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COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

COMPARATIVE STUDY OF PERFORMANCE PROPERTIES OF ORDINARY PORTLAND CEMENT (OPC) AND POZZOMIX CEMENT SANDCRETE BLOCKS

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OCTOBER, 2018

DECLARATION

STUDENT'S DECLARATION

I, ROBERT SENU KWAME, declare that this Dissertation 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 guidance for supervision of Dissertation as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR: ENG. MICHAEL K. TSORGALI

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DATE: ……..

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DEDICATION

I dedicate this work to my Uncle Simon K. Ahiavordi, children Mawuli Kudjo Senu and Delali Kudjo Senu and all family members especially YOU.

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ABSTRACT

The study compared the performance properties of OPC and pozzomix cement sandcrete blocks in existing structures. Properties like compressive, water absorption, density and weights were determined and assessed to see how they enhance performance and its effect on durability of existing structures. Field survey research and experimental research designs were employed for the study. The study sampled eleven (11) research scientists at CSIR-BRRI and thirty-five (35) building contractors working with pozzomix cement and ordinary Portland Cement (OPC). 25 pozzomix cement and 25 OPC sandcrete blocks were used for experiment at CSIR-BRRI laboratory. Questionnaire, laboratory test and observation were used as data collection instrument. Comparatively, the performance properties of OPC and pozzomix cement sandcrete blocks were inconsistent with defects in some of the structures observed. Densities of OPC sandcrete blocks were averagely higher than those of pozzomix cement sandcrete blocks with both above the standard minimum density of 1500kg/m^3 Compressive strength of OPC and pozzomix cement sandcrete blocks failed to meet the required minimum standard respectively, for all curing ages, but pozzomix cement sandcrete blocks performed better than OPC sandcrete blocks. The study further revealed that OPC sandcrete blocks have lower water absorption rate than pozzomix cement sandcrete blocks. Therefore, using both OPC and pozzomix cement sandcrete blocks for construction works will be economically, eco-efficiently and technically beneficial to Ghanaian construction industry with 18%-20% cost reduction on materials. It is recommended that the commercialisation and use of pozzomix cement sandcrete blocks can go hand in hand with OPC sandcrete blocks for all construction works with regard to standard specification in the construction industry.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Andoh (2015) reported on the launching of the National Housing Policy (NHP) in Ghana which demand the use of locally produced and available building materials like Ghana's clay pozzolana cement (pozzomix cement). Danyansah (2017) revealed that Ghana housing deficit to hit two million in the year 2018, hence the Ministry of Work and Housing confirmed that the situation required the introduction of pragmatic and deliberate policies and private sector participation to raise supply (Ghana News Agency, GNA; 2017). From Building and Road Research Institute (BRRI) of Council for Scientific and Industrial Research (CSIR) of Ghana, as stated in Sarfo-Ansah (2010) clay pozzolana cement which is now known as pozzomix cement is a supplementary cementitious material developed over 30 years is to enhance the performance characteristics of concrete mixtures and sandcrete blocks for broad spectrum of applications. In addition, Atiemo (2012) put forward that pozzomix cement made from 40% calcined clay pozzolana is designed to offer increased strength, improved workability, reduced heat evolution and enhanced alkali sulphate reaction (ASR) as well as resistance to sulphate attack or harsh chemical environments.

Quite ironically, there exist in this country these all important local materials which can be used for the production of various types of composite and alternative cements in addition to ordinary Portland cements as stated in Boakye (2012) and established adherence to standardization and quality of our sandcrete blocks. Cement consumed in Ghana is produced from imported clinker and gypsum from other countries (Atiemo, 2012). The Global Cement Report (2011) reported that since the year 2008 more than US$280 million is spent annually on clinker and cement importation in Ghana and is confirmed by Ministry of Trade and Industry Report (2008) and cited in Sarfo-Ansah (2010). Cement consumption will continue to increase because of increasing population growth and increased infrastructure developmental activities by the Government, estate developers, institutions and private individuals as revealed in Bediako, et al. (2016). According to Adzraku, et al. (2016), the making of housing cheaper through the use of locally available walling materials ranked second as a factor, since building materials constitute about 65-70% of the cost of construction. One of such building materials is sandcrete blocks.

According to Bamfo-Agyei (2011), sandcrete blocks are used extensively in many countries all over the world including Ghana in Africa. Even though there is the presence of other building materials such as wood, bricks, compressed earth and hydroform, sandcrete blocks dominate in the construction industry. The 2010 census revealed that, out of the 3.39 million housing stock in Ghana, 57.5% is made with sandcrete blocks (Ghana Statistical Service, 2014). Sandcrete block is a composite material made up of cement, sand, water, moulded into different sizes (BS 6073-1). It can be made solid, hollow or cellular in shape. It comes in different sizes based on their job specification but their sizes usually exceed the length, width, or height of sizes specified for bricks (BS 6073-1). When cured well, sandcrete blocks have high compressive strength and this strength increases with increasing density. The minimum strength requirement for sandcrete block specified by the BS 6073-1 standard is ≥ 2.8 N/mm^2. The strength of sandcrete blocks however is inconsistent due to high cost of the binder, the different production methods employed, duration of curing, sizes of blocks and the properties of constituent materials, method of mixing, mixing ratio and moulding process (Abdullai, 2005).

Adu-Boateng and Bediako, (2006); Atiemo, 1998, 2005, 2012; Boakye (2012); Sarfo-Ansah, (2010) and Sarfo-Ansah et al. (2014), observed that clay pozzolana cement (pozzomix cement) highly active cementitious material made from locally available clay all over the country. Sarfo-Ansah et al. (2014), revealed that clay pozzolana cement (Pozzomix) comes in handy as a possible solution to the economical, technical and environmental effects posed by the manufacturing of Ordinary Portland Cement (OPC). In Sarfo-Ansah et al. (2014), the over-dependence on imported Ordinary Portland Cement (OPC) is a contributing factor to the high cost of housing in Ghana. Adu-Boateng and Bediako (2006) identified that the construction industry in Ghana is generally experiencing difficulties over the years due to rising cost of building construction materials especially cement, hence the need to arrest this phenomenon.

According to Bediako and Frimpong (2013), the construction industry is a vital sector of any economy since infrastructural development forms the indicators used in measuring a country's development. The construction industry constitutes a large part of the economy of many nations with significant contribution to Gross Domestic Growth (GDP) and determining economic growth of countries (Anaman & Osei-Amponsah, 2007; Willar, 2012 as cited by Kheni and Ackon, 2015). The sector currently accounts for more than eleven percent of global GDP as in Betts et al. (2011). From Ghana Statistical Service (GSS) (2014), the sector contributed an average of 9.08 percent of GDP since 2008 and recorded relatively high growth of 11.2% in 2012 and 13.7 in 2016 as reported by GSS (2017). Given that the industry is essential for the infrastructure, its quality management shortcomings will not only affect the economy of Ghana in terms of housing infrastructure development and job creation, but will also make it impossible to achieve the Millennium Development Goals' (now, Sustainable Development Goal) that the nation is striving to attain (Kheni and Ackon, 2015). This study is to compare the performance of the properties of sandcrete blocks produced from OPC and pozzomix cement.

1.2 Problem statement of the study

Quality of sandcrete blocks in Ghana has been compromised due to some factors such as cost of cement and authorities inability to check and inspect for quality and standardization (Bamfo-Agyei, 2011). Poor construction works and disregard for building regulations, codes and standards have given rise to many buildings collapsing in the country. In a research by Acheampong et al. (2014), the cost of construction in Ghana, as in many developing countries is increasing at an exponential rate. In spite of the numerous calls by stakeholders to incorporate the use of indigenous building materials which seek to reduce cost of construction, the use of conventional building materials continues to dominate the construction industry (Acheampong, et al. 2014).

According to Boakye (2012), ordinary Portland cement (OPC) is the most widely used construction material throughout the world. Ordinary Portland Cement (OPC) is a vital construction material and also a strategic commodity (Vlasopoulos, 2010). Such is our dependence on OPC that the world currently produces nearly 3.6 billion metric tonnes of the material each year (USGS Mineral Commodities Summary, 2012), with volume predicted to rise to more than 5 billion metric tonnes by 2030 (Muller and Harnisch, 2008; OECD/IEA and World Business Council for Sustainable Development, 2009) with its economic, ecological and technical disparity. Reducing cement production while maintaining sustainable development has been an important issue in the development of construction materials. Adu-Boateng and Bediako (2006) observed that, the cost of OPC has increased over 500 percent within the last ten years in Ghana and will continue to increase in the next ten years. This phenomenon has by and large increased construction cost in Ghana.

This situation has not only generally affected the construction trends in Ghana but has seriously affected the housing situation in Ghana, bringing the national housing deficit estimated to be in excess of 1.7 million housing units (Ghana News Agency; 2017). Ghana is endowed with local raw materials for the manufacture of building materials. Since 1953, some national efforts have been made into promoting the development of alternative and durable local building materials enhanced performance with minimal environmental impacts (Atiemo, 2005). Arvaniti et al. (2015) explained that the use of pozzolanic materials play an important role in modern day concrete formation in terms of cost reduction and other technical benefits such as enhanced strength development, mitigation of thermal effect from cement and prevention of chemical attacks in concretes as well as sandcrete blocks. It is known that the use of pozzolanic materials for concrete is among the possible ways to produce sustainable concretes (Bediako et al. 2016).

Recent studies have reported that high cost of construction materials remains the most important cause of inadequate infrastructure (Ayeh, 2009; Olutoge, 2010; Sarfo-Ansah, 2010 and Atiemo, 2012). While shelter conditions in the last few decades have been worsening, resources have remained scarce and costs of building materials have escalated due to increase in population, and the urgency to provide immediate practical solutions has become more acute (Kerali, 2001).

1.3 Purpose of the study

The purpose of this research was to ensure that the effectiveness of pozzomix cement was assessed to demonstrate its performance in sandcrete blocks manufacturing.

1.4 Specific objectives of the Study

The specific objectives of the study were to:

1. Examine the performance of pozzomix cement and OPC sandcrete blocks used in existing structures in Ashanti Region.
2. Determine the mechanical and physical properties of OPC and pozzomix cement sandcrete blocks.
3. Assess the durability properties of OPC and pozzomix cement sandcrete blocks.

1.5 Research questions

The following research questions were developed to guide the study

1. What is the performance of pozzomix and OPC sandcrete blocks in existing structures in Ashanti Region?
2. How do mechanical and physical properties enhance the performance of OPC and pozzomix cement sandcrete blocks?
3. What are the durability properties of OPC and pozzomix cement sandcrete blocks?

1.6 Significance of the Study

- The outcome of the study will help the building contractors, sandcrete block manufacturers, professionals and stakeholders in the Ghanaian construction industry on the qualities of pozzomix cement as alternative to OPC in order to reduce the demand for OPC.
- Secondly, the study will contribute to knowledge and create awareness on the effectiveness of physical properties such as compressive strength, density and weight of sandcrete blocks produced from pozzomix cement to that of OPC.

- Furthermore, the results of the study will help Ghana Standard Authority, and other stakeholders to put in place the necessary policies, guidelines to ensure manufacturing of quality sandcrete blocks for construction using pozzomix cement.
- Finally, the research will serve as essential source of reference to future researchers who will be researching into this area and its related studies.

1.7 Scope of the Study

The research was limited to comparing the performance properties of Ordinary Portland Cement (OPC) and Pozzomix cement sandcrete blocks with concentration on general properties of sandcrete blocks, material constituents of sandcrete blocks, ordinary Portland cement pozzolana (pozzomix cement) and their importance to national development. The experiments were limited to few parameters such as compressive strength, weight, density, and water absorption of pozzomix cement and OPC sandcrete block. The experiments were conducted in laboratory at Building and Road Research Institute (BRRI) of Centre for Scientific and Industrial Research (CSIR) Fumesua near Kumasi.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The chapter reviews the previous researches in the field of properties of Ordinary Portland Cement (OPC) and pozzomix cements and the performance of the properties in sandcrete blocks, the contributions of pozzomix cement discovery by BRRI-CSIR to the construction industry which currently contributes 13.7 percent of Gross Domestic Products (GDP) as stated in (Ghana Statistics Service (GSS), 2017). The challenges in the manufacturing of sandcrete blocks in Ghana were reviewed in this study and other relevant topics.

2.2 General Properties of Sandcrete Blocks

Ikechukwu and Asikogu (2017) posited that characteristically for any building material component to perform its intended function, the material must be so designed and manufactured in the way to meet up with some specifications and standards. According to Oyekan and Kamiyo (2008), sandcrete blocks like any typical building components have properties (structural and hygrothermal) that are used for their classification, quality determination and hence their application. In the same study hygrothermal properties were identified as porosity, permeability, water absorption coefficient and sorptivity. Oyekan and Kamiyo (2011) pointed out compressive strength, density, permeability, porosity, sorptivity, thermal conductivity, temperature change on the hygrothermal, specific heat capacity, thermal diffusivity and thermal effusivity as properties of sandcrete blocks containing cement as binder.

Undoubtedly, the properties of sandcrete blocks have been proven to have significant relationship with their constituent ingredients and production processes confirmed in Ikechukwu (2015). Therefore, the need to link the properties of sandcrete blocks with some essential constituents. Atiemo (2012) identified cement as one essential commodity in concrete products and sandcrete blocks in the construction sector. According to Danso and Boateng (2015), cement is one of the key components of most buildings, therefore the fineness of a Portland cement and its chemical composition are the key factors in determining cement strength characteristics (Zhang & Napier-Munn, 1995 as cited by Danso and Boateng, 2015) as well as other properties and their performance. In the same research it was revealed that the quality of cement has strong linkage between particle size distribution (PSD), chemical composition and compressive strength.

In a research by Hammond (2016) the properties of cement were classified as mechanical (Standard strength of a cement is the compressive strength determined in accordance with EN 196-1 at 28 days (EN 197-1), early strength of a cement is the compressive strength determined in accordance with EN 196-1 at either 2 days or 7 days. The rest were physical and chemical properties (setting time, soundness, insoluble residue, loss of ignition and specific surface area). Other properties of cement recorded by Neville (2011) are water absorption, standard consistency, density, specific gravity, braine fineness, heat of hydration, porosity, durability, sorptivity, workability, specific heat capacity and water retentivity. Sam et al. (2013) assessed the quality of the various brands of Portland cement products available on the Ghanaian market. Their study involved the determination of the chemical oxide composition, cement compounds and the control ratios of three cement brands. Their results were compared with the requirements of EN 197 – 1. The study revealed that the quality of one of the cement types was of lower quality hence the need to ascertain the performance of the properties of cement for quality sandcrete blocks manufacturing for building constructions in Ashanti region.

Faleye et al. (2009) studied the chemical and physical properties as chemical oxide composition, setting time, loss on ignition, insoluble residue and specific surface area of some selected cements brands on the Nigerian market. According to Bediako and Amankwah (2015), the influx of cement types into Ghanaian market need to be checked even though cement manufacturing companies perform test on their products to ensure that they are of the desired quality and conforms to the requirement of the relevant national standards, it is also desirable for the users, or for an independent laboratory to make periodic acceptance test or to examine the properties of cement to be used for sandcrete blocks manufacturing and other construction works. Also, Sam et al. (2013) suggested that independent analysis can be performed to check quality of cement on the Ghanaian market conforming to Ghana Standard GS 766-2011, GS 22-2011 and EN 197-1.

2.2.1 Compressive Strength

Sogbey (2015) argues that compressive strength is the most important parameter of cement. Compressive strength is the maximum compressive stress that, under a gradually applied load, a given solid material can sustain without fracture. Compressive strength is calculated by dividing the maximum load by the original cross-sectional area of a specimen in a compression test. Some materials fracture at their compressive strength limit; others deform irreversibly. Compressive strength is a key value for designing concrete structures. The compressive strength of concrete is the most common performance measurement used by engineers when designing buildings and other structures. In the same research it was revealed that there are differences in the standards in the size of test pieces, the quality of sand, the cement: sand ratio and the water-cement ratio (w/c ratio) used in the preparation of test pieces, the kind of compaction employed, and other mixing related activities. Bediako (2009) on compressive strength of blended cement made reference to Voglis et al. (2005) which made comparative study on Portland Limestone Cement (PLC), Pulverished Fly Ash Cement (PFC), Portland Pozzolanic Cement (PPC) and Ordinary Portland Cement (OPC) using 15% content of limestone, fly ash and natural pozzolana respectively and it was concluded that PLC exhibited a higher early strength (7 days).

However, it was found that PLC recorded the lowest strength development at later ages (28-540 days). According to Ettu et al. (2013) many researchers have investigated various aspects of sandcrete blocks as a constructional material. Abdullahi (2005); Afolayan, et al. (2008) and Banuso and Ejeh (2008) found out that tested samples of sandcrete blocks in Kaduna State, Minna and Ondo state of Nigeria respectively, exhibit compressive strengths far below the recommended British standard (BS 6073-1) 2.8N/mm^2 and NIS standard of 2.5N/mm^2. Wenapere and Ephraim (2009) found out that the compressive strength of sandcrete blocks increased with age of curing for all mixes tested at the water cement ratio of 0.5. In Ghana, Baiden and Tuuli (2004) examined the impact of quality control practices by suppliers on the quality of blocks produced in the Kumasi Metropolis. Sandcrete blocks were taken from suppliers and tested for compressive strength, bulk density, water absorption, and dimensional tolerances. Fine aggregate samples were also taken from the suppliers and tested for grading, silt, and organic matter content. The study confirmed that mix ratio, quality, and mixing of the constituent materials affected the quality of sandcrete blocks. Visual inspection rather than laboratory testing was adopted as the means of ascertaining the quality by a few of the staff of contractors who had no formal training in quality control. Mix ratios used ranged from as lean as 1:8 to as weak as 1:19 (cement: sand). Blocks produced were also found to be unsuitable for use as load bearing walls. This study tried to examine how the authorities in the construction industry have over the years complied with the set standardization and quality control of the Ghana Standard Authority code.

Awolusi et al. (2015) revealed in their research that the compressive strengths of sandcrete blocks produced by the manufacturers across Lagos State are far below and do not comply with the minimum requirements of the standards. This low quality could be attributed basically to the inappropriate mix proportions used by these manufacturers. These are often accompanied by other factors such as poor quality of constituent materials in which the sand is in some cases mixed with soft sand (such as clay) to improve its binding ability. Other factors such as poor curing and bad production methods also play major role in the low quality of blocks. Okafor and Egbe (2017) stated that the compressive strength of a block is possibly one of the most important strength properties used to judge the overall quality of the block. The compressive strength is also helpful in determining other properties of block with few exceptions. It was determined by BS EN 12390-4 where the hardened block, after appropriate curing (28 days), is subjected to increasing compressive load until it failed by crushing, and determining the crushing force.

2.2.2 Density

According to Baiden and Tuuli (2004), density is defined as the measure of how many particles of an element or material are squeezed into a given space. In a research, the densities of the sandcrete blocks produced by these manufacturers satisfied the requirements of the standards while the web thicknesses of the blocks did not comply with the requirements of BS 2028:1975 and NIS 87:2004 as reported in Awolusi Soyingbe and Oyeyipo (2015). This is as a result of the fact that the correct mix ratio for the moulds is not used for the production of the blocks. The mix ratio can affect the web thickness either by reducing the thickness (leaner) and changes in volume arising from wetting and drying after curing or maintaining the thickness confirming the undesirability of rich mix ratio that conform to the right application. This study has also revealed that any block produced based on the requirements and conditions stipulated in NIS 87:2004 standards for sandcrete blocks or other relevant standards will always comply with the minimum required value of 1500kg/m^3. These blocks so produced will not be substandard but will be of high quality that can structurally sustain both their self-load and the imposed load when used as walling units in the construction of buildings.

2.2.3 Water Absorption

According to Anosike and Oyebade (2012), water absorption is the ratio of the decrease in mass of dry sample. They further stated that the rate of water absorption of aggregate influences the bond between aggregates and the cement paste, the resistance of concrete to freezing and thawing, chemical stability, resistance to abrasion and specific gravity. Water absorption rate is determined by measuring the decrease in mass of saturated block and surface dry sample. Water absorption was carried out in accordance with the requirement of BS 1881-122. It was expressed as the difference between the weight before and after immersion, expressed as a percentage of the dry weight (Okafor and Egbe, 2017).

