. The reaction is:

$Na_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2NaOH$

Equation 2-3: Caustification

Step 3: Precipitation – Forming alumina crystals

The aluminium oxide which is dissolved by the caustic soda is precipitated out of the pregnant liquor. Precipitation of crystals from the liquor allows alumina to be recovered. Alumina precipitates as the trihydrate ($Al_2O_3.3H_2O$), which is the reverse of the digestion of trihydrate. The reaction is:

$2NaAlO2 + 4H2O \rightarrow \rightarrow Al_2O_3.3H_2O + 2\ NaOH$

Equation 2-4: Precipitation

Step 4: Calcination – High temperature drying of alumina

The aluminium hydrate ($Al_2O_3.3H_2O$) is then washed to remove the process liquor and caustic. This material is then calcined in a fluidised bed calciner to remove both free moisture and chemically bonded water at temperatures around 950-1100° C.

Residual bauxite tailings refer to the bauxite waste removed after the digestion and clarification by filtration and decantation (Davoodi, 2008).

2.4 Composition of Bauxite Mining Waste

According to Mpae and Yalley (2014), the technology and operation procedures at individual refineries will impact the water content and pH values of the material been discharged two factors in bauxite mining waste management.

2.4.1 Chemical Composition of Bauxite Mining Waste

The actual chemical composition of bauxite mining waste depends on the type of bauxite and the process parameter of the Bayer process. No matter what the production process is, the chemical composition of bauxite residue contains six major constituents, namely Fe_2O_3, Al_2O_3, SiO_2, TiO_2, Na_2O and CaO (Liu & Zhang, 2011). The iron present in the residue is responsible for the red color (Hind et al., 1999). The major chemical composition of bauxite mining waste generated in alumina plants in various countriesare presented in Table 2.1. (Liu & Zhang, 2011).

Table 2.1: The major chemical composition of bauxite mining waste generated in alumina plants in various countries (Liu & Zhang, 2011)

Country	Plant	Reference	Major composition (wt. %)					
			Fe_2O_3	Al_2O_3	TiO_2	SiO_2	Na_2O	CaO
India	HINDALCO	Singh et al. (1997)	33.1	18.2	19.6	8.8	5.8	2.7
Italy	Eurallumina	Sglavo et al. (2000)	35.2	20.0	9.2	11.9	7.5	6.7
Turkey	Seydisehir	Altundogan et al. (2002)	36.94	20.39	4.94	15.74	10.10	2.23
UK	ALCAN	Srikanth et al. (2005)	46.0	20.0	6.0	5.0	8.0	1.0
Greece		Tsakiridis et al. (2004)	40.8	19.95	5.8	6.8	2.7	12.6
France	Alu. Pechiney	Pera et al. (1997)	26.62	15.00	15.76	4.98	1.02	22.21
Canada	ALCAN	Vachon et al. (1994)	31.60	20.61	6.23	8.89	10.26	1.66
Jamaica		Gordon et al. (1996)	42.3	16.4	6.0	8.0	4.6	9.1
Jamaica		Gordon et al. (1996)	49.9	16.6	7.0	3.0	2.3	5.5
China		Liu et al. (2009)	27.93	22.00	2.3	20.98	10.5	6.23
China		Zhang et al. (2009)	12.23	6.27	3.27	17.78	2.75	37.52
Australia	AWAAK	Snars and Gilkes (2009)	28.5	24.0	3.11	18.8	3.4	5.26
Australia	AWAAP	Snars and Gilkes (2009)	31.7	18.8	3.17	20.2	4.2	4.44
Australia	AWAAW	Snars and Gilkes (2009)	29.6	17.3	2.65	30.0	3.2	3.64
Australia	WAPL	Snars and Gilkes (2009)	56.9	15.6	4.46	3.0	2.2	2.39
Australia	Nabalco	Snars and Gilkes (2009)	34.8	23.2	8.03	9.2	7.1	2.25
Australia	QAL	Snars and Gilkes (2009)	30.7	18.6	7.01	16.0	8.6	2.51
Brazil	Alunorte	Snars and Gilkes (2009)	45.6	15.1	4.29	15.6	7.6	1.16
Germany	AOSG	Snars and Gilkes (2009)	44.8	16.2	12.33	5.4	4.0	5.22
Spain	Alcoa	Snars and Gilkes (2009)	37.5	21.2	11.45	4.4	3.6	5.51
USA	RMC	Snars and Gilkes (2009)	35.5	18.4	6.31	8.5	6.1	7.74

2.4.2 Mineralogical Composition of Bauxite Mining Waste

In addition, there are various other minerals sometimes found including hydrogarnt, chantalite, hydroxycancrinite, sodium titanate and wide range of other metallic oxides. Some of the elements remain undissolved and so are eliminated with the bauxite mining waste, whilst some are soluble in the Bayer process and either build up in the Bayer liquor or precipitate along with the aluminium hydroxide as presented in Table 2.2 (Mpae et al., 2014).

Table 2.2: Mineralogical composition range for bauxite mining waste

Component	Typical range (%)
Sodalite($3Na_2O,3AI_2O_3.6SiO_2.Na_2SO_4$)	4-40
Goethite (FeOOH)	10-30
Hematite (Fe2O3)	10-30
Magnetite (Fe_3O_4)	0-8
Silica (SiO_2) crystalline and amorphous	3-20
Calcium aluminate ($3CaO.AI_2O_3.6H_2O$)	2-20
Boehmite (AIOOH)	0-20
Titanium Dioxide (TiO_2) anatase and ruti	12-15
Muscovite ($K_2O.3AI_2O_3.6SiO_2.2H_2O$)	0-15
Calcite ($CaCO_3$)	2-20
Kaolinite ($AI_2O_3.2SiO_2.2H_2O$)	0-5
Gibbsite (AI $(OH)_3$)	0-5
Perovskite ($CaTiO_3$)	0-12
Cancrinite (Na6[AI6SiO24].2$CaCO_3$)	0-5
Diaspore (AIOOH)	0-5

International Aluminium Institute (2015)

2.5 Physical Properties of the Bauxite mining waste

The bauxite mining waste from Ghana Bauxite Company at Awaso refineries can be divided into coarse and fine fractions. The physical properties are concerned with the texture and the physical nature of the bauxite mining waste. The physical properties of bauxite mining waste are of greater interest for making concrete as these help to determine shrinkage, bulk density size, moisture content, porosity and permeability.

Hammond (2003) conducted a physical comparison between bauxite residue and road base and reported that “Physical testing undertaken on the treated bauxite residue demonstrated suitability for road sub-grade and general construction fill. However, with present processing techniques, residue sand has unsuitable particle size distribution and insufficient strength characteristics to be considered as road sub-base".

Clearly there is a need for upstream processing of the bauxite residue to improve its physical characteristics for construction applications and to improve its environmental suitability (Jones, 2012).

2.5.1 Particle Size Distribution

The bauxite residue is a very fine grained material in terms of particle size distribution, having an average particle size < 10 µm (Traore` et al., 2014). It has also been shown that a concrete with aggregates that contain material finer than 75 µm can be less workable (Mehta, 1991), thus increasing the water requirement. Jamieson et al. (2006), described the coarse fraction as having a particle size generally > 100 µm with a nominal particle size >150 µm and the fine fraction has a nominal particle size <150 µm.

Mpae (2014) described the coarse fraction (greater than 100 µm) which is high in quartz may be separated from the finer silty muds (typically 80% less than 100 µm). Newson et al. (2006) reported that, a particle size range for bauxite mining waste form the UK (likely Burntisland, Scotland) between 1 and 300 µm with 50% for the particles been large then 5 µm. This inherently increases the water-cement ratio and thus reduces the strength of the concrete. Since the processed red mud has a very small particle size, it follows that large quantities of it would likely be detrimental rather than beneficial (Davoodi, 2008). Singh et al. (1996) described particle size distribution of bauxite residues as having porous structure with a void ratio of 2.5 – 3.0, a high compressibility (Eg = 28 – 40 Mpa) and low shear strength of (C = 9.6 – 74.3 Kpa. $\Phi = 13.5 – 21.0^o$). Despite bauxite residue properties of high porosity and water content, it will not shrink or expand after drying.

2.5.2 Bulk Density

Bulk density relates to the packing density and hence to hydraulic conductivity. The average bulk density of bauxite residues are reported as 2.5 ± 0.7g cm¯3 (Gräfe et al., 2009) bulk densities exceeding 1.5g cm¯3 impede root penetration and therefore the establishment of plants and at bulk densities above 1.6g cm¯3 healthy plant growth is unlikely. Nikraz et al. (2007) worked with bauxite residue that has a bulk density of 1.85 prior to treatment and treatment with carbon dioxide resulted in a bulk density of 1.8 g cm¯3.

2.5.3 Specific Surface Area

Specific surface area influences the rates of dissolution reaction. The average specific surface area of bauxite residue is 32 ± 12.2 m2 g¯1 and ranges between 15 and 58 m2 g¯1, which is consistent with the approximate size / distribution and textural class of the bauxite residue (Gräfe et al. 2009). Specific surface area of bauxite residue is as large as 64 – 187 $m^2.g^{-1}$, which indicates that bauxite residue has a high degree of mineral particles dispension (Traore` et al., 2014).

2.6 Workability of Bauxite Mining Waste

Wahyuni (2005) assessed the effects of substituting natural yellow sand with bauxite mining waste (Unprocessed Red Sand-URS) on the low strength concrete. It was found that concrete using bauxite mining waste as fine aggregate had a low workability in comparison to an equivalent mix using natural sand. This low workability resulted in poor compaction of the concrete, adversely affecting the durability. Specifically, the concrete had high water permeability and chloride diffusion. In terms of strength, it was found that the mixes performed similarly to concrete using natural sand as fine aggregate (Wahyuni, 2005).

2.7 Challenges to Use Bauxite Mining Waste

This section consists mainly on the challenges associated with the use of bauxite mining waste which includes; moisture content, Sodium content and pH.

2.7.1 Moisture Content

The high moisture content of bauxite mining waste will add to transport costs and will be an issue if energy has to be expended in driving it off in drying or firing, so it is advantageous for the bauxite mining waste to have as high solids content as possible. Bauxite residue has large water content up to 700 to 1000 kg/m^3, accounting for 79% - 93% of the total weight (Traore` et al., 2014) this water will be desorbed when the bauxite residue gets shocked, which may lead to a decrease of mechanical properties of bauxite residue. Soltaninaveh (2008) believed an uncontrolled “wet” bauxite mining waste aggregate will introduce extra moisture to the mixture, causing higher water-to-cement ratio and consequently less strength.

Kumar et al. (1989) conducted an investigation on partly replacing Ordinary Portland Cement by the neutralized bauxite residue in different proportions of 0, 5, 10 and 15% to prepare blended cements. They found that the settling rate of solid particles increased after the neutralization of bauxite mining waste. Tests on the physical properties of the Ordinary Portland Cement–red mud blended cements showed that the water demand for the produced blended cements became greater gradually with the increase of bauxite mining waste content, probably due to the increase of finer particlesand absorbing characteristic of bauxite mining waste; all of the blended cements had similar initial and final setting times except for the one with 10% bauxite mining waste exhibiting lower initial setting time.

Soltaninaveh (2008) assessed the properties of geopolymer concrete incorporating v as fine aggregate. It was concluded that, the moisture content of bauxite mining waste prior to use has a great influence on the workability of geopolymer concrete mixture: in order to achieve the desired workability, bauxite mining waste must be in Saturated Surface-Dried (SSD) condition. Now there is a trend back to the use of plate and frame press filters being adopted to reduce water content, which can yield a moisture level of 26/27% or lower (Evans, 2015).

2.7.2 Sodium Content (Na^+)

Sodium is associated with clay dispersal, poor aggregate structure, cementation and dust formation upon drying at the surface (McBride, 1994; Klauber et al. 2009). Study by (Fuller et al. 1982) on bauxite mining waste from Alcoa-Mobile (AL, USA) refinery has shown that the concentration of Na^+ in solution ranges between 17 and 200 mmol L^{-1}, exceeding Ca^2 and Mg^2 concentration by two to four orders of magnitude. Liu et al. (2009) and Courtney and Timpson (2005) showed sodium concentration in solution of 10 and 9 mmol

L^{-1}, respectively, exceeding Ca^{2+} and Mg^{2+} concentrations by two to three orders of magnitude. These concentrations are the result of the low solubility of Ca and Mg carbonates above pH 10.

Thornber and Binet (1999) conducted sequential washings of bauxite mining waste in water and showed that the release of sodium was related to the total alkalinity of the solution extracted after washing. They argued that the main source of sodium was desilicated product, where sodium was exchanged from the cages of desilicated product particles. Gräfe et al. (2009), believed sodium presence in significant quantities at alkaline pH is a significant inhibitor to the creation of aggregate structure and hydraulic conductivities.

2.7.3 pH: The Master Variable

The high pH is a problem from both a health and safety aspect and potentially adverse effects in the particular application. Based on a number of standard test criteria, any waste material with a pH value above 11.5 is often considered hazardous (Evans, 2015). On the other hand, most reactions are a partial function of pH and therefore changing pH can either drive a reaction forward or backward. Thornber and Binet (1999) conducted an experiment in which they sequentially exchanged bauxite mining waste with H_2O. They determined that the weight of the solid decreased with sequential washings, but neither the pH, Na^+, $AI(OH)_4^-$, CO_3^{2-} nor the OH^- concentration changed in solution. This simple experiment demonstrated that the solution pH of the bauxite mining waste was buffered by alkaline solid and that the pH did not change until these solids were completely dissolved and their reaction products removed (Gräfe et al. 2009).

2.8 Alternative Means of Neutralising Bauxite Mining Waste

Partial or complete neutralisation of the bauxite mining waste reduces the potential hazard associated with the use and this can be achieved by the use of gypsum, carbon dioxide and sulfur dioxide.

2.8.1 The Use of Gypsum

The efficacy of gypsum in lowering the pH of bauxite mining waste is related to the ability of gypsum to dissolve and release calcium ion into the solution to react with Hydroxide, Alminium Hydroxide and Carbon dioxide (Gräfe et al. 2009). Polcaro et al. (2000) and Xenidis et al. (2005) observed that gypsum solubility limited the extent of the pH reaction and only upon activation with Sulphuric acid did the desired pH reductions take place. This limitation may have occurred due to the precipitation of Calcium bi-carbonate on gypsum particles as observed by (Kopittke et al., 2004). Common ion effects, particle-size and specific surface area control the dissolution rate of gypsum (Gräfe et al. 2009).

