UNIVERSITY OF EDUCATION, WINNEBA

EFFECTS OF FINES IN SAND AND WATER-TO-CEMENT RATIO ON CONCRETE PROPERTIES

AUGUSTINE SAM

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JULY, 2016

DECLARATION

STUDENT'S DECLARATION

I, SAM AUGUSTINE 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: PETER PAA-KOFI YALLEY (PhD)

SIGNATURE: ……………………………………………………..

DATE: …..

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DEDICATION

I dedicate this dissertation to my family: Mr. Francis Sam, Madam Mary Asare, John Kofi Sam, Monica Efua Sam, Peter Kwabena Sam, Matthew Kwesi Sam, Francis Sam, Emmanuel Opoku Sam, Hannah Nyarko Sam and my wife Mrs. Francisca Owusu-Ansah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The quality of building materials has been documented to be one of the causes of building collapse all over the world. An experimental study was conducted to determine the effect of fines (clay/silt) content in sand and water-to-cement ratio on the workability, compressive strength, tensile strength and flexural strength of concrete. A total of 270 specimens were cast and tested with varying fines content in sand of 2%, 4%, 6%, 8%, 10% and 12%; and variable water-to-cement ratio of 0.55, 0.60 and 0.70. A basic 1:2:4 concrete mix ratio was adopted for the study through trial mix. Mixing, compaction, curing and testing were performed in accordance with BS and ASTM standards. The results show that, workability of concrete decreased and increased as the percentage of fines in sand and water-to-cement ratio respectively increased. The study again revealed that compressive, tensile and flexural strength of concrete increased to 4% fines content in sand beyond which they decreased at constant water-to-cement ratio. Equations for predicting the workability ($Wc = -141.905 – 235.714CS + 310.476w/c$; $R^2=0.899$), and compressive strength ($f_{cu,28} = 45.357 – 37.143CS – 41.136w/c$; $R^2=0.848$), tensile splitting strength ($f_{ct,28} = 3.532 – 3.195CS – 2.798w/c$; $R^2=0.836$) and flexural strength of reinforced concrete ($f_{cf,28} = 30.485 – 23.076CS – 24.507w/c$; $R^2=0.905$) were proposed valid for 4% fines in sand and beyond. It was concluded from the study that, fines percentage in sand and water-to-cement ratio beyond 4% and 0.57 respectively affect concrete properties negatively. Concrete designers and producers are therefore advised to pay attention to the percentage of fines in sand and water-to-cement ratio on site.

CHAPTER ONE

1.0 INTRODUCTION

1.1. Background and Justification of the Research

In the quest for developing countries to achieve the Millennium Development Goals (MDGs), the construction industry is at its peak where high-rise buildings are on the bloom. The key word in the MDGs is "*Development*" and according to Savitha (2012), infrastructural development of a nation eventually leads to the prosperity and growth of that country. In the construction of buildings and other civil infrastructures such as roads, dams, fly-overs among others in developing countries, concrete play its rightful role and a large quantum is consumed.

Concrete is a product which constitutes the mixture of binding agent (cement), fine aggregate (sand), coarse aggregate (stone or gravel) and an appreciable amount of water. In some instances admixtures are added to the mixture to improve the concrete's properties such as colour, setting rate, workability among others. There are various characteristics of concrete such as durability, workability, permeability, strength and others among which strength of concrete is considered the most valuable property. In view of this, careful consideration must be given to factors that affect the strength of concrete (Olanitori, 2006). In the production of concrete the proportion of each material constituent and their quality control the strength and quality of the resultant concrete (Chudley & Greeno, 1999). Ngugi, Mutuku and Gariy (2014) report that, the quality of constituent materials used in the preparation of concrete plays a paramount role in the development of both physical and strength properties of concrete. They again acknowledged that, past researches have established major causes of building failure as: quality of building materials, concrete mix proportion, construction methodology, defective designs and non-compliance with specifications.

Factors that affect the quality of concrete constituent materials include deleterious materials sometimes present in the aggregates used for concrete. Notably among these are fine particles lesser than 75-µm [clay/silt] present in sand used for concrete production. In Ghana, natural sand is largely used for the production of concrete rather than manufactured sand. Pit and river sand are the most common types of sand used in Ghana and the quality thereof should be of concern to the engineer. However, the quality of natural sand from the primary source are most often compromised due to the presence of these deleterious materials such as clay, silt and organic impurities in them. In view of this, construction standards such as BS 882:1992 (British Standards [BSI], 2002a); Nigerian Standards [NS] (as cited in Olanitori & Olotuah, 2005) and C117 (American Society for Testing and Materials [ASTM], 1995) give an allowable limit of 4%, 8% and 10% respectively for fines content in sand.

Thus, the content of impurities in aggregates is expected to be determined before they are used in the building industry (Savitha, 2012; Desire & Leopold, 2013). However, natural sand is directly ordered from its primary source to the building site for construction without checking the fines (clay/silt) content in most cases in Africa as noted by Desire and Leopold. Ahmed and Ahmed (1989) as confirmed by Desire and Leopold (2013) report that, natural and crushed stone sand contain considerable amount of materials finer than 75µm (clay/silt). The presence of these fines in aggregates in excessive quantities creates an interference with the bond between the aggregate and cement paste which may have adverse effects on the properties of both fresh and hardened concrete (Ahmed & Ahmed, 1989; Esmail, 2009). To buttress this point, Gambhir (2002) alludes fines found in sand may affect the strength, workability and long-term performance of concrete.

Another major cause of poor concrete strength is the amount of water used in the concrete mix. The proportion of water in concrete is normally increased to achieve sufficient workability (Reynolds, Steedman & Threlfall, 2008). To buttress this point, Cemex (2013, p. 1) puts it that, “It is not uncommon in the concrete industry for the contractor to add water to the load prior or even during the unloading process to increase the slump and improve the workability of the concrete.” Horpibulsuk, Miura and Nagaraj (2005) report that, cement and clay enter into physiochemical interactions with water whereas fine and coarse aggregates do not in concrete mix. Clay absorbs more water as a result of its quantity in the concrete and nature of the exchangeable cations in the clay (Innovative Pavement Research Foundation [IPRF], 2005) hence will require more water to make the concrete workable. As the water content in concrete mix is increased in excess of the design mix water-to-cement ratio, the workability increases whereas the resultant compressive strength decreases (MacGingley & Choo, 1990; Alawode & Idowu, 2011; Cemex, 2013; Othman, 2013).

It is worth noting that, the role of concrete in buildings and other construction members are so important that its structural performance cannot be overlooked. Ayedun, Durodola and Akinjari (2012) and Ngugi et al. (2014) note that, collapse of buildings resulting to injuries, loss of lives and investments have been largely attributed to the use of poor quality concrete materials, poor workmanship, non-compliance with specifications among others. To buttress this assertion, Danso and Boateng (2013) write that, poor quality materials are mentioned as one of the major causes of building failures worldwide.

Nevertheless, the quality of concrete depends on both its constituent materials and mix proportions as noted in the BS 8110-1:1997 (BSI, 2005).

A press statement released by the Ghana Institute of Safety & Environmental Professionals (GhISEP) gives statistics of about some prominent building collapses in Ghana from the year 2000 to 2012. Notably among them was the Melcom building (shopping center) collapse in 2012 at Achimota a suburb of Accra – Ghana. One of the questions the Institute was asked was: “Were the right and quality materials used for the construction?” (GhISEP, 2012). Ghana has recorded several building collapses resulting in deaths, injuries and loss of properties which is indeed a worry (refer to Appendix A for data on some collapse of buildings in Ghana from the year 2002 to 2015). The need to research into the role fines in sand and water-to-cement ratio have on concrete properties is therefore paramount as they may contribute to the collapse of buildings in Ghana.

1.2. Statement of Research Problem

Collapse of building resulting in death, injuries and loss of properties is a worry to building engineers and every nation at large. Poor concrete materials are largely acknowledged as one of the causes of these collapses (Ede, 2011; Ayedun et al., 2012; Ngugi et al., 2014). Natural sand collected from sources used for construction purposes have some deleterious materials in them and the level of percentage present have consequential effect on the concrete strength (Olanitori & Olotuah, 2005; Desire & Leopold, 2013; Ngugi et al., 2014). It was recommended by Danso and Boateng (2013) to investigate the quality of sand and its contributing factor to the collapse of buildings in

Ghana after they found the strength of Ghana grey cement (class 32.5R) to be comparable with UK grey cement (class 32.5R) in their study.

Moreover, in spite of extensive publications on the effects of fines (clay/silt) as well as water-to-cement ratio on the strength of concrete in other countries, the topic has not been researched into detail in Ghana. Meanwhile, the prescription of different acceptable limits of fines content in sand by the BS 882:1992 (BSI, 2002a), NS (as cited in Olanitori & Olotuah, 2005) and the C117 (ASTM, 1995) of 4%, 8% and 10% respectively gives concern for further studies on local basis. Finally, as some studies have attempted to model the relationship between the content of fines (clay/silt) in sand with concrete compressive strength, there is a gap in the literature for the relationship (numbers involved) between the combined effects of fines (clay/silt) in sand and water-to-cement ratio used for concrete production with the compressive strength of concrete among other strengths.

1.3. Purpose and Objectives of the Research

1.3.1 Purpose

The purpose for this research is to assess the combined effect of the presence of fines (clay/silt) in sand and water-to-cement ratio on concrete properties to determine their contribution to building collapses in Ghana.

1.3.2 Specific objectives

In order to achieve the goal of the research, the following specific objectives have been set forth:

1.3.2.1 To determine the combined effect of fines in sand and water-to-cement ratio on concrete workability;

1.3.2.2 To predict the combined effect of fines in sand and water-to-cement ratio at different levels on concrete compressive strength;

1.3.2.3 To establish the combined effect of fines in sand and water-to-cement ratio on the splitting tensile strength of concrete;

1.3.2.4 To assess the combined effect of fines in sand and water-to-cement ratio on the flexural strength of reinforced concrete.

1.4. Research Questions

The research questions which this research seeks to answer are as follows:

1.4.1 What is the effect of fines in sand and water-to-cement ratio on concrete workability?

1.4.2 At what level does fines in sand and water-to-cement ratio have significant effect on the compressive strength of concrete?

1.4.3 What is the effect of fines in sand and water-to-cement ratio on the tensile splitting strength of concrete?

1.4.4 How significant do fines percentage in sand and water-to-cement ratio affect the flexural strength of reinforced concrete?

1.5. Significance of the Research

The result of the research will be useful for the following purposes:

1.5.1 It will help in the documentation of the quantitative effect that the percentage of fines in sand and variable water-to-cement ratios have on concrete strength.

1.5.2 It will try to propose the allowable limit of fines in sand to be used in Ghana.

1.5.3 It will help engineers performing consultancy roles to ensure sand used for concrete production in Ghana do not exceed the allowable percentage for fines in sand.