Rodrigues et al. (2013) posited that the relationship between density and water absorption are very important in determining the good quality of a material for that matter sandcrete blocks and concrete is characterized by having minimal voids left by excess water and therefore, water absorption test for precast concrete pipes is adopted for checking the quality of concrete in terms of density and imperviousness. Cement will mix with more water than is required to eventually combine during hydration of cement paste. As such, some voids will be left behind after the hydration process that affects the strength and durability of concrete. With the presence of air voids in concrete, it is vulnerable to penetration and attack by aggressive chemicals.

The water absorption of a block is defined as the weight of water taken up by the block under given laboratory test conditions or specification, and is expressed as a percentage of the dry weight of the unit. Absorption of water depends on properties such as density, porosity and manufacturing process and practices like method of moulding, curing and mixing of constituent materials. Absorption determines the durability of concrete or sandcrete blocks. High absorption capacity causes mortar to be dry and results in incomplete hydration of cement in the mortar. Dadzie and Yankah (2015) using palm kennel shell (PKS) as partial replacement for sand in sandcrete block production, the water absorption test result indicates that up to 40% PKS replacement, the water absorption capacity of the block produced exceeds the minimum standard recommended by ASTM C55, (2011).

However, from 10% to 40% PKS aggregate replacement, the resulting water absorptions are more than the 130kg/m³ being the minimum standard water absorption density of block made of lightweight aggregates (ASTM Standard C55, 2011). Water absorption is defined as the transport of liquids in porous solids caused by surface tension acting to the capillaries. The resulting decrease in water absorption of the samples as the PKS content increases can therefore be as a result of the coarse nature of the PKS aggregates which tend to make the block porous the more its contents increases. In terms of water absorption capacity, the study revealled that sandcrete blocks produced with more than 40% PKS aggregate replacement for sand content tend to be more porous since its water absorption decreases below the 130kg/m3 recommended by the ASTM Standard

C55 (2011). Nevertheless, the 10% to 40% PKS aggregates blocks could be used in most areas where the traditional sandcrete block is recommended to be used. Also, it was found from the study that, the amount of water absorption reduces as the percentage replacement of the PKS aggregates increases.

2.3 Sandcrete Blocks

In Nigeria, Cisse and Laguerbe (2000); Abdullai (2005); Afolayan et al. (2008); Oyekan and Kamiyo (2008); Anosike and Oyebade (2012) and others tried over the years to use alternative locally available materials to improve the quality and standardization of construction materials especially the sandcrete blocks. Nevertheless, a few Ghanaian researchers Baiden and Tuuli (2004), Danso (2005) and Bamfo-Agyei (2011), worked on this important building material. Nearly 90% of both residential and institutional buildings in Ghana are constructed with sandcrete blocks (Andam, 2005). The past research conducted in the central region by Bamfo-Agyei (2011) showed dismal results for the production of sandcrete blocks with compressive strength far below the standardized strengths for construction works. With recent call from Owiredu (2015) on Ghana Standard Authority (GSA) that a comprehensive census of all these manufacturing outfits is needed in order to draw a pragmatic monitoring policy to ensure that the required quality and standards are not compromised on.

According to Nigeria Industrial standard- NIS 87:2000, sandcrete block is a composite material made up of cement, sand, water, moulded into different sizes. Sandcrete blocks can be made either in solid, hollow and cellular rectangular types. These sizes are usually 450mm by 225mm by 225mm (solid) for load bearing walls and 450mm by 150mm by 225mm (Hollow) for non-load bearing walls (Nene, 2009; BS 2028, 1364). The hollow blocks have a void that runs from top to bottom and occupy around one third of the volume of the blocks. However, solid sandcrete block does not have any void in it. Figure 2.1 and figure 2.2 show the various types of sandcrete blocks (solid, hollow and cellular).

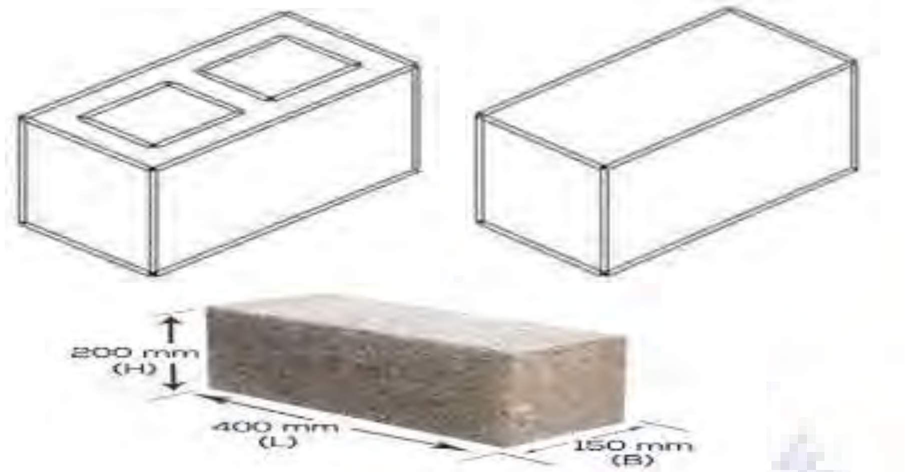

Figure 2.1: Line diagrams of types of solid and hollow sandcrete blocks from Baiden and Tuuli (2004) research work.
Source: Baiden and Tuuli (2004)

Figure 2.2: Types of special sandcrete blocks from Concrete Block Association library.
Source: (www.cba-blocks.org.uk)

Solid and hollow sandcrete blocks have been used in many nations including Ghana (Baiden and Tuuli, 2004). Sholanke et al., (2015) defined sandcrete blocks as masonry units manufactured from a mixture of cement, sand and water. Sandcrete blocks are prismatic precast units made from a mixture of cement, sand and water. This mixture is often described as cement stabilized sand. Thus sandcrete block is the product of cast in the particulate sandcrete mixture into desired block geometry under pressure or a combination of vibration and pressure for effective consolidation. It is sometimes referred to as a micro-concrete due to fine aggregate particles making up the material as compared to coarse aggregate and fine aggregate in concrete. This term has probably misled people to think of sandcrete blocks as having the same properties as concrete.

Traditionally, walls of houses have been constructed of mud but this practice is fast dwindling to obscurity since the advent of sandcrete blocks. The early history of its manufacture is not known but by the beginning of the twentieth century, it had been established as an important material in the Ghanaian building industry. Early production of sandcrete blocks started with hand-moulding technique and natural curing but it is now made by semi-mechanized and fully automatic plants as in figure 2.3 and manual operated machine in figure 2.4. Major development is seen plainly in the design and use of power operated machine for making blocks.

Figure 2.3: Automated block moulding machines from Ave Maria concrete products-Tanoso, Sunyani
Source: Researcher Field Construct, 2018

Figure 2.4: Manual block moulding machine at Ave Maria concrete products-Tanoso, Sunyani
Source: Researcher Field Construct, 2018

2.4 Raw materials for sandcrete blocks manufacturing

The raw materials for sandcrete blocks are: ordinary Portland cement, sand and water (Ikechukwu and Asikogu, 2017). Sometimes quarry dust is added to improve the strength. The water used in preparing the mortar serves three purposes:

- It combines with the cement to form a hardened paste
- It lubricates the aggregates to form a plastic and workable mass
- It aids the hydration process for strength development.

The water that combines with the cement varies from about 22 to 28% of the total amount of mixing water in the mortar Sholanke et al. (2015). Mineral aggregates (sand and quarry dust) are normally divided into two fractions based on their particle size. Aggregate particles according to BS 882:1992 passing through the Number 4 or 4.7 mm Standard sieve are known as fine aggregate. The particles retained on this sieve are designated as coarse aggregate. Natural sand is often used as fine aggregate in the manufacture of sandcrete blocks. Coarse aggregate is crushed stone chips. Crushed stone chips broken into particle sizes passing through the 4.7 mm sieve may also be used as fine aggregate.

2.5 Manufacturing process

In the manufacturing of the sandcrete blocks, hand mixing is generally employed and the materials are turned over a number of times until an even colour and consistency are attained (Goncalves and Bergmann, 2007). Oyekan and Kamiyo (2011) posited that sandcrete blocks (solid or hollow or cellular) are manufactured with the use of various means like vibrating, manual, or automated machine as shown in figure 2.3 and figure 2.4. The size of the block produced varies in size as classified by BS 2028 (1975) into three types;

- Dense aggregate blocks with density not less than 1,500 kg/m^3 with dimensions as 225 x 225 x 450mm
- Lightweight aggregate blocks for load bearing walls with density less than 1,500 kg/m^3 but not less than 625 kg/m^3.
- Lightweight aggregate blocks for non load bearing partitions with dimensions as 100 x 150 x 450mm with one-third of the volume void if the type produced is hollow sandcrete blocks commonly used for construction of buildings worldwide. The process of manufacture of cement concrete hollow blocks involves the following 5 stages:

  (1) Proportioning

  (2) Mixing

  (3) Compacting

  (4) Curing

  (5) Drying

2.5.1 Proportioning of materials for sandcrete blocks production

The determination of suitable amounts of raw materials needed to produce sandcrete blocks of desired quality under given conditions of mixing, placing and curing is known as proportioning. As per Ghanaian Standard specifications, the combined aggregate content in the mix proportion used for making sandcrete blocks should not be more than 6 parts by volume of Portland cement. The standard mix proportion is 1:6 cement-sand batching by volume or by weight BS 2028. If this ratio is taken in terms of weight basis this may average approximately at 1:7 (cement: fine aggregate). However, there have been instances of employing a lean mix as high as 1:9 by manufacturers where hollow blocks are compacted by power operated vibrating machines as stated in Bamfo-Agyei (2011). The water cement ratio of 0.62 by weight basis can be used for concrete hollow blocks.

2.5.2 Mixing of materials for sandcrete blocks production

According to Baiden and Tuuli (2004), the objective of thorough mixing of sand, cement and water is to ensure that the cement-water paste completely covers the surface of the aggregates. In the same research, mixing of materials can be done manually or mechanically. Good quality blocks are produced when mixes are thorough and uniform. For a large number of blocks, mechanical mixing is recommended; however, manual mixing can also be used where a small number of blocks are required as employed by most contractors on site in the Ashanti region. It is important to control the water content during mixing, as excessive water in the mix causes shrinkage and distortion of the blocks on drying.

2.5.3 Compacting during moulding of sandcrete blocks

The purpose of compacting is to fill all air pockets with mortar as a whole without movement of free water through the mortar. Excessive compaction would result in formation of water pockets or layers with higher water content and poor quality of the product. Semi-automatic vibrating table type machines are widely used for making cement concrete hollow blocks. The machine consists of an automatic vibrating unit, a lever operated up and down metallic mould box and a stripper head contained in a frame work.

Wooden pallet is kept on the vibrating platform of the machine. The mould box is lowered on to the pallet. The mixture is poured into the mould and evenly leveled (Okoli et al. 2008). The motorised vibrating causes the mortar to settle down in the mould. More of mortar is then raked across the mould level. The stripper head is placed over the mould to bear on the levelled material. Vibration causes the mixture come down to its limit position. Then the mould box is lifted by the lever. The moulded hollow blocks resting on the pallet is removed and a new pallet is placed and the process repeated. The machine can accommodate interchangeable mould for producing blocks of different sizes of hollow or solid blocks.

2.5.4 Curing of sandcrete blocks

Sandcrete blocks removed from the mould are protected until they are sufficiently hardened to permit handling without damage. This may take about 24 hours in a shelter away from direct sun and winds. The hardened blocks therefore are cured in a curing yard to permit complete moisturisation for at least 7 days. Water is sprinkled on the blocks to aid hydration and also to avoid quick drying which results in warping and cracks. When the blocks are cured by immersing them in a water tank, water should be changed at least every four days. The curing water is changed to prevent the water becoming cooler than the blocks or concrete products 11^{oc} to prevent thermal stresses that could result in cracking (Neville, 2011). The greatest strength benefits occur during the first three days and valuable effects are secured up to 10 or 14 days. The longer the curing time permitted the better the product.

2.5.5 Drying of sandcrete blocks

Sandcrete blocks shrink slightly with loss of moisture. It is therefore essential that after curing is over, the blocks should be allowed to dry out gradually in a shade (Ghana Standards Board, 1995) so that the initial drying shrinkage of the blocks is completed before they are used in the construction work. Sandcrete blocks are stacked with their cavities horizontal to facilitate thorough passage of air. Generally, a period of 7days of drying will bring the blocks to the desired degree of dryness to complete their initial shrinkage.

2.6 Durability of Sandcrete blocks

It is essential that every concrete structure and sandcrete block should continue to perform its intended functions, which is maintained its required strength and serviceability, during the specified or traditionally expected service life. It follows that concrete must be able to withstand the processes of deterioration to which it can be expected to be exposed (Neville, 2011). Franklin and Chandra (1972), stated that the word durability originates from the Latin word 'durabilis' which means 'lasting' and as such can be used in the context of most building material to mean resistance to weakening and disintegration.

BS 7543: 2015 defines durability as the ability of a building together with its parts to perform its required function over a period of time. Durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration to maintain its original form, quality, and serviceability when exposed to its intended service environment (Mehta and Monteiro, 2006). Zongjin (2011) define durability as most likely to relate to long-term serviceability of concrete and concrete structures. In the same book, serviceability refers to the capability of the structure to perform the functions for which it has been designed and constructed after exposure to a specific environment. Thus, it is rare for concrete structures to fail due to lack of intrinsic strength.

However, gradual deterioration, caused by the lack of durability, makes concrete structures fail earlier than their specified service lives in ever increasing numbers. The extent of the problem is such that concrete durability has been recently described as a "multimillion dollar opportunity" (Anonymous, 1988). To solve the durability problem, many researchers have conducted deep studies. The studies cover the carbonation, alkali aggregate reaction, reinforcing bar corrosion, sulfate attack, CH leaching, and freezing–thawing. Many researchers have extended their work from a single environmental factor to the coupling effects of multiple factors, including mechanical loading (Ulm et al., 2000; Sun et al., 2002; Le Bell´ego et al., 2003; Kuhl et al., 2004; Nguyen et al., 2007). As a result of durability studies, many countries have proposed durability-based design guidelines (DuraCrete, 2000; CCES, 2004; MDPRC, 2007).The durability of concrete depends, to a large extent, on its permeability and diffusivity. Permeability is defined as the property that governs the rate of flow of a fluid into a porous material under pressure (Zongjin, 2011). The permeability of concrete can be measured by determining the rate of water flow through a concrete specimen. The porosity in concrete can largely affect the permeability. The large amount of porosity in concrete resides at the interface between the aggregate and the cement paste.

In his own opinion, Kerali (2001) proposed that the definition and concept of durability should be based on three key parameters, namely: intended function of the material, the standardized conditions of its use and the time the material is required to fulfill its functions. The proposed definition was drawn from the definition of Carroll (1992), with due consideration for the intended function of sandcrete blocks as an internal and external walling unit stated that the primary desirable characteristics of walling units are strength, dimensional stability and resistance to weathering.

Webb (1988) stated that these properties are governed to a large extent by the choice of constituent materials and by the quality of the manufacturing process used in their production. The definition of durability in this regard was the 'ability of a block to sustain its distinctive characteristics under service conditions for the service lifetime of the structure. Omopariola (2014) posited that the durability of a building is to a great extent determined by the properties of the various components of the building of which sandcrete block is major.

Omopariola (2014) studied the durability of sandcrete blocks for construction. From the experimental results it was observed that the dry densities of all samples tested fell within the category of type "A" blocks according to the specification of BS 2038, (1970). The water absorption capacities of the commercial samples were higher than the control experiment, although all the samples are within the specified range and compared favorably well with recommended values for other like materials. It is obvious to deduce that the durability of sandcrete blocks depend on other factors as discussed above.

2.7 Pozzolana

The American Society for Testing and Materials (ASTM Standard C618) describes pozzolana as siliceous and aluminous mineral substance which, though having no cementitious qualities themselves, in their finely divided form, reacts with lime in the presence of water at room temperature to form compounds possessing cementitious properties.

The early known use of pozzolana dates back to the ancient times (Snellings et al. (2012). In the same research, lime-natural pozzolana mixtures were used in the masonry construction of aqueducts, bridges, retaining walls and buildings during Roman times.

These binders were strong and durable and had been used for centuries by different cultures all over the world. The invention of Portland cement in the 19th century resulted in the reduction in the use of lime-pozzolana binders. Atiemo (2012) stated that pozzolana is used in combination with Portland cement due to their additional technical benefits. Pozzolana comprises part of the cement of ancient structures in Egypt, Greek and Rome. There is also evidence to suggest that crushed pottery was used during the early Minoan period (3000-1500 B.C.) to make lime mortars (Cartwright, 2018). Clay deposits are found in all regions of Ghana (Kesse, 1985 as cited in Sarfo-Ansah, 2010) as shown in figure 2.6 that suggested that getting pozzolana in Ghana is easy.

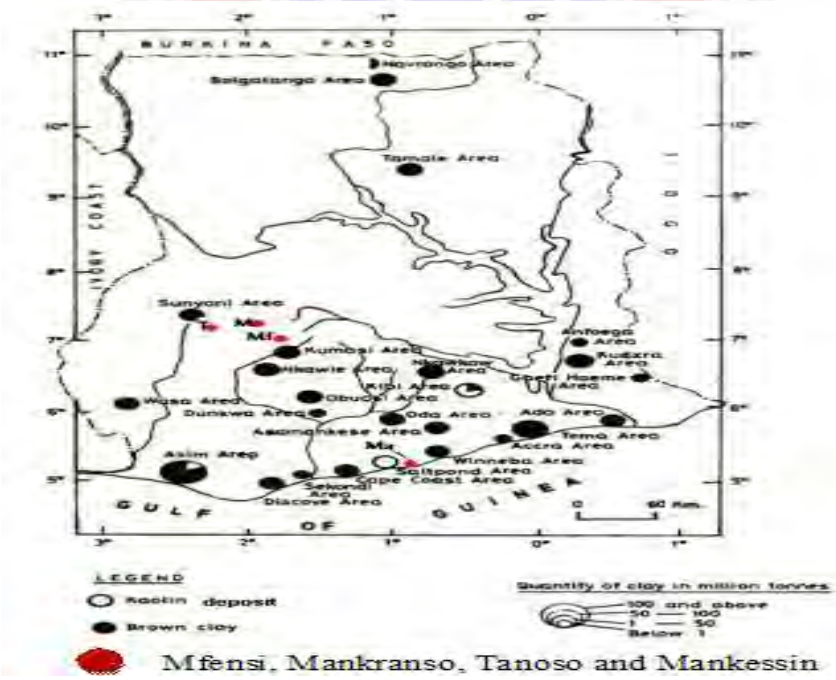

Figure 2.5: Map of Ghana showing locations of clay deposits.
Source: Kesse, 1985 as cited by Sarfo-Ansah, 2010)

In Malhotra, (1987) and Malhotra and Mehta, (1996) as cited in Boakye, (2012) the general term pozzolana is used to designate natural as well as industrial co-products that contain a percentage of vitreous silica. This vitreous (amorphous) silica reacts at ambient temperature with the lime produced by the hydration of C_3S and C_2S to form C-S-H (Malhotra, 1987; Malhotra and Mehta, 1996 as cited in Boakye, 2012). When a pozzolanic reaction takes place the lime produced into calcium silicate hydrate. This can be described as the weakness link of the hydration products of Portland cement in terms of mechanical properties and durability (lime can easily be leached out). Therefore, a pozzolanic reaction improves the intrinsic quality of the cement paste and consequently, the quality of concrete (Massazza; 1998 as cited by Sarfo-Ansah et al. 2014).