2.8.2 The Use of Carbon Dioxide (CO_2) and Sulphur Dioxide (SO_2)

Larg scale neutralisation of bauxite mining waste with CO_2 began in 2000 at Alcoa's Kwinana refinery (Western Australia) (Cooling et al., 2002; Guilfoyle et al., 2005) reaching full capacity to treat all Kwinana residues by 2007 with the construction of a CO_2 pipeline from a nearby ammonia plant.

Gräfe et al. (2009), reported that refineries in Japan (Sumitomo) and Italy (Eurallumina) have been using residue to scrub SO_2 from flue gases, thus neutralising small quantities of bauxite mining waste, since the mid-1970s and early 2000 respectively (Anderson et al.

2008; Cooling et al. 2002; JP74025118-B, 27 Jun 1974, 1974; Cooling, 2007; Fois et al. 2007). The neutralisation reactions by either gas phase are based on the diffusion of gases into solution (Gräfe et al. 2009).

Khaitan et al. (2009) have shown that the pH of bauxite mining waste slurries treated with CO_2 decrease within 1 day to an apparently stable value, but that it will subsequently increase over time. A 30-day exposure to 1 atm of CO_2 was required to stabilise the pH of the bauxite residue slurries at 7.5. This is explained on the basis that the initial neutralization reaction occurs primarily in the liquid phase and that the rebounding of the pH is caused by the continuous dissolution of buffering solid and primarily tri-calcium aluminate (Cooling et al. 2002; Khaitan et al. 2009). According to Leoni & Penco, (2002) prolonged treatment of bauxite mining waste with sulphur oxide (g) depletes (free) sodium in solution and increases the Hydrogen concentration and thereby contributes to the dissolution of sodium bearing minerals, including desilication product.

2. 9. Review of Past Studies on Bauxite Mining Waste

Over the years, extensive work has been done by researchers worldwide to develop various economic ways for the utilization of bauxite mining waste. The various applications that have been investigated include: traditional concrete, road construction, glass ceramics, bricks/block, cementitious additives, geopolymers, pozzolanic material, land filling capping etc.

2.9.1 Traditional Concrete

Wahyuni et al. (2005) investigated the utilization of bauxite mining waste as fine aggregate in traditional concrete. The mechanical and durability features of concrete including bauxite mining waste was tested and it was concluded that its inclusion did not affect the strength of concrete; however, the durability tests resulted in higher water permeability and chloride diffusion due to the "porosity" of concrete made with bauxite mining waste.

A key finding of the research was the lower workability of bauxite mining waste concrete and the consequent high volume of pores. It was reported that "bauxite mining waste concrete had more pores due to the low, almost zero, slump value".

Davoodi et al. (2007) studied the behavior of concrete made with red sand (bauxite mining waste) in marine environment. In the laboratory work, washed and carbonated bauxite mining waste and its derivatives i.e. high Iron sand and high silica sand were used along with bauxite mining waste. The research studied various properties of concrete mixtures made with different types of fine aggregate. They concluded that concrete mixes incorporating bauxite mining waste and low portions of bauxite mining waste (10%) are likely to be useful in practice. However, in line with previous studies, the workability of the mixes containing washed and carbonated bauxite mining waste was reported lower than control mixes using natural sand.

2.9.2. Road Construction

Jitsangiam et al. (2007) looked into use of red sand (bauxite mining waste) as a road base material in Western Australia. The soil stabilization technique, a pozzolanic-stabilized mixture, was used to improve the properties of bauxite mining waste to satisfy minimum requirements of road base material. The outcome of the study revealed that stabilized bauxite mining waste is a viable option for use as a base course material in roads. Figure 2.1 illustrates the processes of using bauxite mining waste as a road base material presented by (Jitsangiam et al. 2007).

Figu 0re 2.1: Road construction in Western Australia (Jitsangiam et al. 2007)

2.9.3 Bauxite Mining Waste in the Production of Glass Ceramics

A study carried out by Pontikes et al., (2006) was aimed at using bauxite mining waste in heavy clay industry in which the plasticity of clay mixtures with bauxite mining waste and polymer addition was evaluated. They found that addition of 30 wt% bauxite mining waste substituting the clay mixture increased the maximum cohesion of the mixture. To make its use as a traditional ceramic, behavior of bauxite mining waste was studied in different firing atmospheres (Air, N2, Ar/4% H2), for different maximum temperatures (950 - 1050ºC) and different soaking times (30 – 300 min.). The content of bauxite mining waste did not affect the sample porosity, but more deflocculated system originated, in which critical moisture content was increased. By augmenting bauxite mining waste content to 20 %, after calcination at the temperatures of 950 and 1050 °C, growth of density and flexural strength were noticed in final ceramic products (Lalík & Schwarz, 2011).

2.9.4 Bauxite Mining Waste in the Production of Blocks or Bricks

Mpae et al. (2014) investigated the possibility of using bauxite mining waste as partial replacement for sandcrete blocks. It was found out that, compressive strength, abrasion loss and resistance to absorption of the blocks declined as the quantity of bauxite mining waste increased beyond 20% replacement. The outcome of the study also revealed that, the bauxite mining waste used performed satisfactorily as replacing material up to 20% for sand in the production of blocks for structural application. A study carried out by Peter (1997) was aimed at using bauxite mining waste to make bricks for inexpensive housing. The bauxite mining waste was pressed into bricks using a standard brick press, immersed in sodium silicate followed by drying in the sun and the main compressive strength was 24.10 MPa. Cablik (2007) added bauxite mining waste a pigment in various proportions (dried not ground, calcinated) to concrete mixes of standard test blocks (ground limestone size fraction–3.3+0 mm, cement and water). The test blocks varied in colour depending on the mix and the amount of bauxite mining waste added. The blocks were tested for compressive strength after having curing for 7, 14 or 28 days at the room temperature (18 to 23°C). Compressive strengths from 14.83 to 27.77MPa of the blocks that contained bauxite mining waste from 1 to 32% were satisfactory. Figures 2.2 and 2.3 show buildings built with bauxite mining waste bricks in Kingston at JBI, Jamaica (Evans 2015).

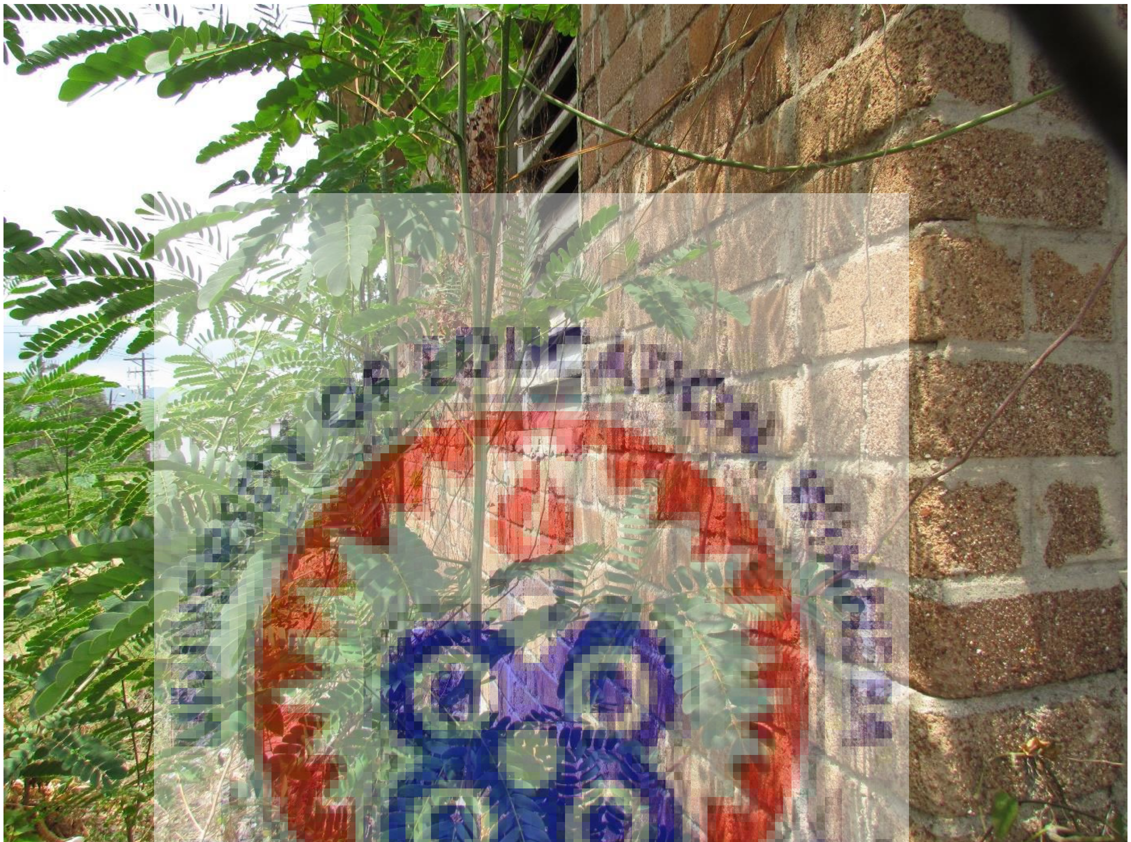

Figure 2.2: **Building in Kingston bricks (Evans, 2015)**

Figure 2.3: Building at JBI, Jamaica (Evans, 2015)

2.9.5 Cementitious Additives

Singh et al. (1996, 1997) conducted investigation on preparation of special cement using (lime ¼ 50%, bauxite mining waste ¼ 5–50% and bauxite ¼ 45–0%) were hard with a dark brown colour. It was found that their hardness, intensification of colour, glassy nature and relative density increased with the bauxite mining waste addition. Figure 2.3 displays the effect of bauxite mining waste addition on the 28-day compressive strength of special cements made from lime bauxite mining waste bauxite. Therefore, it was concluded that bauxite mining waste addition of 25–40% in the raw mixes and a firing temperature of 1250ºC for 1.0–1.5h presented the best results for the preparation of special cement using lime red mud bauxite. Figure 2.4 presents the effect of bauxite mining waste content on the 28-day strength of cements made from lime and bauxite mining waste (Singh et al., 1996).

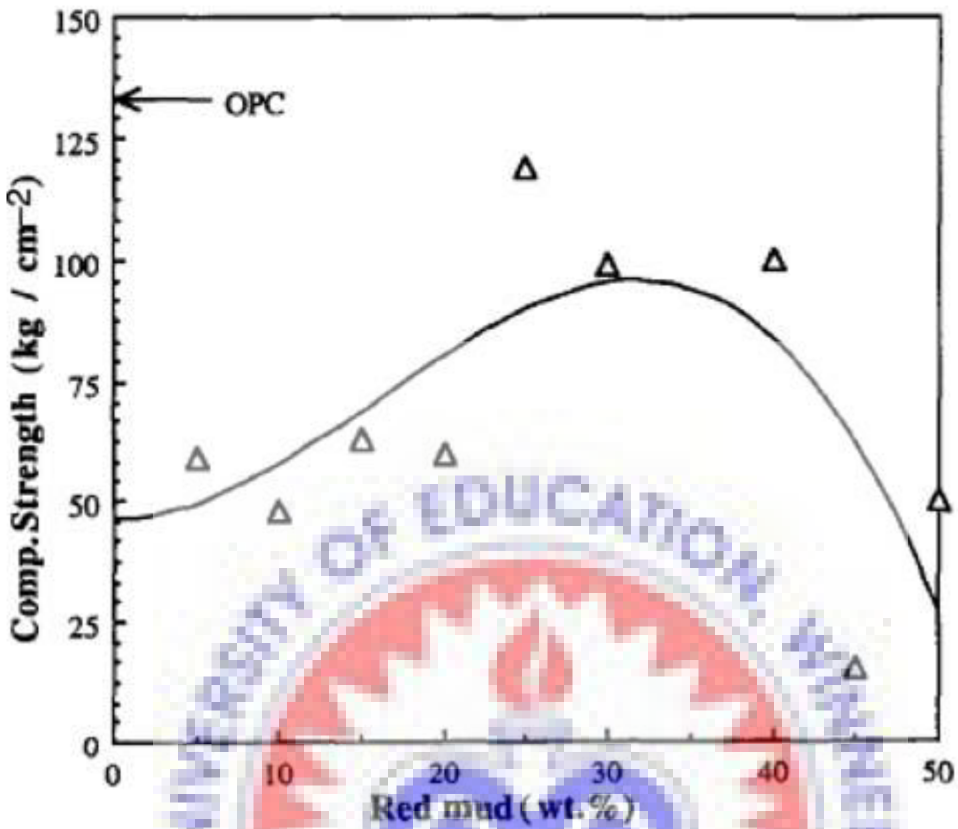

Figure 2.4: The effect of red mud (bauxite mining waste) content on the 28-day strength of cements made from lime and bauxite miming waste by (Singh et al., 1996).

Tsakiridis et al. (2004) assessed the feasibility of producing Portland cement clinkers by addition of red mud (bauxite mining waste) into the raw meals. They used 3.5% Bayer-process red mud blended with 74.8% limestone, 11.4% schist, 3% bauxite and 7.3% Milos sand as a raw mix composition to prepare Portland cement clinkers which were sintered from the raw meal at 1450ºC. They also found that the physical properties of the produced cement, including grindability, setting time, water content for standard consistency and expansibility were similar to those obtained for Ordinary Portland Cement. The red mud addition of 3.5% did not negatively affect the compressive strength of the produced cement (about 55MPa at 90 days).

Another interesting investigation of producing Ordinary Portland Cement by the addition of red mud (bauxite mining waste) was reported by (Vangelatos et al., 2009). Red mud (bauxite mining waste) was firstly dewatered by a filter press. The filtrand with water content of 26–28%, named ferroalumina, was added at 1, 3 and 5%, respectively, into the raw meals composed of limestone and sandstone to produce Ordinary Portland Ccement clinker. Tests on physical properties showed that the produced Ordinary Portland Cement with ferroalumina addition had good physical properties including specific surface area, setting time and water demand, which can be comparable to those for the reference Ordinary Portland Cement. With extremely high early-age strength (26.5–30.8MPa at 2 days and 57.5–62.9MPa at 28 days), the produced ferroalumina containing cements can be ranked into CEM I52.5N category, and the compressive strength at 360 days was around 70 MPa, which was significantly higher than that of the reference Ordinary Portland Cement (OPC).