1.5.4 It will help to reduce the role that fines in sand and water-to-cement ratio plays in the collapse of buildings.

1.5.5 It will add knowledge to literature on the percentage of fines is Ghanaian sand and their effect on concrete strength which will serve as a basis for further studies.

1.6. Limitations of the Study

The limitation of this study may be using only one source of sand for the research whose properties might differ from other sources of sand in the country which may also yield slightly different results.

1.7. Delimitation of the Study

The scope of the research was concerned only with fines as a deleterious material in sand and water-to-cement ratio’s effects on concrete strength.

1.8. Organization of the Research

The structure of the dissertation is made up of six chapters: chapter one which talks about the general introduction of the study; chapter two reviews the relevant related literature; chapter three outline the research methodology used for the study; chapter four presents the results of the study; chapter five discusses the findings; and chapter six presents the summary of findings, conclusions and recommendations for policy implementation and future research.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Introduction

Concrete in its normal state constitute a mixture of coarse aggregate (stone), fine aggregate (sand), cement and water. The quality and quantity of these constituent materials are very important as they influence the quality of the concrete properties. Due to that, fines content in sand and water-to-cement ratio which affect concrete negatively when used in larger quantities are of interest to researchers. Literature shows that the quality of water used for making concrete should be potable and suitable for drinking (Neville, 1996; More & Dubey, 2014; Nikhil, Sushma, Gopinath & Shanthappa, 2014). The quantity, however is based on the water-to-cement ratio adopted for the concrete mixture. When this is used in large amount it also deteriorates the strength of concrete. Fines (clay/silt) on the other hand are invariably present in sand and where found in large amount affect the strength of concrete adversely (Olanitori & Olotuah, 2005; Olanitori, 2012; Cho, 2013; Dammo et al., 2014). This section of the study reviews the relevant related literature that researchers have conducted in relation to the objectives set for the current study. It deals into a brief review of theoretical and empirical literature related to this research on the variables under study.

2.2. Fines (Clay/silt) Content in Sand for making Concrete

The BS 882:1992 (BSI, 2002a) specifies that any solid material passing through the 75µm sieve is considered as fines in sand. These fines are in the form of clay and silt present in crushed and uncrushed sand. Guggenheim (1997) defines clay as a naturally occurring material which composes primarily of fine-grained minerals, which is generally plastic at appropriate water contents and becomes hard when fired or dried. The minerals found in clay are generally silicates less than 2µm (one-millionth of a meter) in size, about the same size as a virus. Clays are very abundant at the earth's surface which can form rocks known as 'shales' and are a major component in nearly all sedimentary rocks. They are also naturally and artificially placed in sand in a considerable amount (Ahmed & Ahmed, 1989; Desire & Leopold, 2013). The small size of the clay particles and their unique crystal structures give clay materials special properties, including cation exchange capabilities, plastic behavior when wet, catalytic abilities, swelling behavior, and low permeability. Clay has a very small particle size with a very large surface area which enables it to absorb and retain water than sand. Moreover, the presence of clay coatings on aggregate interferes with the bond between the aggregate and cement paste (Neville, 1996).

Silt on the other hand are considered as fine particles which have a size ranging from 2 to 60µm. They may form particles similar to the formation of clay or may be found in the form of un-bonded loose particles to aggregates (Neville, 1996).

2.3. Water-to-Cement Ratio in Concrete

The role of water in the process of cement hydration is important to be understood by the concrete producer (or engineer). The strength of concrete is developed by the hydration of cement with the addition of water to form a complex series of hydrates (Apebo, Shiwua, Agbo, Ezeokonkow & Adeke, 2013) called Calcium-Silicate-Hydrate (C-S-H). The amount of cement in a concrete needs an amount of water to hydrate and form these Calcium-Silicate-Hydrate (C-S-H) which is the glue that holds the concrete together (Cemex, 2013). They reported that, water is consumed chemically during the reaction with the cement at approximately 11.34kg (25 pounds) of water to every 45.36kg (100 pounds) of cement. This explains that a water-to-cement (w/c) ratio of 0.25 is needed for the Calcium-Silicate-Hydrate and hydration products to be formed. Apart from the water needed for Calcium-Silicate-Hydrate, there is also additional water needed for physical binding between the cement hydrates. For this reason, approximately 9.07kg (20 pounds) of water to every 45.36kg (100 pounds) of cement is required for the concrete mix. This results in a total of 20.41kg (45 pounds) of water to every 45.36kg (100 pounds) of cement which gives a water-to-cement (w/c) ratio of 0.45.

Neville (1996) considers this process as effective (free or net) water in the mix which describes the quantity of water in the concrete mix which occupies space outside the aggregate particles at the time of setting (gross volume of concrete has become stabilized). Powers as cited in Cemex (2013) reported that an approximate water-to-cement ratio (w/c) of 0.4 was adequate for complete hydration of the cement. It is again documented that a water-to-cement ratio of 0.50 is appropriate for normal concrete (Yalley & Kwan, 2009) and that the maximum water-to-cement ratio for concrete strength class of C20/25 is 0.70 specified by the BS 8500 (BSI, 2006).

In contrast to the fact that increasing water-to-cement ratio (w/c) results in the maximum potential for cement hydration, concrete designers are faced with the reality that lower water-to-cement ratio values often enhance strength and other durability characteristics of their concrete products (Cemex, 2013). They attribute this to the higher amounts of water in the mixture causing greater dispersion, but not because the crystals formed during hydration are weaker. Due to greater dispersion of concrete as a result of high amount of water, less bridging of the Calcium-Silicate-Hydrate crystals can take place resulting in lower density, lower strength, and higher permeability of concrete.

2.4. Coarse Aggregate in Concrete

Aggregate type, size, surface texture and content used in concrete production play an important role on the fresh and hardened properties of concrete (Arum & Olotuah, 2006). Coarse aggregate types used for producing concrete include: quartzite, granite, river gravel, basalt, limestone, sandstone, marble among others and the sizes range from 5mm to 50mm. River gravels in sometime past was mostly used in Ghana for producing concrete for structural buildings but are of low use today due to its scarcity. Granite, granodiorites, gneiss and quartzite are mostly supplied by commercial quarries to the construction industry in Ghana today (Adom-Asamoah, Tuffour, Afrifa & Kankam, 2014). The authors report that granite aggregates are largely found in the Central and part of the Northern belt of the country usually supplied commercially for construction whereas gneissic and quartzite aggregates are largely found in the southern part of Ghana particularly Greater Accra Region.

Abdullahi (2012) stated in his work that, concrete strength at the interfacial zone fundamentally depends on the integrity of the cement paste and the nature of coarse aggregate used in the concrete. In his investigation, three types of coarse aggregates were used (river gravel, crushed quartzite and crushed granite stones) to produce normal concrete of which the highest slump was obtained for concrete produced from river gravel. The highest slump achieved for the river gravel was as a result of relatively smooth and round shape which is also water-worn due to the running water thereby enhancing the workability. Quartzite aggregate concrete had the second highest slump followed by concrete produced from the crushed granite aggregate. He however recorded the highest compressive strength for quartzite aggregate concrete, followed by river gravel concrete and then granite aggregate concrete at all ages. He accounts that the lower strength observed for concrete made from granite aggregate may be attributed to greater voids in them to be occupied by mortar resulting to concrete with weaker mortar/aggregate interface. Growth of crack develops at this region upon application of load which leads to lower compressive strength.

Meanwhile, in the study by Adom-Asamoah et al. (2014), they reported that about 86% of the 28-day compressive strength of granite concrete was achieved for concrete made from partially-weathered quartzite aggregate. They acknowledged that sound quartzite aggregate have very good engineering properties giving an excellent use as coarse aggregate in concrete. They also reported un-weathered quartzite aggregates showed very little difference in quality to the sound granite aggregates while the partially weathered quartzite aggregates had a marginal quality and high water absorption values as compared to the sound granite aggregates.

Ajamu and Ige (2015) investigated the effect of coarse aggregate size on the compressive strength and flexural strength of concrete. For a mix ratio of 1:2:4 with water-to-cement ratio of 0.65, they reported compressive strength of 21.26N/mm^2, 23.41N/mm^2, 23.66N/mm^2, 24.31N/mm^2 and flexural strength of 4.78N/mm^2, 4.53N/mm^2, 4.49N/mm^2, 4.40N/mm^2 for concrete made from 13.2mm, 19.0mm, 25.0mm and 37.5mm size of aggregates respectively. This indicates that compressive strength is directly proportional to aggregate size, thus, strength increases with an increase in aggregate size. This was in agreement with the report by Kong and Evans (1987) who observed the same trend in their study.

However, the flexural strength from Ajamu and Ige's (2015) work also shows an inverse proportion with the coarse aggregate size. They again achieved higher slumps with increase in aggregate size which were 15mm, 60mm, 165mm, 166mm and 180mm for 9.0mm, 13.2mm, 19.0mm, 25.0mm and 37.5mm size of aggregates respectively. It can be computed from their report that, the percentage difference between the lowest and highest slump was 91.7% between 9mm and 37.5mm aggregate sizes, compressive strength was 12.5% and flexural strength was 7.9% between 13.2mm and 37.5mm size of aggregate concrete.

Kozul and Darwin (1997) in their investigation reported that high-strength concrete containing basalt aggregate produced slightly higher compressive strength than that containing limestone aggregate. On the other hand, normal strength concrete containing limestone had compressive strength slightly higher than that containing basalt aggregate. They obtained higher compressive strength for 12mm aggregate than 19mm aggregate in high strength concrete whereas the opposite occurred in normal strength concrete. In all situations except high strength concrete with limestone, the compressive strengths were higher for concrete with higher coarse aggregate content. Meanwhile, as the flexural strength of high strength concrete was higher for basalt concrete than limestone concrete, the flexural strength for normal strength concrete was not affected by aggregate type or size.