When mixed with Portland cement to produce pozzolana cement, the silica of the pozzolana combines with the free lime released during the hydration of cements. This action is called pozzolanic action. The pozzolanic activity is due to the presence of fairly divided glassy silica and lime which produces calcium silicate hydrate similar to that produced during hydration of Portland cement (ACI 201-2R, 2008). The silica in the pozzolana reacts with the lime produced during hydration of Portland cement and contributes to development of strength. Slowly and gradually additional calcium silicate hydrate is formed which fills up the space and gives impermeability, durability and ever increasing strength (Duggal, 2009). But in decreasing the permeability of the concrete, Aitcin (2008) reports that a pozzolanic reaction also decreases the vulnerability of reinforced concrete to the penetration of aggressive agents.

At ambient temperature, the development of pozzolanic reaction is much slower than the rate of Portland cement hydration, but a water-cured concrete that contains pozzolana has a strength that increases and a permeability that decreases with time (Aitcin, 2008). Pozzolana can be classified as natural and artificial. The basic classification into natural and artificial has no real or engineering purpose. With respect of economy and performance, it does not matter whether the source is "natural" or not (Day, 1990).

2.7.1 Types of pozzolana

Pozzolana can be divided into two categories namely natural and artificial as reported in Boakye (2012). The basic classification into natural and artificial has no real or engineering purpose. With respect of economy and performance, it does not matter whether the source is naturall or artificial (Day, 1990 as cited in Boakye, 2012). Naturally occurring pozzolana include clays, shales, opaline materials, volcanic tuffs and pumicites whereas artificial pozzolana are mainly obtained from industrial wastes and include fly ash, silica fume and some slags (Thevarasa et al, 1979 as cited in Eshun, 2014). Both the natural and artificial pozzolana are generally described as supplementary cementitious materials (SCMs). Pozzolana both natural or artificial according to Mertens et al. (2008) increase durability, lower the heat of hydration, increase the resistance to sulphate attack and reduce the energy cost per cement unit. Pozzolana have been used in the past as ingredients of Portland cement to construct massive civil engineering structures such as the Bhakra Dam in India Palta and Rao, (1964) as cited in Solomon-Ayeh et al. (2009) and in public and private structures in Ghana identified by Solomon-Ayeh et al. (2009).

In Ghana clay is most abundant in almost all the regions with other materials that possess pozzolanic properties (Atiemo, 2005). The "Clay Pozzolana" replaces up to 40 per cent of imported ordinary Portland cement to produce pozzolana cement for both concrete and general cement works. Initial studies on possible pozzolanic materials in Ghana were undertaken by Hammond (1987) using bauxite waste from Awaso mines and agricultural waste such as rice husk, coconut fibres, groundnut husks, sugarcane bagasse. Hammond, (1987) researched on bauxite wastes indicated that with a 20 to 30%

replacement of OPC with calcined (700-900^{0}C) bauxite wastes to mortar and concrete produces the strength comparable to those using only OPC as confirmed by studies carried out in Ghana by Atiemo (1998) with satisfactory strength are obtainable with up to 30% replacement of OPC with pulverized burnt clay showing better performance in saline atmosphere.

2.7.2 Natural Pozzolana

According to Malquori (1960) as cited by Sarfo-Ansah (2010) natural pozzolanas are of two types: the true natural pozzolanas and the pseudo natural pozzolanas. The true natural pozzolanas are ashes and lavas originating from alkalitrachytic, leucitic, leucotephritic and hauynophric types of magma. These ashes result from explosive eruptive volcanoes and are forced to solidify as a pyroclastic glass (glass fragments formed by rapid quenching of magma produced by volcanic explosions). Most natural pozzolana deposits contain more than one lime reactive constituent and that their composition and properties vary widely. Volcanic glasses such as rhyoliticpumicites, pumice and obsidian derive their lime-reactivity mainly from their very high volcanic tuff, such as zeolitic minerals, consist of volcanic glass altered under hydrothermic conditions, and derive their lime-reactivity from a base exchange reaction between calcium(lime) and alkalis in the tuff (Mehta, 2004). Within the volcanic natural pozzolana, shown in figure 2.6, there exist the more reactive materials that contain substantial proportions of zeolites.

Natural clays or shale containing substantial proportions of kaolinite-type or montmorillonite-type clay minerals, or combinations thereof, require calcinations at temperatures in the range of 540ºC to 980ºC to induce optimum pozzolanic activity. During calcinations, which may occur naturally or may need to be carried onto as part of a processing operation, the clay minerals decompose to form an amorphous or disordered aluminosilicate structure that reacts readily with lime at ordinary temperatures. Opaline materials, including diatomaceous earths and silica gel, are very reactive to lime, but typically have a very large surface area which may result in a very high water demand or requirement when these materials are used in Portland cement concrete mixtures. The reactivity of these materials is primarily dependent upon the chemical instabilities of certain phases such as volcanic glass, opal, clay minerals, zeolites and hydrated oxides of aluminum where present (Davarcioglu, 2011). These types of pozzolana are not common in Ghana.

Figure 2.6: Volcanic ash pozzolana at BRRI material laboratory
Source: Researcher Field Construct, 2018

2.7.3 Artificial pozzolana

Artificial pozzolana are those materials in which the pozzolanic property is not well developed and hence usually have to undergo pyro-processing before they become pozzolanic (Hammond, 1983). Artificial pozzolana include materials such as fly ash, blast furnace slag, surkhi (burnt clay), siliceous and opalineshales, spent oil shale (used in Sweden to make "gas concrete"), rice husk ash, burnt banana leaves burnt sugar cane stalks and bauxite waste (Grane; 1980, Lea; 1970 as cited in Bediako, 2015). Other potential materials, such as bagasse ash, laterite soils and red tropical soils which require firing to induce pozzolanicity would also presumably be classified as artificial pozzolana, but if calcination was not required then they would be a natural pozzolana. Artificial pozzolana also include industrial pozzolana (flay ash, blast-furnace slag) which are not available in suitable quantity and quality in many developing countries along with the lower-grade pozzolana which may not be appropriate for developed countries but which may be more than satisfactory for the construction of low-cost housing (e.g. bauxite waste or laterite soils).

2.7.3.1 Fly ash pozzolana

Fly ash in accordance with ASTM C618-15 (2015) collected from the flue gases of thermal plants and boilers that use powdered coal as fuel, is the most widely used artificial pozzolana in the world. The use of fly ash in the cement industry has been estimated as 70% in Australia and 40% in the United Kingdom and France each (Bin et al. 2006). The composition and properties of fly ash depend both on the coal burnt and the efficiency of the burning process. Thus, the value of the material as a pozzolana from different power stations can vary widely. The composition of the ash approximates to that of burnt clay high in alumina and iron oxide. The major constituent, about 60 – 90%, is glass with quartz (SiO_2), mullite ($3Al_2O_3 \cdot 2SiO_2$), hematite (Fe_2O_3) and magnetite (Fe_3O_4) as the more important crystalline components. The glass consists mainly of reactive silica (SiO_2) and alumina (Al_2O_3) with some amount of iron oxide (Fe_2O_3), lime (CaO), alkalis and magnesia (MgO). Some sulphate (determined as SO_3) is present together with combustible matter which is always below 10% in well-burnt materials (Lea, 1970).

The glass is the active material in fly ash with the mineral constituents being inert. Increasing SiO_2 or SiO_2 + Al_2O_3 content seems to have a favorable influence on pozzolanic value (Givi, et al. 2010). The fly ashes in figure 2.7, possessing little or no cementing value reacts with calcium oxide in the presence of water and produce highly cementitious water insoluble products. The metastable silicates present in self-cementitious fly ash react with calcium ions in the presence of moisture to form water insoluble calcium alumino-silicate hydrates.

The pozzolanic activity of fly ash depends on its fineness, calcium content, structure, specific surface, particle size distribution, and LOI content. Though one of the major uses of fly ash has been in dam construction — partly on economic grounds and partly on its influence on workability and heat evolution — it is also used in other concrete works. Thus in some countries it is used in the manufacture of ready-mixed concrete or in some classes of Portland cement (Okumu et al. 2017).

Figure 2.7: Fly ash from BRRI material laboratory
Source: Researcher Field Construct, 2018

2.7.3.2 Bauxite waste pozzolana

Bauxite waste is an artificial pozzolana obtained by firing the waste materials from the manufacture of aluminum. Bauxite waste consists of about 50% alumina, 14% silica, 30% ferrite and if ground to a fineness of about 5000cm2/g has pozzolanic properties (Figure 2.8). The minerals present are meta-kaolinite, anatase, hematite, titanium oxide, aluminum oxides and hydroxides (Bediako and Atiemo, 2014).

Calcination of bauxite waste from Ghana results in the minerals gibbsite, boehmite and diaspore (Von-Kiti, 2016).

Figure 2.8: Bauxite wastefrom BRRI material laboratory
Source: Researcher Field Construct, 2018

2.7.3.3 Rice husk ash pozzolana

Rice husk is an agricultural residue obtained from the outer covering of rice grains during milling process. It consists of 40-50% cellulose, 25-30% liguin, 15-20% silica and 8-15% moisture (Mehta, 1992). Rice husk ash in figure 2.9 is generated by burning the husk. On burning, cellulose and liguin are removed leaving behind the silica ash. The ash produced by controlled burning of the rice husk between 550ºC and 700ºC incinerating temperature for 1 hour transforms the silica content of the ash into amorphous phase. The ash so produced is pulverized to required fineness and mixed with cement to produce blended cement. Rice husk ash reactivity is attributed to its high content of amorphous silica, and to its very large surface area, governed by the porous structure of the particles.

As a byproduct of the combustion of rice husk to generate energy, rice husk ash (RHA) is formed by silica and carbon, apart from small amounts of other constituents. Several treatments can be used to increase the purity of the silica obtained, or even produce pure silica. Amorphous silica can be produced by maintaining the combustion temperature below 500ºC under oxidizing conditions for prolonged periods or up to 680ºC with a hold time less than 1 minute (Mehta, 1992). Kartini, (2011) pointed out that in this century, the utilization of rice husk ash (RHA) as cement replacement is a new trend in concrete technology. Besides, as far as the sustainability is concerned, it will also help to solve problems otherwise encountered in disposing of the wastes (Chandra, 1997). Disposal of the husks is a big problem and open heap burning is not acceptable on environmental grounds, and so the majority of husk is currently going into landfill. The disposal of rice husks creates environmental problem that leads to the idea of substituting RHA for silica in cement manufactured. The content of silica in the ash is about 92-97%.

Research had shown that small amounts of inert filler have always been acceptable as cement replacements, what more if the fillers have the pozzolanic properties, in which it will not only impart technical advantages to the resulting concrete but also enable larger quantities of cement replacement to be achieved. There are many advantages in using pozzolans in concrete, and they are; improved workability at low replacement levels and with pozzolans of low carbon content, reduced bleeding and segregation, low heat of hydration, lower creep and shrinkage, high resistance to chemical attack at later ages (due to lower permeability and less calcium hydroxide available for reaction), and low diffusion rate of chloride ions resulting in a higher resistance to corrosion of steel in concrete (Krishna, 2008). Studies by Kartini (2011); Gambhir (2006); Mehta (1992) had showed the outstanding technical benefit of incorporating cement replacement materials (RHA) in which it significantly improves the durability properties of concrete. These properties are difficult to achieve by the use of pure Portland cement alone.

Figure 2.9: Rice husk ashfrom BRRI material laboratory

Source: Researcher Field Construct, 2018

2.7.3.4 Calcined clay pozzolana (pozzomix cement)

The use of calcined clay in concrete dates back to the Phoenician times. When clay is calcined at a temperature of 700 to 750 ºC, the clay is dehydrated and its crystalline structure is totally disorganized. In doing so the water molecules are driven off and a quasi-amorphous material, relative with lime is obtained. Silica tetrahedral becomes active so that they can react at ambient temperature with the lime liberated by the hydration of C_3S and C_2S (Massazza 2004). However, the addition of calcined clay increases the water demand in concrete. In composition, most calcined clay pozzolana contains silica (SiO_2) in excess of 50% as the most active constituent. Other important constituents are the alumina (Al_2O_3) and hematite (Fe_2O_3) (commonly referred to as total R_2O_3) which usually exceeds 20%. An important criterion for a good burnt clay pozzolana as well as most other pozzolana in terms of constituents is that the sum of SiO_2, Al_2O_3 and Fe_2O_3 contents should exceed 70% (Lea, 1970 and ASTM C 618). Calcined clay normally produces binder paste with a higher normal consistency value than the normal cement (Bediako et al, 2012, Bediako and Osei Frimpong, 2013).

Research done with various Ghanaian clay deposits has shown that such clay pozzolana when milled to cement fineness can replace up to 30% of ordinary Portland cement in structural applications. These clay pozzolana-cement mixes have been successfully used for various housing construction projects in Ghana (Atiemo; 2005 and Sarfo-Ansah, 2010). Figure 2.10 shows a sample of pozzomix cement from Ghana.

Figure 2.10: Calcined clay pozzolana (now called pozzomix cement) from BRRI material laboratory
Source: Researcher Field Construct, 2018

2.8 Importance of clay pozzolana (pozzomix cement)

Jayawardane et al. (2012) after their findings on the physical and chemical properties of fly ash based Portland Pozzolana Cement (PPC) checked whether they satisfied the requirements given in ASTM C 150. According to their results, the cement certified to be called blended cement. Some of the properties worked on were compressive strength, fineness, soundness, setting time, and specific gravity, loss on ignition, and insoluble residue as physical properties of cement and chloride content. According to the measured physical properties and chemical composition of fly ash based Portland pozzolana cement manufactured by Tokyo Cement, it was found that the fly ash based blended cement has the properties that are required for a cement to be called “blended cement”. As the blended Cement reduces CO2 emission, and improves strength, workability, and durability it will be very effective in green building construction (Jayawardane et al. 2012). In a research, substitution with locally available material (pozzomix cement) up to 30% will greatly reduce 20% cost of cement production with clinker importation by 15 % to save Ghana US$30million annually. Studies on the pozzolanic activity of some clay samples in Ghana for housing construction carried out recently by Sarfo-Ansah (2010), Atiemo (2004, 2012) and Momade and Atiemo; 2004), showed that in 28 days, the compressive strength of pozzolana cement mortar up to 30% satisfied the class 32.5R cement as recommended by EN197-1 (2000) for concrete works and general construction.

Ghassan et al. (2006) found that pozzolana usage reduced heat of hydration damage and increased strength. Natural pozzolanas reduce heat of hydration anywhere from 10-40% during the first 100 hours, depending on the ultimate mix design, therefore lowering the threat of thermal cracking and allowing for a cooler controlled set. After 100 hours the cement-water hydration process wanes while the pozzolana mixes continue to hydrate until one of the two remaining hydration agents. Calcium hydroxide or natural pozzolana has been consumed. This slows down pozzolanic hydration process for months and even for years, bringing the long term strength of natural pozzolana based concrete well beyond that of OPC concretes.

Also, Bunici and Aksogam (2006) viewed pozzolana to inoculate against chemical attacks. When the chlorides (CH) migrate out of the concretes' interior capillary action, it leaves behind a maze of porosity that both weakens the concrete and allows for the future ingress of water. This infiltrating water can contain sulphates, chlorides and other damaging chemicals. In cold climates, the invasive water will freeze, causing freeze-thaw damage to the concrete. Natural pozzolana are so effective in consuming the problem-causing CH to boast concrete high sulphate resistant. According to the same research, natural pozzolana contributes to a concrete matrix so densely packed that liquid and gas cannot penetrate to cause the steel to corrode.

Furthermore, as concrete hardens, natural pozzolana readily react with calcium hydroxide as it becomes available, trapping any present alkali inside the densified cement paste, which alleviates capillary action and virtually eliminates Alkali-Silica Reaction (ASR) and efflorescence (Rodriguez-Camacho and Uribe-Afif, 2002). Natural pozzolana will mitigate and eliminate unslightly efflorescence. According to Eshun et al. (2018), pozzolana are free of crystalline silica and other hazardous materials as confirmed by research scientists from BRRI-CSIR, Bediako and Atiemo (2014) that while cement is saddled with occasional variability in their chemical and physical properties, a carefully mined and refined natural pozzomix cement is environmentally safe and consistent choice with no health issues.

Finally, Freedar and Tensing (2010) and Ghrici et al. (2007) elucidated in their research that pozzolana reduces carbon footprint up to 40 percent as Supplementary Cementitious Materials (SCMs) while enhancing its performance and durability and significantly increasing both high early and long-term strength workability in mortar and concrete.

2.9 National development and pozzolana industry

Ghana needs a paradigm shift from the monopoly of cement as the binding agent in the construction industry. In Odeyemi et al. (2015), housing is one of the requirements of man; the ambition of all people to own or have access to decent shelter is not a luxury but a necessity. Different materials are used around the globe for housing especially for walling as specified in (Ajagbe et al. 2013). Freestanding walls and building structures with load bearing walls are common in Africa because they are simple to construct and easily affordable. According to Odeyemi et al. (2015), sandcrete blocks and skin panels can sometimes be used to provide aesthetic value to buildings and also, when adequately prepared, to control moisture infiltration and wind action. This utility value of sandcrete in comparison to its cost and its adaptability to climatic factors is responsible for its wide application; most especially in small to medium buildings in countries within tropical rainforests where a considerable amount of precipitation and high average temperatures are predominant (Omoregie, 2012). Omoregie (2012) identified that sandcrete blocks are used predominantly in partition or load bearing walls. They transmit structural loads from overlaying structural element down to foundations for stability. For this reason, Omoregie (2012) posited that sandcrete blocks are globally considered appropriate and very adaptable in the building materials industry.

However, the majority of sandcrete blocks used in developing countries, especially sub-Sahara Africa, have fallen short of the local and global specification standard as revealed in Bamfo-Agyei (2011) and Odeyemi et al. (2015). Quality and standardization of sandcrete blocks are of paramount importance in the study of building components as housing is one of the basic requirements of man. This will serve as basis for measurement, reflecting the level of development attained by a nation. Significantly, the use of locally available material pozzomix cement is the answer that guarantees quality; reduce cost of housing delivery (Ahadzie, 2010) and make life comfortable.

Bediako and Frimpong (2013) posited that the importance of pozzolanic materials in construction could be viewed from three different angles for sustainable development; economic, ecological and technical. In the economic sense, the production of pozzolanic materials is far less expensive than OPC. Bediako et al. (2016) confirmed that cement use in Ghana has grown from 2.6 million tons in 2005 to 6 million tons in 2015, representing about 130 per cent. “Cement consumption has always been increasing every year, an average of 6-7 percent". According to Atiemo (2016), this has resulted in high cost of housing. The price of 50 kilogram (kg) bag of cement has consistently gone up over the years; from equivalent of Gh₵5.20 in 2000 to Gh₵33.00 currently (Ghacem.com).

Government currently spends, at least, 350 million dollars every year to import about 85 per cent of cement materials. Research and development activities by CSIR-BRRI have proven that calcined (burnt) clay can replace up to 40 per cent of cement for concrete works and general construction. From the ecological perspective, Bediako et al. (2016) opined that pozzolanic materials contribute little effects to the environmental hazards as compared with cement production in terms of CO_2 emissions and promote climate change with greenhouse effects. The Kyoto Protocol which came into being in 1997 highlights the principles of Clean Development Mechanism (CDM) (UNEP Collaborating Centre on Energy and Environment). CDM allows emission reduction in developing countries like Ghana. In contributing to the global net effects of CO_2 emission, then the need to use more pozzolanic materials like pozzomix cement in Ghana and less of cement to achieve this aim. Atiemo (2012) observed that since pozzomix cement refines pore structure of cement by making it denser, it will mean that there will be reduction of chemical attacks, early shrinkage and minimize the leaching action of cement compounds.

2.10 Portland Cement

According to Bediako and Amankwah (2015), Portland cement is the most commonly utilized cement in almost every part of the world including Ghana. The mixture was ground beaten or rolled to a fine powder and the name Portland cement was given to it due to the resemblance of its colour after setting to Portland stone (Meo, 2004). The understanding of the embodiment of Portland cement could lead to a more sustainable concrete and mortar design. It chemically reacts with water to attain setting and hardening properties when used in the construction of buildings, roads, bridges, and other structures. Portland cement was patented by Joseph Aspdin in 1824 and was named after the cliffs on the isle of Portland in England, (Kosmatka, Kerkhoff, and Panarese, 2002).