Gordon et al. (1996) conducted a preliminary investigation on strength development of Jamaican bauxite mining waste composites incorporating hydrated lime, condensed silica fume and limestone. The bauxite mining waste composite was attempted to be used as a construction material without applying Portland cement as binder. They reported that the red mud composite exhibited compressive strength in the range of 15–18MPa at 28days and 18–22MPa at 122 days. Although the compressive strength of the red mud composites cannot be comparable with that of Ordinary Portland Cement (OPC), it helps in the understanding of the strength-giving processes operating inthese composites, and provides a fundamental point for the investigation of red mud-based composite cements.

2.9.6 Geopolymer

Soltaninavel (2008) described geopolymer as using fly ash and alkali in place of ordinary Portland cement as the binding agent. Regarding durability features, geopolymer concrete exhibits low drying shrinkage and shows good resistance to acid and sulfate environments (Hardjito & Rangan 2005a). Soltaninavel (2008) studied the properties of gceopolymer concrete incorporating red sand as fine aggregate. It was reported that, the indirect tensile strength, flexural strength and modulus of elasticity and Poisson's ratio of red sand geopolymer concrete have been found to be higher or comparable to natural sand geopolymer concrete. Also, the concentration of a sodium hydroxide solution is a governing factor affecting the strength of red sand geopolymer concrete: 14 molar sodium hydroxide proved to increase the compressive strength of a mixture up to 67 % more than 8 molar sodium hydroxide.

2.9.7 Pozzolanic

Pera et al. (1997) evaluated the possibility of using Bayer process red mud to develop a new admixture for concrete. They investigated the pozzolanic activity of calcined red mud (600–800ºC, at a step of 50ºC) by monitoring $Ca(OH)_2$ consumption of pastes composed of 50% calcined red mud and 50% $Ca(OH)_2$. The results showed that the calcined red mud was pozzolanic, and the red mud calcined at 700 and 800ºC seemed to have greater activity than those calcined at other temperatures. It was found that amorphous alumina was formed during the calcination probably due to the decomposition of boehmiteand gibbsite. Part of the calcite in the red mud decarbonated yielding quick lime (CaO) from 750ºC, having negative effects on the reactivity and resulting in a drastic decrease in early-age strength of the blended cements containing 20% (or more) red mud calcined at 750 or 800ºC. To increase the pozzolanic activity, the calcined red mud at these temperatures required to be prehydrated with 25% of water to completely transform the quick lime into Ca $(OH)_2$. It was reported that a replacement of 20% Ordinary Portland cement (OPC) by the prehydrated red mud calcined at 800ºC gave good mechanical properties with 90-day compressive strength of 59.9 MPa.

2.9.8 Land Filling Capping

The plant growth development on the pond from 2007, when the bare residue was still apparent, to autumn 2015. Evans (2016) reported bauxite mining waste soil amelioration or landfill capping in Kirkvine, Jamaica. Figures 2.5., 2.6., 2.7. and 2.8. illustrate his report.

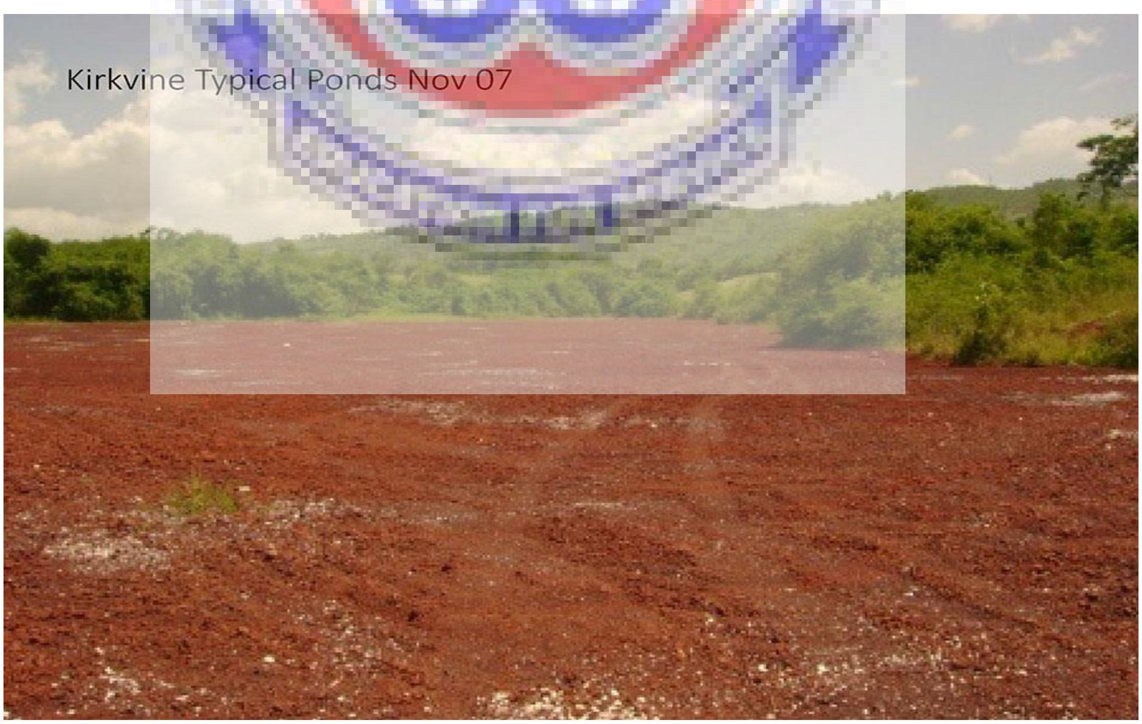

Figure 2.5: Kirkvine, Jamaica bauxite mining waste pond November 2007 (Evans, 2016)

Figure 2.6: Kirkvine, Jamaica bauxite mining waste pond September 2008 (Evans, 2016)

Figure 2.7: Kirkvine, Jamaica bauxite mining waste pond April 2011 (Evans, 2016)

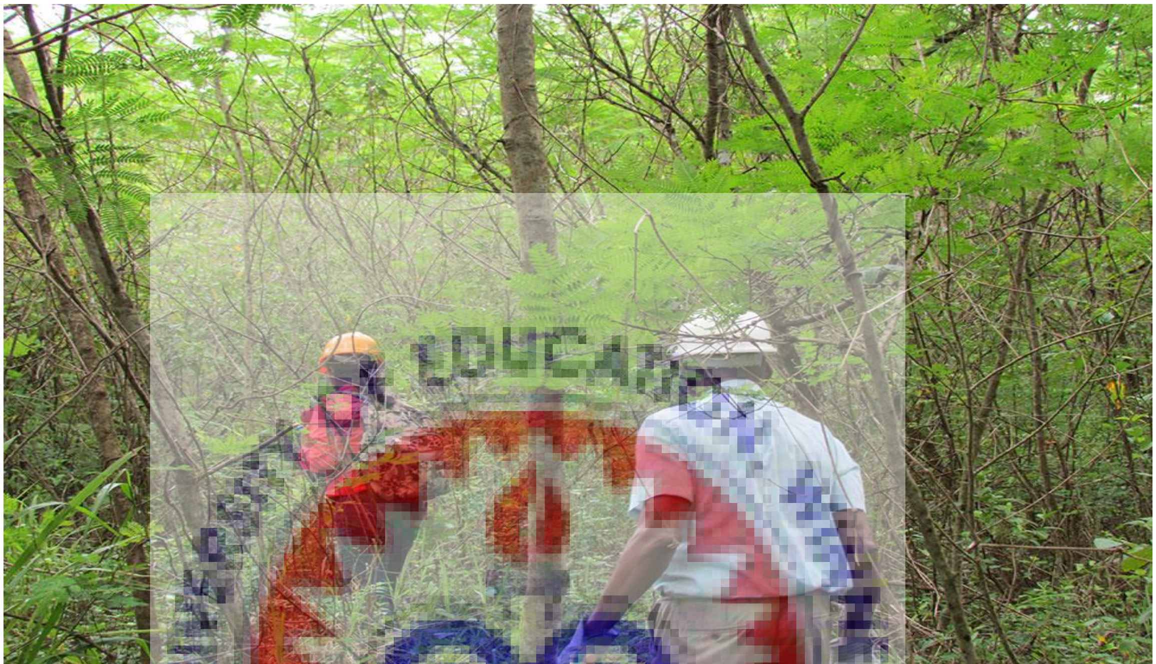

Figure 2.8: Kirkvine, Jamaica bauxite mining waste pond September 2015 (Evans, 2016)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

This chapter explains the materials and methods used to determine the properties of concrete produced with bauxite mining waste as fine aggregate replacement. The chapter also consists of the types of materials and methodology for determining the physical and mechanical properties.

3.2 Materials

Different types of materials were utilized for the purpose of achieving the objectives set out in the study. They include bauxite mining waste, fine aggregate (sand), coarse aggregate (stones), cement and water.

3.2.1 Bauxite Mining Waste

The bauxite mining waste used in this study was taken from Ghana Bauxite Company at Awaso in the Western Region of Ghana. The bauxite mining waste samples were collected from an impoundment area stored in sacks and transported to Sunyani Technical University Laboratory. Figure 3.1 (A and B) shows a dump site and sample of bauxite mining waste from Ghana Bauxite Campany at Awaso.

Figure 3.1: Bauxite Mining Waste from Ghana Bauxite Campany at Awaso Dump site (A) and sample (B)

3.2.2 Fine Aggregates (Sand)

The fine aggregate (sand) used in the research was pit sand obtained from Sunyani in the Brong Ahafo region of Ghana and conformed to the requirements of (British Standards BS 882: 1992).

Figure 3.2: Fine aggregate (sand)

The clay and silt contents of bauxite mining waste and fine aggregate (sand) were determined because it can affect the strength and durability properties, as smaller particles are likely to pack between the coarse aggregate. The test was conducted in accordance with (British Standards Institute (BS 1377:2, 1990). The process required the use of hydrometer test. 125 ml of sodium metaphosphate ($NaPO_3$) solution and sufficient distilled water were prepared in the control jar. The samples were dry, weighted and mix with the sodium metaphosphate ($NaPO_3$) solution. After carefully mixing the content, they were transfer into sedimentation cylinder and were shaking for about 1 minute. Hydrometer bulb was inserted into the sedimentation cylinder and readings were taking at appropriate time intervals. Figure 3.3 illustrate the hydrometer test process. The results obtained from the hydrometer tests were put together and the clay and silt content graph plotted.

Figure 3.3: Hydrometer Test Process

3.2.3 Coarse Aggregates

Coarse aggregate (stone) used in the research were crushed granite with nominal maximum size of 14 mm and was obtained from a local quarry site at Sunyani in the Brong Ahafo Region of Ghana.

Figure 3.4: Coarse Aggregate

3.2.4 Cement

A normal general purpose ordinary Portland cement of strength grade 42.5R produced by GHACEM, which satisfies ASTM requirements as Type I cement, was employed as the binder. Figure 3.5 illustrate Ordinary Portland Cement.

Figure 3.5: Ordinary Portland cement

3.2.5 Water

Water from Ghana Water Company limited (GWCL), in the Sunyani Technical University laboratory stand tap, were considered as potable for mixing of concrete. Figure 3.6 illustrate standup tap.

Figure 3.6: Standup tap

3.3 Methodology

This section consists of batching, mixing, moulding, curing, chemical composition and pH, workability, density, compressive strength, split tensile strength and flexual strength.

3.3.1 Batching

Batching of materials was done by weight using electronic weighing machine with the mix ratio of 1: 2: 4 (M30) grade and water cement ratio of 0.60.

Replacement content

(% replacement with respect to bauxite mining waste)

0% of bauxite mining waste as fine aggregate

25% of the fines aggregate were bauxite mining waste

50% of the fines aggregate were bauxite mining waste

75% of the fines aggregate were bauxite mining waste

100% bauxite mining waste as fine aggregate

3.3.2 Types of Specimen Prepared

Four (4) different types of test were conducted to determine their rate of strength on concrete which include (density, compressive strength, tensile strength and flexural strength). The purpose of density is to determine the specimens weight. The purpose of the compressive strength (cube) test is to ascertain the ability of the concrete to resist applied load in compression. The purpose of split tensile strength (cylinder) test is to measure the resistance of the concrete when a load is applied at the central point which tends to split the concrete into two while the purpose of flexural strength (beam) is to find out the ability of the concrete to resist failure in bending.

3.3.3 Mixing

Mixing of concrete was done by hand. Target mean strength for mix proportion was 30N/mm^2 for the corresponding water to cement ratio of 0.60. The fine aggregate was first batched to the platform before cement was added and was mixed before coarse aggregate was added. The three materials were mixed thoroughly untill a uniform colour was achieved after which the required quantity of water was added. Further mixing was done until a homogeneous mix was achieved.

Table 3.1: Shows mix design detail and number of specimens for the test

Mix Design	Mix Ratio	W/CRatio (Vol.)	Cement (kgs)	Fine Aggregate Sand(kg)	Fine Aggregate Waste(kg)	Coarse Agg.(Kg)	Test Density	Test Comp St.	Test Ten. St.	Test Flex. St.
B1 0%	1:2:4	0.60	10kgs	20kgs	–	40kgs	12	12	12	12
B2 25%	1:2:4	0.60	10kgs	15kgs	5kgs	40kgs	12	12	12	12
B3 50%	1:2:4	0.60	10kgs	10kgss	10kgs	40kgs	12	12	12	12
B4 75%	1:2:4	0.60	10kgs	5kgs	15kgs	40kgs	12	12	12	12
B5 100%	1:2:4	0.60	10kgs	–	20kgs	40kgs	12	12	12	12

3.3.4 Moulding

The specimens were moulded immediately after mixing the concrete. Each specimen was cast in three layers and was compacted manually with a steel rod of 16 mm diameter and 600 mm height before the next layer was poured.

3.3.5 Demoulding and Curing

After moulding the specimens, a 24-hour rest period was given to the specimens. After 24 hours the specimens were demoulded and were immersed water for curing. The procedure was in accordance with (British Standard Institute BS 1881: part 114, 1983). The specimens were subjected to 7 days, 14 days, 21 days and 28 days curing. Figure 3.7 illustrate the specimens in curing tank.