2.5. Compaction of Concrete

According to Neville (1996) and Li (2004), water-to-cement ratio and the degree of compaction of concrete is a factor for determining the strength of concrete at a given age. The strength of a fully compacted concrete is inversely proportional to the water-to-cement ratio which was established by Duff Abrams in 1918. He expressed this relationship in an equation as: $f_c = \frac{K_1}{{K_2}^{w/c}}$ ……...…………………………...…………… (Eqn. 2.1);

where f_c is the compressive strength of concrete, w/c is the water-to-cement ratio used in the concrete mixture, and K_1 and K_2 are empirical constants. Neville (1996) also indicates that the water-to-cement ratio is the largest single factor responsible for the strength of fully compacted concrete in practice. This relationship between water-to-cement ratio and compressive strength based on degree of compaction is illustrated in Figure 2.1 below:

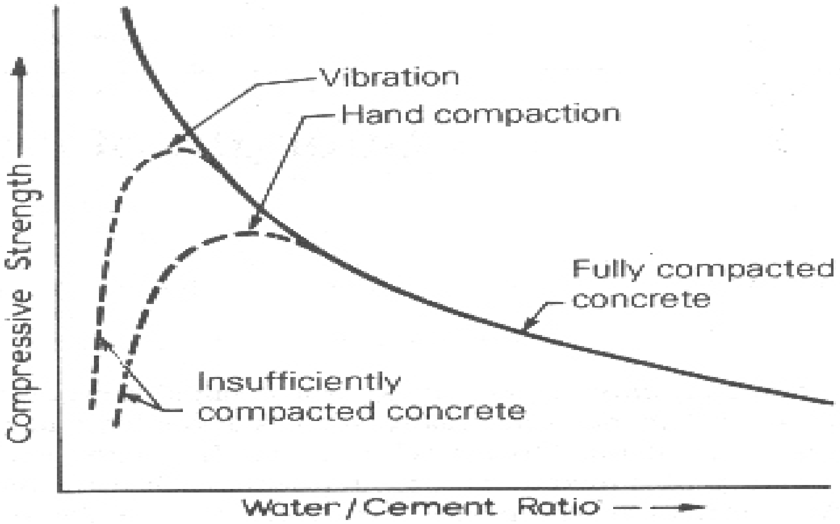

Figure 2.1. Relationship between Compressive Strength and Water/Cement Ratio of Concrete (Source: Neville, 1996)

According to Chen, Huang and Zhou (2012), voids are present in high amount in concrete which include gel pores, capillary pores and flaws. These voids may be either fully filled with water at saturation of concrete or with air when the concrete has completely dried. The aim of compacting concrete therefore is to remove entrapped air since the presence of air in concrete mixes is unavoidable. The air is intentionally or unintentionally trapped in fresh concrete as a result of mixing and placing (Hover, 1993). The air in concrete is normally in the form of gas bubbles surrounded by a thin liquid film and suspended in the mix water since air and water do not mix. These bubbles can vary in size and shape, expand or contract, merge or rapture or be removed from fresh concrete through compaction (vibration). As a result, air voids are formed in hardened concrete when the bubbles are fixed in place of which coarse voids are called *entrapped air* voids and fine voids called *entrained air* voids as noted again by Hover (1993).

The entrapped air reduces the strength of concrete considerably (Barua, 2012). He asserts that a study shows concrete strength reduces to 30% with 5% voids in the mix due to improper compaction whereas a reduction of more than 50% is found due to the presence of 10% voids. On the other hand, the entrained air is recommended for all types of concrete under any climate due to its enormous benefits (Panarese, 1963). Entrained air can be achieved by two methods, thus, using air entraining agents (admixtures) or air entraining cements. Concrete of which neither air entraining admixture nor air entraining cement has been used is termed *non-air entraining* concrete. The non-air entrained concrete produces better strength of concrete (Cemex, 2013). The relationship between water-to-cement ratio and compressive strength on non-air entrained and air entrained concrete is shown in Figure 2.2 below:

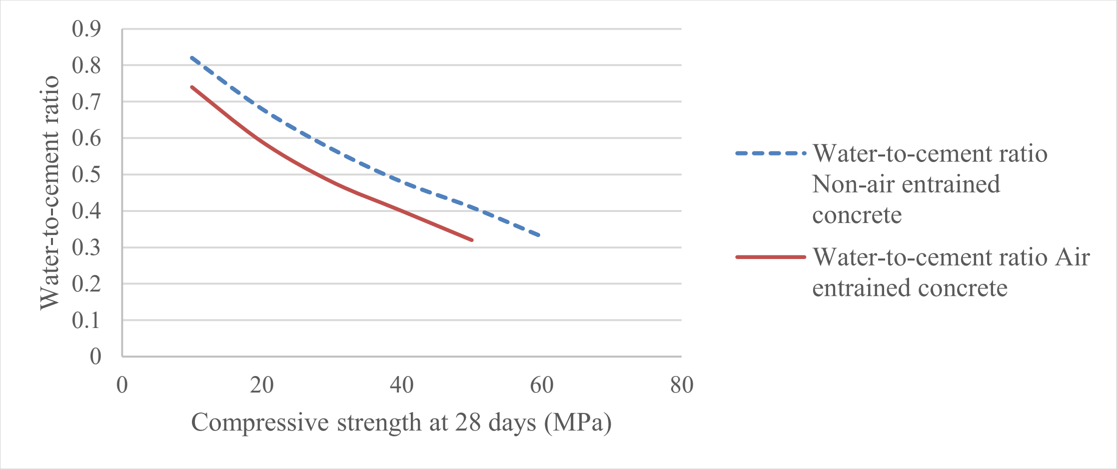

Figure 2.2. Relationship between Water-to-Cement Ratio and Compressive Strength using 19mm to 25mm Nominal Maximum Size Aggregate at 28 Days Cylindrical Specimens. Adapted from Cemex (2013).

2.6. Workability of Concrete

Workability relates to the mobility, compatibility, and stability of fresh concrete and can be defined as the amount of mechanical work required for suitable placing and full compaction of concrete without segregation. Workability is also defined as the property of fresh concrete or mortar that determines the ease and homogeneity with which it can be mixed, placed, compacted and finished to a homogenous condition. In determination of the workability of concrete, the water content expressed as mass per unit volume (kg/m^3) of concrete is the major factor influencing the workability of fresh concrete (Marsh, 1997; Kosmatka, Kerkhoff & Paranese, 2002).

Additionally, the type and maximum size of aggregate used for concrete production will require higher water content to produce higher slump (Marsh, 1997). This is because the free-water content required to produce concrete of a specified slump (workability) depends on the characteristics of aggregate. He reports that smaller size of aggregates requires higher amount of water to produce a workable concrete. Uncrushed aggregates are also found to require smaller amount of water content than crushed aggregates to make concrete of equal workability.

2.6.1 Testing workability

No acceptable test measures workability directly, but there are tests that measure the properties of concrete workability (Neville, 1996; Marsh, 1997; Osei & Jackson, 2012). Such among them are the slump test, vebe time test and compacting factor test. It is observed that, for a given type and maximum size of aggregate, the higher the water content, the higher the slump and the lower the vebe time. Slump test is commonly used and more appropriate for measuring concrete's workability (Marsh, 1997; Yurdakul, 2010).

For building columns, beams and reinforced walls, the American Concrete Institute [ACI] 211.1 – 91 as cited in Neville and Brooks (2010) recommends a satisfactory slump of 20 – 100mm whereas Gambhir (2002) gives some recommended slump values with their respective water-to-cement ratios as shown in Table 2.1 for different works.

Table 2.1. Recommended Slumps for Different Concrete Works

Name of works	Slump (mm)	Water-to-cement ratio
Concrete for roads and mass concrete	25 to 50	0.70
Concrete for R.C.C. beams and slabs	50 to 100	0.55
Columns and retaining walls	75 to 125	0.45
Mass concrete in foundation	25 to 50	0.70

Source: Gambhir (2002)

Table 2.2 presents the degree of workability for concrete mix with 19 or 38mm maximum size of aggregate as recommended by the British Standards cited in Neville and Brooks (2010).

Table 2.2. Description of Concrete Workability

Degree of workability	Slump	
	mm	in.
Very low	0 – 25	0 – 1
Low	25 – 50	1 – 2
Medium	50 – 100	2 – 4
High	100 – 175	4 – 7

Source: (Neville & Brooks, 2010)

2.6.2 Effects of fines (clay/silt) on concrete workability

It is well documented by researchers that higher fines (clay/silt) content in concrete mix reduces the workability of concrete (MacGingley & Choo, 1990; IPRF, 2005; Esmail, 2009; Cemex, 2013; Ngugi et al., 2014). Iyappan and Manu (2015) reported from their investigations that, the workability of concrete decreased as the clay/silt content increased. Meanwhile, upon addition of superplasticizer to the mixture of concrete, as the clay/silt content increased, the workability also increased. Superplasticizers when used as admixture in concrete wrap themselves around the cement particles and give them negative charge. As a result of this negative charge, the cement particles repel each other resulting in ‘deflocculation’ and dispersion of the cement particles which consequently improves (increase) concrete workability (Neville, 1996).

In the report of Cho (2013) from an experimental investigation, slump values of 24.5mm, 24.5mm, 23.5mm, 22.0mm, 20.0mm and 17.5mm for concrete with silt content of 0%, 1%, 3%, 5%, 7% and 9% respectively were recorded indicating a reduction in workability as the silt content increased.

2.6.3 Effects of water-to-cement ratio on concrete workability

Studies have shown that water-to-cement ratio is directly proportional to the workability of concrete. That is, an increase in the water-to-cement ratio will cause an increase in the workability of concrete and vice versa. Olusola, Babafemi, Umoh and Olawuyi (2012) reported that water-to-cement ratio of 0.55, 0.60, 0.65 and 0.70 used for concrete batched by mass and mix proportion of 1:2:4 yielded a slump of 5, 44, 84 and 174mm respectively whereas that batched by volume yielded a slump of 2, 36, 63 and 166.5mm respectively. This implies that concrete batched by mass yields better slumps than that batched by volume. Alawode and Idowu (2011) in their study obtained a slump of 9, 15, 20, 25 and 180mm for normal concrete mixed with water-to-cement ratio of 0.55, 0.60, 0.65, 0.70 and 0.80 respectively for the same mix proportion of 1:2:4 batched by mass. The variation in slump as found in the two reports may be as a result of other factors affecting concrete slump such as quality of sand, and aggregate type and size among others.

Druta (2003) reported from his investigation that the higher the water-to-cement ratio used for mixing self-compacting concrete, the higher the slump flow. In his work, concrete was mixed with 5 different water-to-cement ratios, thus; 0.30, 0.40, 0.45, 0.50 and 0.60 which produced a slump of 655mm, 670mm, 685mm, 700mm and 740mm respectively. The higher slump values obtained was as a result of the chemical admixtures used in their work. Buttressing the above literatures, Mallikarjuna, Seshagiri, Srilakshmi and Sateesh (2013) reported that as the water-to-cement ratio increased, the workability also increased.

2.7. Compressive Strength of Concrete

This is the strength of concrete specimens made from fresh concrete under standard conditions and tested when hardened, usually specified as a strength class or grade of a 28-day characteristic strength. The results of compressive strength tests are used routinely for control of production and contractual conformity purposes (Reynolds et al., 2008). Browne (2007) asserts that concrete specimens subjected to compression usually fail at the aggregate-paste interface. The author concludes that concrete strength is dictated by the interface bond strength but not the strength of the individual constituent materials. The compressive strength is given by the equation expressed in the nearest 0.5 MPa (N/mm^2) as: $f_{cu} = \frac{F}{A_c}$ ………………………………………………………... (Eqn. 2.2)

where; f_{cu} is the compressive strength, in megapascal (Newton per square millimeter);

F is the maximum load at failure, measured in Newton;

A_c is the cross-sectional area of the specimen on which the compressive force acts, calculated from the designated size of the specimen as given by BS EN 12390-3 (BSI, 2002b).