The production of Portland cement is heating raw materials with an appropriate chemistry, usually mixture of limestone and clay to a temperature between 1400ºC and 1600ºC, (Lea, 1970: cited by Bediako and Amankwah, 2015). Calcareous substances are of calcium oxide origin usually found in limestone, chalk, or oyster shells whereas argillaceous substances are of silicate and aluminate origin predominantly found in clays, shale, and slags, Mamlouk and Zaniewski (2006). The calcination process between well-proportioned argillaceous and calcareous substances leads to the production of clinker. Portland cement is obtained when the produced clinker is mixed together with a predefined ratio of gypsum and milled together in a ball mill.

2.10.1 Chemical composition of Portland cement

In Bediako and Amankwah (2015) the performance of Portland cement in concrete or mortar formation is very well influenced by chemical compositions among other factors. The chemical composition of Portland cement involves both major and minor oxides (Punmatharith et al. 2010). Some modern cement specifications, such as EN 197-1, also permit adding up to 5% limestone in the course of clinker grinding. The calcium sulfate, which is commonly described as gypsum, controls the rate of set and influences the rate of strength development. Ordinary Portland cement is composed mainly of the four clinker minerals, namely, tricalcium silicate, $3CaO.SiO_2$ (C_3S); dicalcium silicate, $2CaO.SiO_2$ (C_2S); tricalcium aluminate $3CaO.Al_2O_3$ (C_3A); and tetracalciumaluminoferrite (C_4AF) to which 3-5% gypsum ($CaSO_4.2H_2O$) is added. Chemically, CaO, SiO_2, Al_2O_3 and Fe_2O_3 constitute about 80% of ordinary Portland cement. The other significant minor oxides are MgO, SO_3, K_2O, and Na_2O. Although the amounts of these oxides are relatively small, they affect the hydration process of ordinary Portland cement (OPC) and the composition of hydration products (Lea, 1970). The clinker typically has a composition in the region of 67% CaO, 22% SiO_2, 5% Al_2O_3, and 3% Fe_2O_3, and 3% other components. Cement clinker particles are multiphase solids. Each phase has a specific reaction with water to produce a range of hydration products.

Alite is the most important constituents of all normal Portland cement clinkers, of which it constituents 50-70%. It is tricalcium silicate (Ca_3SiO_5) modified in composition and crystal structure by ionic substitutions. It reacts relatively quickly with water, and normal Portland cements is the most important of the constituent phases for strength development; at ages up to 28 days. It is by far the most important. Belite constitutes 15-30% of normal Portland cement clinkers. It is dicalcium silicate (Ca_2SiO_4) modified by ionic substitutions and normally present wholly or largely as polymorph. It reacts slowly with water, thus contributing little to the strength that occurs at later ages. Aluminate constitutes 5-10% of most normal Portland cement clinkers. It is tricalcium aluminate ($Ca_3Al_2O_6$), substantially modified in composition and sometimes also in structure by ionic substitutions.

It reacts rapidly with water, and can cause undesirably rapid setting unless a set-controlling agent, usually gypsum, is added. Ferrite makes up 5-15% of normal Portland cement clinkers. It is tetracalciumaluminoferrite (Ca_2AlFeO_5), substantially modified in composition by variation in Al/Fe ratio and ionic substitutions. The rate at which it reacts with water appears to be somewhat variable, perhaps due to differences in composition or other characteristics, but in general is high initially and low or very low at later ages.

2.10.2 Hydration of Portland cement

The chemical reaction between cement and water is known as hydration of cement. The reaction takes place between the active components of cement (C_4AF, C_3A, C_3S and C_2S) and water. The factors responsible for the physical properties of concrete are the extent of hydration of cement and the resultant microstructure of the hydrated cement. When the cement comes in contact with water, the hydration products start deposition on the outer periphery of the nucleus of hydrated cement. This reaction proceeds slowly for 2-5 hours and is called induction or dormant period (Duggal, 2009). The induction period is caused by the need to achieve a certain concentration of ions in solution before crystal nuclei form from which the hydration products grow (Young et al. 2003). As the hydration proceeds, the deposit of hydration products on the original cement grain makes the diffusion of water to unhydrated nucleus more and more difficult, consequently reducing the rate of hydration with time. At any stage of hydration, the cement paste consists of gel (a fine-grained product of hydration having large surface area collectively), the unreacted cement, calcium hydroxide, water and some minor compounds.

The crystals of the various resulting compounds gradually fill the space originally occupied by water resulting in the stiffening of the mass and subsequent development of the strength. The product C–S–H gel represents the calcium silicate hydrate also known as to bermorite gel which is the gel structure. The C–S–H phase makes up to 50% - 60% of the volume of solids in a completely hydrated Portland cement paste and is, therefore, the most important in determining the properties of the paste. The lime thus produced is a source of weakness in cement products, especially concrete for several reasons. The free lime has a low strength and poor stability — leading to lower strength and less durability of cement paste and concrete (Pu, 1999). The free lime, on account of its low stability, is also easily attacked by sulphate solutions. Additionally, by a preferential growth in one direction in the presence of water, the free lime crystals may cause unsoundness in cement products especially in mass concrete leading to disruptions and failure of structures, several years after setting (Lea, 1970).

The Ca $(OH)_2$ liberated during the silicate phase crystallizes in the available free space. The calcium hydroxide crystals also known as Portlandite consists of 20-25% volume of the solids in the hydrated paste. The calcium hydroxide crystals formed in the process dissolve in water providing hydroxyl in water providing hydroxyl (OH^-) ions, which are important for the protection of reinforcement in concrete. As hydration proceeds the two crystal types become more heavily interlocked increasing the strength, though the main cementing action is provided by the gel which occupies two-thirds of the total mass of hydrate.

2.11 Cement industry in Ghana

Cement is a basic building material that will continue to be in demand far into the future. A world without cement is hard to imagine. OPC is vital construction material and also a strategic commodity (Vlasopoulos, 2010). The world currently produces nearly 3.6 billion metric tonnes of cement each year, (USGS Mineral Commodities Summary, 2012) with volume predicted to rise to more than 5 billion metric tonnes by 2030, (Muller and Harnisch, 2008; OECD/IEA and World Business for Sustainable Development, 2009). In Ghana, Bediako et al. (2015) indicated that the major problem with regard to the Ghanaian cement industry is the dependence of cement manufacturers such as Ghana Cement Company Limited (Ghacem), West Africa Cement Factory Limited (Wacem), Diamond cement, Dangote cement and Cemaf cement on the market import of clinker and gypsum which is the main ingredients for cement production. In other words, these manufacturing companies and other brands in the market do not produce clinker and gypsum in Ghana on their own.

According to Meo et al. (2008), occupational exposure to cement dust can cause various health problems. General clinical manifestations of cement workers due to exposure to cement dust includes chronic cough, phlegm production, impairment of lung function, chest tightness, bronchial asthma, restrictive lung disease, skin irritation, stomach ache, watery and itching eyes, headache, boils, fatigue as well as cancers of the lung, stomach and colon (Oleru, 1984; Johansson et al 1992; Rafnsson et al. 1997). About 50% of the CO_2 produced during cement manufacture is due to fossil fuel consumption and the rest due to the calcination of the limestone (Claus and Guimaraes, 2007). The cement industry accounts for 5 – 8% of global CO_2 emission. This makes the cement industry the second largest producer of this greenhouse gas (Scrivener and Kirk, 2007). Also the chemicals released as a result of Portland cement manufacture can cause serious environmental impact such as greenhouse effect and acid rain (Dongxu et al. 2000).

2.12 Performance of pozzomix cement as against OPC

In Portland cement concrete, clay pozzolana (metakaolin) reacts at normal temperatures with calcium hydroxide in cement paste to form mainly calcium silicate hydrates (C-S-H), C_2ASH_8 (gelignite hydrate) and C_4AH_{13} (Tetracalcium aluminate hydrate). The formation of secondary C-S-H by this reaction reduces total porosity and refines the pore structure, improving the strength and impermeability of the cementitious matrix (Siddique and Khan; 2011). The optimum replacement percentage of cement with clay pozzolana is associated with the changes in the nature and proportion of the different reaction products, temperature, and reaction time. Hydration reaction depends upon the level of reactivity of pozzolana in terms of the processing conditions and purity of feed clay. The feed clay (kaolin) should be either naturally pure or refined by standard minerals processing techniques; otherwise the impurities would act as diluents (Kostuch et al. 1993).

Reactivity level of clay pozzolana (metakaolin) can be determined by Chapelle test (Asbridge et al. 1994). It is expressed as consumption rate of calcium hydrate per gram of pozzolana. The amount of CH in hardened concrete can be determined by thermogravimetric analysis (TG) and differential thermal analysis (TGA) Kostuch et al; (1993) observed that (1) CH was significantly reduced with age for all replacement levels (0, 10, 20%); and (2) 20% by metakaolin was required to fully remove all the CH in concrete at 28 days.

2.13 Effect of pozzomix cement on the properties of sandcrete blocks

Oyekan and Kamiyo (2008) also studied the effect of rice husk ash on some engineering properties of sandcrete blocks. Per their observation, rice husk ash does not appreciably enhance the compressive strength of the conventional sandcrete block. The blocks actually decreased in strength as the rice husk ash content in the mix increased. At a mix proportion of 1:8 and for 450 × 150 × 225 mm blocks, the compressive strength of the sandcrete blocks increased at 5% RHA content in the mix. Oyekan and Kamiyo (2008) observed that all the blocks containing RHA were more porous than the control block. Blocks containing 30% RHA were found to be more porous than that containing 10% RHA. The inclusion of RHA also produced sandcrete blocks which were lighter in weight than the control. The density of the blocks actually decreased as the percentage of RHA in the mix increased.

There is the need to produce sandcrete blocks from another alternative material (pozzomix) and compare the performance of the properties with that of the OPC. Oyetola and Abdullai (2006) argued that sandcrete has been in use throughout West Africa for over 5 decades as a popular building material for preparation of building blocks and bricks. They posit that it is predominantly used and suitable for load and non-load bearing walls, or for foundations. The material constituents, their mix, presence of admixtures and the manufacturing process are important factors that determine the properties of sandcrete blocks. In Nigeria, 95% of walling materials in buildings are made of sandcrete blocks Chandrasekhar et al. (2003) and 57.5% is made with sandcrete blocks in Ghana (GSS, 2017). Anwar et al. (2000) put forward that sandcrete walls have adequate strength and stability, provide good resistance to weather and ground moisture, durable and easy to maintain. They also provide reasonable fire, heat, airborne and impact sound resistance. As material for walls, its strength is less than that of fired clay bricks, but sandcrete is considerably cheaper. Chandrasekhar et al. (2003) argued that sandcrete is the main building material used for the construction of walls of most post-independent buildings and the blocks are the major cost component of the most common buildings. Oyekan and Kamiyo (2011) opined that hollow sandcrete blocks containing a mixture of sand, cement and water are used extensively in many countries of the world especially in Africa. The high and increasing cost of constituent materials of sandcrete blocks has contributed to the non-realization of adequate housing for both urban and rural dwellers.

Hence, availability of alternatives to these materials especially the binder for construction is very desirable in both short and long terms as a stimulant for socio-economic development (Atiemo 2012). Materials that can complement cement in the short run, and especially if cheaper, will be of great interest. Oyekan (2001) argued that over the past decade, the presence of mineral admixtures in construction materials has been observed to impart significant improvement on the strength, durability and workability of cementitious products. The author added that in the areas prone to flood, hydrothermal properties of the construction materials are of importance. Also, energy requirements for residential and commercial buildings are known to be influenced by building design and by the materials used.

Nair et al. (2006) posited that in both temperate and tropical regions, thermal properties of building materials are of significant importance to the determination of the heating or cooling load within the building and hence the capacity of the mechanical equipment required in handling the load. This is necessary to provide a given level of thermal comfort within the building and over the annual climatic cycle. Substitution with admixtures is aimed at enhancing at least one of the properties of the block and environmental friendliness. Pozzomix cement is highly pozzolanic from Ghana and very suitable for use in construction works and for Portland cement replacement. Effect of blended cement on the strength and permeability properties of concrete has been investigated by (Ganesan et al. 2008). On sandcrete block, Cisse and Laguerbe (2000) observed that the mechanical resistance of sandcrete blocks obtained when unground ash resulted to increase in performance over the classic mortar blocks.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents details of the methodology for conducting the study. It discusses the research design, population of the study, sampling and sampling technique employed, data collection instrument and data collection procedure described. It also discusses the materials used for this study, these include: ordinary Portland Cement (OPC) types, Pozzomix cement and ordinary pit sand.

3.2 Research Design

The study adopts survey research design which seeks to obtain views from building contractors and research scientists in Kumasi Metropolis. In addition, experimental research design was employed in determining the mechanical and physical properties such as compressive strength, density and weight of sandcrete blocks produced from pozzomix and OPC, and the water absorption of sandcrete blocks produced from pozzomix and OPC.

3.3 Site survey and familiarization visit

The researcher visited CSIR-BRRI to familiarize with the research scientists in charge of the laboratory for the experiment in order to get firsthand information on pozzomix cement products. The aim was to identify the required and relevant population for the study. At the research centre at Fumesua near Kumasi, the laboratory technician took time to introduce the researcher to the various experiments undertaken in the laboratory and how they go about their experimental procedures. Other information received from the CSIR-BRRI revealed the different types of contractors working on projects in the metropolis. With this information from the marketing department of CSIR-BRRI, the researcher was able to identify the various contractors and their sites for a visit especially those who work with both Ordinary Portland Cement and Pozzomix cement. During the visit photographs were taken of projects under construction and those projects that have been completed are displayed in Appendix A.

3.4 Population

Contractors working on projects in the Kumasi Metropolis and its environs and research scientists were the targeted population, but after the researcher's site survey and familiarization visit, it was clear that majority of the target population did not have any knowledge about pozzolana or pozzomix cement in the market for construction. However, the population of the study comprised building contractors working with both pozzomix cement and ordinary Portland cement (OPC) at the various construction sites in Ashanti Region, research scientists working at CSIR-BRRI and sample sandcrete blocks manufactured from pozzomix cement and OPC for laboratory experiment from construction sites by the researcher.

3.5 Sampling Technique and Sample Size

Purposive sampling technique which is a non-probability sampling method was used for the study. This technique was employed for the study to identify the contractors who use both pozzomix cement and OPC for their construction works and to get the information needed for the study. Considering the purpose of the study, thirty-five (35) building contractors and their construction sites, and eleven (11) research scientists working on pozzomix cement and ordinary Portland cement at CSIR-BRRI were used for the study. These contractors have different sites scattered all over the metropolis and its environs. The researcher collected 25 blocks totaling 50 sandcrete blocks moulded from pozzomix cement and OPC respectively for laboratory experiment.

3.6 Data collection technique and instrument

Data for the study were obtained from observation, open and close ended structured questionnaires and laboratory experiment. Other sources used were literature and documentary searching on standards.

3.6.1 Observation and Visit

The personal visit and participatory observations were undertaken to the various construction sites that have been identified and selected for the study based on the simple reason that the use of both ordinary Portland cement and pozzomix cement for their works under the Kumasi metropolis and its environs. Initially, the visits were undertaken to the construction sites to familiarize with the construction practices and processes especially with the manufacturing process involved in sandcrete blocks. This forms the basis upon which subsequent visits and observations were made on the following schedules:

- Identification of the structures under construction and those that have been completed.
- Examining the process involved in getting materials for the sandcrete blocks especially sand, water and cement.
- Physical observation of the quality of sand and water for the moulding of the sandcrete blocks.
- Observation of the process involved in the manufacturing of sandcrete blocks on site.
- Observation of the laid down standard for the manufacturing process.

- Observation of practices after moulding the sandcrete blocks (curing, testing, stacking and usage).

3.6.2 Questionnaires

Questionnaires were designed and developed to allow the respondents the opportunity to select the responses from the options and express their opinion on issues such as demographic, the performance of ordinary Portland cement (OPC) and the performance of pozzomix cement in sandcrete blocks used in existing structures as shown in Table 3.1

Table 3.1: Composition of the questionnaires for the survey on OPC and pozzomix cement sandcrete blocks

S/N	Section of the questionnaire	Concept Measured
1	Section A	Demographic characteristics of respondents
2	Section B	The performance of the properties of ordinary Portland cement sandcrete blocks
3	Section C	The performance of the properties of pozzomix cement sandcrete blocks

Source: Researcher Field Construct, 2018

The questionnaires were self administered by the researcher to the contractors and research scientists at the CSIR-BRRI. These groups were selected based on the direct roles they play with pozzomix cement and ordinary Portland cement. The distribution was done as in Table 3.2.

Table 3.2: Distribution of questionnaires to participants

S/N	Names of Participants	Number of Participants	Number Retrieved
1	Contractors	35	30
2	Research Scientists	11	11
3	**Total**	**46**	**41**
4	**Percentages (%)**	**100%**	**89%**

Source: Researcher Field Construct, 2018

3.7 Materials for the manufacture of the sandcrete blocks for the experiment on the properties of the pozzomix cement and OPC

3.7.1 Ordinary Portland cement (OPC)

Ordinary Portland cements from Dangote Cement, Ghacem cement and others of Class 32.5R that conformed to (GS 22 (2005) and EN 197- 1) were used for the manufacturing of the sandcrete blocks.

3.7.2 Pozzomix cement

Pozzomix cement of class 32.5N manufactured by CSIR-BRRI as shown in figure 3.1 in accordance with Ghana Standard and International Standards (GS 803; 2009 and GS 964 and ASTM C618 specifications), was also used for the sandcrete blocks manufacturing.

Figure 3.1: Sample of pozzomix cement from BRRI- CSIR Fumesua near Kumasi
Source: Researcher Field constructs 2018

3.7.3 Pit sand

Ordinary pit sand from local suppliers as shown in figure 3.2 in the Ashanti region was used for the mortar mixes and their quality assessment physically shows that they do not satisfy the BS 4550: Part 6 requirements. Sand which is an extremely needful material for any construction is the product of natural or artificial disintegration of rocks and minerals. Clean sharp sand, free from waste stone and impurities are supposed to be used in the production of the sandcrete blocks but that was not the case identified by this research work.

Figure 3.2: Sample sand for manufacturing pozzomix cement and OPC sandcrete blocks at Aprade construction site
Source: Researcher Field construct 2018

3.7.4 Water

Water used for moulding the sandcrete blocks in this study was drinkable, clean and free from deleterious substances as specified by Ghana Standard (GS).

3.8 Manufacturing of pozzomix cement and OPC Sandcrete blocks

The site to be used for moulding the blocks was already cleared of any weed or unwanted materials to make it accessible. With the assistance of site foremen, the supervision and monitoring was done on all the sites for the moulding of the blocks. A single chamber manual block moulding machine as shown in Figure 3.3 was used for the moulding. The mixture of cement and sand was done with no regards to laid down mix ratio standard which is 1:6. Mixing was done thoroughly on the ground using a shovel. No definite water - cement ratio was used in all the sites visited, water was being added randomly as deemed fit by the block manufacturers until workability was achieved. The semi-dry mortar mixture was placed in the moulding machine and pressed into shape as demonstrated in Figure 3.3. The moulded block was removed and dried in open space as shown in figure 3.3. The process was repeated until the desired quantity of blocks was attained. Curing was done by sprinkling water on the blocks the following day for 3days. Blocks manufactured were covered with a black polythene sheet to prevent rain falling on the blocks and also to ensure that the blocks did not lose moisture quickly and thereby avoiding warping and cracking. After 7days, the blocks for the experiment were parked and transported to the centre for the experiment.

Figure 3.3: Pressing of cement and sand mixture in the manual moulding machine to manufacture pozzomix cement and OPC sandcrete blocks at Aprade construction site
Source: Researcher Field construct 2018

3.9 Experiment to determine the various properties of the sandcrete blocks

3.9.1 Measurement of the dimension and weights

In determining the dimension and weight of sandcrete blocks, steel tape measure and top pan balance as in Figure 3.4 were used to check the lengths, widths and thicknesses and weight respectively of the block samples and the result was recorded. The weighing of the blocks guided the researcher to group the blocks for other properties to be determined.