Figure 3.7: Specimen in Curing Tank

3.3.6 Chemical Composition and pH

The chemical composition test and acidity (pH) level of the bauxite residue and the fine aggregate (sand) were conducted to determine the rate of effect on the material. The test was made in accordance with the standard guideline of (British Standard Institute BS EN 13037, 2011). The bauxite mining waste was digested in a 1000ml Pyrex volumetric flask containing a hot (135°C - 140 °C) 2M NaOH solution for about 30minutes under constant stirring to allow even dispersion. The homogenous mixture was then allowed to cool to ambient temperature and the particles allowed to sediment. The liquid phase was then decanted and the residue (bauxite mining waste) dried in an autoclave at 110ºC for approximately 48 hours. The samples were then allowed to cool overnight to room temperature. The samples were dried at 100°C and roasted at 1000°C to determine Loss on Ignition (LOI) values. X-Ray Florescence Spectroscopy analytical tools were used to analyzise the chemical composition.

The pH measurements were determined in accordance with the guideline of British Standard (British Standard Institute BS EN 13037, 2011). A 25g of sample aggregates was collected and placed in 150ml of deionised water. After stirring in the aqueous suspension for 1 minute, the meter was inserted and the pH of the sample aggregates was observed.

3.3.7 Workability

The most important characteristic of a concrete is its workability when it is wet (prior to setting of cement into a hardened state). The reasons are placement becomes difficult if the concrete is too stiff and it may not be able to be pumped and also the concrete may not be able to be compacted adequately thus leading to voids in the hardened concrete. An increase in voids will lead to a decrease in the durability of the concrete. The workability was determined in accordance with British Standard Institute BS 1881: part 104 (1983). Slump test on fresh concrete was employed using slump cone of 300 mm height, 200 mm bottom diameter and 100 mm top diameter. Figure 3.8 illustrate the slump test process.

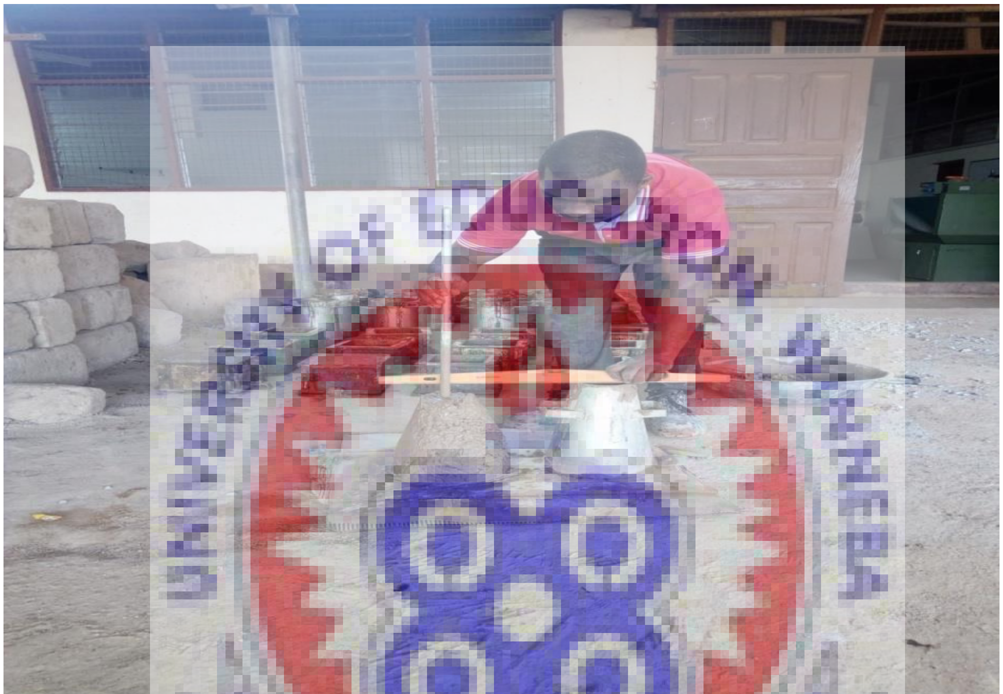

Figure 3.8: Slump Test process

3.3.8 Density

After curing prior to testing the specimens were weighted to determine their weight and the density of each was calculated. Density of the specimen was determined in accordance with British Standard Institute BS 1881: part 114 - 1983: Method for determination of density of hardened concrete. Figure 3.9A, 3.9B and 3.9C illustrate the weighing of specimen process.

Density (p) = M ⁄ V

Where: M= the mas of the saturated specimen in (kg).

V = the volume of the specimen determined by the displacement of waterin (m^3).

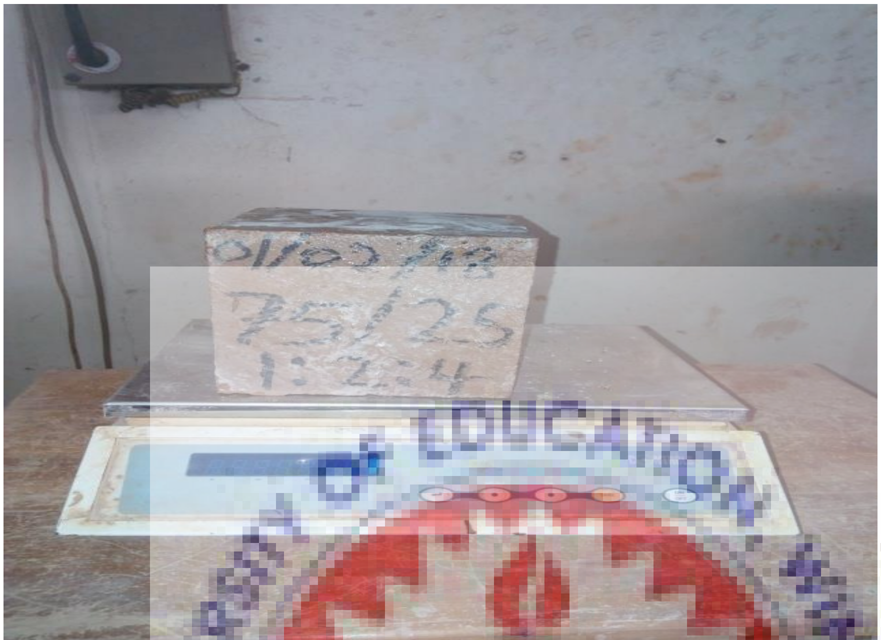

Figure 3.9A: Weighing of specimen (Cube)

Figure 3.9B: weighting of specimen (Cylinder)

Figure 3.9C: Weighing of specimen (Prism)

3.3.9 Compressive Strength

A total of sixty (60) cubes specimens were prepared and each had a size of 150 mm x 150 mm x 150 mm. Compressive strength test was conducted in accordance with British Standard Institute BS 1881: part 116 - 1983. The specimens were first weighed to calculate the density after which the specimens were subjected to computerized universal testing machine of capacity 2000 KN. The specimens were placed in the machine and load was applied gradually at a uniform rate until the specimens failed. The specimens were tested at 7 days, 14 days, 21 days and 28 days respectively. Figure 3.10 illustrates the compressive strength process.

Figure 3.10: Compressive Strength Test

3.3.10 Split Tensile Strength

The split tensile strength test was conducted following the principles of British Standard Institute BS 1881: part 117 - 1983. A total of sity (60) specimens were prepared. The cylindrical mould box of 150mm diameter and 300mm height was used to mould the concrete to determine the split tensile strength. The specimens were first weighed to calculate the density after which the specimens were subjected to computerized universal testing machine of capacity 2000 KN. The specimens were placed in the machine horizontally. Load was applied gradually at a uniform rate until the specimens failed. The specimens were tested at 7 days, 14 days, 21 days and 28 days respectively. Figure 3. 11. illustrates the split tensile strength process.

Figure 3.11: Split Tensile Strength Test

3.3.11 Flexural Strength

Testing for flexural strength was also conducted following the principles of British Standard Institute BS 1881 part 118 - 1983 testing concrete; Method for determination of flexural strength. The total of sixty (60) specimens of size 150 mm x 150 mm x 450 mm were tested. Testing took place at 7days, 14 days, 21 days and 28 days after specimens were removed from the curing tanks 30 minutes prior to testing. The test was conducted using the computerized universal testing machine of capacity 2000 KN and the specimens were tested up to failure under three-point loading. Each beam was loaded with a central-point load located at mid-span and on top of the beam, whilst the bottom face was supported on two simply supported ends with different shear spans. Figure 3.12A and 3.12B illustrates the flexural strength process.

Figure 3.12A: Flexural Strength Test

Figure 3.12B: Flexural Strength Test

3.4 Statistical Analysis

The statistical analyses were established to determine the mean, standard deviation and median of the results conducted. Correlations were carried-out to determine the relationships between mechanical properties measured and density. ANOVA test results at 95% confidence interval were used to test for significant difference and variation between the test results.

CHAPTER FOUR

4.0 TEST RESULTS

4.1 Introduction

This chapter presents the results of the different tests conducted on bauxite mining waste as fine aggregate replacement. The detail of the physical, chemical and mechanical characteristics of the constituent materials for the production of concrete including silt and clay content, chemical composition, workability, density of concrete, compressive strength, split tensile strength and flexural strength are presented.

4.2 Clay and Silt Content of Bauxite Mining Waste and Sand

This test was conducted to determine the silt and clay content of bauxite mining waste and sand. Sedimentation by hydrometer bulb method was used to determine the clay and silt content of the soil samples. The results have been presented in Appendix A. The results indicate that, the clay content is 0.9% for bauxite mining waste and 0.3% for fine aggregate. The silt content is 25% for bauxite mining waste and 26.2% for fine aggregate. The sand content is 73.8% for bauxite mining waste and 73.2% for fine aggregate. And the gravel content is 0.3% for bauxite mining waste and 0.4% for fine aggregate.

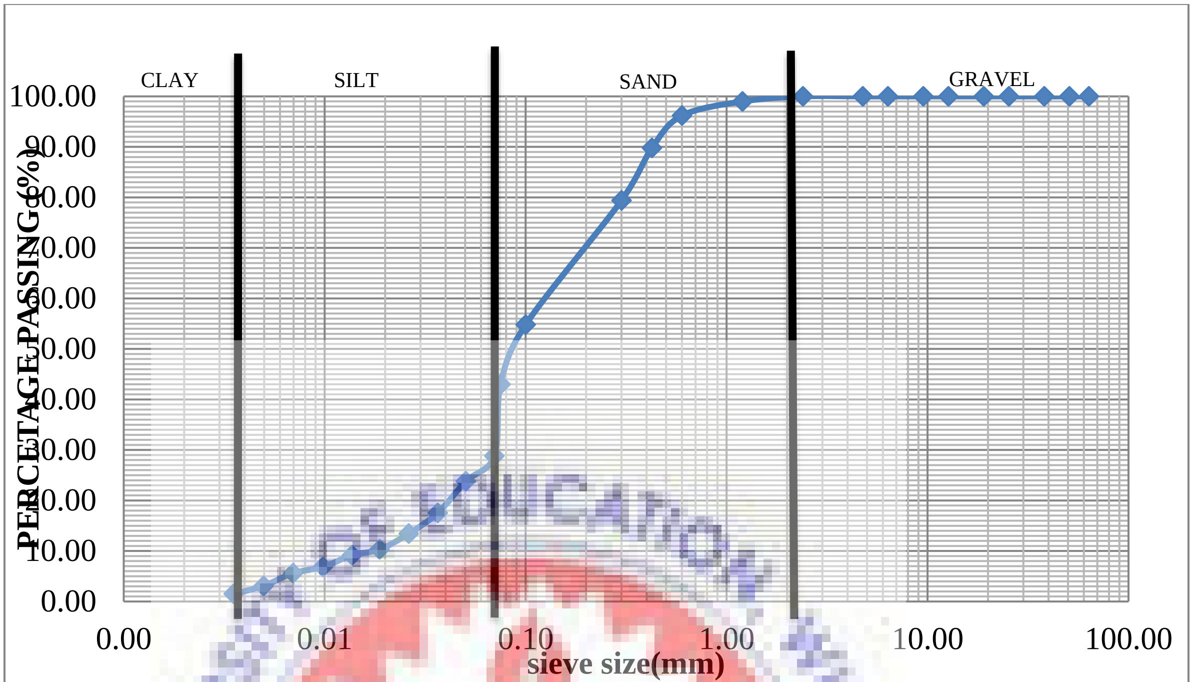

Figure 4.1: Clay and Silt Content (bauxite mining waste)

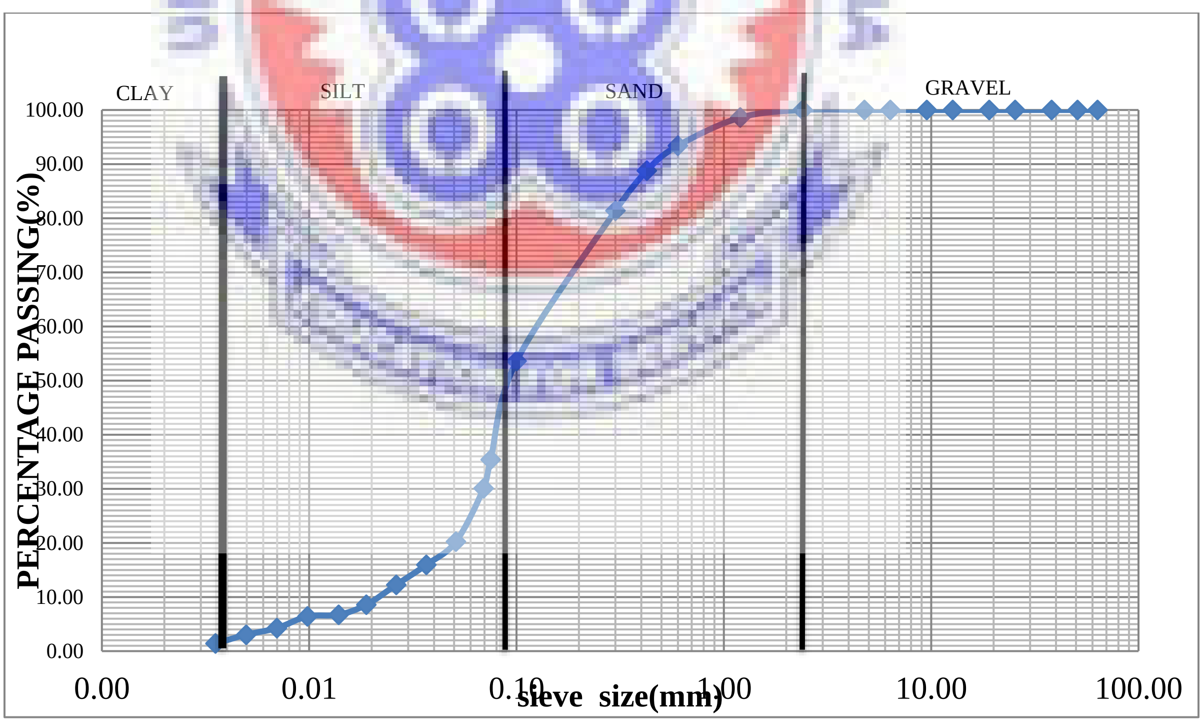

Figure 4.2: Clay and Silt Content (Sand)