2.7.1 Effects of fines on concrete compressive strength

IPRF (2005) reports that, studies have shown that when some types of clay are found in cement mixture when producing concrete will result in a decrease in strength and an increase in shrinkage. Unikowski as cited in IPRF noted that a 3% replacement of sand for montmorillonite clay decreased the compressive strength by 40% and doubled the amount of shrinkage. Among the types of clay examined by Norvell, Stewart, Juenger and Fowler (2007), they discovered that montmorillonite clay increase significantly in shrinkage and decreased in strength whereas kaolinite and illite had no effect on compressive strength or shrinkage. The reduction in strength is theorized by Pike as cited in IPRF (2005) as a result of clay absorbing some of the water used for cement to form impermeable envelopes around the grains of the cement which slows the rate of the pozzolanic reactions.

In the study of Dammo et al. (2014), compressive strength of concrete increased initially from 0% to 4% and then decreased for 6%, 8% and 10% clay content when tested at 7, 14, 21 and 28 days curing age. They recorded compressive strength of 23.3N/mm^2, 24.4N/mm^2, 26.8N/mm^2, 21.8N/mm^2, 20N/mm^2 to 19.4N/mm^2 for 0%, 2%, 4%, 6%, 8% and 10% clay contents respectively at 28 days curing. They concluded that the presence of 2% and 4% clay content in sand is desirable whereas from 6% content is not welcome since it reduces the concrete strength. According to Cho (2013), compressive strength of concrete decreased from 3N/mm^2 to 5N/mm^2 when the silt content increased from 7% to 9% respectively. In support of the above assertions is the finding by Iyappan and Manu (2015) who confirmed that the higher the clay/silt content, the lower the strength of concrete whereas, concrete with 3 – 4% clay/silt produced better mechanical properties than those with lesser or no clay/silt content.

On the other hand, Olanitori and Olotuah (2005) report that compressive strength of concrete having sand content replaced with a percentage of clay/silt content decreased continually as the clay/silt content increased. With an expected strength of 21N/mm^2, they concluded that the maximum allowable percentage clay/silt content in sand should be 3.4% instead of the 8% prescribed by the Nigerian Standards Organization. To buttress this, Olanitori (2012) recorded higher compressive strength for concrete with 0%, 1%, 2% and

3% clay/silt content (f_{cu} = 22.35, 21.95, 21.25 and 20.85N/mm^2 respectively) with a decrease in compressive strength from 4% to 10% clay/silt content (f_{cu} = 19.00 to 10.15N/mm^2 respectively) against an expected strength of 20N/mm^2 at 28 days curing.

Additionally, a study conducted by Ngugi et al. (2014) on the combined effect of clay/silt and organic materials in sand sourced from 8 supply points in Kenya shows that, 38% of concrete cubes made from sand with varying level of impurities ranging from 3.3% to 42% for clay/silt content, and 0.029 to 0.738 photometric ohms of organic materials failed to meet the expected compressive strength of 25N/mm^2 at 28 days. In their work, they developed a model using regression analysis for the combined effect of clay/silt and organic impurities on compressive strength for a concrete mix ratio of 1:1.5:3:0.57 given as $f_{cu,28} = -23.20SCI - 2.146ORG + 25.57$ with $R^2 = 0.444$. The percentage of clay/silt content used for developing the model were 0.3%, 8.2%, 12.8%, 13.5% and 15.8%. This model may suffer from its limitation to the presence of clay/silt content and organic impurities in the sand. The level of clay/silt used is also found to be non-uniform which may influence the outcome of the model. The need to compare the explanatory variables especially clay/silt content of uniform difference then arises. They also concluded from a correlational analysis conducted in their study that, clay/silt contributes a significant 65% to the compressive strength of concrete.

2.7.2 Effects of water-to-cement ratio on concrete compressive strength

The strength of concrete largely depends on the proportion of water-to-cement ratio of the concrete mixture. There is reduction in the compressive strength of concrete when water content is increased beyond the design mix ratio (Cemex, 2013; Kumar, Zhaoyu &

Matovu, n.d.). Experimental investigation by Fu and Chung (1997) shows that an increase in water-to-cement ratio caused a decrease in compressive strength and tensile strength with an increase in the drying shrinkage of concrete. Moreover, a study conducted by Alawode and Idowu (2011) on a normal concrete mixed at a ratio of 1:2:4 with water-to-cement ratio of 0.55, 0.60, 0.70 and 0.80 resulted in a compressive strength of 20.00N/mm^2, 17.33N/mm^2, 17.11 N/mm^2 and 16.31N/mm^2 respectively. This indicates a percentage reduction in compressive strength of approximately 13%, 14% and 18% respectively for an increase in water-to-cement (w/c) ratio beyond 0.55 (f_{cu28} = 20N/mm^2). Olusola et al. (2012) reported that the higher the water-to-cement ratio, the lower the compressive strength of concrete batched by either mass or volume method.

Mallikarjuna et al. (2013) studied the effects of water-to-cement ratio on workability and mechanical properties of self-compacting concrete and reported a decrease in compressive strength for an increase in the water-to-cement ratio. In their work, the compressive strength of concrete reduced from 83.42N/mm^2 to 81.43N/mm^2 for water-to-cement ratio of 0.23 to 0.27 respectively at 28 days curing. They developed a regression equation as $f_{cu} = - 47.6w/c + 94.466$, where f_{cu} is the compressive strength at 28 days curing and w/c is the water-to-cement ratio. Moreover, Druta (2003) reported from his experimental investigation that, the compressive strength of normal and self-compacting concrete were inversely proportional to the water-to-cement ratio used. For 0.30, 0.40, 0.45, 0.50 and 0.60 w/c used, the compressive strength obtained for normal concrete were 40.94N/mm^2, 33.43N/mm^2, 27.61N/mm^2, 23.13N/mm^2 and 17.68N/mm^2; whereas that of self-compacting concrete were 65.74N/mm^2, 55.45N/mm^2, 48. 46N/mm^2, 36.98N/mm^2 and 29.08N/mm^2 respectively.

2.8. Tensile Strength of Concrete

The tensile strength of concrete is considered one of its basic and important properties. It plays a basic role in the determination of the fracture mechanics of a hardened concrete (Li, 2004). Concrete has low tensile strength and it is brittle in nature and, due to that, it is not usually expected to resist the direct tension in the member (Suresh, n.d.). The tensile strength of concrete is much lower than its compressive strength, typically about one-tenth. Due to the ease with which cracks develop under tensile stresses the tensile strength is assumed to be zero (Li, 2004). Nevertheless, the determination of tensile strength of concrete is necessary to obtain the load at which the concrete members may crack which is a form of tension failure. Mindess, Young and Darwin (2002) noted that the failure of concrete in tension is governed by microcracking, associated particularly with the interfacial region between the hydrated cement paste and the aggregate particles. This according to Li (2004), is generally accepted that concrete fracture occurs through cracking.

2.8.1 Testing of tensile strength

Tensile strength of concrete is most often evaluated by flexural test where plain concrete is loaded in bending. Apart from the flexure test, the other methods to determine the tensile strength of concrete can be broadly classified as *direct methods* and *indirect methods* (Kumar et al., n.d; Suresh, n.d.). The direct method suffers from a number of difficulties relating to holding the specimen properly in the testing machine without introducing stress concentration, and to the application of uniaxial tensile load which is free from eccentricity to the specimen (Neville & Brooks, 2010). The case of uniaxial tension is rarely encountered in practice and in laboratory; tests can be obtained only with care (Li, 2004). However, significant principal tensile stresses may be associated with multiaxial states of stress. As the concrete is weak in tension even a small eccentricity of load will induce combined bending and axial force condition and the concrete fails at the apparent tensile stress other than at the limiting stress corresponding to the tensile strength.

As there are many difficulties associated with the direct tension test, a number of indirect methods have been developed to determine the tensile strength. Generally, in these tests, a compressive force is applied to a concrete specimen in such a way that the specimen fails due to tensile stresses developed in the specimen (Suresh, n.d.). The tensile stress at which the failure occurs is termed the *tensile strength* of concrete. Some of the indirect tensile tests are: flexure test, splitting tensile test and the pressure tensile test. The strengths obtained from the indirect tests yield values which are higher than the ‘true’ tensile strength under uniaxial loading (Neville & Brooks, 2010). The most commonly adopted indirect tensile strength test is the splitting tensile test.

2.8.1.1 Splitting tensile test

This type of tensile test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive platens. That is, a concrete cylinder is placed between the platens of a compressive testing machine and the load is increased until failure by indirect tension in the form of splitting along the vertical diameter takes place (Neville, 1996). Due to the compression loading, a fairly uniform tensile stress is developed over nearly two-third of the loaded diameter as obtained from an elastic analysis. The splitting tensile stresses can be determined through horizontal tensile stress and vertical tensile stress. The formulas for evaluating the tensile strength given by the BS EN 12390-6 (BSI, 2000a) is as:

Horizontal tensile stress, $f_{ct} = \frac{2F}{\pi Ld}$; …………………………… (Eqn. 2.3)

Vertical tensile stress, $f_{ct} = \frac{2F}{\pi Ld}\left(\frac{D2}{r(d-r)} - 1\right)$ …………………… (Eqn. 2.4)

Where f_{ct} = tensile splitting strength, in megapascal (newton per square millimeter);

F = compressive load on the cylinder, in newton;

L = length of the cylinder, in millimeters;

d = diameter of the cylinder, in millimeters; and

(d – r) and r = distances of the element from the two loads respectively.

2.8.2 Effect of fines on tensile strength of concrete

Iyappan and Manu (2015) conducted an investigation on the effect of clay in sand on the tensile splitting strength of concrete and reported the strength increased with increasing clay content from 0% to 3%, thereafter decreased from 4% to 15% clay content in the sand. The maximum tensile splitting strength obtained at the 28 days curing was about 3.4N/mm^2 for 3% clay content and the minimum of 3.1N/mm^2 for 15% clay content in the sand.

2.8.3 Effects of water-to-cement ratio on tensile strength

Li (2004) reported from his study on the effect of moisture content on tensile strength properties of concrete that, water-to-cement ratio is inversely proportional to the tensile strength of concrete. In his study, he obtained higher splitting tensile strength for concrete with 0.45w/c than 0.65w/c for all curing ages of the test. All his cylindrical specimen were submerged in lime-saturated water until the 28 days curing was due. This was carried out after the initial 24-hour curing. After the standard moist curing, all the specimens were exposed to ambient laboratory conditions for 28 days. Followed the exposure of specimens to 28 days ambient environment, all specimens were re-immersed in the lime-saturated water bath except those which were to be tested at 0 day of saturation. After strength testing, the splitting tensile strength obtained for 0.45w/c were 4.12N/mm^2, 3.78N/mm^2, 3.73N/mm^2, 3.44N/mm^2, 3.53N/mm^2 and 3.41N/mm^2 for 0, 1, 3, 5, 7 and 14 days lime-water immersion periods respectively. On the other, he recorded 2.86N/mm^2, 2.51N/mm^2, 2.36N/mm^2, 2.51N/mm^2, 2.59N/mm^2 and 2.60N/mm^2 splitting tensile strength for 0.65w/c at the same lime-water immersion periods respectively.