Figure 3.4: Top pan balance and Steel tape measure for measuring the dimensions and weight of pozzomix cement and OPC sandcrete block samples at CSIR-BRRI Civil Engineering Laboratory
Source: Researcher Field construct 2018

3.9.2 Determination of density

The first durability parameter measured on the manufactured blocks was the density. Compatibility of the constituents of the blocks has a good bearing on durability hence the need to determine the density of the block specimen. The more closely packed the particles in the sandcrete blocks, the higher the density of the blocks as stipulated in the Ghana Standard (GS 297; 2010) and BS 2028. The test specimens were dried and cured for the specific days for the test 7, 14, 28 and 60 days and their weight (mass) measured and recorded. The dimensions of the blocks as already measured were used to calculate for the volume of each specimen and recorded. Densities of the samples were calculated using the formula:

$$\textbf{Density} = \frac{\text{Mass}}{\text{Volume}} (\textbf{kg/mm}^3)$$

3.9.3 Determination of Compressive strength

The compressive strength tests of the blocks were determined at ages 7, 14, 28 and 60 days using the Automatic Tensile and Compressive Strength Testing Machine as shown in figure 3.5 at the CSIR-BRRI Civil Engineering Laboratory. The compressive test was conducted to ascertain the early strength of the two sandcrete blocks, to determine the strength for classification of the sandcrete blocks as reiterated by the Ghana Standard (GS 297;2010) and to see the consistency of the late strength of the sandcrete blocks with its durability. Pozzomix cement is a slow reactor according to literature; this test was done to confirm the literature of longevity. Five blocks each were taken from OPC and pozzomix cement sandcrete blocks and prepared for the crushing tests as shown in figure 3.6. The samples were placed in the compression testing machine positioned between the stationary and movable plates of the machine with load applied. The maximum load in KN at which fracture occurred was recorded and used to calculate the compressive strength as:

$$\textbf{Compressive Strength (R)} = \frac{\boldsymbol{F}}{\boldsymbol{A}}$$

Where

R= compressive strength (MPa)

F= maximum load at which fracture occurs (KN)

A = area of the block (mm^2)

Figure 3.5: Automatic Tensile and compressive machine CSIR-BRRI Civil Engineering Laboratory
Source: Researcher Field construct 2018

Figure 3.6: The sample specimen pozzomix cement and OPC sandcrete blocks for the crushing testat BRRI-CSIR Civil Engineering Laboratory
Source: Researcher Field construct, 2018

3.9.4 Determination of Water absorption

According to ASTM D570 water absorption is used to determine the amount of water absorbed under specified conditions such as temperature and length of exposure. Durability of blocks can be judged by water absorption test (BS 1881-122). Water absorption test was conducted to measure the ability of the specimen to resist the absorption and retention of water and the performance of blocks in water logged or humid environments for durability property. The blocks were prepared according to laboratory size (100 x 100 x 100mm) weighed using a sensitive digital balance as in figure 3.7 and kept in an oven and shown in figure 3.8 for 24 hours. Blocks were weighed again oven dried after 24 hours and immersed in water in a basin as shown in figure 3.8 to determine the percent water absorption for 24 hours. Water absorption (% mass) after 24 hours' immersion in cold water is given by the formula;

$$W = \frac{M_2 - M_1}{M_1} \times 100$$

W = water absorption (%)

M_1 = before oven dry (Dry weight)

M_2 = after absorption (Wet weight)

Figure 3.7: Digital balance for measuring pozzomix cement and OPC sandcrete blocks prepared for water absorption test at CSIR-BRRI Civil Engineering Laboratory
Source: Researcher Field construct, 2018

Figure 3. 8: Oven for curing pozzomix cement and OPC sandcrete blocks for water absorption test at CSIR-BRRI Civil Engineering Laboratory
Source: Researcher Field construct, 2018

Figure 3.9: Immersion of pozzomix cement and OPC sandcrete block specimen in water at CSIR-BRRI Civil Engineering Laboratory
Source: Researcher Field constructs 2018

3.10 Data analysis

Data analysis is an integral part of research constituting an essential component in data gathering and in relating the research findings to the concepts. After successful collection of data, respondents' scores were computed for frequency analysis and descriptive statistics were performed using Statistical Package for the Social Sciences (SPSS), version 9.0.1, statistical data programme performed by a computer.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of the study as collected from questionnaire, experiment and observation.

4.2 Results of Questionnaire

Response rate

A total of 46 questionnaires were sent out to collect data from respondents comprising 35 building contractors and 11 research scientists out of the number of contractors and research scientists in the Kumasi Metropolis and its environs. However, after the data collection exercise, it was realised that 41 out of the 46 questionnaires sent out were good to be included in the analysis. Whilst some of the questionnaires were not returned, key questionnaires that were critical in meeting the study objectives were not answered on some of the returned questionnaires. In spite of this, 41 questionnaires comprising 30 building contractors and 11 research scientists deemed good to be used gave a response rate of 89.1%.

The questionnaire for the contractors and research scientist first and foremost took a general profile of the respondents, physical properties from Pozzomix and OPC, and performance of OPC and pozzomix sandcrete blocks. Samples of the questionnaires designed and used can be found in (Appendix C and D).

4.2.1 Results of Questionnaire from Contractors

Demographic Information of Respondents

Issues covered under the demographic information of the building contractors include their gender, working experience and highest educational level of the respondents. Knowing the background characteristics of respondents was very necessary as that could help in determining the authenticity of the responses. Table 4.1 presents the demographic information of the contractors.

Table 4.1: Demographic information of the Contractors

Variables	Category	Frequency (N)	Percentage (%)
Gender	Male	30	100.0
	Female	0	0%
	Total	30	100.00
Working experience	1-5 years	3	10.0
	6-10 years	6	20.0
	11-15 years	9	30.0
	16-20 years	5	16.7
	21-25 years	3	10.0
	Above 26 years	4	13.3
	Total	**30**	**100.0**
Educational level	Vocational /Technical/Commercial	5	16.7
	Diploma	8	26.7
	Bachelor degrees	15	50.0
	Masters degrees	2	6.7
	Total	**30**	**100.0**

Source: Researcher Field Work, 2018

As shown in Table 4.1, all (N=30) the building contractors representing 100% were males. This underlines the dominance of male professionals in the construction industry. This is an indication of the fact that the construction works is a preserve for a particular sex as men are seriously engaged in it.

Table 4.1 further shows the distribution of the respondents according to number of years of site experience. From the data gathered, 9 contractors representing 30% said that they have 11-15 years working experience in the construction industry, 6 contractors representing 20% have 6-10 years working experience, 5 contractors representing 16.7% have 16-20 years working experience, 4 contractors representing 13.3% have more than 26 years working experience, while 3 contractors representing 10% have 1-5 years and 21-25 years working experience in the construction industry. The number of years working experience put the contractors at advantageous point to justify the quality of their work using OPC and pozzomix cement sandcrete blocks with reference to the comments from their clients after handing over and the use of the property for a number of years.

On the educational level of the respondents, 15 contractors representing 50% were Bachelors' degree holders, 8 contractors representing 26.7% were Diploma holders, 5 contractors representing 16.7% were holding vocational/Technical/ Commercial qualifications while 2 contractors representing 6.7% were holding Masters Degree's as their highest academic qualification. It appeared from the study that majority of building contractors holds Bachelor degree. This implies that the building contractors are in good position to comments on the problem of the study.

Properties from OPC and pozzomix cement sandcrete blocks

This section addresses the properties of sandcrete blocks produced from OPC and Pozzomix cement. Lists of the most properties were sourced from an extensive literature review, and some were confirmed in a series of unstructured interviews with the contractors. In the questionnaire, the respondents were asked to identify the properties of sandcrete blocks from OPC and pozzomix cement based on their experience, using a rating of "5" as being strongly agreed, "4" agreed, "3" as uncertain, "2" as disagreed and "1" as strongly disagreed.

Table 4.2: Properties of Sandcrete block from OPC and pozzomix

Properties	N	OPC			Pozzomix		
		Actual response	Mean	Std. Dev.	Actual response	Mean	Std. Dev.
High compressive strength	**30**	8	3.80	1.215	8	3.97	1.066
Low shrinkage	**30**	8	3.83	1.085	8	3.43	1.104
Low moisture movement	**30**	8	3.80	.997	7	4.33	.661
Low thermal movement	**30**	13	2.17	1.642	12	2.93	1.721
Denseness and durability	**30**	7	4.27	.785	7	4.27	.785
Standard consistency	**30**	7	4.43	.679	7	4.37	.809

Source: Researcher Field Work, 2018, Mean > 3.0=agreed

From Table 4.2, the respondents agreed that OPC has high compressive strength ($\bar{x}$=3.80, SD=1.215), low shrinkage ($\bar{x}$=3.83, SD=1.085), low moisture movement ($\bar{x}$=3.80, SD=.997), low thermal movement ($\bar{x}$=2.17, SD=1.642), denseness and durability ($\bar{x}$=4.27 SD=.785), standard consistency ($\bar{x}$=4.43 SD=.679). Moreover, the contractors agreed that Pozzomix has high compressive strength ($\bar{x}$=3.97, SD=1.066), low shrinkage ($\bar{x}$=3.43, SD=1.104), low moisture movement ($\bar{x}$=4.33, SD=.661), low thermal movement ($\bar{x}$=2.93, SD=1.721), denseness and durability ($\bar{x}$=4.27, SD=.785), and standard consistency ($\bar{x}$=4.37, SD=.809).

The view of the respondents indicates that sandcrete blocks from Pozzomix cement has a higher compressive strength, lower moisture movement and lower thermal movement than that of sandcrete blocks from OPC. Conversely, sandcrete blocks from OPC have a lower shrinkage and standard consistency than that of Pozzomix cement. As per Danso and Boateng (2013), cement is one of the key components of most buildings, therefore the fineness of a Portland cement and its chemical composition are the key factors in determining cement strength characteristics. However, the responses from the contractors on pozzomix cement agreed with several studies that revealed the qualities of pozzomix cement (Atiemo, 2005); Boakye et al. 2017); Boakye et al. 2014).

Faleye et al. (2009) studied the chemical and physical properties of Pozzolanic Portland Cement (PPC). According to the study, the use of a pozzolanic material serves some purposes such as partial replacement for cement to reduce heat generation, increase workability and compressive strength at late ages, if the material has high pozzolanic activity with cement, then it increases durability. Zhang and Napier-Munn (1995) indicated that pozzolana may slow the curing rate of concrete, resulting in low break strengths at early tests, such as a 1-3day test when compared to Ordinary Portland Cement (OPC).

Satisfaction level of Contractors on OPC and Pozzomix cement

Table 4.3 summarises the responses of the contractors regarding the satisfaction level of OPC and pozzomix cement. The analysis was based on the respondents rating for the key properties of each item in the questionnaire, with a rating of; "1" = not satisfied, "2" = slightly satisfied, "3"= Not sure, “4”= satisfied, “5”=very satisfied. Table 4.3 presents the results.

Table 4.3:Satisfaction level of Contractors on OPC and Pozzomix cement

Satisfaction level	N	OPC			Pozzomix		
		Actual response	Mean	Std. Dev.	Actual response	Mean	Std. Dev.
Durability	**30**	7	4.17	1.177	7	4.53	.819
Availability	**30**	7	4.33	.884	7	4.23	.898
Suitability	**30**	7	4.20	1.031	7	4.07	1.081
Weather resistivity	**30**	7	4.37	.765	7	4.10	1.094
Workability	**30**	8	3.83	1.177	7	4.10	1.094
Dampness resistance	**30**	7	4.37	.809	7	4.03	1.066

Source: Researcher Field Work, 2018, Mean > 3.0=satisfied

The study results revealed that the contractors were very satisfied with the durability of the pozzomix cement ($\bar{x}$=4.53, SD= .819) as compared to that of OPC cement ($\bar{x}$=4.17, SD=1.177). Concerning the availability of both cements, the contractors were satisfied with the availability of OPC ($\bar{x}$=4.33, SD= .884) as compared to that of pozzomix ($\bar{x}$=4.23, SD= .898).Moreover, majority of the contractors bringing the means score to 4.20 and a standard deviation of 1.031 were satisfied with the suitability of the pozzomix cement as compared to that of OPC with a means score of 4.07 and standard deviation of 1.081. With a mean score of 4.37 and a standard deviation of 0.765, the contractors were very satisfied with the weather resistibility of the pozzomix cement as compared to OPC with a mean of 4.10 and standard deviation of 1.094.

Concerning workability of the two cements, the contractors were very satisfied with the workability of the pozzomix cement ($\bar{x}$=3.83, SD=1.177) as compared to that of OPC ($\bar{x}$= 4.10, SD=1.094). Furthermore, majority of the contractors ($\bar{x}$=4.37, SD=.809) were satisfied with the dampness resistance of the pozzomix cement as compared to the

OPC with a mean score of 4.03 and standard deviation of 1.066. This indicates that the contractors are more satisfied with the durability and workability of pozzomix as compared to OPC. The view of the contractors agrees with the study by Aguwa (2010) who affirmed that pozzomix cement has higher fineness than OPC, therefore it has lower permeability and as a result it has high durability and the structure will last longer and have longer life. Raheem, Momoh and Soyingbe (2012) confirmed that pozzomix cement is environment friendly as it utilises non toxic materials locally available and by-products from the coal fired thermal stations. Consequently, it is green material, hence biodegradable and helpful in achieving green rating and climate change. On the other hand, the building contractors are satisfied with the availability, suitability, weather resistivity and dampness resistance of OPC as compared to the pozzomix cement.

Performance of OPC and pozzomix cement sandcrete blocks

In order to examine the performance of OPC and pozzomix cement sandcrete blocks, respondents were asked to rate the level of the performance indicators of OPC and pozzomix cement sandcrete blocks with "5" as being strongly agreed, "4" agreed, "3" as uncertain, "2" as disagreed and "1" as strongly disagreed. Table 4.4 presents the means and standard deviations of each performance indicators.

Table 4.4: Performance of the OPC and pozzomix cement sandcrete blocks

Performance	N	OPC			Pozzomix		
		Actual Response	Mean	Std. Dev.	Actual Response	Mean	Std. Dev.
Good for all construction works	**30**	8	3.47	1.112	7	4.43	.719
Does not get damaged easily	**30**	7	4.13	1.284	7	4.23	1.213
Easy hardening	**30**	8	3.41	1.131	7	4.17	1.211
It is better for water logged areas in the country	**30**	13	2.37	1.765	7	4.10	1.094
Has very good technical properties	**30**	8	3.83	1.177	7	4.11	1.234
Its workability is major factor in performance delivery	**30**	7	4.37	.809	7	4.03	1.066

Source: Researcher Field Work, 2018, Mean > 3.0=agreed

The study results revealed that pozzomix cement ($\bar{x}$=4.43, SD= 0.719) is good for all construction works as compared to OPC ($\bar{x}$=3.83, SD=1.177). In addition, the contractors agreed that pozzomix cement ($\bar{x}$=4.23, SD= 1.213) does not get damage easily as compared to OPC ($\bar{x}$=4.13, SD= 1.284). Conversely, the contractors agreed that pozzomix cement ($\bar{x}$=4.17, SD= 1.211) is easy to become hardened comparing it to OPC ($\bar{x}$=3.41, SD= 1.131).

With a mean score of 4.11 and a standard deviation of 1.234, the contractors agreed that pozzomix cement is better for water logged areas in the country than OPC which had a mean of 2.37 and a standard deviation of 1.765. The contractors further agreed that pozzomix cement has very good technical properties with a mean score of 4.11 and a standard deviation of 1.234, while OPC had a mean score of 3.83 and a standard deviation of 1.177 in terms of its technical properties. However, it appeared that the workability of OPC ($\bar{x}$=4.37, SD= 0.809) is a major factor in performance delivery as compared to pozzomix cement ($\bar{x}$=4.03, SD= 1.066).

The results show that pozzomix cement is good for all construction works, does not get damaged easily, is easy to become hardened, is good for water logged areas in the country and has very good technical properties as compared to OPC. Moreover, the contractors believed that OPC has a better performance in terms of its workability than pozzomix cement. The responses given by the contractors agreed with the study by Momade and Atiemo, (2004) that Pozzolanic Portland Cement (PPC) has certain distinct advantages over OPC as follows:

- Low heat of hydration reducing chances of surface cracks
- Easily harden compared to OPC
- Longer setting time making it more workable than OPC
- Ultimate strength higher than OPC
- Good for all construction works compared to OPC
- Lower porosity imparting the concrete more water tightness
- Lower manufacturing cost compared to OPC
- Waste utilization making it more environmental friendly
- Better workability than OPC (Momade & Atiemo, 2004)

Furthermore, Rodriguez-Camacho and Uribe-Afif (2002) Pozzolanic Portland Cement (PPC) cement is best for brick masonry, plastering, tiling and waterproofing works. PPC has better workability and finishing than OPC. Jayawardane, et al. (2012) conducted a study on the physical and chemical properties of fly ash based Portland Pozzolana Cement (PPC), it was checked whether they satisfy the requirements given in ASTM C 150.

According to the results obtained, the cement certifies to be called blended cement. Some of the properties worked on were compressive strength, fineness, soundness, setting time, and specific gravity are some physical properties of cement. Loss on ignition, chloride content, and insoluble residue. The study also concluded that PPC has higher durability of concrete structure due to less permeability of water, more resistance towards the attack of alkalis, sulphates, chlorides, chemicals and better work ability.

Table 4.5: Satisfaction on projects completed with OPC and pozzomix cement

Clients satisfaction	**OPC**		**Pozzomix**	
	f	**%**	***f***	**%**
Very satisfied	12	40.0	14	46.7
Satisfied	14	46.7	13	43.3
Not sure	4	13.3	3	10.0
Total	**30**	**100.0**	**30**	**100.0**

Source: Researcher Field Work, 2018

From Table 4.5 the contractors were asked whether their clients are satisfied with the projects completed with OPC and pozzomix cement. According to the data from table 4.5, 12 and 14 contractors representing 40.0% and 46.7% respectively indicated that their clients were very satisfied and satisfied when they complete a project using OPC sandcrete blocks. However, 4 contractors constituting 13.3% indicated that they are not sure as to whether their clients are satisfied with the projects completed with OPC sandcrete blocks. Conversely, 14 contractors constituting 46.7% and 13 contractors forming 43.3% indicated that their clients were very satisfied and satisfied respectively with the projects completed with pozzomix sandcrete blocks, whilst 3 contractors constituting 10.0% were not sure to that effect. This affirmed that the clients are more satisfied with projects completed with pozzomix sandcrete blocks (90.0%) than that of OPC (86.7%).

Table 4.6: Responses on the reasons for choosing OPC/ Pozzomix cement

Performance	N	OPC		Pozzomix	
		Mean	Std. Dev.	Mean	Std. Dev.
I buy because of certain strength class requirement and cost efficiency	**30**	3.44	1.284	4.13	1.315
To ensure prescribed specification	**30**	3.41	1.131	4.47	1.208
To ensure good quality of work done	**30**	3.53	1.363	4.33	1.014
To be able to control the manufacturing process	**30**	2.58	1.677	3.01	1.317
The choice depends on the mode of the experiment be undertaken	**30**	2.37	1.802	2.59	1.671
To satisfy the laboratory rules and regulations	**30**	1.91	1.723	2.13	1.523

Source: Researcher Field Work, 2018

As shown in Table 4.6, the contractors indicated that they buy OPC ($\bar{x}$=3.44, SD= 1.284) and pozzomix cement ($\bar{x}$=4.13, SD= 1.315) because of certain strength class requirement and cost efficiency. In addition, the contractors agreed that they buy OPC ($\bar{x}$=3.41, SD= 1.131) and pozzomix cement ($\bar{x}$=4.47, SD= 1.208) to ensure prescribed specification. The contractors further asserted that they buy OPC ($\bar{x}$=3.53, SD= 1.363) and pozzomix ($\bar{x}$=4.33, SD= 1.014) to ensure good quality of work done.