4.3 Chemical Composition

The chemical properties of the bauxite mining waste and fine aggregate (sand) samples based on the soluble components are presented in Table 4.1. The main compositions are Aluminium Oxide (Al_2O_3), Iron Oxide (Fe_2O_3), Titanium Dioxide (TiO_2), Cilica (SiO_2), Sodium Oxide (Na_2O), Calcium Oxide (CaO) and Loss of ignition (L.O.I). The major differences between the bauxite mining waste from Ghana Bauxite Company at Awaso and the fine aggregate form Sunyani were the amount of Al_2O_3, Fe_2O_3, SiO_2 and L.O.I content. Bauxite mining waste had a high Al_2O_3, Fe_2O_3 and L. O. I. (51.07, 7.15 and 33.9 respectively) as compared to the fine aggregate (0.57, 0.80 and 0.29 respectively). But the SiO_2 content in fine aggregate was higher than bauxite mining waste (55.12) and (2.27) respectively. The differences might be due to deposition of minerals of the different locations where the samples were obtained.

Table 4.1: Chemical Composition

Chemical Composition	Bauxite Residue	Fine Aggregate
Aluminium Oxide (Al_2O_3)	51.07	0.57
Iron Oxide (Fe_2O_3)	7.15	0.80
Titanium Dioxide (TiO_2)	1.77	0.55
Silica (SiO_2)	2.27	55.12
Sodium Oxide (Na_2O)	2.84	0.11
Calcium Oxide (CaO)	1.07	0.02
Loss of ignition (L.O.I)	33.9	0.29

The pH results are reported in Table 4.2. Based on a number of standard test criteria, any waste material with a pH value above 11.5 is often considered hazardous (Evans, 2015). A study by Liu and Zhang (2011) obtained high alkalinity of (pH 10–12.5) characteristic of bauxite mining waste. The results indicate that both samples sand did not contain soluble substance that may affect human interaction.

Table 4.2: pH result

Soil	pH
Bauxite Residue	10.28
Sand	6.33

4.4 Workability

Figure 4.3 summarises the results of the fresh concrete tests on the various proportions of concrete. Slump cone test was used to determine the workability of concrete. This test was carried out before casting the specimens. The results have been presented in Appendix A. The variation of slump for the partial replacement of fine aggregate with bauxite mining waste increased in the order of 24, 29, 35, 41 and 45mm for B1 10%, B2 25%, B3 50%, B4 75% and B5 100% proportions respectively.

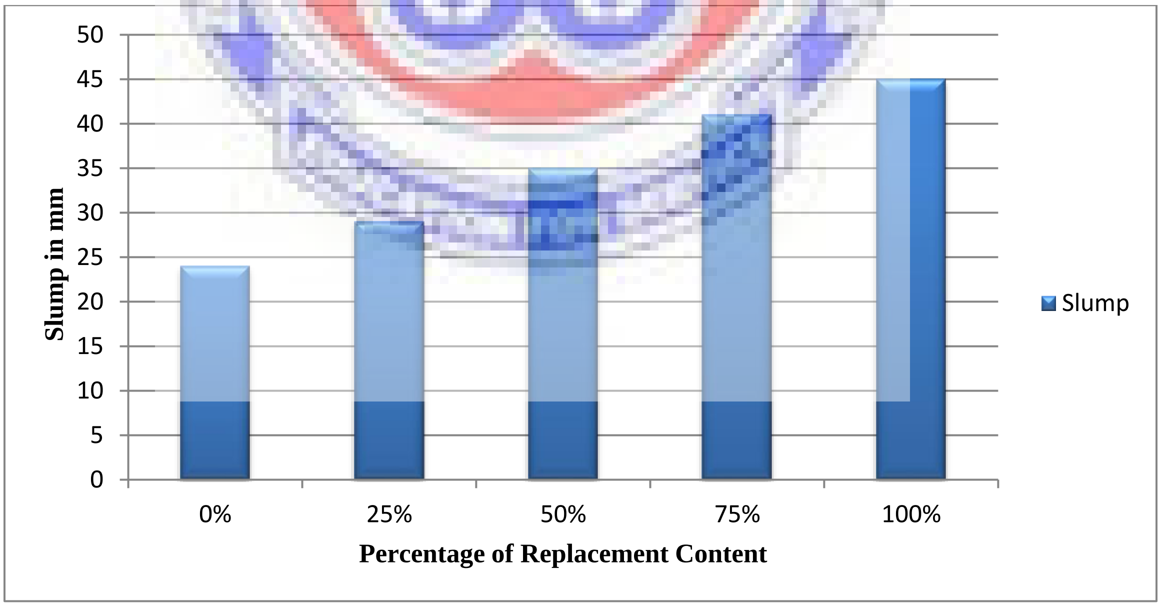

Figure 4.3: Variation of Slump

4.5 Density of Concrete

The density test results of concrete for Conpressive Strength are summarised in Figure 4.4. The results have been presented in Appendix B. The result indicates that, there was slight difference in the density among the various proportions, and the 100% placement achieved the highest density followed by 75%, 50%, 25% and 0%. With values of 2293 kg/m^3, 2285 kg/m^3, 2279 kg/m^3, 2268 kg/m^3 and 2267 kg/m^3 respectively. They show a close related average density among the different proportion, between 2267 kg/m^3 and 2293 kg/m^3. They show the relationship between the volume and the mass of the concrete.

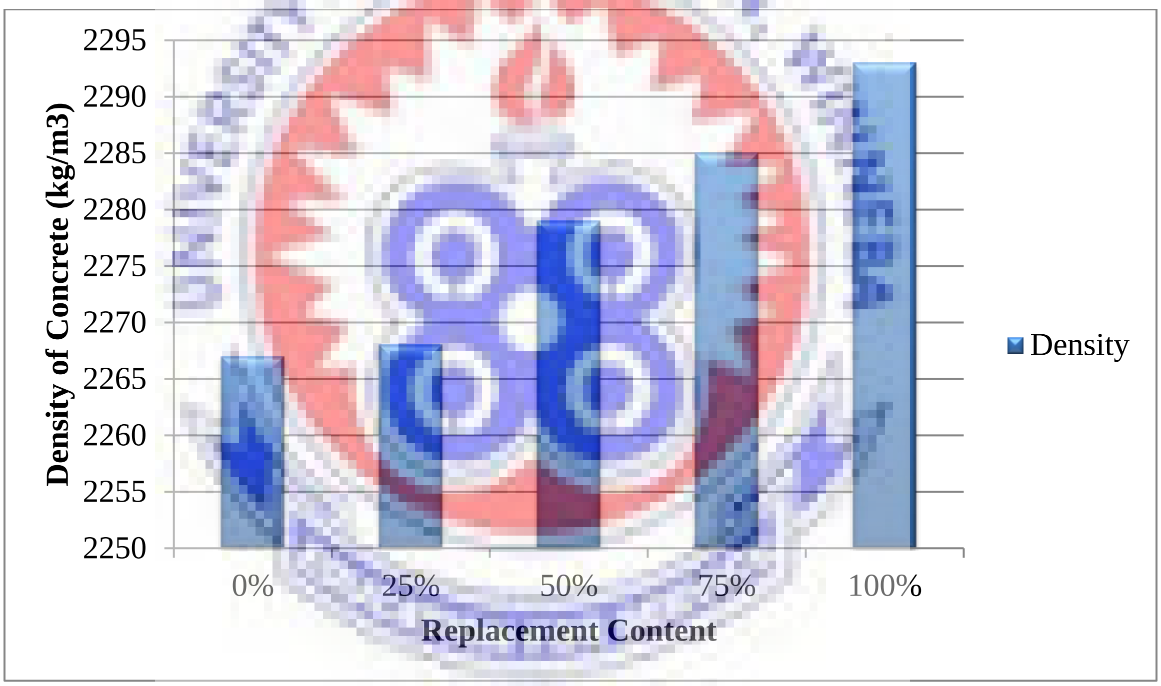

Figure 4.4: **Density of concrete for Compressive Strength**

Table 4.3: ANOVA for Density of Concrete Tests Results

	Sum of Squares	df	Mean Square	F- Value	Sig.

Between Group	18369.067	3	6122.689	1.297	0.284
Within Group	264282.667	56	4719.33		
Total	282650.733	59			

4.6 Compressive Strength

Figure 4.5 presents the summary of the compressive strength test results. The results have been presented in Appendix B. The results show that, the highest compressive strength value of 25.22 N/mm^2 was obtained from 100% replacement at 28 days, which represent an increase of 15% as compared to the control mix at 28 days of 16.56N/mm^2. However, all the bauxite mining waste concrete mixes showed compressive strength values that are slightly higher than those of the control mix.

Figure 4.5: Compressive Strength of Concrete mix proportion

Table 4.4 and Table 4.5 present the summary descriptive statistics and ANOVA test results at 95% confidence interval; the tables show the differences in the values among the different proportions and their statistical significance.

Table 4.4: Descriptive statistics of compressive strength (N/mm^2) of test concrete

Mix Proportion	Mean±SD	Median	Min.	Max.	CoV (%)
0%	15.99 ± 0.47	16.06	15.16	16.57	2.94
25%	17.05 ± 0.93	17.02	15.91	18.28	5.45
50%	18.03 ± 1.27	17.95	16.40	19.84	7.04
75%	19.81 ± 2.19	19.66	17.11	22.82	11.06
100%	21.78 ± 2.70	21.99	18.30	25.23	12.40

SD= Standard deviation; CoV= coefficient of variation

Table 4.5: ANOVA for Compressive Strength Tests Results

	Sum of Squares	df	Mean Square	F – value	Sig.
Between Groups	252.682	4	63.171	21.403	0.000
Within Groups	162.335	55	2.942		
Total	415.017	59			

Figure 4.6 summarises the relationship between the compressive strength and the density of the concrete. The results align with Walker (1995) observation that a given increase in density will result in a greater increase in strength.

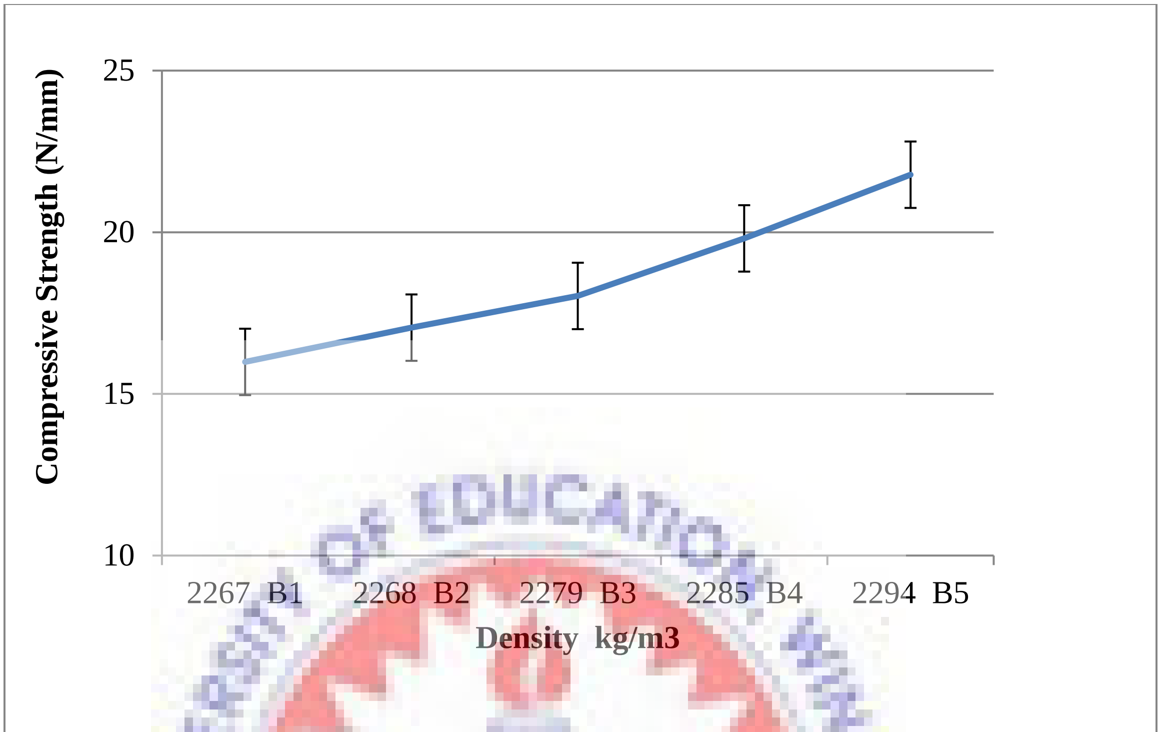

Figure 4.6: Relationship between compressive strength and density of concrete

4.7 Split Tensile Strength

The summary of the splitting tensile strength test result is presented in Figure 4. 7. The result is similar to the compressive strength. The results have been presented in Appendix B. The results show that the highest tensile strength (6N/mm^2) was observed form 100% replacement of bauxite mining waste at 28 days of curing when compared to the control specimens of 3.50N/mm^2 at 28 days of curing. However, all the bauxite mining waste concrete mixes also showed split tensile strength values are slightly higher than those of the control mix.