An investigation by Druta (2003) reveals an inverse relation between the water-to-cement ratio and the splitting tensile strength for both normal and self-compacting concrete. Thus, 0.30, 0.40, 0.45, 0.50 and 0.60w/c used in his work respectively produced splitting tensile strength of normal concrete of 2.92N/mm^2, 2.60N/mm^2, 2.38N/mm^2, 2.07N/mm^2 and 1.76N/mm^2 respectively. In the case of self-compacting concrete, splitting tensile strength of 3.77N/mm^2, 3.37N/mm^2, 3.08N/mm^2, 2.76N/mm^2 and 2.35N/mm^2 were obtained for the water-to-cement ratios respectively. Supporting the literatures above is the report of Mallikarjuna et al. (2013) who obtained splitting tensile strength of 4.37N/mm^2, 4.27N/mm^2, 4.15N/mm^2, 4.10N/mm^2 and 3.97N/mm^2 for 0.23, 0.24, 0.25, 0.26 and 0.27w/c respectively for high strength self-compacting concrete. They came out with a formula as $f_t = -9.64w/c + 6.5814$, where f_t is splitting tensile strength at 28 days curing and *w/c* is the water-to-cement ratio.

2.9. Flexural Strength of Concrete

The flexural strength of concrete as mentioned earlier is a measure of the tensile strength of concrete. It is defined as a measure of the ability of a plain (unreinforced) concrete beam or slab to resist failure in bending (National Ready Mixed Concrete Association [NRMCA], 2000). The strength of concrete in flexure is an important requirement for designing concrete pavements, unreinforced concrete roads and runways. Elayesh as cited in Ukpata and Ephraim (2012) that that, flexural strength of concrete provides two useful parameters which are: the *first crack strength* and the *ultimate flexural strength*. It is however used by few concrete producers or designers for structural concrete. The flexural strength in practice is expressed as a *modulus of rupture* (MR) measured in MPa or psi which is determined by two standard methods, thus: two-point (third-point) loading or center-point loading. Modulus of rupture measured from a test specimen is the theoretical maximum tensile stress reached in the bottom fibre of the test beam (Neville, 1996).

The flexural MR of concrete is about 10 – 20 percent of the compressive strength depending on the type, size and volume of the coarse aggregate used. The measurement of flexural strength made from a third-point loading is lower than that made from a center-point loading. This is as a result of induced total load shared among the two-point loads where maximum stress is present over the center one-third while total loads are exerted at one point in center-point loading with maximum stress present only at the center of the beam (Neville, 1996). According to the NRMCA (2000), the determination of both compressive and flexural strength of concrete is necessary for each trial batch, in other to develop correlation between them for field control. Again, flexural properties of structural materials are considered to be generally important to design engineers to guide the appropriate selection of materials (Ukpata & Ephraim, 2012).

2.9.1 Testing of flexural strength

In testing the flexural strength of concrete, beams are usually tested on their side in relation to the position the concrete was cast (Neville, 1996). Meanwhile, Neville also cited Shacklock and Keene as well as Walker and Bloem that the flexural strength will not be affected by the position of the beam as tested relative to the as-cast position provided the concrete was unsegregated. The flexural strength is calculated on the basis of ordinary elastic theory if fracture occurs within the central one-third (two-point loading) of the beam using the equation:

$$f_{cf} = \frac{Fl}{bd^2} \qquad \text{.. (Eqn. 2.5)}$$

Where f_{cf} = flexural strength, in megapascal (Newton per square millimeter)

F = maximum total load on the beam, in newton

l = distance between supporting rollers (span), in millimeters

b = width of the beam, in millimeters and

d = depth of the beam, in millimeters.

An alternative method of calculating the flexural strength using the center-point loading is given by the equation:

$$f_{cf} = \frac{3Fl}{2bd^2} \qquad \text{.. (Eqn. 2.6)}$$

Where nomenclature has the same meaning as in equation 2.5.

The two arrangements of test specimen for the flexural test are illustrated in Figure 2.3 and Figure 2.4 for two-point loading and center-point loading respectively (BSI, 2000b).

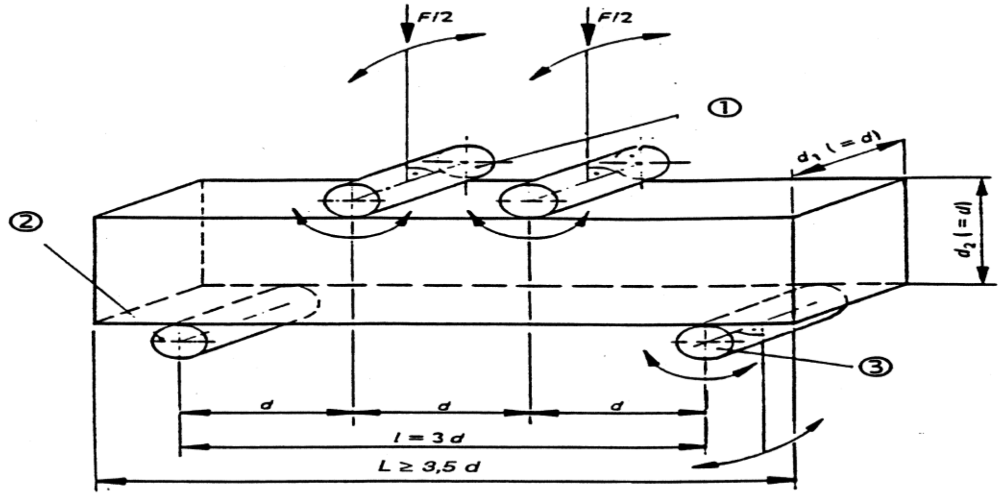

Figure 2.3. Two-Point Loading Arrangement of Loading of Test Specimen (BS EN 12390-5)

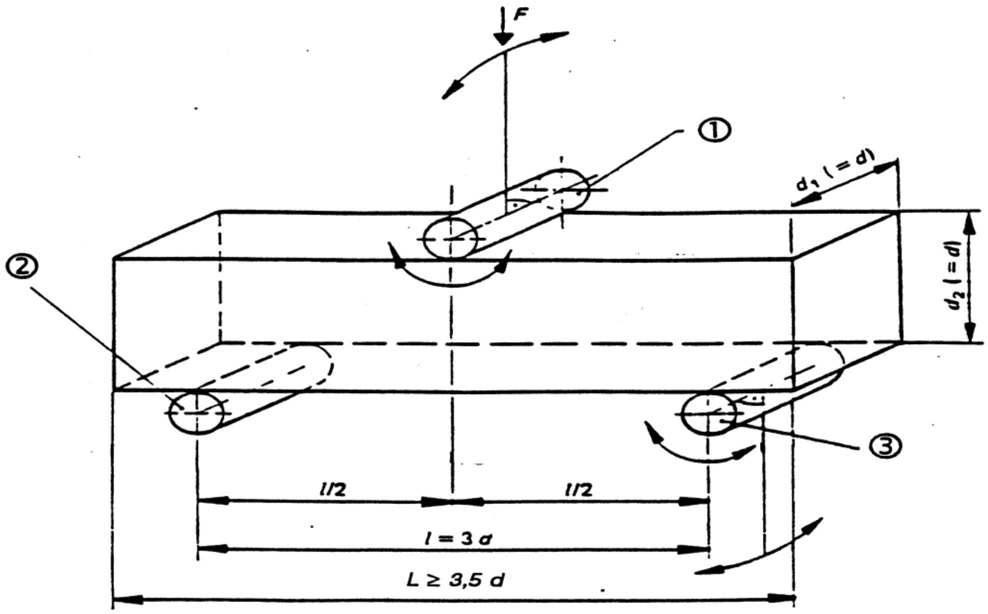

Figure 2.4. Center-Point Loading Arrangement for Test Specimen (BS EN 12390-5)

Key:
1 – Loading roller (capable of rotation and of being inclined)
2 – Supporting roller
3 – Supporting roller (capable of rotation and of being inclined)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Introduction

This chapter of the study describes the materials that were used for conducting the study and their appropriateness as well as systematic methodology adopted for conducting the experimental works. The equipment and apparatus used are also briefly captured in this chapter.

3.2. Materials

3.2.1 Coarse aggregates

Crushed granite aggregate sourced from a commercial quarry at Buoku in the Brong Ahafo Region was used for the study which had 19mm maximum size of aggregate.

3.2.2 Fine aggregate

Natural pit sand which was sourced from Chiraa in the Sunyani West district of Ghana was used for the study.

3.2.3 Cement

The cement used for the study was super rapid Portland cement of class 32.5R. The brand of this cement was GHACEM which is one of the commonly used cements for construction works in Ghana conforming to BS EN 197-1 (BSI, 2000c).

3.2.4 Water

Potable drinking water from Ghana Water Company supplied to the Sunyani Polytechnic Materials laboratory of the Building Technology Department was used for the study.

3.3. Experimental Methods

In experimental research the methods used by the researcher is very essential and must conform to standards. Careful examination, preparation and testing of materials and specimens are of utmost importance. For these reasons, the methods used for the study are systematically presented below.

3.3.1 Testing of physical properties of aggregates

Preliminary tests were conducted in accordance with the ASTM and BS standards on the aggregates (sand and crushed stones) to ascertain their appropriateness for concrete production. These tests included: specific gravity, water absorption and fineness modulus for both aggregates. Additionally, test was conducted to determine the percentage of fines in the sand. The aggregates were again observed to determine the particle texture, particle shape and colour.

3.3.1.1 Testing of fines content in sand. The field test method was used for determining the level of fines (clay/silt) content in the fine aggregate in accordance with BS 1377-1 (BSI, 1990). A cylindrical jar of 250ml was first filled with 50ml of salt solution, samples of study sand was then added, and shaken to a level of 200ml. The container was then filled with more water and thoroughly shaken by covering the tip with the palm to allow water solution to submerge the sand content. Afterwards, the mixture was left on a flat surface for 24 hours to allow particles settlement after which readings were recorded as 151ml and 172ml for volume of sand and volume of sand plus silt respectively. The percentage of fines content in the sand was calculated using the equation:

$$\text{Fines (F) \%} = \frac{X_{2-}X_1}{X_1} * 100 \qquad \text{(Eqn. 3.1)}$$

where, X_1 = Volume of sand and X_2 = Volume of sand + silt.