Furthermore, the contractors disagreed and agreed that they buy OPC ($\bar{x}$=2.58, SD= 1677) and pozzomix cement ($\bar{x}$=3.01, SD= 1.317) respectively to be able to control the manufacturing process. On the other hand, the contractors disagreed that the choice of OPC ($\bar{x}$=2.37, SD= 1.802) and pozzomix cement ($\bar{x}$=2.59, SD= 1.671) depends on the mode of the experiment undertaken. The respondents further disagreed that they choose OPC ($\bar{x}$=1.91, SD= 1.723) and pozzomix cement ($\bar{x}$=2.13, SD= 1.523) to satisfy the laboratory rules and regulations. The study reveals that contractors opt for OPC and pozzomix cement because of certain strength class requirement and cost efficiency, to ensure prescribed specification, and good quality of work done.

4.2.2 Results of Questionnaire from Research Scientists

Demographic Information of Respondents

The background information of the research scientists concentrates on their gender, educational level and the number of years they have been in practice as a research scientist. Table 4.7 presents the demographic information of the research scientists.

Table 4.7: Demographic information of the research scientists

Variables	Category	Frequency (N)	Percentage (%)
Gender	Male	11	100.0
	Female	0	0
	Total	**11**	**100.0**
Working experience	1-5 years	3	27.3
	6-10 years	3	27.3
	11-15 years	1	9.1
	16-20 years	1	9.1
	21-25 years	2	18.1
	Above 26 years	1	9.1
	Total	**11**	**100.0**
Educational level	Bachelor degrees	9	81.7
	Masters degrees	3	27.3
	Total	**30**	**100.0**

Source: Researcher Field Work, 2018

From Table 4.7, all the 11 research scientists who responded to the questionnaires were males. This is an indication of the fact that men are seriously engaged as pozzolana or pozzomix cement research scientists despite few women doing their best to work in the field. Concerning the number of years the respondents have been in practice as a research scientist, 3 respondents representing 27.3% each have been working as a research scientists for 1-5 years and 6-10 years. On the other hand, 1 respondent constituting 9.1% each had been a research scientists for 11-15 years, 16-20 years and above 26 years respectively. However, the remaning 2 respondents constituitng 18.1% had been working as a research scientists for 21-25 years. From the questionnaire survey most (n=9) of the respondents representing 81.7% had first degree, while 3 of them representing 27.3% had Masters Degree. The results clearly indicate that the research scientists were very educated and well-informed people.

Properties of Pozzomix and OPC sandcrete Blocks

The properties of OPC and pozzomix sandcrete blocks were assessed in this section of the study with the aid of Likert Scaling questioning type. Table 4.8 presents the means and standard deviations of each physical property.

Table 4.8: Properties of Sandcrete block from OPC and pozzomix

Properties	N	OPC			Pozzomix		
		Actual response	**Mean**	**Std. Dev.**	**Actual response**	**Mean**	**Std. Dev.**
High compressive strength	**30**	8	3.55	.820	7	4.36	1.027
Low shrinkage	**30**	8	3.82	1.471	8	3.93	1.618
Low moisture movement	**30**	8	3.18	1.328	8	3.64	1.027
Denseness and durability	**30**	8	3.55	1.368	7	4.09	.831
Standard consistency	**30**	8	3.73	1.009	7	4.18	1.168

Source: Researcher Field Work, 2018, Mean > 3.0=agreed

In addressing the properties of OPC and pozzomix sandcrete blocks, the research scientists agreed that OPC ($\bar{x}$= 3.55, SD= .820) and pozzomix ($\bar{x}$= 4.36, SD= 1.027) has high compressive strength when the right mix ratio and water cement ratios are used. The results indicate that averagely the compressive strength of pozzomix cement sandcrete block was higher than that the compressive strength of OPC. The research scientists further agreed that OPC ($\bar{x}$= 3.82, SD= 1.471) and Pozzomix ($\bar{x}$=3.93, SD= 1.618) sandcrete blocks had low shrinkage. Moreover, the research scientists agreed that OPC ($\bar{x}$= 3.18, SD= 1.328) and Pozzomix ($\bar{x}$= 3.64, SD= 1.027) had low moisture movement. With respect to denseness and durability, the research scientists agreed that Pozzomix sandcrete blocks ($\bar{x}$= 4.09, SD= .831) are denser and more durable than OPC ($\bar{x}$= 3.55, SD= 1.368).The study further reveals that pozzomix sandcrete blocks ($\bar{x}$= 4.18, SD= 1.168) has better standard consistency than OPC sandcrete blocks ($\bar{x}$= 3.73, SD= 1.368).

The result reveals that pozzomix has higher compressive strength, lower shrinkage, lower moisture movement, better denseness and durability, and better standard consistency as compared to OPC. According to Neville (2011), reduction in permeability of pozzomix cement offers many other advantages, such as better durability than OPC sandcrete blocks. The Portland pozzolana cement (PPC) improves pore size distribution and also reduces the micro-cracks in the cement paste at the transition zone due to pozzolanic action and being finer than OPC (Neville, 2011).

Performance of OPC and pozzomix sandcrete blocks

Table 4.9 summarises the responses of the research scientist regarding the performance of OPC and Pozzomix sandcrete blocks. The means and standard deviations of the performance variables were determined.

Table 4.9: Performance of the OPC and pozzomix cement sandcrete blocks

Performance	N	OPC			Pozzomix		
		Actual response	Mean	Std. Dev.	Actual response	Mean	Std. Dev.
Good for all construction works	**30**	8	3.09	1.375	7	4.64	.505
Does not get damaged easily	**30**	8	3.18	1.471	7	4.82	.405
Easy to hardening	**30**	8	3.27	1.348	7	4.73	.647
It is good for water logged areas in the country	**30**	13	2.64	1.362	7	4.91	.302
Has very good technical properties	**30**	8	3.27	1.272	7	4.36	.505
Its workability is major factor in performance delivery	**30**	7	4.18	.405	7	4.73	.467

Source: Researcher Field Work, 2018, Mean > 3.0=agreed

Table 4.9 gives a summary of the responses to the six statements that were used to measure the performance of OPC and Pozzomix sandcrete blocks.

It is clear from the Table that pozzomix sandcrete blocks ($\bar{x}$= 4.64, SD= .505) are good for all construction works as compared to OPC sandcrete blocks ($\bar{x}$= 3.09, SD= 1.375). The study further indicates that Pozzomix sandcrete blocks ($\bar{x}$= 4.82, SD=.405) does not get damaged easily as compared to OPC sandcrete blocks ($\bar{x}$= 3.18, SD= 1.471). According to the respondents Pozzomix cement sandcrete blocks ($\bar{x}$= 4.73, SD= 0.647) easily get hard as compared to OPC cement sandcrete blocks ($\bar{x}$=3.27, SD=1.348).

In addition, the research scientists disagreed with the assertion that OPC sandcrete blocks ($\bar{x}$=2.64, SD= 1.362) and agreed that pozzomix sandcrete blocks ($\bar{x}$=4.91, SD= .302) is good for water logged areas in the country. Conversely, the research scientist agreed that OPC sandcrete blocks ($\bar{x}$=3.27, SD= 1.272) and pozzomix sandcrete blocks ($\bar{x}$=4.36, SD= .505) have very good technical properties (strength and durability) performance delivery. Moreover, it appeared that the workability of OPC sandcrete blocks ($\bar{x}$= 4.18, SD= .405) and Pozzomix cement sandcrete blocks ($\bar{x}$= 4.73 SD= .467) is major factor in performance delivery.

The result shows that pozzomix is good for all construction works, does not get damaged easily, it is good for water logged areas in the country, has very good technical properties, and its workability is major factor in performance delivery in agreement with studies on the pozzolanic activity of some clay samples in Ghana for housing construction (Momade & Atiemo, 2004; Sarfo-Ansah, 2010 and Atiemo, 2012). Their studies showed that in 28 days, the compressive strength of pozzolana cement mortar up to 30% satisfied the class 32.5R cement as recommended by EN197-1 (2000) for concrete works and general construction. According to their study pozzolana is good for all construction works and does not get damaged easily. Bediako and Frimpong (2013) posited that the performance of pozzolanic materials in construction could be viewed from three different angles for sustainable development: economic, ecological and technical. In the economic sense, the production of pozzolanic materials is far less expensive than OPC. Technically, the benefits such as enhanced strength development, mitigation of thermal effect from OPC and prevention of chemical attacks in concretes as well as sandcrete blocks as in OPC. It is known that the uses of pozzolanic materials for concrete and sandcrete blocks are among the possible ways to produce sustainable concretes and concrete products including blocks. Pozzolanic materials contribute little effects to the environmental hazards as compared with OPC production in terms of CO_2 emissions and promote climate change with greenhouse effects.

4.3 Results of Experiment

The results of the experiment conducted to determine the various properties (mechanical and physical properties such as compressive strength, density, weights and water absorption) of sandcrete blocks produced from pozzomix cement and OPC as presented below.

Compressive strength test result of OPC and Pozzomix cement blocks

The compressive strength tests were carried out for 7, 14, 28, and 60 days of sandcrete blocks from OPC and pozzomix cement respectively. Table 4.10 presents the average results of the compressive strength test report of the OPC and pozzomix cement sandcrete block specimen.

Table 4.10: Compressive strength of OPC and Pozzomix sandcrete blocks

Samples	OPC					Pozzomix					
	Dimensions (mm)	**Results (N/mm^2)**	**Mean (N/mm^2)**	**Std. dev.**	**Std. Error mean**	**Dimensions (mm)**	**Results (N/mm^2)**	**Mean (N/mm^2)**	**Std. dev.**	**Std. Error mean**	**Period of test (Days)**
1		0.038					0.558				
2		0.078					0.130				
3	455 x 238 x	0.076	0.073	0.0	0.009		0.448	0.319	0.178	0.081	**7**
4	122	0.093		21		454 x 230 x	0.208				
5		0.078				118	0.245				
1		0.134					1.168				
2		0.141					1.126				
3	428 x 223 x	0.161	0.148	0.0	0.006	430 x 223 x	1.061	0.94	0.940	0.288	**14**
4	110	0.141		14		120	0.463				
5		0.166					0.884				
1		0.395					1.288				
2		0.428					1.236				
3	428 x 223 x	0.398	0.278	0.1	0.078	430 x 223 x	1.223	1.129	0.174	0.078	**28**
4	110	0.330		77		120	0.876				
5		0.271					1.022				
1		0.431					0.934				
2		0.284					1.551				
3	425 x 230 x	0.274	0.354	0.1	0.048	430 x 230 x	1.288	1.275	0.282	0.126	**60**
4	110	0.503		06		110	1.551				
5		0.279					1.050				

Mix ratio (inverted 1:16 to 1:18) Pozzomix: [t=10.6336, sig. (2-taileed) =.001]; OPC: [t=11.568, sig.(2-tailed) =0.008]

Source: Researcher Field Work, 2018

As shown in Table 4.10, the compressive strength of sandcrete blocks produced from OPC and Pozzomix cement were tested. During the familiarization visit and field survey, it was observed that specified standard basic mix ratio of 1:6 or 1:4 cement sand proportion and water cement ratio of 0.6 to achieve the minimum compressive strength value of the sandcrete blocks were being undermined by the block manufacturers in the construction sites. Majority of the construction sites investigated used their own inverted mix ratio of between 1:16 to 1:18 to produce (450mm x225mm x150mm) both sandcrete blocks respectively. The test carried out indicated that the average compressive strength of the sandcrete block from OPC cement for 7, 14, 28 and 60days ranges between 0.073 N/mm^2 to 0.354 N/mm^2. The average compressive strength of sandcrete blocks produced from pozzomix cement at curing age for 7, 14, 28 and 60 days ranges between 0.319N/mm^2 to 1.275 N/mm^2. Comparatively, the test results show that compressive strength of pozzomix cement sandcrete blocks were higher than that of OPC sandcrete blocks for all curing ages. The average comprehensive strength of both pozzomix cement and OPC sandcrete blocks failed to meet the specified minimum compressive strength of 2.8N/mm^2 for sandcrete blocks prescribed by British standard (BS 6073-1) and Ghana Standard 297, (2010). On the bases of observation this result can be associated with the visual inspection of the qualities of sandcrete blocks, selection of poor quality sand, poor mix ratio, poor water-cement (w/c) ratio, inadequate curing methods and poor mixing and compacting methods in the manufacturing of sandcrete blocks.

Despite the two sandcrete blocks (pozzomix cement and OPC) not meeting the standard like other similar studies elsewhere in Nigeria (Ewa and Ukpata (2013); Abdullahi (2005) and in Ghana by Bamfo-Agyei (2011), this study shows a positive relationship between the compressive strengths and age of curing for the sandcrete blocks produced from OPC ($t=11.568$, $p=0.008<0.01$) and pozzomix ($t=10.6336$, $p=.001<0.01$). This indicates that the sandcrete blocks increase gradually in compressive strength for each curing age. Banuso and Ejeh (2008), Abdullahi (2005) and Afolayan et al. (2008) found out that tested samples of sandcrete blocks in Nigeria, exhibited compressive strengths far below that recommended in the Nigerian Industrial Standard (NIS 87, 2000) 2.5N/mm^2 and British standard (BS 6073-1) 2.8N/mm^2 as well as Ghana Standard (GS 297, 2010) 2.8N/mm^2. The result aligns with the study by Aguwa (2010) who found a relationship between the compressive strengths and age of curing for the two types of blocks. According to Aguwa (2010), pozzolana cement blocks have higher compressive strength than the Ordinary Portland cement (OPC). This is an indication that building construction with pozzomix cement blocks will likely withstand considerable load and enhance performance before total failure. Wenapere and Ephraim (2009) found out that the compressive strength of sandcrete blocks increased with age of curing for all mixes tested at the water cement ratio of 0.5. This trend was noted by Metcalfe (1997) that in general, the strength increases is in direct proportion to cement content, but at different rates for different soils. However, higher cement contents result in prohibitive cost of blocks which places the sand-cement blocks at a disadvantage.

Bediako, (2009) on compressive strength of blended cement made reference to Voglis et al. (2005) which made comparative study on Portland Limestone Cement (PLC), Pulverished Fly Ash Cement (PFC), Portland Pozzolanic Cement (PPC) and Ordinary Portland Cement (OPC) using 15% content of limestone, fly ash and natural pozzolana respectively and it was concluded that Pozzolanic Cement exhibited a higher compressive strength under control experiment.

Weight test result of OPC and Pozzomix cement sandcrete blocks

Presented in Table 4.11 are the results of the weight of OPC and Pozzomix cement blocks. The weight tests were carried out for 7, 14, 28, and 60 days respectively.

Table 4.11: Weight test results of OPC and Pozzomix sandcrete blocks

Samples	OPC sandcrete block				Pozzomix sandcrete block				Period of test (Days)
	Dimensions (mm)	Weight (Kg)	Mean	Std. dev.	Dimensions (mm)	Weight (Kg)	Mean	Std. dev.	
1		24.9				25.5			
2	425 x 230 x 110	24.9				25.5			
3		24.9	24.90	.000[a]		25.5	25.50	.000[a]	7
4		24.9			454 x 230 x 118	25.5			
5		24.9				25.5			
1		24.3				25			
2		24.1				25			
3	428 x 223 x 110	24.5	24.38	.1924	430 x 223 x 120	25	25.08	.1304	14
4		24.4				25.1			
5		24.6				25.3			
1		23.2				24.7			
2	428 x 223 x 110	23.3				24.9			
3		23.8	23.36	.3050	430 x 230 x 110	24.4	24.40	.3647	28
4		23.5				24.0			
5		23.0				24.2			
1	455 x 238 x 122	23.2				24.8			
2		23.4				24.7			
3		24.8	23.64	.6693	430 x 223 x 120	24.9	24.64	.2408	60
4		23.6				24.3			
5		23.2				24.5			

(Mix ratio: inverted 1:16 to 1:18/0.6 and cement: sand/w/c)

Source: Researcher Field Work, 2018

The average result obtained for OPC sandcrete blocks indicated that the weight ranges from 24.90kg to 23.6kg for 7days and 60days respectively. Also, the average weight results of pozzomix sandcrete block ranges from 25.50kg to 24.64kgat 7days and 60 days respectively. It can be observed that the average score of pozzomix (25.50kg) was greater than OPC (24.90 kg) for 7 days with the same weight for OPC and pozzomix cement sandcrete blocks due to the difference in volume. At 14 days curing age, weight of pozzomix cement sandcrete block (25.08kg) was higher as compared to the weight of average of the sandcrete block produced from OPC cement (24.38kg). When the sandcrete block for the 28 days was cured, the average pozzomix cement blocks (24.40kg) was higher than OPC sandcrete block (23.36kg). In addition, the average weights of pozzomix cement sandcrete blocks (24.64kg) for 60 days curing age was higher than the average weight of OPC sandcrete block (23.64kg). The study reveals that the average weight score of pozzomix was higher than OPC for each curing age days but failed below BS EN 771-3 which is 26kg for 150 x 225 x 450mm blocks (6 inches) used for this research work. This may be due to the degree of compaction, "inverted" mix ratio and water-cement ratio used by the contractors. According to Smith (1973), nominal size of a 200 x 200 x 400mm was given to be of weight approximately (40 to 50 lbs) 18.16 to 22.7 kg when made with heavy aggregates and 25 to 35 lbs when made with light weight aggregates. Heavy weight blocks are made from aggregates such as sand, gravel and crushed stones and air-cooled slag. Light weight units are made from cinders, expanded shale, pumice and scoria. The mean weights of sandcrete blocks produced from OPC and pozzomix cement were 24.07kg and 24.91kg respectively. This means that there is the need to check the weight of the sandcrete blocks manufactured by contractors so that any inconsistency may be solved for safe weight compliance. The weight of the blocks if more than the required specification may lead to musculoskeletal disorders which are injuries at various body parts like the joints, nerves, bones especially the shoulders, hands, wrists, necks low backs, hips and knees of construction workers from constant wear and tear due to lifting heavy materials like sandcrete blocks and it is suggested that there is the need to use lighter materials to mould blocks to reduce weight to reduce the incidence of musculoskeletal disorders. In order to reduce dead weight or load on the building structure, safe weight of the sandcrete blocks used in the structure is very important. A study by Ismaila and Aderele (2015) indicated that the mean weights of block that are presently produced by block manufacturers were 17. 9 kg for 6 inches and 22.76 kg for 9 inches block which are higher than the Safe Weight of Lift (SWL) and Maximum Safe Weight of Lift (SWL_{max}). According to the study, the mean Load Strain Susceptibility Index (LSSI) for safe, tolerable and hazardous were 1.0 (±0.00), 2.48 (± 0.26) and 3.94 (±0.52) respectively.

Density test result of OPC and Pozzomix cement blocks

Table 4.12 shows the results of the density of OPC and Pozzomix cement blocks. The density tests were carried out for 7, 14, 28, and 60 days of sandcrete blocks from OPC and pozzomix cement respectively.

Table 4.12: Density of OPC and Pozzomix Sandcrete Blocks

Samples	OPC sandcrete block			Pozzomix sandcrete block			Period of test (Days)
	Density (Kg/M^3)	Mean	Std. dev.	Density (Kg/M^3)	Mean	Std. dev.	
1	1884.7			2070.5			
2	1884.7			2070.5			
3	1884.7	1884.7	.000[a]	2070.5	2070.5	.000[a]	**7**
4	1884.7			2070.5			
5	1884.7			2070.5			
1	2172.4			2030.9			
2	2154.5			2030.9			
3	2190.3	2180.6	18.84	2030.9	2037.4	10.61	**14**
4	2181.4			2039.05			
5	2204.6			2055.3			
1	2074.08			2006.6			
2	2088.06			2022.8			
3	2132.9	2090.4	28.97	1982.19	1985.4	29.63	**28**
4	2100.9			1949.69			
5	2056.2			1965.94			
1	2101.7			2130.95			
2	2119.85			2122.35			
3	2156.09	2123.5	23.64	2139.54	2117.2	20.70	**60**
4	2137.97			2087.98			
5	2101.7			2105.17			

Net Volume of block = 0.038342365m^3(OPC), 0.03985026m^3 (Pozzomix)
Source: Researcher Field Work, 2018

From Table 4.12, the average density of pozzomix cement blocks ranges from 2070.5 kg/m^3 to 2117.2 kg/m^3. These values are slightly lower than those of Raheem et al. (2012) which range from 2002.21 kg/m^3 to 2203.03 kg/m^3. On the other hand, the density of OPC cement blocks ranges from 1884.7 kg/m^3 to 2123.5 kg/m^{3}as against 2041.3 kg/m3 to 2160.9 kg/m3 in Raheem (2006). From the densities of the sandcrete blocks, it can be seen that the average density of pozzomix (2070.5 kg/m^3) was greater than OPC (1884.7 kg/m^3) for 7 days. For the 14days curing age, OPC recorded an average density of 2180.6 kg/m^3 as compared to pozzomix cement which had an average density of2037.4 kg/m^3. This indicates that there was decrease in the density of pozzomix cement sandcrete blocks as the curing age increases whilst an increase in density of OPC as the curing age increases.