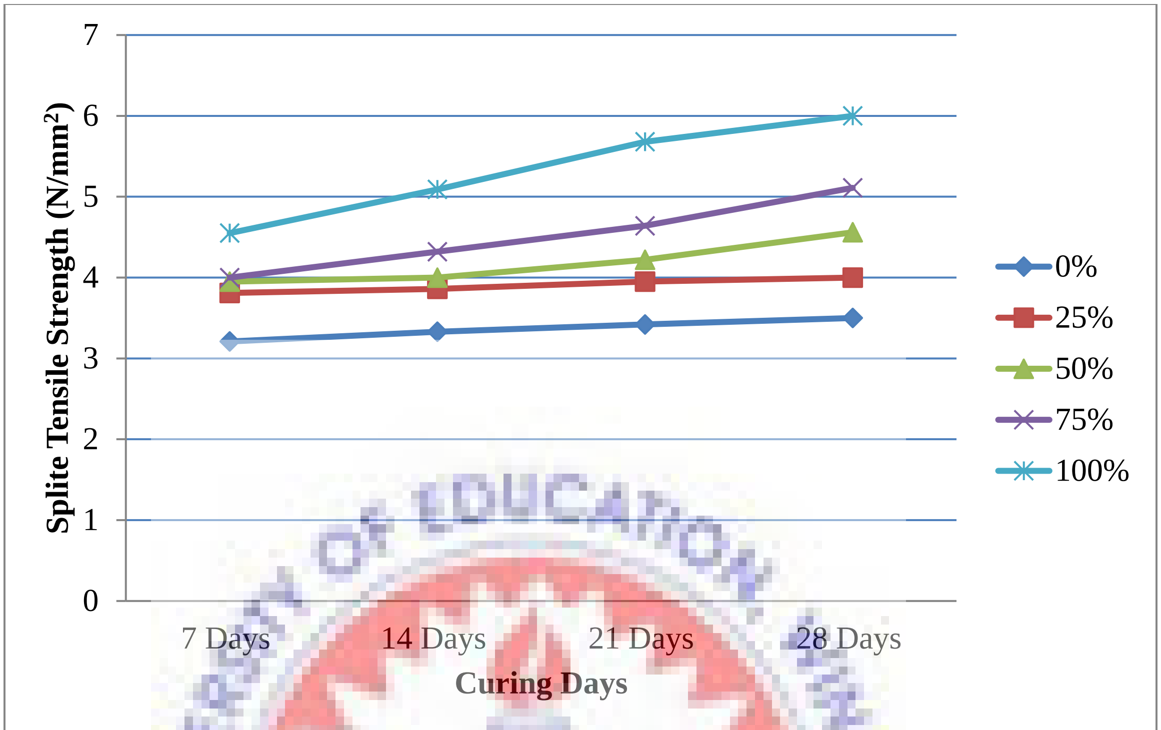

Figure 4.7: **Split Tensile Strength**

ANOVA test results at 95% confidence interval indicate that the differences in the values among the different replacement contents are significant. There is therefore a statistically significant difference among the replacement content of concrete.

Table 4.6: **Descriptive statistics of Split Tensile Strength (N/mm^2) of test concrete**

Mix Proportion	Mean ±SD	Median	Min.	Max.	CoV (%)
0%	3.37 ±0.11	3.37	3.20	3.51	3.26
25%	3.91 ±0.08	3.91	3.80	4.01	2.05
50%	4.18 ±0.25	4.11	3.93	4.57	5.98
75%	4.52 ±0.43	4.49	3.99	5.13	9.51
100%	5.41 ±0.61	5.67	4.54	6.01	11.28

SD= Standard deviation; CoV= coefficient of variation

Table 4.7: ANOVA for Tensile Strength Tests Results

	Sum of Squares	df	Mean Square	F - Value	Sig.
Between Group	4.290	3	1.430	2.636	0.001
Within Group	30.379	56	0.542		
Total	34.669	59			

Figures 4.8 show the relationship between split tensile strength and density of concrete. The results indicate a good relationship between tensile strength and density. The results align with Walker (1995) observation that a given increase in density will result in a greater increase in strength.

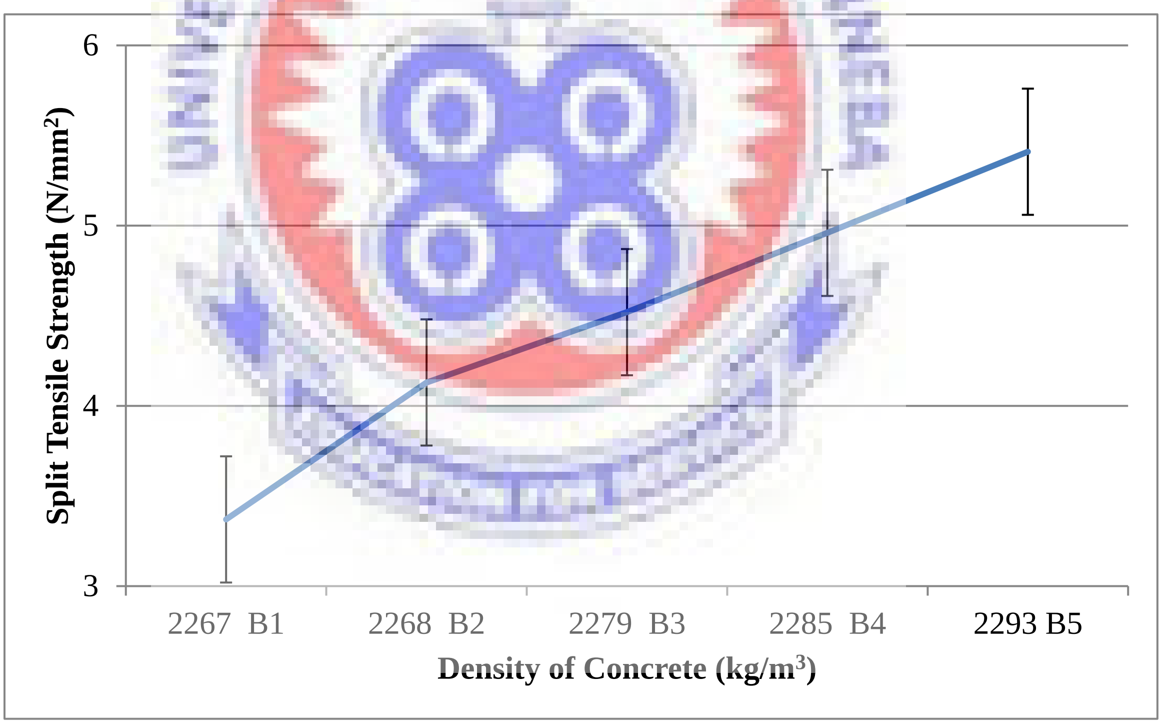

Figure 4.8: Relationship between Split Tensile Strength and Density

4.8 Flexural Strength

The summary of the flexural strength test result is presented in Figure 4.9. The result is similar to the compressive strength and split tensile strength. The results have been presented in Appendix B. The flexural strengths increase as the bauxite mining waste proportion increased. The results show that, the highest flexural strength value of 4.84 N/mm^2 was obtained from 100% replacement at 28 days, which represent an increase of 2.65% as compared to the control mix.

However, all the bauxite mining waste concrete mixes showed flexural strength values that are slightly higher than those of the plain mixes.

Figure 4.9: Flexural Strength

ANOVA test results at 95% confidence interval indicate that the differences in the values among the different proportion are significant. There is therefore a statistically significant difference between flexural strength and replacement levels.

Table 4.8: Descriptive statistics of Flexural Strength (N/mm^2) of test concrete

Mix Proportion	Mean ±SD	Median	Min.	Max.	CoV (%)
0%	2.70 ± 0.44	2.84	2.08	3.20	16.296
25%	3.33 ± 0.40	3.23	2.85	3.88	12.012
50%	3.73 ± 0.31	3.85	3.21	4.01	8.311
75%	4.13 ± 0.22	4.09	3.86	4.46	5.327
100%	4.48 ± 0.30	4.48	4.09	4.86	6.696

SD= Standard deviation; CoV= coefficient of variation

Table 4.9: ANOVA for Flexural Strength Tests Results

	Sum of Squares	df	Mean Square	F - Value	Sig.
Between Group	22.038	4	5.510	46.356	0.000
Within Group	6.537	56	0.119		
Total	28.575	59			

Figures 4.10 shows the relationship between flexural tensile strength and density of concrete. The results indicate good relationship between Flexural strength and density. The results align with Walker (1995) observation that a given increase in density will result in a greater increase in strength.

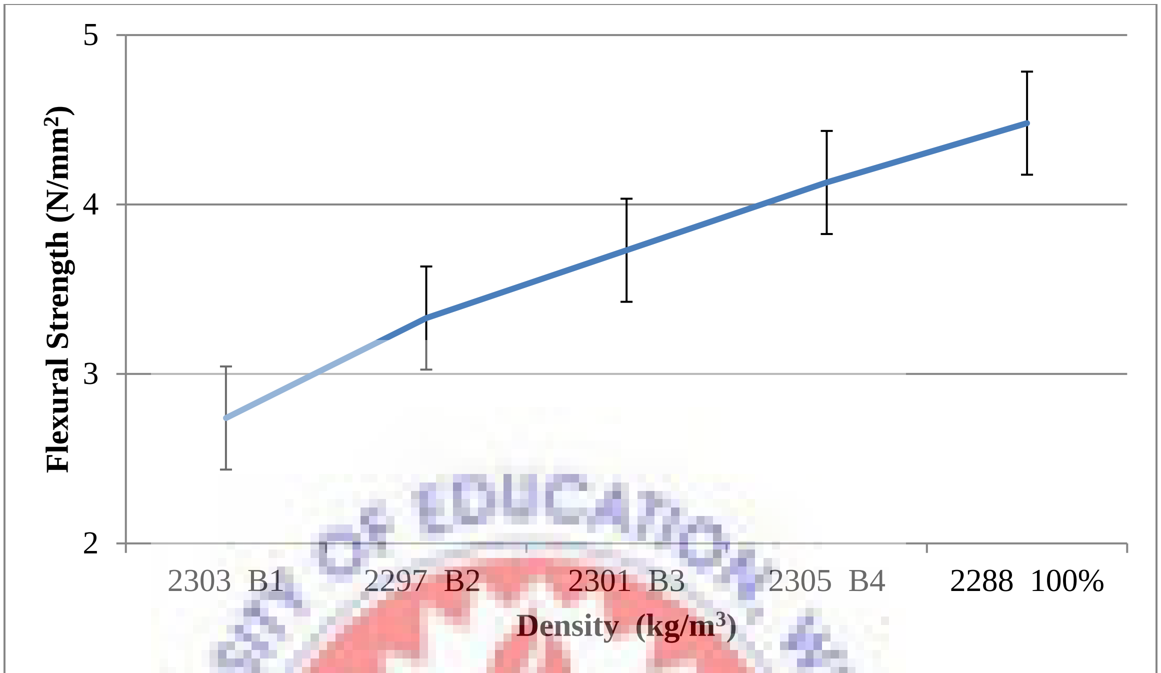

Figure 4.10: Relationship between Flexural Strength and Density

CHAPTER FIVE

5.0 DISCUSSION OF THE RESULTS

5.1 Introduction

This chapter presents discussions of the results obtained in chapter four. The chapter also sets to link the findings of this present study to perspectives in literature. The aim is to establish the level of consistency among knowledge contribution in this field.

5.2 Clay and Silt Content

The results indicate that, the clay content is 0.9% for bauxite mining waste and 0.3% for fine aggregate. The silt content is 25% for bauxite mining waste and 26.2% for fine aggregate. The sand content is 73.8% for bauxite mining waste and 73.2% for fine aggregate. And the gravel content is 0.3% for bauxite mining waste and 0.4% for fine aggregate. Fuller et al. (1986) reported a particle size range for bauxite mining waste from Alcoa refinery at Mobile (Alabama, USA), the residue become increasingly finer with increasing distance from the embankment. Ten to twenty metres from the embankment, the residue is sandy (sand, silt, clay and gravel % = 76 – 90, 4 – 16, 4 – 8, 0.01 – 1.1 respectively); 30 – 40 metres away, they are loamy (sand, silt, clay and gravel % = 19 – 43, 30 – 43, 26 – 38, 0.4 – 1.8 respectively); and at > 50 metres, the residues are silty-clayey (sand, silt, clay and gravel % = 5 - 7, 41 – 43, 53 – 54, 0.5 – 1.2 respectively). The bauxite mining waste and fine aggregates samples were found to be within the overall limits given in BS 882, (1992).

5.3 Chemical Composition

From the results, the two materials mainly bauxite mining waste and fine aggregate (sand) are predominantly Fe_2O_3, Al_2O_3, SiO_2, TiO_2, Na_2O and CaO for the following percentage compositions: (7.15, 51.07, 2.27, 1.77, 2.84, 1.07) for bauxite mining waste (0.57, 0.80, 55.22, 0.55, 0.11, 0.11, 0.02) for fine aggregate respectively. The results agree with results obtained by (Liu et al. 2009; Deshmukh and Sarode 2014).

Altundogan et al. (2002) conducted investigation and reported the following chemical composition of bauxite mining waste constituents: Fe_2O_3 36.94%, Al_2O_3 20.39%, SiO_2 15.74%, TiO_2 4.98%, Na_2O 10.10% and CaO 2.23%. Srikanth et al. (2005) also conducted investigations from ALCAN plant UK and reported the following chemical composition on bauxite mining waste Fe_2O_3 46.0%, Al_2O_3 20%, SiO_2 5.0%, TiO_2 6.0%, Na_2O 8.0% and CaO1.0%. Davoodi (2008) also reported natural sand (fine aggregate) constituents of Fe_2O_3 0.81%, AI_2O_3 0.58%, SiO_2 97.6%, TiO_2 0.56%, Na_2O 0.81%, CaO 0.01%, LOI 0.29%. This might be due to the different deposition of chemicals of the different locations where the bauxite mining waste and fine aggregate samples were obtained.

The pH value for bauxite mining waste was 10.28 and 6.33 for fine aggregate. The results indicate that both bauxite mining waste and sand did not contain soluble substance that may affect human interaction. Based on a number of standard test criteria, any waste material with a pH value above 11.5 is often considered hazardous (Evans, 2015).