3.3.1.2 Testing the specific gravity and water absorption of aggregates. The specific gravity of fine aggregate was conducted in accordance with ASTM C128 (ASTM, 1997). A sample of 500g of the study sand was initially measured and then dried in an oven at a temperature of 110°C ± 5°C for 24 hours. The sand was allowed to cool after removing from the oven for 1 hour where the mass of the oven-dried sample was measured and recorded as 493g. A 500ml capacity of pycnometer was clean, dried and the mass measured with the balance as 127g. Afterwards, the pycnometer was filled with the oven-dried sand sample. The pycnometer with sand was filled with water to about half full, manually shaken for 15 minutes to remove the entrapped air present and allowed to settle for some few minutes. The pycnometer was filled with more water to the calibration mark and allowed to settle for 10 minutes. A paper towel was also used to remove the foam and organic impurities that settled at the surface of the water and the mass of the pycnometer with contents was measured and recorded as 1006g. The pycnometer was emptied, cleaned, dried and filled with water to the calibration mark. The mass of pycnometer filled with only water to the calibration mark was measured and recorded as 698g. The specific gravity of saturated surface-dry specimen and water absorption of the fine aggregate were then calculated using the equations below respectively:

Bulk specific gravity = $S / (S + B - C)$ (Eqn. 3.2)

Water absorption% = $[(S - A) / A] \times 100$ (Eqn. 3.3)

Where; A = mass of oven-dry specimen in air measured in grams,

B = mass of pycnometer filled with water measured in grams,

C = mass of pycnometer with specimen and water to calibration mark in grams,

S = mass of saturated surface-dry specimen measured in grams.

The specific gravity and water absorption of coarse aggregate were tested in accordance with ASTM C127 (ASTM, 2007). Riffling method was first used to sample the coarse aggregate. The coarse aggregate was sieved to have a minimum size greater than 4.75mm and maximum size of 19mm. The aggregates were afterwards washed with clean water to remove all dust at the surface of the aggregates and oven dried to a constant mass at a temperature of 110 ± 5ºC for 24 hours. The aggregates were removed from the oven and allowed to cool for 2 hours of which 5,500g was measured and immersed in water at room temperature for 24 hours. After the 24 hours immersion, the water was sieved away from the coarse aggregates. The surface of coarse aggregates were then cleaned with a cloth to remove water from the surface and the mass of saturated surface-dry coarse aggregate was measured and recorded as 5,526g. The specimens were then placed in a water container containing distilled water, shaken for 20 minutes to remove entrapped air and the mass measured and recorded as 11,733g. The container was emptied, cleaned and then filled with an equal volume of water to the mark of which the mass was measured as 8,323g. Specific gravity and water absorption of the aggregate were then computed and presented in Table 4.1.

3.3.1.3 Testing for fineness modulus of aggregates. Sieve analysis for particle size distribution of fine and coarse aggregates were conducted in accordance with the BS882. The percentage mass retained on each sieve was recorded and the fineness modulus calculated from the sum of cumulative percentage mass retained and presented in Table 4.1. See also Table 4.2 and Table 4.3 for particle size distribution (sieve analysis) of coarse and fine aggregates respectively. The grading curve for each type of aggregate were presented in Figure 4.1 and Figure 4.2 respectively using the percentage mass passing in accordance with the BS 882.

3.3.1.4 Testing of surface texture of aggregates. The surface texture of the fine and coarse aggregates used for the study were examined by rubbing the aggregates in the palm and close observation by the researcher. The texture felt in the palm was used as the surface texture of the fine and coarse aggregates respectively.

3.3.1.5 Testing of particle shape of aggregates. To determine the particle shape of the aggregates, the researcher closely observed the shape of samples of the aggregates and conclusion drawn for the predominant shape observed.

3.3.1.6 Testing of aggregates colour. The colour of the fine and coarse aggregates used for the study were determined by close observation with the eye by the researcher. The obvious colour observed as against the documented colours of aggregates in literature were recorded as the colour of the aggregate.

3.3.2 Extraction of fines (clay/silt) from sand

The content of fines used in the mixture of the concrete was obtained by sieving it from the sand using the 75µm (No. 200) test sieve. The sand was first dried in air for 7 days and was sieved using the 600µm test sieve. Afterwards, the particles passing through the 600µm test sieve were further sieved by dry method using the 75µm test sieve. Figure 3.1 shows dry sieving of fines (clay/silt) from sand which was added in different quantities as partial replacement of sand content in the concrete mix proportion.

Figure 3.1. Sieving of Fines (Clay/Silt) from Dry Sand

3.3.3 Mix design

The various mix designs showing the quantity of each material batched for producing the concrete are presented in Table 3.2, Table 3.3 and Table 3.4 for cubes, cylinders and beams respectively. A concrete mix ratio of 1:2:4 was chosen for the study with variable water-to-cement ratio (0.55, 0.60 and 0.70w/c).

3.3.3.1 Designed compressive strength. The sand was washed free from fines (clay/silt) content and dried in air for four days before using. A trial mix was designed and tested at 28 days to give a compressive strength class of C20 using a mix proportion of 1:2:4.

3.3.3.2 Quantity of materials used for each batch. Using the 1:2:4 mix proportion, the amount of each material needed for producing concrete that could cast 9 specimens of cubes for a batch, and 3 specimens each of cylinders and beams for a specific batch were computed and batched accordingly. The amount of water needed in a batch were also computed for each water-to-cement ratio as shown in Table 3.1, Table 3.2 and Table 3.3.

Table 3.1. Concrete Mix Proportion of Materials for Casting Cubes

Fines (%)	Cement (kg)	Sand (kg)		Coarse Aggregate (kg) (19mm max. size)
		% Passing 75μm sieve (fines)	% Retained on 75μm sieve (normal sand)	
2	10.526	0.421	20.631	42.104
4	10.526	0.842	20.210	42.104
6	10.526	1.263	19.789	42.104
8	10.526	1.684	19.368	42.104
10	10.526	2.105	18.947	42.104
12	10.526	2.526	18.526	42.104
		Water Proportion in the Mix		
Water/Cement Ratio		0.55	0.60	0.70
Amount (kg)		5.789	6.316	7.368

Table 3.2. Concrete Mix Proportion of Materials for Casting Cylinders

Fines (%)	Cement (kg)	Sand (kg)		Coarse Aggregate (kg) (19mm max. size)
		% Passing 75μm sieve (fines)	% Retained on 75μm sieve (normal sand)	
2	5.263	0.211	10.315	21.052
4	5.263	0.421	10.105	21.052
6	5.263	0.632	9.894	21.052
8	5.263	0.842	9.684	21.052
10	5.263	1.053	9.473	21.052
12	5.263	1.263	9.263	21.052
		Water Proportion in the Mix		
Water/Cement Ratio		0.55	0.60	0.70
Amount (kg)		2.895	3.158	3.684

Table 3.3. Concrete Mix Proportion of Materials for Casting Prisms

Fines (%)	Cement (kg)	Sand (kg)		Coarse Aggregate (kg) (19mm max. size)
		% Passing 75µm sieve (fines)	% Retained on 75µm sieve (normal sand)	
2	15.789	0.632	30.946	63.156
4	15.789	1.263	30.315	63.156
6	15.789	1.895	29.683	63.156
8	15.789	2.526	29.052	63.156
10	15.789	3.158	28.420	63.156
12	15.789	3.789	27.789	63.156
		Water Proportion in the Mix		
Water/Cement Ratio		0.55	0.60	0.70
Amount (kg)		8.684	9.473	11.052

3.3.4 Mixing procedure, casting and test on fresh concrete

3.3.4.1 Batching and mixing method. Hand mixing method was adopted for the study. Sand particles retained on the 75µm test sieve was first measured and placed on a cement screed platform. Fines (clay/silt) content was subsequently measured and poured on the sand and mixed thoroughly to have uniform colour. The cement content needed for the mix was measured afterwards, mixed with the sand and fines mixture with some little amount (about 20%) withheld for a while. Coarse aggregate was measured and spread on the mixture. The amount of cement withheld earlier was then added to the materials, and mixed thoroughly again to obtain a uniform colour. About 80% of the quantity of water needed for a specific batch having measured was added to the materials for mixing to obtain a uniform paste. The amount of water withheld was added thereafter and mixed again to obtain a uniform colour and paste.

3.3.4.2 Workability test. Slump test was taken immediately after mixing the concrete for the various batches and the values recorded (See Figure 3.2 for slump measurement).

Figure 3.2. Measurement of Concrete Slump

3.3.4.3 Concrete moulds used. Shapes and dimensions of moulds and specimens used for the study conformed to BS EN 12390-1: 2000 (BSI, 2003a). The moulds used for cubes were made of plastic whereas those for cylinders and beams were made of steel. The size of the moulds used were: cube of sides 150mm, cylindrical moulds of diameter and height 150 x 300mm, and beam moulds of length, breadth and height 600 x 150 x 150mm internally. These moulds were coated with oil just before placing concrete into them.

3.3.4.4 Casting. Concrete after mixing was placed in the moulds by using hand trowel in three layers for all cubes, cylinders and beams. Each layer for cubes and cylinders was uniformly tamped 30 strokes using a 16mm diameter steel tamping rod to remove entrapped air. On the other hand, each layer of the beams was uniformly given 120 strokes of tamping. Excess of concrete was cut off and the surface levelled with the trowel.

3.3.4.5 Reinforcing beam specimens. With respect to the casting of beams, ϕ12mm deformed mild steel with yield strength of 250N/mm^2 was used to reinforce the concrete. Two bars each were placed at the bottom and top of beam respectively. A concrete cover of 30mm was provided for all sides of beam. The cover was chosen to withstand 2-hour fire resistance in accordance with the BS 8110-1:1997 (BSI, 2005). A deformed mild steel bar of ϕ8mm was used as shear reinforcement which was spaced at 75mm centers. Figure 3.3 illustrates the arrangement of reinforcements in the beams with all dimensions in mm.

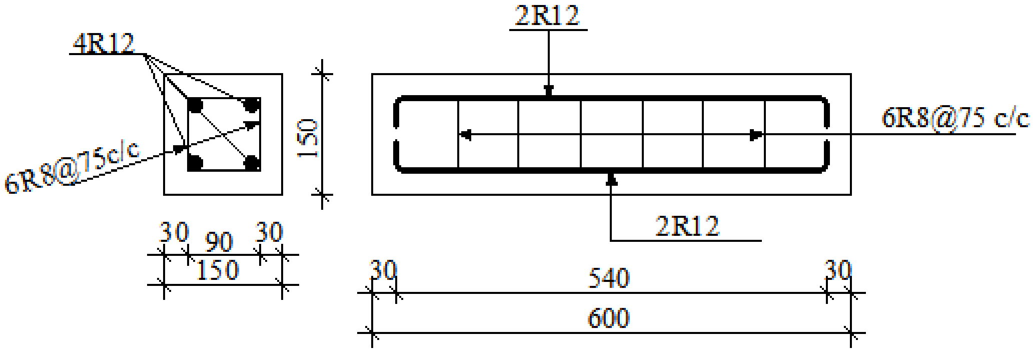

Figure 3.3. Arrangement of Reinforcement in Test Beams

3.3.4.6 Curing. After placing the concrete in the moulds, the specimens were initially air cured and demoulded after 24 hours. The specimens were then marked with an indelible marker for easy traceability and transported into a water curing tank for curing until the specified days for strength testing. The temperature of water in the curing tank was kept constant at room temperature of 20°C ± 2°C. The methods adopted for casting and curing specimens conformed to the BS EN 12390-2: 2000 (BSI, 2003b). Figure 3.4 shows concrete specimens in a curing tank filled with water to submerge the surface of specimens.