In addition, the densities of the OPC and Pozzomix cement sandcrete blocks for 28 days and 60 days curing was (2090.4 - 2123.5 kg/m^3) and (1985.4 - 2117.2 kg/m^3) respectively. This implies that for 28 and 60 days, the densities of OPC and pozzomix cement sandcrete blocks increased (2090.4 - 2123.5) kg/m^3 and (1985.4 - 2117.2) kg/m^3 respectively. For all cases considered, sandcrete blocks produced from OPC recorded highest densities as compared to sandcrete blocks produced from pozzomix cement. Again, the minimum density obtained was 1884.7kg/m^3 for 7days of OPC and 1985.4 kg/m^3 for pozzomix cement sandcrete blocks for 28 days. These values were above the minimum value of 1500kg/m^3 recommended for first grade sandcrete blocks or load bearing sandcrete blocks considered for this study by International Standard Industrial Classification (ISIC) (2008) and BS 2028. This can be affirmed that OPC sandcrete blocks are less porous than pozzomix cement sandcrete blocks and this could be as a result of higher value of density recorded by the OPC sandcrete blocks. The strength of sandcrete block is low and the durability is reduced drastically when the porosity of blocks is higher as reported by (Aguwa, 2010).

These values are slightly higher than those of Raheem (2006) which range from 2073.5 kg/m3 to 2166.3 kg/m^3. Similar trend was observed by (Raheem et al. 2012) with density ranging from 2146.46kg/m^3 to 2209.60kg/m^3. The higher values of densities recorded in the above-mentioned previous studies may be attributed to the mix ratio used and degree and quality of compaction. According to Anon (1996) material and their proportional of mix decides the density of sandcrete blocks manufactured from cement. Anon (1996) indicated that using slag with higher percentage (85%) in super sulphate cement which is also pozzolana cement makes the density more than OPC. Also, by using general fly ash content cement then Pozzolana will have low density as compared to OPC.

Sandcrete blocks with a high amount of laterite have lower densities than those made with sand (Joshua et al. 2014) and Oyekan and Kamiyo, 2011). This is attributed to the lower specific gravity of the lateritic material compared to sand. According to Aguwa (2010) sandcrete blocks produced from Ordinary Portland Cement (OPC) have high densities of 1920 to 2080Kg/m^3. Dinesh et al. (2016) reported that lightweight density sandcrete block is often more important than strength.

Water absorption of OPC and Pozzomix cement blocks

The water absorption test was done for 28 days curing age. Table 4.13 presents the average results of water absorption of sandcrete blocks produced from OPC and pozzomix cement.

Table 4.13: Water absorption of OPC and pozzomix cement sandcrete blocks

Category	Results (%)	Mean	Std. Dev.	Std. Error Mean	T	Sig. (2-tailed)	95% Confidence Interval of the Difference	
							Lowe	Upper
Water absorption of OPC	11.57 9.99 10.97 9.58 12.69	10.960	1.246	.55724	19.66	.000	9.413	12.507
Water absorption of pozzomix cement	10.97 12.76 12.83 6.29 12.36	11.042	2.760	1.23435	8.95	.001	7.615	14.469

Source: Researcher Field Work, 2018

The water absorption results in Table 4.13 suggest that the amount of water absorbed by the OPC sandcrete block samples (10.96%) is lower than that absorbed by the pozzomix cement samples (11.04%). Water existing in the pores of masonry units tends to cyclically expand and contract creating stresses within the material thereby resulting in the weakening of masonry units. According to Dodoo-Arhin et al. (2013), masonry units with lower water absorption restricts the amount of water which could cause deterioration. This indicates that pozzomix cement sandcrete blocks have high water absorption than OPC sandcrete blocks making pozzomix cement sandcrete blocks porous.

Anosike and Oyebade (2012) indicated that water absorption is the ratio of the decrease in mass of dry sample. Anosike and Oyebade (2012) further stated that the rate of water absorption of aggregate influence the bond between aggregates and the cement paste, the resistance of concrete to freezing and thawing, chemical stability, resistance to abrasion and specific gravity. Water absorption rate is determined by measuring the decrease in mass of saturated block and surface dry sample. Okafor and Egbe (2017) reported that good quality concrete is characterized by having minimal voids left by excess water and therefore, water absorption test for precast concrete pipes is adopted for checking the quality of concrete in terms of density and imperviousness.

From the samples of the OPC sandcrete blocks, it can be seen that at 95% Confidence Interval of the Difference, the lower water absorption of OPC was 9.4% and the highest water absorption was 12.5%. On the samples of pozzomix cement, at 95% Confidence Interval of the Difference, the lower water absorption was 7.6% and the highest water absorption was 14.5%. The study shows a positive relationship between the water absorption and results of the sample for the sandcrete blocks produced from OPC ($t=19.66$, $p=0.000<0.0$) and pozzomix cement ($t=8.95$, $p=.001<0.01$). This implies that all samples showed a progressive increase in water absorption over the course of the experiment within the acceptable recommended range of 11% and 16% by ASTM C642 (1990) having positive effect on durability. On the contrary, Pavia and Condren (2008) suggested that the amount of water absorbed by the pozzolana samples is lower than that absorbed by the OPC samples, and that the higher the pozzolana content the lower the amount of water absorbed.

The results of Pavia and Condren (2008) also agreed with those by Kleinlogel (1960); McCloskey et al. (1997) and De Belie et al. (1996 and 2000), concluding that pozzolana samples absorbed less water and enhanced concrete possesses a higher resistance to acid attack. The high-water permeability in the blocks was found to be associated with lower densities as found to be the case of pozzomix cement sandcrete blocks in this study (Okafor and Egbe, 2017).

4.4 Results of Observation

Observation was done on several sites based on the procedure with photographs to accompany the items from the various construction sites observed.

4.4.1 Results of Observation at Aprade construction site

The researcher was at Aprade construction site, the process involved in the manufacturing of sandcrete blocks for the construction of three classroom blocks was observed. It was found that Ordinary Portland Cement (OPC) was used in the construction of major parts of the structure under construction in addition to pozzomix cement. The following observations were made after spending some days with the workers on the site.

- The source of sand used was pit sand but they have workers who are supposed to hand pick all unwanted materials in the sand before being used for the manufacturing of the sandcrete blocks using OPC and pozzomix cement.
- During the manufacturing of the sandcrete blocks using pozzomix cement, batching was done by employing ‘rule of thumb’. The workers pour cement onto a heap of sand without measuring by weight or volume as shown in the figure 4.2. The workers said this method was employed because of their number of years’ experience with the work.
- One significant thing observed was the use of clean drinking potable water. Potable water which is free from suspended particles, salts and oil contamination was used throughout the manufacturing of the sandcrete blocks and the construction of the structure as shown in figure 4.1.

The structure was uncompleted as shown in figure 4.1 at site as at the time of writing the final part of this research. Other existing structures constructed with OPC and pozzomix cement sandcrete blocks under the same contractor are shown in Appendix A

Figure 4.1: Classroom under construction with OPC and Pozzomix cement sandcrete blocks at Aprade construction site.
Source: Researcher Field Construct, 2018

Figure 4.2: Sand for manufacturing of OPC and pozzomix cement sandcrete blocks and the batching and mixing processes at Aprade construction site.
Source: Researcher Field Construct, 2018

It was observed during the process of manufacturing of the sandcrete blocks that the volume of water needed was not measured. According to Neville (2011) water is one of the most important elements in concrete production as well as sandcrete block manufacturing. Water is needed to begin the hydration process by reacting with the cement to produce concrete. There has to be a sufficient amount of water available so that the reaction can take its full course but if too much water is added, this will in fact decrease the strength of the concrete (Neville, 2011). The water-cement ratio is an important concept because other than the recipe for the concrete mix, the amount of water used would also determine its final strength.

One significant thing was the use of clean drinking water. Potable water which is free from suspended particles, salts and oil contamination was used. It was also found that the majority of the contractors employed 'rule of thumb' for batching. These findings show that workers pour cement onto a heap of sand without measuring by weight or volume as shown in Figure 4.2. This method is common mostly among people using hand moulds. This might lead to the sandcrete blocks exhibiting the inconsistency in the number of properties tested in the laboratory. Literature has shown that at a controlled test for pozzomix cement and OPC, the quality exhibited by pozzomix cement sandcrete blocks surpasses that of OPC sandcrete blocks as read from CRIR-BRRI leaflet shown in Appendix D.

4.4.2 Results of Observation at Electricity Company of Ghana (ECG) site and Kumasi Anglican SHS dormitory block

The researcher visited Kumasi Anglican Senior High School to observe a dormitory block constructed some years ago using pozzomix cement sandcrete blocks and OPC blocks as well as Electricity Company of Ghana office complex at Kentikrono. Figure 4.3 revealed the condition of the existing structures at the time of visit. The difference in the structures as observed was that the OPC structures have developed defects all over while the pozzomix cement structures are still without minor defects. It was released that the pozzomix cement sandcrete block structures have weather resistivity property as against that of the OPC structures. The contractor who was in charge of the construction confirmed that the unavailability of pozzomix cement is a challenge for the use of OPC sandcrete blocks for other projects.

Figure 4.3: Pozzomix cement sandcrete blocks office complex for ECG and Dormitory Block for Kumasi Anglican SHS
Researcher Field Construct, 2018

4.4.3 Results of Observation of CSIR-BRRI entrance at Fumesua

The construction of new entrance at CSIR-BRRI Fumesua, the following observations were made; At Fumesua, CSIR-BRRI an ongoing construction of an entrance using pozzomix cement sandcrete blocks and burnt bricks was observed as one of the existing structures for the study. The contractor in charge of the project revealed that the properties of pozzomix cement sandcrete blocks are enormous but was quick to add that the supply is limited to the areas close to where the pozzomix cement is being manufactured. The contractor further admitted that where the supply of pozzomix cement is adequate and closer to the construction site, pozzomix cement is used for all aspects of the work as identified in Figure 4.4 under construction.

Figure 4.4:The newly constructed entrance of CSIR-BRRI at Fumesua near Kumasi with pozzomix cement sandcrete blocks.
Source: Researcher Field Construct, 2018

4.4.4 Results of Observation at Danyame

At Danyame, a construction of hotel complex in a water-logged area is shown in Figure 4.5. It was observed that pozzomix cement sandcrete block was used directly on the concrete foundation, while OPC cement sandcrete blocks were used for the construction of the super structure due to the clay content in the pozzomix cement sandcrete blocks. The mix ratio for the blocks used at typical areas like Danyame ranges from 1:6 (one part of cement to six parts of sand) and 1:9 (one part of cement to nine parts of sand) so that the strength of the sandcrete blocks can withstand the weather and water permeability to enhance durability. According to the site foreman, the properties of pozzomix cement sandcrete blocks make them restrain water movement more than OPC sandcrete blocks at the ground level. The blocks used (225 x 225 x 450 mm, 9 inches) were specially manufactured using the correct mix ratio making it not applicable to this research work.

Figure 4.5: Construction of hotel complex in a water-logged area at Danyame, Kumasi
Source: Researcher Field Construct, 2018

4.4.5 Results of Observation at Fumesua

Figue 4.6 shows an existing project at `BRRI-CSIR Fumesua which was constructed using pozzomix cement and pozzomix cement sandcrete blocks. The structure has been in existence for some years now without any defects. During the observation, it was realised that the structure was able to resist abrasion where the surface is worn out by rubbing or friction. Moisture and environment conditions that affect and damage structures have not affected this existing structure as observed. Other exposure conditions (rain, humidity, chemicals, and freezing) which cause serious damage to structures reducing their durability property were not able to attack this structure at the center as shown in figure 4.6

Figure 4. 6 : Picture of pozzomix cement factory under construction with pozzomix cement sandcrete blocks for pozzolana factory at BRRI-CSIR, Fumesua.

Source: Researcher Field Construct, 2018

CHAPTER FIVE

5.0 SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter sums up the findings from the study, draws conclusions arising from the study and makes relevant recommendations based on the findings.

5.2 Summary of Findings

The following are the summary of findings:

- It was revealed that the performance of pozzomix cement and OPC sandcrete blocks in existing structures were inconsistent with cracks and other defects found on the existing structures due to the non compliance with the right process of manufacturing (batching, mixing, compacting, curing, water/cement ratio etc) both pozzomix cement and OPC sandcrete blocks.
- The performance of the properties of sandcrete blocks manufactured from pozzomix cement and OPC and used in existing structures cannot be ascertained by the use of visual inspection of the quality of the material constituents (sand, cement and water) based on the number of years' experience therefore making the pozzomix cement and OPC sandcrete blocks susceptible and non-performing materials in existing structures.
- After determining the weight and density of pozzomix cement and OPC sandcrete blocks, it became clear that the two samples, pozzomix cement and OPC sandcrete blocks were above the GS 297 (2011) specified minimum density (1500kg/m^3) with OPC sandcrete blocks being higher than that of pozzomix cement sandcrete blocks making the two samples of sandcrete blocks good materials for load bearing

structures and non-load bearing structures and enhance performance of other properties.

- It was revealed that the compressive strength of both OPC and pozzomix cement sandcrete blocks used in the laboratory test for all the curing ages failed to meet the specified minimum compressive strength of 2.8N/mm^2 (GS 297, 2010) but pozzomix cement sandcrete blocks were slightly higher than that of OPC sandcrete blocks for all curing ages which can negatively affect the performance of other properties of pozzomix cement and OPC sandcrete blocks and the existing structures.
- The water absorption test indicated that the pozzomix cement sandcrete blocks absorb more water than OPC sandcrete blocks making OPC sandcrete blocks more durable than that of pozzomix cement sandcrete blocks but the experiment conducted turn out to disagree with what has been observed in the field survey by the researcher but the two samples are within the acceptable recommended range of 11% and 16% by ASTM C642 (1990). Dodoo-Arhin, et al (2013) stated that lower water absorption in the test pieces will have higher strength and durability. Since if the water absorption is lower, it restricts the amount of water that may cause deterioration. Water existing in the pores of the products will be cyclically expanded and contracted and this will generate stresses within the material thereby resulting in the weakening of the products or the structures.
- It was revealed in the results that both materials' strength with clay pozzolana which is now pozzomix cement and OPC in the laboratory and on the field, can be assessed on compressive strength, water absorption, workability, durability low shrinkage, weather resistance and other properties as major factor in performance delivery but in their right mix ratio pozzomix cement sandcrete blocks strength

and durability surpass the strength and durability properties of OPC sandcrete blocks.

5.3 Conclusion

Sandcrete blocks are used extensively in many countries all over the world including Ghana in Africa. Even though there is the presence of other building materials such as wood, bricks, compressed earth, sandcrete blocks dominate in the construction industry. The strength of sandcrete blocks is however inconsistent due to high cost of cement as a binder, the different production methods employed, duration of curing, sizes of blocks and the properties of constituent materials, method of mixing, mixing ratio and moulding process identified by (Abdullai, 2005). There is an alternative locally produced material (pozzomix cement) that can reduce the over-dependence on the Ordinary Portland Cement (OPC) as a binder in Ghana. Contractors claimed to know all the properties especially compressive strength to ensure that the sandcrete blocks they manufacture meet the standards, but this was not confirmed by the laboratory test results.

A comparative study of the performance properties of sandcrete blocks produced from OPC and Pozzomix cement revealed that the Pozzomix cement sandcrete blocks have higher compressive strength and weight than the OPC sandcrete blocks for each curing age. The study found some qualities of OPC sandcrete blocks like water absorption to be less making OPC sandcrete blocks more durable than that of pozzomix cement sandcrete blocks as the two samples are within the recommended range. The study concluded that sandcrete blocks produced from OPC have the highest densities as compared to sandcrete blocks produced from pozzomix cement. The study concluded that pozzomix cement sandcrete blocks are good alternative to OPC sandcrete blocks for all construction works with its economic, technical and ecological values and properties that enhance performance and affect durability of structures.

Finally, the cost of a 50kg bag of cement as at the time of concluding this study, OPC was GHc33.00 and pozzomix cement was GHc28.00 meaning 18% price difference which is very significant on reducing the cost of constructing houses if pozzomix cement is available in the market all over Ghana.

5.4 Recommendations

Based on the findings of the study, the following recommendations were made:

- To enhance the performance of properties of sandcrete blocks manufactured from OPC and pozzomix cement in existing structures and ongoing structures, there is the need to use the right process in manufacturing (batching, mixing, compacting, curing, water/cement ratio etc) under strict supervision by authorities.
- The quality of the material constituents (sand, cement and water) used in manufacturing sandcrete blocks can only be ascertained by avoiding visual inspection and send the materials and the sandcrete blocks from OPC and pozzomix cement to the laboratory for testing to satisfy the recommended values of sandcrete blocks to enhance performance of their properties and serviceability.
- The strict implementation of standard specification by authorities (Ghana Standard Authority) can lead to quality control of sandcrete blocks with weight, density and other properties contributing significantly to the higher compressive strengths of sandcrete blocks to meet the recommendations of BS 2028 and GS 297-1, (2010) thereby enhancing performance and durability properties of sandcrete blocks manufactured from OPC and pozzomix cement.

- Compressive strength is a major property in sandcrete blocks manufactured from OPC and pozzomix cement has a link with other properties, therefore the failure to meet its recommended minimum value has adverse effect on existing structures therefore the need to comply with standard specification to enhance performance.
- Durability of sandcrete blocks used in construction can be affected by high level of water absorption of sandcrete blocks manufactured from OPC and pozzomix cement if the right mix ratio and other factors are ignored, so authorities (Ghana Standard Authority) must check regularly to maintain strict adherence to laid down manufacturing process to prolong the serviceable life of OPC and pozzomix cement sandcrete blocks in existing structures and ongoing structures.
- The use of pozzomix cement as alternative in manufacturing sandcrete blocks with the required specification to reduce over dependence on the OPC in Ghana with its economical, ecological and technical benefits can be assessed based on the various properties (compressive strength, water absorption, workability, durability low shrinkage, weather resistance).

5.5 Suggestions for Further Studies

Further research can be conducted to find out comparative study of cost analysis of using Ordinary Portland Cement (OPC) and pozzomix cement sandcrete blocks for construction. Comparative study of strength properties of sandcrete blocks produced by block manufacturers on the field and laboratory. Investigation into the compliance to standard specification by sandcrete blocks manufacturers in the construction industry of Ghana. Assessing the availability of pozzomix cement in the Ghanaian market.