5.4 Workability

From the results, there are increases in the slump values in the various mix proportions incorporating bauxite mining waste as fine aggregate replacement. As a result of the increase in the slump values, the bauxite mining waste concrete mixes were considered workable. Deshmukh and Sarode (2014) reported that using the high proportion of the bauxite mining waste as fine aggregate replacement increase the slump values of the concrete. Davoodi, (2008) related the increase of the slump values to the low specific gravity of bauxite mining waste, which results in fine grain particles. Due to a higher percent of fines in bauxite mining waste, its surface area is greater than natural sand and it can be concluded that the workability of concrete mixes incorporating bauxite mining waste as a fine aggregate will increase significantly (Neville, 1995). All the increases in slump conformed to British standard code of BS EN 12350 – 2 (2009).

5.5 Density

The result clearly shows that, there was a systematic increase in the average densities of the concrete as the quantity of the bauxite mining waste increased in proportion. This aligns with Gooding and Thomas (1997) and Walker (1995) observation that a given increase in density will result in a greater increase in strength. The results show a close related average density among the different proportion, between 2267 kg/m^3 and 2293 kg/m^3. This lies within the range of 2200 to 2600 kg/m^3 specified as the density of normal weight concrete (Neville, 2000; BS EN 12390-6:2009).

The results align with the results obtained by (Osadebe and Nwakonobi, 2007; Mtallib and Marke, 2010; Joseph and Maurice, 2012; Akeem et al., 2013; Mpae, 2014; Francis et al., 2016).

ANOVA test results at 95% confidence interval indicate that the differences in the values among the different proportions are insignificant. Therefore, no statistical significant difference ($F= 1.297$; $Sig= 0.284$) in density among the proportion of the concrete.

5.6 Compressive Strength

From the results, it clearly shows that the highest results of compressive strength are obtained from 100% replacement at 28 days of curing. Even 50% replacement at 28 days of curing is better as compared to 0% replacement at 28 days of curing. The compressive strength values of 0% are found to be lowest compared to the rest of the results. This results align with the results obtained by (Raheem and Aderounmu, 2002; Adesanya and Raheem, 2002; Raheem and Abimbola, 2006; Soltaninaveh, 2008; Akeem et al. 2013). Similar studies on bauxite mining waste as fine aggregate replacement was reported by Davoodi, (2008) where the specimens were subjected to 28-days curing with strength of 10 to 36 MPa. The increase in strength is attributed to the high presence of Fe_2O_3 and AI_2O_3 as well as some silica as they contribute to the production of cement clinker. Deshmukh and Sarode (2014) attribute the increase strength to the presence of allumina, silica ferrous oxide and the binding properties due to presence of calcium oxide that helps bauxite mining waste to develop higher strength in concrete. The results are aligning with BS EN 12390-3 (2009).

The ANOVA test results at 95% confidence interval indicate that the differences in the values among the different proportions are significant. There is a statistical significant difference ($F= 21.403$; Sig = 0.000) in compressive strength among the proportions of the concrete produce.

The relationship between the compressive strength and the density of the concrete produced was achieved using correlation trend line. The results indicate a positive linear relationship between the compressive strength and the density. The result is similar to the result obtained by (Akeem et al., 2013; Danso et al., 2015; Adinkrah-Appiah, 2015).

5.7 Splitting Tensile Strength

The result clearly shows that the highest tensile strength was observed with 100% replacement (6.00 N/mm^2) of bauxite mining waste at 28 days of curing when compared to the control specimens of (3.50N/mm^2) at 28 days of curing. However, all the bauxite mining waste concrete mixes also showed split tensile strength values are slightly higher than those of the control mix.

These results align with the results obtained by (Davoodi, 2008; Joseph and Maurice, 2012; Sakthivel et al., 2013). The increase in tensile strength after replacement of fine with varying proportions of bauxite mining waste are mainly attributed to the bauxite mining waste rigid particles and the high presence of Fe_2O_3 and AI_2O_3 as well as some silica as they contribute to the production of cement clinker. And also, the increase is due the addition of higher amounts of bauxite mining waste up to 25%, which filled the voids of the composite samples.

The ANOVA test results at 95% confidence interval indicate the differences in the values among the different proportions are significant. There is a statistical significant difference ($F= 2.636$; $Sig = 0.001$) in tensile strength among the proportions of the concrete produced.

The relationship between the tensile strength and the density of the concrete produced was achieved using correlation trend line. The results indicate a positive linear relationship between the tensile strength and the density. The result is similar to the result obtained by (Akeem et al., 2013; Danso et al., 2015; Adinkrah-Appiah, 2015).

5.8 Flexural Strength

From the results, it clearly shows that, the highest flexural strength value of 4.84 N/mm^2 was obtained from 100% replacement at 28 days, which represent an increase of 2.65% as compared to the control mix. Even 50% replacement at 28% days of curing is better as compared to 0% replacement at 28 days of curing. The flexural strength values of 0% at 7 days of curing were found to be lower compared to the rest of the results. The results align with the results obtained by (Soltaninaveh, 2008; Joseph and Maurice, 2012; Sakthivel et al., 2013; Deshmukh and Sarode, 2014). The increase in flexural strength after replacement of fine with varying proportion of bauxite mining waste are mainly attributed to the bauxite mining waste rigid particles and the high presence of Fe_2O_3 and AI_2O_3 as well as some silica as they contribute to the production of cement clinker.

Thaer (2014) believed the increase is expected since the bauxite mining waste particle is inherently rigid and thus influences the rigidity of the composite as a whole (bulk). This indicates that the composite becoming increasingly brittle with lesser deflection is observed during flexural loading. And also, the increase is due to the addition of higher amounts of bauxite mining waste up to 25%, which filled the voids of the composite samples.

The ANOVA test results at 95% confidence interval indicate that the differences in the values among the different proportions are significant. There is therefore a statistical significant difference (F= 46.356; Sig= 0.000) in flexural strength among the proportions of the concrete produced.

The relationship between the flexural strength and the density of the concrete produced was achieved using correlation trend line. The results indicate a good linear relationship between the flexural strength and the density. The result is similar to the result obtained by (Akeem et al., 2013; Adinkrah-Appiah, 2015).

CHAPTER SIX

6.0 SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents findings summarized from the interpretation and discussions in the previous chapters, drawn conclusions from the major findings and recommendations.

6.2 Summary of Findings

The study revealed that chemical composition that was found in bauxite mining waste had a high Aluminium Oxide Al_2O_3, Iron Oxide Fe_2O_3 and Loss of ignition L.O.I. (51.07, 7.15 and 33.9). The pH value for bauxite mining waste was 10.28. Also, the fine aggregate had high Silica (SiO_2) of 55.12 and the pH value of 6.33. This means the experimental bauxite mining waste and sand did not contain soluble substance that may affect human interaction and also found to be good to be used as fine aggregate for construction purpose.

The study revealed that partial replacement of bauxite mining waste as fine aggregate replacement has significant effect on the workability of the concrete. However, looking at individual composite mix there was systematic increase on the workability as the quantity of bauxite mining waste increased. Data from the study showed that there was slightly increase in density of composite concrete as the quantity of bauxite mining waste increase. The study revealed that there was significant increase in compressive strength, tensile strength and flexural strength as the quantity of bauxite mining waste increase beyond 25%. The study further revealed that the test of significance by ANOVA at 95% confidence interval for the test types (compressive strength, tensile strength and flexural strength) proved that there was a statistically significant difference among the different proportions of the concrete produced. The study also revealed that there was a good relationship between the test types including compressive strength, tensile strength and flexural strength test results that are associated with the density test results of the concrete.

6.3 Conclusions

The following conclusions are presented based on the findings of the experimental work which have direct link to the objectives of the study.

- Based on the results obtained from the bauxite mining waste and fine aggregate, the study concludes that the properties and characteristics of the samples aggregate were suitable to be used for making concrete.
- From the findings, the experimental work concludes that all the mixs containing bauxite mining waste as fine aggregate replacement show increase in slump. This indicates that bauxite mining waste composite mix is workable. In spite of the increase in the slump values, the bauxite mining waste concrete mixes were considered workable.
- The study concludes that the density of the specimens concrete slightly increase as the quantity of bauxite residue increase and fall into the category of normal weight concrete.
- The study concludes that there was significant increase in the various mix strength properties as the quantity of bauxite mining waste increase. The significant increase in the test type includes compressive strength, tensile strength and flexural strength.
- The study also concludes that there was positive correlation between the density of the concrete produced and the test type, namely, compressive strength, tensile strength and flexural strength.

6.4 Recommendations

Based on the findings of the study, the following recommendations are proposed.

- From on the physical and chemical properties of bauxite mining waste, Bauxite mining waste is a potential construction material and can be used as a complete replacement of fine aggregate for low cost materials. It is recommended to use as construction material to solve the environmental problems and disposal of environmental waste materials.
- The mechanical properties performance of enhanced concrete may show possible improvements with consideration of the use of super plasticizer to produce bauxite mining waste concrete of higher compressive strength, tensile strength and flexural strength is recommended.

  However, in the absence of the super plasticizer, it is recommended that the bauxite mining waste be used to produce with ordinary Portland cement for concrete production.
- It is recommended that more education should be embarked on the use of bauxite mining waste as fine aggregate replacement for concrete production in the area where the bauxite mining wastes are deposited.

6. 4. 1. Further Studies

- Further work is required to incorporate bauxite mining waste with other wastes (slags, ashes, etc.) applications with higher added value.

- Further investigation with the use of bauxite mining waste to develop optimal compositions and technologies of manufacture of geopolymer final products.
- Although there was improvement in the mechanical properties of the concrete made with bauxite mining waste over the concrete made with fine aggregate. further investigation with the introduction of varying cement content and water to cement ratio by researchers may be undertaken to provide increased mechanical properties
- An effective method to improve the utilization ratio of bauxite mining waste in cement production and deep research into the solidification mechanics of Na+ in bauxite mining waste containing cement is also required.

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APPENDICES

Appendix A: Workability of Concrete

Mix Design	Water-Cement Ratio (vol)	Height of Cone (mm)	Height of Concrete (mm)	Slump (mm)
B1 0%	0.60	300	276	24
B2 25%	0.60	300	271	29
B3 50%	0.60	300	265	35
B4 75%	0.60	300	259	41
B5 100%	0.60	300	255	45

Appendix B: Mechanical properties of concrete

Compressive Strength

0%				**25%**			
Curing	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**	**Curing**	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**
7days	7.500	154.6	15.16	**7days**	8.084	230.9	15.91
	8.076	158.9	15.15		8.367	201.6	15.95
	7.238	210.9	15.17		7.558	222.5	15.96
Mean	**7.60467**	**174.800**	**15.1600**	**Mean**	**8.00300**	**218.333**	**15.9400**
Std. D.	**.428693**	**31.3374**	**.01000**	**Std. D.**	**.410537**	**15.0879**	**.02646**
Median	**7.50000**	**158.900**	**15.1600**	**Median**	**8.08400**	**222.500**	**15.9500**
14days	7.723	248.7	15.84	14days	7.328	237.0	16.50
	7.618	257.8	15.84		7.723	247.5	16.49
	7.530	299.8	15.87		7.610	236.3	16.48
Mean	**7.62367**	**268.767**	**15.8500**	**Mean**	**7.55367**	**240.267**	**16.4900**
Std. D.	**.096625**	**27.2581**	**.01732**	**Std. D.**	**.203436**	**6.2740**	**.01000**

Median	**7.61800**	**257.800**	**15.8400**	**Median**	**7.61000**	**237.000**	**16.4900**
21days	7.911	241.1	16.05	21days	7.339	258.0	17.54
	8.408	257.0	16.06		8.042	271.6	17.54
	7.704	247.1	16.07		7.658	251.8	17.54
Mean	**8.00767**	**248.400**	**16.0600**	**Mean**	**7.67967**	**260.467**	**17.5400**
Std. D.	**.361818**	**8.0293**	**.01000**	**Std. D.**	**.352000**	**10.1278**	**.00000**
Median	**7.91100**	**247.100**	**16.0600**	**Median**	**7.65800**	**258.000**	**17.5400**
28days	7.627	200.6	16.56	28days	7.531	281.2	18.20
	7.388	204.3	16.57		8.028	248.9	18.22
	7.864	190.3	16.55		7.960	270.9	18.24
Mean	**7.62633**	**198.400**	**16.5600**	**Mean**	**7.83967**	**267.000**	**18.2200**
Std. D.	**.238001**	**7.2547**	**.01000**	**Std. D.**	**.269467**	**16.4994**	**.02000**
Median	**7.62700**	**200.600**	**16.5600**	**Median**	**7.96000**	**270.900**	**18.2200**

50% **75%**

Curing	**Weight**	**Load**	**Strength**	**Curing**	**Weight**	**Load**	**Strength**

	(KG)	(KN)	(N/mm^2)		(KG)	(KN)	(N/mm^2)
7days	7.722	284.4	16.40	**7days**	7.630	286.4	17.11
	7.086	306.0	16.41		7.464	293.7	17.11
	7.532	399.7	16.42		7.616	277.9	17.11
Mean	**7.44667**	**330.033**	**16.4100**	**Mean**	**7.57000**	**286.000**	**17.1100**
Std. D.	**.326474**	**61.2921**	**.01000**	**Std. D.**	**.092065**	**7.9076**	**.00000**
Median	**7.53200**	**306.000**	**16.4100**	**Median**	**7.61600**	**286.400**	**17.1100**
14days	7.300	349.5	17.71	**14days**	7.990	277.8	18.89
	7.260	379.3	17.72		8.060	279.2	18.88
	8.200	316.6	17.70		7.487	333.6	18.87
Mean	**7.58667**	**348.467**	**17.7100**	**Mean**	**7.84567**	**296.867**	**18.8800**
Std. D.	**.531539**	**31.3628**	**.01000**	**Std. D.**	**.312580**	**31.8197**	**.01000**
Median	**7.30000**	**349.500**	**17.7100**	**Median**	**7.99000**	**279.200**	**18.8800**
21days	7.928	371.5	18.20	**21days**	7.977	333.3	20.45
	7.737	389.6	18.19		7.476	346.2	20.44
	8.073	389.2	18.18		7.624	322.4	20.43
Mean	**7.91267**	**383.433**	**18.1900**	**Mean**	**7.69233**	**333.967**	**20.4400**
Std. D.	**.168524**	**10.3365**	**.01000**	**Std. D.**	**.257395**	**11.9140**	**.01000**
Median	**7.92800**	**389.200**	**18.1900**	**Median**	**7.62400**	**333.300**	**20.4400**
28days	7.426	431.6	19.82	**28days**	7.830	342.2	22.80
	7.831	418.3	19.80		7.845	355.1	22.81
	7.523	427.1	19.81		7.772	369.2	22.82
Mean	**7.59333**	**425.667**	**19.8100**	**Mean**	**7.81567**	**355.500**	**22.8100**
Std. D.	**.211462**	**6.7649**	**.01000**	**Std. D.**	**.038553**	**13.5044**	**.01000**