Figure 3.4. Samples of Concrete Specimens under Curing

3.3.5 Sample size used

A total number of 270 specimens were cast for the study: 162 specimens for cubes, and 54 specimens each for cylinders and beams. Three samples were used from each batch for strength testing in accordance with BS 1881 (BSI, 1983).

3.3.6 Testing of hardened concrete

Concrete specimens were removed from the curing tank just before the time for strength testing and cleaned of moisture on the surfaces with a duster. The mass of each specimen was measured and recorded before crushing. The average mass was then computed and input into the machine with specimen dimensions before starting the machine. The load at which the specimen crushed and the corresponding strength of specimens were recorded from the machine. All specimens were tested using the Controls Digimax Plus V1.04R, model C46G2 testing machine of 2000kN maximum load capacity.

3.3.6.1 Compressive strength testing

The compressive strength of concrete specimens were obtained by inserting specimens in the testing machine of which the surface of the cubes were aligned perpendicularly to the platens. An automatic loading rate within the range of 0.04MPa/s to 0.06MPa/s was applied to the specimen until failure occurred. Test specimens illustration for cube compression test is shown in Figure 3.5.

Figure 3.5. Compressive Strength Testing of Cube Specimen

3.3.6.2 Tensile splitting strength testing

The splitting tensile strength was obtained by applying diametrical compressive force on a cylindrical specimen placed centrally with its axis horizontal between the platens of the testing machine. The specimen were supported in a jig with a plywood used as parking strips conforming to EN 316. An automatic constant rate of loading within the range of 0.04MPa/s to 0.06MPa/s was applied without shock which increased continuously until splitting of specimen occurred. Figure 3.6 illustrates the testing of cylindrical specimens.

Figure 3.6. Tensile Splitting Strength Testing of Cylindrical Specimen

3.3.6.3 Flexural strength testing

The surfaces of beams were cleaned of water after removing from the curing tank. After a while when the surfaces had dried, marks were drawn at the lower part of the beam to determine the positions of the supporting rollers, that is 75mm from each end to give 450mm effective length (distance between the supporting rollers) of the beam. The beams were then placed in the testing machine, aligning the supporting rollers to the mark and eccentricity checked. The machine was set to apply load on a beam specifying the dimensions and 28 days curing age for flexural strength. The center-point loading method was employed to apply load on the beam until crushing occurred. The ultimate load at which the beams failed and flexural strength as giving by the testing machine were recorded. A digital veneer caliper was used to measure and record the width of cracks on each beam. The crack lengths were also measured from one face end of the beam using a steel tape measure with respect to the position in the testing machine. Figure 3.7 shows the arrangement of beams in the testing machine.

Figure 3.7. Flexural Strength Testing of Beam Specimen

3.4 Data Analysis

The data obtained from the study were analyzed using the Statistical Product and Service Solutions (version 21). Regression analysis and correlation among study variables were determined to establish the extent of effect fines percentage in sand and water-to-cement ratio have on concrete properties (workability, compressive strength, tensile splitting strength, flexural strength of reinforced concrete and energy absorption capacity).

CHAPTER FOUR

4.0 ANALYSIS OF RESULTS

4.1. Introduction

This chapter of the study presents the findings discovered from the research. The results obtained from the experimental study have been carefully presented in Tables and Figures with explanations. Correlation and Regression analysis as a statistical tool were basically adopted for analyzing the results and explanations given. Where appropriate percentages were used to explain the findings of the study.

4.2. Physical Properties of Aggregates

Table 4.1 gives the physical properties of the aggregates that were used for the study. The specific gravity of saturated surface-dry samples measured were 2.60 and 2.61 for fine and coarse aggregates respectively. This indicates the aggregates used for the study were within the accepted specified values for concrete production in accordance with BS EN 1097-6 (BSI, 2013). The water absorption for the study sand used was high (Absorption = 1.4%) yet within accepted range. This explains that, much of the water used for mixing the concrete will be absorbed by the aggregate to keep it at the saturated surface dry state and the rest for mixing the concrete and hydration of cement. On the other hand, the water absorption of coarse aggregate was within the normal range as expected (Absorption = 0.5%). The fineness modulus obtained suggest that, the aggregates used had an approximately average sizes of 600µm and 12.5mm for fine and coarse aggregates respectively. Thus, the sand used was normal sand since it lies within Zone II of geological grading.

Table 4.1. Physical Properties of Study Aggregates

Property	Fine aggregate	Coarse aggregate
Fines (%)	13.91	–
Specific gravity	2.6	2.61
Water absorption (%)	1.4	0.5
Fineness modulus	2.61	2.50
Surface texture	Rough	Rough
Particle shape	Angular	Irregular
Colour	Gray	Imperial gray

4.2.3 Particle size distribution of aggregates

Table 4.2 and Table 4.3 present the results obtained for particle size distribution for coarse and fine aggregates respectively. The cumulative percentage mass retained divided by 100 gives a fineness modulus of 2.50 and 2.61 for coarse and fine aggregates respectively. The grading curve using the percentage mass passing each sieve size are presented in Figure 4.1 and Figure 4.2 for coarse and fine aggregates respectively which show the aggregates used for the study are within specified rage in accordance with the BS 882 (BSI, 2002a).

Table 4.2. Sieve Analysis of Coarse Aggregate

Sieve Size (mm)	Mass Retained (g)	Percentage Mass Retained (%)	Cumulative Percentage Mass Retained [CPMR] (%)	Percentage Mass Passing (%)
25.0	0	0	0	100
19.0	395	7.9	7.9	92.1
12.5	2,329	46.7	54.6	45.4
6.3	1,658	33.2	87.8	12.2
4.75	610	12.2	100	0.0
Pan	0	0	–	
Total	4,992		250.3	

*FM = ∑CPMR/100

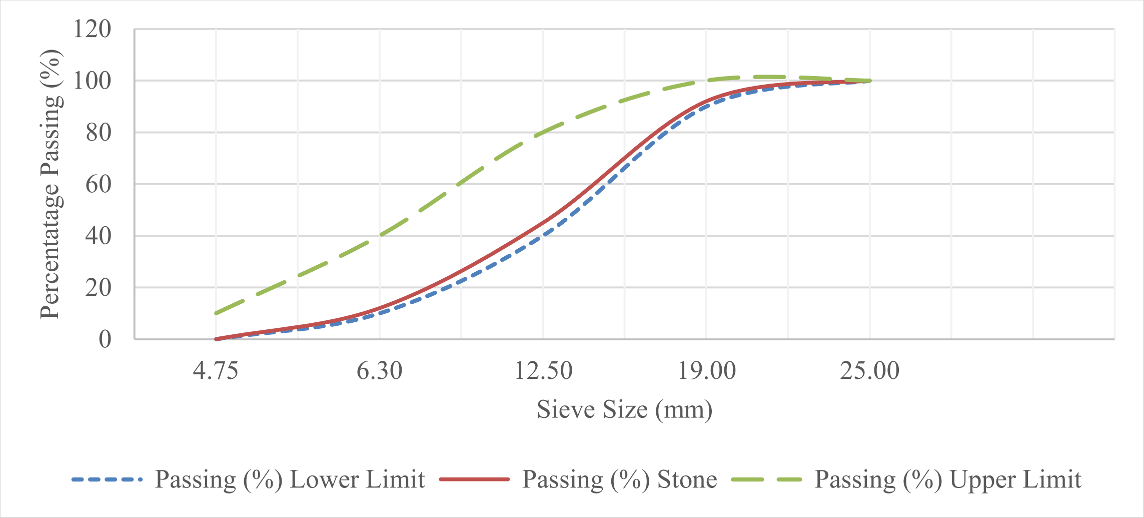

Figure 4.1. Grading Curve of Coarse Aggregate

Table 4.3. Sieve Analysis of Fine Aggregate (Sand)

Sieve Size (mm)	Mass Retained (g)	Percentage Mass Retained (%)	Cumulative Percentage Mass Retained [CPMR] (%)	Percentage Mass Passing (%)
6.3	0	0	0	100
4.75	21	4.2	4.2	95.8
2.36	53	10.6	14.8	85.2
1.18	69	13.9	28.7	71.3
0.60	42	8.4	37.1	62.9
0.30	216	43.4	80.5	19.5
0.15	73	14.7	95.2	4.8
Pan	24	4.8	–	–
Total	498		260.5	

FM = ∑CPMR/100

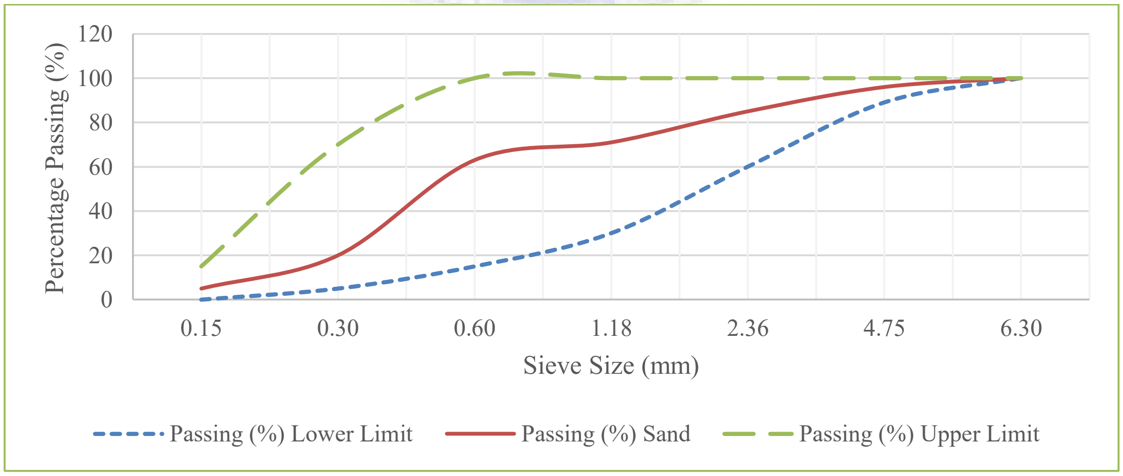

Figure 4.2. Grading Curve of Fine Aggregate (Sand)

4.3. Workability Test Results

Table 4.4 gives the slump values as measured for the various batches of concrete used for the study. It can be observed that, the slump values for concrete decreased as the percentage of fines (clay/silt) in sand increased whereas it increased when the water-to-cement ratio increased. This may be because finer aggregates absorb more water due to their large surface area thereby leaving the concrete mixture with little free water for mixing. On the other hand, more water in the mixture will result in dispersing the concrete constituents as well as cement particles after the free mixing water has been used leading to higher slumps.