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APPENDIX A

STRUCTURES CONSTRUCTED WITH POZZOMIX AND OPC SANDCRETE BLOCKS

A residential structure under construction with pozzomix cement at Fumesua

A front view of a structure constructed with OPC sandcrete block at Aprade

Other existing structures at Anglican SHS constructed with OPC sandcrete blocks

APPENDIX B

CSIR-BRRI CIVIL ENGINEERING LABORATORY

P.O.BOX UP 40, KNUST CAMPUS, KUMASI
Tel: 0322060064/5; Fax: 0322060080

TITLE: COMPRESSIVE STRENGTH TEST REPORT
Your Reference:

TO: MR. ROBERT SENU KWAME

CODE: BC01081802 (Pozzo) 28Days

TEST CODE	TEST CONDUCTED	UNIT	RESULTS	TEST METHODS
DIM	Dimension			
	length	mm	430	
	width	mm	120	
	height	mm	223	
CSA	Cross sectional area	mm^2	27600	
T	Temperature	°C	27	
COS	Compressive strength	MPa(N/mm^2)		
	Sample 1	"	1.288	
	Sample 2	"	1.236	
	Sample 3	"	1.223	
	Sample 4		0.876	
	Sample 5		1.022	
	Average strength		1.022	
M	Mass	Kg		
	Sample 1	"	24.7	
	Sample 2	"	24.9	
	Sample 3	"	24.4	
	Sample 4		24	
	Sample 5		24.2	

…………………………………….. ………………………………………

Operator Manager

Note: The results relate only to the items tested

Condition:

1. Not valid without the approval of the facility manager.

2. The report does not signify that product tested has been certified

3. Not to be used for litigation and advertisement without the written consent of the Director of CSIR-BRRI

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CSIR-BRRI CIVIL ENGINEERING LABORATORY

P.O.BOX UP 40, KNUST CAMPUS, KUMASI
Tel: 0322060064/5; Fax: 0322060080

TITLE: COMPRESSIVE STRENGTH TEST REPORT
Your Reference:

TO: MR. ROBERT SENU KWAME

CODE: BC01081802 (OPC) 28Days

TEST CODE	TEST CONDUCTED	UNIT	RESULTS	TEST METHODS
DIM	Dimension			
	length	mm	428	
	width	mm	110	
	height	mm	223	
CSA	Cross sectional area	mm^2	25080	
T	Temperature	°C	27	
COS	Compressive strength	MPa(N/mm^2)		
	Sample 1	"	0.395	
	Sample 2	"	0.428	
	Sample 3	"	0.398	
	Sample 4		0.330	
	Sample 5		0.271	
	Average strength		0.330	
M	Mass	Kg		
	Sample 1	"	23.2	
	Sample 2	"	23.3	
	Sample 3	"	24.8	
	Sample 4		23.5	
	Sample 5		23	

……………………………………..   ………………………………………
Operator   Manager

Note: The results relate only to the items tested

Condition: 1. Not valid without the approval of the facility manager.

2. The report does not signify that product tested has been certified

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P.O.BOX UP 40, KNUST CAMPUS, KUMASI
Tel: 0322060064/5; Fax: 0322060080

TITLE: COMPRESSIVE STRENGTH TEST REPORT
Your Reference:

TO: MR. ROBERT SENU KWAME

CODE: BC01091803 (Pozzo) 60Days

TEST CODE	TEST CONDUCTED	UNIT	RESULTS	TEST METHODS
DIM	Dimension			
	length	mm	430	
	width	mm	110	
	height	mm	230	
CSA	Cross sectional area	mm^2	25300	
T	Temperature	°C	27	
COS	Compressive strength	MPa(N/mm^2)		
	Sample 1	"	0.934	
	Sample 2	"	1.551	
	Sample 3	"	1.288	
	Sample 4		1.551	
	Sample 5		1.050	
	Average Strength		1.301	
M	Mass	Kg		
	Sample 1	"	24.8	
	Sample 2	"	24.7	
	Sample 3	"	24.9	
	Sample 4		24.3	
	Sample 5		24.5	

……………………………….. ……………………………………
Operator Manager

Note: The results relate only to the items tested

Condition: 1. Not valid without the approval of the facility manager.

2. The report does not signify that product tested has been certified

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Tel: 0322060064/5; Fax: 0322060080

TITLE: COMPRESSIVE STRENGTH TEST REPORT
Your Reference:

TO: MR. ROBERT SENU KWAME

CODE: BC01091803 (OPC) 60Days

TEST CODE	TEST CONDUCTED	UNIT	RESULTS	TEST METHODS
DIM	Dimension			
	length	mm	*425*	
	width	mm	110	
	height	mm	230	
CSA	Cross sectional area	mm^2	24750	
T	Temperature	°C	27	
COS	Compressive strength	MPa(N/mm^2)		
	Sample 1	"	0.431	
	Sample 2	"	0.284	
	Sample 3	"	0.274	
	Sample 4		0.503	
	Sample 5		0.279	
	Average strength		0.279	
M	Mass	Kg		
	Sample 1	"	23.2	
	Sample 2	"	23.4	
	Sample 3	"	24.8	
	Sample 4		23.6	
	Sample 5		23.2	

…………………………………..   ……………………………………

Operator   Manager

Note: The results relate only to the items tested
Condition: 1. Not valid without the approval of the facility manager.
2. The report does not signify that product tested has been certified
3. Not to be used for litigation and advertisement without the written consent of the Director of CSIR-BRRI
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CSIR-BRRI CIVIL ENGINEERING LABORATORY

P.O.BOX UP 40, KNUST CAMPUS, KUMASI
Tel: 0322060064/5; Fax: 0322060080

TITLE: WATER ABSORPTION TEST REPORT
Your Reference:

TO: MR. ROBERT SENU KWAME

CODE: BC01081802 (OPC) 28Days

TEST CODE	TEST CONDUCTED	UNIT	RESULTS	TEST METHODS
DIM	Dimension			
	length	mm	100	
	width	mm	100	
	height	mm	100	
CSA	Cross sectional area	mm^2	10000	
T	Temperature	°C	27	
WA	Water Absorption	(%)		
	Sample 1	"	11.57	
	Sample 2	"	9.99	
	Sample 3	"	10.97	
	Sample 4	"	9.58	
	Sample 5	"	12.69	
	Average strength		10.18	
SD	Standard deviation		0.007142	
COV	Coefficient of Variance	(%)	7	

…………………………………..   …………………………………….
Operator   Manager

Note: The results relate only to the items tested

Condition: 1. Not valid without the approval of the facility manager.

2. The report does not signify that product tested has been certified

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P.O.BOX UP 40, KNUST CAMPUS, KUMASI
Tel: 0322060064/5; Fax: 0322060080

TITLE: WATER ABSORPTION TEST REPORT
Your Reference:

TO: MR. ROBERT SENU KWAME

CODE: BC01081802 (Pozzo) 28Days

TEST CODE	TEST CONDUCTED	UNIT	RESULTS	TEST METHODS
DIM	Dimension			
	length	mm	100	
	width	mm	100	
	height	mm	100	
CSA	Cross sectional area	mm^2	10000	
T	Temperature	°C	27	
WA	Water Absorption	(%)		
	Sample 1	"	10.97	
	Sample 2	"	12.76	
	Sample 3	"	12.83	
	Sample 4	"	6.29	
	Sample 5	"	12.36	
	Average strength		12.65	
SD	Standard deviation		0.002536	
COV	Coefficient of Variance	(%)	2	

……………………………….. ……………………………………

Operator Manager

Note: The results relate only to the items tested

Condition: 1. Not valid without the approval of the facility manager.

2. The report does not signify that product tested has been certified

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CSIR-BRRI CIVIL ENGINEERING LABORATORY

P.O.BOX UP 40, KNUST CAMPUS, KUMASI

Tel: 0322060064/5; Fax: 0322060080

TITLE: COMPRESSIVE STRENGTH TEST REPORT

Your Reference:

TO: MR. ROBERT SENU KWAME

CODE: BC17071801 (OPC) 14Days

TEST CODE	TEST CONDUCTED	UNIT	RESULTS	TEST METHODS
DIM	Dimension			
	length	mm	228	
	width	mm	110	
	height	mm	223	
CSA	Cross sectional area	mm^2	25080	
T	Temperature	°C	27	
COS	Compressive strength	MPa(N/mm^2)		
	Sample 1	"	0.134	
	Sample 2	"	0.141	
	Sample 3	"	0.161	
	Sample 4		0.141	
	Sample 5		0.166	
	Average strength		0.1486	
M	Mass	Kg		
	Sample 1	"	24.1	
	Sample 2	"	24.3	
	Sample 3	"	24.5	
	Sample 4		24.3	
	Sample 5		24.3	

……………………………………..   ……………………………………….

Operator   Manager

Note: The results relate only to the items tested

Condition: 1. Not valid without the approval of the facility manager.

2. The report does not signify that product tested has been certified

3. Not to be used for litigation and advertisement without the written consent of the Director of CSIR-BRRI

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CSIR-BRRI CIVIL ENGINEERING LABORATORY

P.O.BOX UP 40, KNUST CAMPUS, KUMASI
Tel: 0322060064/5; Fax: 0322060080

TITLE: COMPRESSIVE STRENGTH TEST REPORT
Your Reference:

TO: MR. ROBERT SENU KWAME

CODE: BC17071801 (Pozzo) 14Days

TEST CODE	TEST CONDUCTED	UNIT	RESULTS	TEST METHODS
DIM	Dimension			
	length	mm	230	
	width	mm	120	
	height	mm	223	
CSA	Cross sectional area	mm^2	27600	
T	Temperature	°C	27	
COS	Compressive strength	MPa(N/mm^2)		
	Sample 1	"	1.168	
	Sample 2	"	1.126	
	Sample 3	"	1.061	
	Sample 4		0.463	
	Sample 5		0.884	
	Average strength		0.9404	
M	Mass	Kg		
	Sample 1	"	25	
	Sample 2	"	25	
	Sample 3	"	25.4	
	Sample 4		25	
	Sample 5		24.6	

……………………………….. ……………………………………

Operator Manager

Note: The results relate only to the items tested

Condition: 1. Not valid without the approval of the facility manager.

2. The report does not signify that product tested has been certified

3. Not to be used for litigation and advertisement without the written consent of the Director of CSIR-BRRI

4. The report shall not be reproduced, except in full, without the written approval of the Director of CSIR-BRRI

APPENDIX C

UNIVERSITY OF EDUCATION, WINNEBA
COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGY

EDUCATION

QUESTIONNAIRE FOR RESEARCH SCIENTISTS

The researcher is a student of University of Education, Winneba in the Department of Construction and Wood Technology Education, Kumasi Campus. He is writing thesis on the topic:

"COMPARATIVE STUDY OF THE PERFORMANCE OF THE PROPERTIES OF ORDINARY PORTLAND CEMENT (OPC) AND POZZOMIX CEMENT SANDCRETE BLOCKS".

How to complete the questionnaire

Answers have been provided for some of the questions. Please respond by ticking [ ] the most appropriate answers. Other questions require that you provide your own responses. Write your responses in the spaces provided. Thank you.

SECTION A: SOCIO-DEMOGRAPHIC PROFILE OF RESPONDENT

1. Indicate your gender? Male [ ] Female [ ]
2. How long have you been a research scientist in the construction industry?

   1-5 years [ ] 6 – 10years [ ] 11 – 15years [ ]

   16 – 20 years [ ] 21 – 25 years [ ] 26 years – above [ ]
3. What is your level of education?

   SHS/Secondary [ ] Vocational/Technical/Commercial [ ]

   Diploma [ ] Bachelor [ ] Master [ ]

SECTION B

The performance of properties of OPC sandcrete blocks in existing structures in Ashanti Region.

4. How long have you been working with OPC?

   1-5 years [ ] 6 – 10years [ ] 11 – 15years [ ]

   16 – 20 years [ ] 21 – 25 years [ ] 26 years – above [ ]

5. Have you ever conducted a research with OPC sandcrete blocks?

   Yes [ ] No [ ]

6. a) Do you buy the OPC sandcrete blocks? Yes [ ] No [ ]

   b) Do you mould the sandcrete blocks on your own? Yes [ ] No [ ]

7. Provide reasons for you choice.

   a) ……………………………………………………………………………

   b) ……………………………………………………………………………

8. Do you feel satisfy when you complete a research using OPC?

   Yes [ ] No [ ]

1. How will you rate the following properties of OPC sandcrete blocks using the following likert scales?

   1. Strongly agree 2. Agree 3. Disagree 4. Strongly disagree 5. Not sure

S/N	PROPERTIES	1	2	3	4	5
1	High compressive strength					
2	Low shrinkage					
3	Low moisture movement					
4	Low thermal movement					
5	Denseness and durability					
6	Standard consistency					

9. How will you rate the following performance of OPC sandcrete blocks using the following likert scales?

   1. Strongly agree 2. Agree 3. Disagree 4. Strongly disagree 5. Not sure

S/N	PERFORMANCE	1	2	3	4	5
1	Good for all construction works					
2	Does not get damaged easily					
3	Easy hardening					
4	It is better for water logged areas in the country					
5	Has very good technical properties					
6	Its workability is a major factor in performance delivery					

10. What other comments do you have on OPC for construction in Ghana?

……………………………………………………………………………………

……………………………………………………………………………………

SECTION C:

The performance of properties of Pozzomix cement sandcrete blocks in existing structures in Ashanti Region.

11. Do you have any knowledge about pozzomix cement?

    Yes [ ] No [ ]

12. How long have you been working with pozzomix cement?

    1-5 years [ ] 6 – 10years [ ] 11 – 15years

    16 – 20 years [ ] 21 – 25 years [ ] 26 years – above [ ]

13. Have you used pozzomix cement sandcrete blocks for your research work?

    Yes [ ] No [ ]

14. Do you know the properties of pozzomix cement?

    Yes [ ] No [ ]

15. How will you rate the following properties of pozzomix cement sandcrete blocks using the following likert scales?

    2. Strongly agree 2. Agree 3. Disagree 4. Strongly disagree 5. Not sure

S/N	PROPERTIES	1	2	3	4	5
1	High compressive strength					
2	Low shrinkage					
3	Low moisture movement					
4	Low thermal movement					
5	Denseness and durability					
6	Standard consistency					

16. What will you say about the performance of the properties of pozzomix cement in sandcrete blocks?

………………………………………………………………………………………

………………………………………………………………………………………

17. How will you rate the following performance of pozzomix cement sandcrete blocks using the following likert scales?

1. Strongly agree 2. Agree 3. Disagree 4. Strongly disagree 5. Not sure

S/N	PERFORMANCE	1	2	3	4	5
1	Good for all construction works					
2	Does not get damaged easily					
3	Easy hardening					
4	It is better for water logged areas in the country					
5	Has very good technical properties					
6	Its workability is a major factor in performance delivery					

18. List some factors that need to be adhere to for quality sandcrete blocks

………………………………………………………………………………………

………………………………………………………………………………………

19. What other suggestions do you have on the use of pozzomix cement for constructional works?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

APPENDIX D

UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGY EDUCATION

QUESTIONNAIRE FOR CONTRACTORS

The researcher is a student of University of Education, Winneba in the Department of Construction and Wood Technology Education, Kumasi Campus. He is writing thesis on the topic:

"COMPARATIVE STUDY OF THE PERFORMANCE OF PROPERTIES OF ORDINARY PORTLAND CEMENT (OPC) AND POZZOMIX CEMENT SANDCRETE BLOCKS".

How to complete the questionnaire

Answers have been provided for some of the questions. Please respond by ticking [ ] the most appropriate answers. Other questions require that you provide your own responses. Write your responses in the spaces provided. Thank you.

SECTION A

SOCIO-DEMOGRAPHIC PROFILE OF RESPONDENT

20. Indicate your gender.

    Male [ ]

    Female [ ]

21. Where in the Kumasi Metropolis is your construction firm is located?

    ……………………………………………………………………..

22. How long have you been in the construction industry?

1-5 years	[ ]	6 – 10years	[ ]	11 – 15years	[ ]
16 – 20 years	[ ]	21 – 25 years	[ ]	26 years – above	[ ]

23. What is your level of education?

SHS/Secondary	[ ]
Vocational/Technical/Commercial	[ ]
Diploma	[ ]
Bachelor	[ ]
Master	[ ]

SECTION B

The performance of properties of OPC sandcrete blocks in existing structures in Ashanti Region

24. Do you mould sandcrete blocks on site for your construction works?

    Yes [ ] No [ ]

25. Do you buy sandcrete blocks from block manufacturers?

    Yes [ ] No [ ]

26. If you mould sandcrete blocks on site which type of cement is used for the moulding?

    OPC [ ] Pozzomix cement [ ]

    others: ………………………………….

27. If you buy from block manufacturers, are you aware of the type of cement used for the moulding?

    Yes [ ] No [ ]

28. How do you assess the quality of the sandcrete blocks from these block manufacturers?

    ………………………………………………………………………………………

    ………………………………………………………………………………………

29. How will you rate the following properties of OPC sandcrete blocks using the following likert scales?

3. Strongly agree 2. Agree 3. Disagree 4. Strongly disagree 5. Not sure

S/N	PROPERTIES	1	2	3	4	5
1	High compressive strength					
2	Low shrinkage					
3	Low moisture movement					
4	Low thermal movement					
5	Denseness and durability					
6	Standard consistency					

30. What will you say about the performance of the properties of OPC sandcrete blocks?

……………………………………………………………………………………

……………………………………………………………………………………

31. How satisfied are you with the performance of the following properties in OPC sandcrete blocks? Use the following Likert Scale; "1" = very satisfied, "2" = satisfied, "3"= slightly satisfied, "4"= not satisfied and "5"= Not sure,

S/N	PROPERTIES	1	2	3	4	5
1	Durability					
2	Availability					
3	Suitability					
4	Weather resistivity					
5	Workability					
6	Dampness resistance					

32. How will you rate the following performance of OPC sandcrete blocks using the following likert scales?

1. Strongly agree 2. Agree 3. Disagree 4. Strongly disagree 5. Not sure

S/N	PERFORMANCE	1	2	3	4	5
1	Good for all construction works					
2	Does not get damaged easily					
3	Easy hardening					
4	It is better for water logged areas in the country					
5	Has very good technical properties					
6	Its workability is a major factor in performance delivery					

33. How satisfy are your clients when you complete a project using OPC sandcrete blocks?

Very satisfied [ ] Satisfied [ ] Not sure [ ]

34. What are the comments you get from your clients on OPC sandcrete blocks?

………………………………………………………………………………………

………………………………………………………………………………………

35. What are the other qualities that make you choose OPC sandcrete blocks for your construction works?

………………………………………………………………………………………

………………………………………………………………………………………

SECTION C

The performance of properties of Pozzomix cement sandcrete blocks in existing structures in Ashanti Region.

36. Do you use any other cement for your construction work?

    Yes [ ] No [ ]

37. Which other types of cement do you know?

    ……………………………………………………………………………………………

38. How long have you been working with pozzomix cement?

    ……………………………………………………………………………………………

    ……………………………………………………………………………………………

    ……………………………………………………………………………………………

39. Do you mould sandcrete blocks with pozzomix cement?

    Yes [ ] No [ ]

40. Do you know the properties of pozzomix cement?

    Yes [ ] No [ ]

41. Give some of the properties of pozzomix cement.

………………………………………………………………………………………………………

………………………………………………………………………………………………………

42. How will you rate the following properties of pozzomix cement sandcrete blocks using the following likert scales?

1. Strongly agree 2. Agree 3. Disagree 4. Strongly disagree 5. Not sure

S/N	PROPERTIES	1	2	3	4	5
1	High compressive strength					
2	Low shrinkage					
3	Low moisture movement					
4	Low thermal movement					
5	Denseness and durability					
6	High standard consistency					

43. What will you say about the performance of the properties of pozzomix cement sandcrete blocks?

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…………………………………………………………………………………………

44. How satisfied are you with the performance of the following properties in OPC sandcrete blocks? Use the following Likert Scale; "1" = very satisfied, "2" = satisfied, "3"= slightly satisfied, “4”= not satisfied and “5”= Not sure,

S/N	PROPERTIES	1	2	3	4	5
1	Durability					
2	Availability					
3	Suitability					
4	Weather resistivity					
5	Workability					
6	Dampness resistance					

45. How will you rate the following performance of pozzomix cement sandcrete blocks using the following likert scales?

1. Strongly agree 2. Agree 3. Disagree 4. Strongly disagree 5. Not sure

S/N	PERFORMANCE	1	2	3	4	5
1	Good for all construction works					
2	Does not get damaged easily					
3	Easy hardening					
4	It is better for water logged areas in the country					
5	Has very good technical properties					
6	Its workability is a major factor in performance delivery					

46. How satisfy are your clients when you complete a project using pozzomix cement sandcrete blocks?

Very satisfied [ ] Satisfied [ ] Not sure [ ]

47. Will you recommend pozzomix cement sandcrete blocks to other contractors?

Yes [ ] No [ ]

48. How often do you get the supply of pozzomix cement from the dealers?

Very often [ ] often [ ] not often [ ] not sure [ ]

49. What other general performance that made you choose pozzomix cement sandcrete blocks for your construction works?

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APPENDIX E.

LEAFLETS FROM BRRI-CSIR AT FUMESUA NEAR KUMASI