Median	**7.52300**	**427.100**	**19.8100**	**Median**	**7.83000**	**355.100**	**22.8100**

100%

Curing	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**	**Curing**	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**
7days	7.780	321.8	18.30	**21days**	8.008	388.6	22.95
	7.573	311.2	18.30		7.815	342.8	22.96
	7.464	325.8	18.33		7.717	379.9	22.97
Mean	**7.60567**	**319.600**	**18.3100**	**Mean**	**7.84667**	**370.433**	**22.9600**
Std. D.	**.160513**	**7.5445**	**.01732**	**Std. D.**	**.148062**	**24.3233**	**.01000**
Median	**7.57300**	**321.800**	**18.3000**	**Median**	**7.81500**	**379.900**	**22.9600**
14days	8.011	369.8	20.62	**28days**	7.316	388.0	25.21
	7.994	347.8	20.61		7.745	357.4	25.22
	7.049	348.6	20.60		7.415	411.7	25.23
Mean	**7.68467**	**355.400**	**20.6100**	**Mean**	**7.49200**	**385.700**	**25.2200**
Std. D.	.550569	**12.4772**	**.01000**	**Std. D.**	.224626	**27.2230**	**.01000**
Median	7.99400	348.600	**20.6100**	**Median**	7.41500	**388.000**	**25.2200**

Split Tensile Strength

0% **25%**

Curing	Weight (KG)	Load (KN)	Strength (N/mm^2)	Curing	Weight (KG)	Load (KN)	Strength (N/mm^2)
7days	12.18	71.71	3.21	**7days**	11.93	62.80	3.82
	12.05	61.20	3.20		12.08	74.10	3.80
	11.92	60.10	3.23		12.00	67.70	3.81
Mean	**12.0517**	**64.3367**	**3.2133**	**Mean**	**12.0017**	**68.2000**	**3.8100**
Std. D.	**.13052**	**6.40914**	**.01528**	**Std. D.**	**.07810**	**5.66657**	**.01000**
Median	**12.0540**	**61.2000**	**3.2100**	**Median**	**11.9970**	**67.7000**	**3.8100**
14days	12.04	61.10	3.31	**14days**	11.88	65.20	3.85
	12.08	71.20	3.34		12.03	75.50	3.87
	12.12	66.70	3.34		12.04	76.80	3.86
Mean	**12.0840**	**66.3333**	**3.3300**	**Mean**	**11.9833**	**72.5000**	**3.8600**
Std. D.	**.04000**	**5.05997**	**.01732**	**Std. D.**	**.08985**	**6.35531**	**.01000**
Median	**12.0840**	**66.7000**	**3.3400**	**Median**	**12.0270**	**75.5000**	**3.8600**
21days	12.60	77.60	3.44	**21days**	11.97	83.90	3.95
	11.41	51.90	3.42		12.08	74.60	3.95
	11.71	49.90	3.40		11.99	75.80	3.95
Mean	**11.9063**	**59.8000**	**3.4200**	**Mean**	**12.0110**	**78.1000**	**3.9500**
Std. D.	**.61882**	**15.4476**	**.02000**	**Std. D.**	**.05745**	**5.05866**	**.00000**
Median	**11.7080**	**51.9000**	**3.4200**	**Median**	**11.9900**	**75.8000**	**3.9500**
28days	12.07	70.70	3.51	**28days**	12.19	81.90	4.01
	12.20	69.50	3.49		12.03	77.00	4.00
	12.13	74.90	3.50		12.18	67.30	3.99
Mean	**12.1337**	**71.7000**	**3.5000**	**Mean**	**12.1350**	**75.4000**	**4.0000**

Std. D.	**.06350**	**2.83549**	**.01000**	**Std. D.**	**.08764**	**7.43034**	**.01000**
Median	**12.1340**	**70.7000**	**3.5000**	**Median**	**12.1800**	**77.0000**	**4.0000**

50% **75%**

Curing	Weight (KG)	Load (KN)	Strength (N/mm^2)	Curing	Weight (KG)	Load (KN)	Strength (N/mm^2)
7days	12.05	79.40	3.93	**7days**	11.90	77.10	3.99
	12.11	83.00	3.98		11.95	61.90	4.00
	12.28	74.80	3.95		12.02	67.00	4.01
Mean	**12.1463**	**79.0667**	**3.9533**	**Mean**	**11.9583**	**68.6667**	**4.0000**
Std. D.	**.11566**	**4.11015**	**.02517**	**Std. D.**	**.06217**	**7.73585**	**.01000**
Median	**12.1130**	**79.4000**	**3.9500**	**Median**	**11.9530**	**67.0000**	**4.0000**
14days	12.12	98.20	4.01	**14days**	12.10	96.20	4.34
	12.06	88.70	4.00		12.01	76.30	4.30
	12.03	84.20	3.99		11.98	69.20	4.32
Mean	**12.0703**	**90.3667**	**4.0000**	**Mean**	**12.0280**	**80.5667**	**4.3200**
Std. D.	**.05002**	**7.14726**	**.01000**	**Std. D.**	**.06296**	**13.99655**	**.02000**
Median	**12.0620**	**88.7000**	**4.0000**	**Median**	**12.0100**	**76.3000**	**4.3200**
21days	11.99	105.30	4.20	**21days**	12.11	90.60	4.64
	12.08	81.10	4.22		11.97	90.20	4.65
	12.08	103.50	4.24		11.91	71.70	4.63
Mean	**12.0477**	**96.633**	**4.2200**	**Mean**	**11.9970**	**84.1667**	**4.6400**
Std. D.	**.05428**	**13.4823**	**.02000**	**Std. D.**	**.10641**	**10.79830**	**.01000**

Median	**12.0780**	**103.500**	**4.2200**	**Median**	**11.9710**	**90.2000**	**4.6400**
28days	11.99	105.60	4.56	**28days**	12.03	90.20	5.13
	12.13	80.60	4.55		11.97	83.20	5.09
	11.96	113.00	4.57		11.89	84.40	5.11
Mean	**12.0277**	**99.7333**	**4.5600**	**Mean**	**11.9630**	**85.9333**	**5.1100**
Std. D.	**.09151**	**16.9780**	**.01000**	**Std. D.**	**.07076**	**3.74344**	**.02000**
Median	**11.9900**	**105.600**	**4.5600**	**Median**	**11.9700**	**84.4000**	**5.1100**

100%

Curing	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**	**Curing**	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**
7days	12.12	96.00	4.55	**21days**	12.09	109.80	5.66
	11.88	98.00	4.54		12.12	99.60	5.68
	11.95	79.60	4.56		11.97	104.70	5.70
Mean	**11.9820**	**91.2000**	**4.5500**	**Mean**	**12.0577**	**104.7000**	**5.6800**
Std. D.	**.12205**	**10.09554**	**.01000**	**Std. D.**	**.08036**	**5.10000**	**.02000**
Median	**11.9460**	**96.0000**	**4.5500**	**Median**	**12.0910**	**104.7000**	**5.6800**
14days	12.12	91.30	5.08	**28days**	12.13	113.80	6.00
	12.80	98.00	5.08		12.02	122.40	6.00
	11.95	90.40	6.01		11.83	111.50	6.00
Mean	**12.2883**	**93.2333**	**5.3900**	**Mean**	**11.9933**	**115.9000**	**6.0000**
Std. D.	**.45223**	**4.15251**	**.53694**	**Std. D.**	**.15052**	**5.74543**	**.00000**
Median	**12.1180**	**91.3000**	**5.0800**	**Median**	**12.0180**	**113.8000**	**6.0000**

Flexural Strength

0% **25%**

Curing	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**	**Curing**	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**
7days	23.72	5.51	2.08	**7days**	23.14	5.56	2.88
	23.21	6.50	2.10		23.01	5.59	2.88
	23.20	5.48	2.09		23.29	5.45	2.85
Mean	**23.3777**	**5.8297**	**2.0900**	**Mean**	**23.1497**	**5.5343**	**2.8700**
Std. D.	**.29569**	**.58062**	**.01000**	**Std. D.**	**.13859**	**.07297**	**.01732**
Median	**23.2140**	**5.5050**	**2.0900**	**Median**	**23.1440**	**5.5600**	**2.8800**
14days	23.21	5.35	2.66	**14days**	23.35	5.41	3.04
	23.17	5.41	2.68		23.36	5.40	3.04
	23.01	5.41	2.67		23.29	5.39	3.10
Mean	**23.1317**	**5.3907**	**2.6700**	**Mean**	**23.3320**	**5.3997**	**3.0600**
Std. D.	**.10375**	**.03612**	**.01000**	**Std. D.**	**.03568**	**.01002**	**.03464**
Median	**23.1710**	**5.4100**	**2.6700**	**Median**	**23.3490**	**5.3990**	**3.0400**
21days	23.41	5.44	3.00	**21days**	23.13	5.39	3.57
	24.02	5.52	3.02		23.04	5.50	3.55
	23.49	5.49	3.04		23.26	5.52	3.56
Mean	**23.6427**	**5.4833**	**3.0200**	**Mean**	**23.1460**	**5.4693**	**3.5600**
Std. D.	**.33174**	**.04041**	**.02000**	**Std. D.**	**.10908**	**.06992**	**.01000**
Median	**23.4920**	**5.4900**	**3.0200**	**Median**	**23.1330**	**5.4960**	**3.5600**
28days	23.09	9.09	3.20	**28days**	23.43	6.65	3.84

	23.18	6.24	3.19		23.52	6.46	3.80
	23.15	6.81	3.18		23.19	5.86	3.88
Mean	**23.1403**	**7.3777**	**3.1900**	**Mean**	**23.3830**	**6.3203**	**3.8400**
Std. D.	**.04576**	**1.50997**	**.01000**	**Std. D.**	**.17016**	**.41308**	**.04000**
Median	**23.1460**	**6.8060**	**3.1900**	**Median**	**23.4310**	**6.4580**	**3.8400**

50% **75%**

Curing	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**	**Curing**	**Weight (KG)**	**Load (KN)**	**Strength (N/mm^2)**
7days	23.24	5.55	3.28	7days	23.22	6.38	3.91
	23.35	5.48	3.21		23.32	5.92	3.86
	23.39	5.51	3.23		23.38	5.65	3.87
Mean	**23.3247**	**5.5127**	**3.2400**	**Mean**	**23.3067**	**5.9797**	**3.8800**
Std. D.	**.07558**	**.03547**	**.03606**	**Std. D.**	**.07941**	**.36802**	**.02646**
Median	**23.3450**	**5.5060**	**3.2300**	**Median**	**23.3160**	**5.9170**	**3.8700**
14days	23.21	5.42	3.77	**14days**	23.54	8.65	3.98
	23.26	5.41	3.77		23.44	6.93	3.99
	23.21	5.40	3.73		23.52	6.51	4.00
Mean	**23.2287**	**5.4073**	**3.7567**	**Mean**	**23.5003**	**7.3640**	**3.9900**
Std. D.	**.02715**	**.00961**	**.02309**	**Std. D.**	**.05029**	**1.13050**	**.01000**
Median	**23.2140**	**5.4090**	**3.7700**	**Median**	**23.5210**	**6.9310**	**3.9900**
21days	23.21	5.55	3.93	**21days**	23.25	5.49	4.17
	23.24	6.58	3.94		23.42	6.51	4.19
	23.77	5.61	3.95		23.68	6.39	4.21

Mean	**23.4087**	**5.9137**	**3.9400**	**Mean**	**23.4497**	**6.1273**	**4.1900**
Std. D.	**.31662**	**.57871**	**.01000**	**Std. D.**	**.21723**	**.55794**	**.02000**
Median	**23.2380**	**5.6100**	**3.9400**	**Median**	**23.4230**	**6.3860**	**4.1900**
28days	23.02	8.16	3.98	**28days**	23.05	6.30	4.42
	23.29	8.53	4.00		23.49	7.14	4.44
	23.54	7.44	4.01		23.32	5.24	4.46
Mean	**23.2823**	**8.0447**	**3.9967**	**Mean**	**23.2853**	**6.2250**	**4.4400**
Std. D.	**.26301**	**.55734**	**.01528**	**Std. D.**	**.22557**	**.95316**	**.02000**
Median	**23.2850**	**8.1620**	**4.0000**	**Median**	**23.3160**	**6.2990**	**4.4400**

100%

Curing	Weight (KG)	Load (KN)	Strength (N/mm^2)	Curing	Weight (KG)	Load (KN)	Strength (N/mm^2)
7days	23.01	9.15	4.09	**21days**	23.05	6.41	4.61
	23.12	6.09	4.11		23.34	6.46	4.64
	23.29	6.24	4.10		23.09	6.67	4.70
Mean	**23.1417**	**7.1590**	**4.1000**	**Mean**	**23.1587**	**6.5133**	**4.6500**
Std. D.	**.14093**	**1.72582**	**.01000**	**Std. D.**	**.16029**	**.13855**	**.04583**
Median	**23.1230**	**6.2370**	**4.1000**	**Median**	**23.0890**	**6.4580**	**4.6400**
14days	23.07	5.30	4.30	**28days**	23.32	7.42	4.83
	23.04	8.38	4.32		23.48	13.59	4.83
	23.05	8.92	4.34		23.01	7.32	4.86
Mean	**23.0553**	**7.5313**	**4.3200**	**Mean**	**23.2710**	**9.4400**	**4.8400**

Std. D.	**.01206**	**1.94959**	**.02000**	**Std. D.**	**.23702**	**3.59002**	**.01732**
Median	**23.0540**	**8.3750**	**4.3200**	**Median**	**23.3180**	**7.4170**	**4.8300**