Table 4.4. Measurement of Slump for Workability Test

Water/Cement Ratio (w/c)	Fines (%)	Slump (mm)	Degree of Workability
0.55	2	25	Low
	4	15	Very low
	6	13	Very low
	8	12	Very low
	10	11	Very low
	12	9	Very low
0.60	2	35	Low
	4	30	Low
	6	26	Low
	8	24	Very low
	10	19	Very low
	12	17	Very low
0.70	2	95	Medium
	4	60	Medium
	6	56	Medium
	8	52	Medium
	10	49	Low
	12	47	Low

Table 4.5 gives the correlation between workability of concrete and the percentage of fines content in sand as well as water-to-cement ratio which shows mild association between the percentage of fines in sand and workability of concrete. That is, as fines (clay/silt) content in sand increased, workability of concrete decreased ($r = -0.364$, $p > 0.05$). On the other hand, as the water-to-cement ratio increased in the concrete mix, the

workability of concrete also increased at a strong association level ($r = 0.876$, $p < 0.001$) indicating direct proportion.

Table 4.5. Correlation among Workability, Clay/Silt in Sand and Water-to-Cement Ratio

	Fines (F)	Water/Cement Ratio (w/c)	Workability (Slump)
Fines (F)	1	0.000	-0.364^{a}
Water/Cement Ratio (w/c)		1	0.876^{b}
Workability (Slump)			1

$^{a}P > 0.05$, $^{b}P < 0.001$

Table 4.6 presents the regression analysis which suggests that fines (clay/silt) content in sand and water-to-cement ratio explain about 89.9% (Adjusted $R^2 = 88.6\%$) of the variations in the workability (slump values) of concrete. The ANOVA generated suggest the adequate prediction of concrete workability using the model developed ($F = 67.111$, $p < 0.001$). The model developed is hence given in equation 4.1 as:

$$Wc = -141.905 - 235.714F + 310.476w/c \qquad \text{(Eqn. 4.1)}$$

where *Wc* is the workability of concrete (slump value), *F* is the fines percentage in sand and *w/c* is water-to-cement ratio.

The equation 4.1 explains that, with all other variables kept constant, when the content of fines in sand is increased by one percent, the slump value will decrease by 235.714mm ($t = -4.448$, $p < 0.001$) whereas it increases by 310.476mm when the water-to-cement ratio is increased by one unit ($t = 10.697$, $p < 0.001$). It is also noted that when the content of fines in sand is increased by one standard deviation, the workability of concrete decreased on the average by 0.364mm. Meanwhile, an increase of the water-to-cement ratio by one standard deviation causes an average increase of 0.876mm in the workability of concrete when all other variables are kept constant.

Table 4.6. Regression Coefficients for Workability (Slump) of Concrete

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	-141.905	18.367		-7.726	0.000
Fines (F)	-235.714	52.989	-0.364	-4.448	0.000
Water/Cement Ratio (w/c)	310.476	29.023	0.876	10.697	0.000

R^2 = 89.9% (Adjusted R^2 = 88.6%); F = 67.111, $p < 0.001$

4.4. Compressive Strength

The results of the designed 28-day compressive strengths are presented in Table 4.7 which indicate only specimens with 0.55w/c met the targeted concrete strength class of C20 whereas the two others felled below.

Table 4.7. Designed Compressive Strength after 28 Days

Water-to-cement ratio	Crushing Load (kN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
0.55	475.2	21.12	21.55
	489.5	21.76	
	489.6	21.76	
0.60	408.9	18.17	18.73
	464.3	20.63	
	391.5	17.40	
0.70	263.1	11.69	12.00
	273.6	12.16	
	273.7	12.16	

The average compressive strengths measured after 7, 28 and 91 days curing of cube specimens are presented in this section. The results have been grouped in accordance to the water-to-cement ratio used. The raw data of the test results of compressive strength properties are presented in Appendices B, C and D for cross references.

Table 4.8 shows that, at constant water-to-cement ratio, concrete with 4% fines in sand had the highest compressive strength. There was a decline in compressive strength as the content of fines in sand increased beyond 4%. At constant fines (clay/silt) content, compressive strength of concrete decreased with increase in water-to-cement ratio. It was noted that concrete with fines content of 4% and 0.55w/c ratio had the highest compressive strength. Table 4.11 and Table 4.14 show these trends of concrete compressive strength. That is, at all curing ages, concrete with 4% fines in sand had the highest compressive strength, beyond which the compressive strength started decreasing.

Table 4.8. Average Compressive Strength after 7 Days Curing

Water/Cement Ratio	Fines (%)	Mass (kg)	Crushing Load (kN)	Compressive Strength (N/mm^2)
0.55	2	8.391	353.9	15.73
	4	8.266	405.0	18.00
	6	8.116	362.4	16.11
	8	8.280	312.9	13.90
	10	8.328	290.5	12.91
	12	8.316	289.8	12.88
0.60	2	8.497	318.6	14.16
	4	8.306	351.4	15.62
	6	8.371	292.1	12.98
	8	8.469	272.8	12.12
	10	8.497	272.1	12.09
	12	8.025	261.2	11.61
0.70	2	8.214	271.9	12.08
	4	8.179	280.5	12.47
	6	8.131	276.8	12.30
	8	8.266	271.3	12.06
	10	8.178	255.9	11.37
	12	8.304	250.4	11.13

Table 4.9 indicates that compressive strength of concrete decreased as fines content in sand and water-to-cement ratio increased at the 5% level of significance ($r = -0.564$, $p < 0.05$ and $r = -0.639$, $p < 0.05$ respectively) showing strong association. This means that, the content of fines in sand and water-to-cement ratio contributes about 56.4% and 63.9% respectively to the strength of concrete after 7 days curing.

Table 4.9. Correlation among Compressive Strength, Clay/Silt in Sand and Water-to-Cement Ratio

	Fines (F)	Water/Cement Ratio (w/c)	Compressive Strength (f_{cu})
Fines (F)	1	0.000	-0.564^a
Water/Cement Ratio (w/c)		1	-0.639^a
Compressive Strength (f_{cu})			1

$^a P < 0.05$

From Table 4.10, the coefficient of multiple determination, R^2 indicates that about 72.7% of variations in the compressive strength of concrete after 7 days curing can be explained by the content of fines in sand and water-to-cement ratio used for the concrete production. The analysis of variance (ANOVA) obtained suggests a significant model for predicting the strength of concrete ($F = 19.947$, $p < 0.001$). The model for predicting 7 days compressive strength of concrete is given in equation 4.2 as:

$$f_{cu,7} = 27.142 - 30.581F - 18.964w/c \qquad \text{(Eqn. 4.2)}$$

where $f_{cu,7}$ represents the compressive strength of concrete after 7 days curing, F represents fines percentage in sand and w/c represents water-to-cement ratio. It should be noted that the regression equation developed is valid for concrete with 4% fines in sand and beyond. That is, with fines percentage in sand less than 4%, the compressive strength of concrete will increase instead of decreasing as observed from the experimental study. These argument are true for equation 4.3 and equation 4.4.

Again, the model from Table 4.10 as expressed in equation 4.2 shows that when the content of fines in sand is increased by one percent with all other variables kept constant, compressive strength of concrete after 7 days curing will decrease by 30.581N/mm^2 ($t = -4.181$, $p = 0.001$) whereas an increase in water-to-cement ratio by one unit keeping all other variables constant will result in a decrease in compressive strength by 18.964N/mm^2 ($t = -4.734$, $p < 0.001$). It is to be noted that the equation 4.2 is valid with inclusion of 4% content of fines in sand and beyond. The standardized coefficients indicate that increasing fines content in sand by one standard deviation will decrease the compressive strength of concrete after 7 days curing by 0.564N/mm^2 on the average. When water-to-cement ratio is also increased by one standard deviation, the compressive strength of concrete will decrease by 0.639N/mm^2 on the average. This implies that, though fines content in sand reduce compressive strength of concrete by 30.581 after 7 days curing, water-to-cement ratio contributes the highest decrease to compressive strength on the average (63.9%).

Table 4.10. Regression Coefficients for Compressive Strength after 7 Days Curing of Specimens

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	27.142	2.535		10.706	0.000
Fines (F)	-30.581	7.314	-0.564	-4.181	0.001
Water/Cement Ratio (w/c)	-18.964	4.006	-0.639	-4.734	0.000

$R^2 = 72.7\%$ (Adjusted $R^2 = 69\%$); $F = 19.947$, $p < 0.001$

The findings from the 28-day results are presented in Table 4.11 which had same trend of 7 days curing as mentioned earlier.

Table 4.11. Average Compressive Strength after 28 Days Curing

Water/Cement Ratio	Fines (%)	Mass (kg)	Crushing Load (kN)	Compressive Strength (N/mm^2)
0.55	2	8.160	468.7	20.83
	4	8.453	488.0	21.69
	6	8.505	478.1	21.25
	8	8.204	467.9	20.80
	10	8.260	458.6	20.38
	12	8.317	434.6	19.32
0.60	2	8.387	426.6	18.96
	4	8.442	448.4	19.93
	6	8.245	440.3	19.57
	8	8.354	355.1	15.78
	10	8.468	354.9	15.77
	12	8.096	297.6	13.23
0.70	2	8.224	330.3	14.68
	4	8.126	361.1	16.05
	6	8.350	338.9	15.06
	8	8.264	315.9	14.04
	10	8.292	303.5	13.49
	12	8.346	274.3	12.19

Correlational matrix at the 5% level of significance presented in Table 4.12 indicates that compressive strength of concrete associate mildly with the content of fines (clay/silt) in sand ($r = -0.408$, $p < 0.05$) and strongly with the water-to-cement ratio used ($r = -0.826$, $p < 0.001$). This implies water-to-cement ratio contributes highest (about 82.6%) of reduction in compressive strength of concrete.

Table 4.12. Correlation among Compressive Strength, Clay/Silt in Sand and Water-to-Cement Ratio

	Fines (F)	Water/Cement Ratio (w/c)	Compressive Strength (f_{cu})
Fines (F)	1	0.000	-0.408[a]
Water/Cement Ratio (w/c)		1	-0.826[b]
Compressive Strength (f_{cu})			1

[a]$P < 0.05$, [b]$P < 0.001$

To predict the 28 day compressive strength of concrete with content of fines in sand and water-to-cement ratio effects on concrete, regression analysis was conducted and the result presented in Table 4.13. At the 5% level of significance, the analysis of variance (ANOVA) presented suggest an adequate model for making predictions ($F = 41.998$, $p < 0.001$). This implies the model can be used to predict concrete compressive strength after 28 days curing in relation to fines content in sand and water-to-cement ratio. The coefficient of multiple determination, R^2 indicates that the percentage of fines in sand and water-to-cement ratio explains about 84.8% of the variations in the compressive strength of concrete at 28 days curing (Adjusted $R^2 = 82.8\%$). Hence, the model developed from the experimental study for predicting the compressive strength of concrete using the unstandardized coefficients is given as:

$$f_{cu,28} = 45.357 - 37.143F - 41.136w/c \qquad \text{(Eqn. 4.3)}$$

where $f_{cu,28}$ is the compressive strength of concrete after 28 days curing, F is the fines percentage in sand and w/c is the water-to-cement ratio.

This explains that, an increase by one percent of fines content in sand will contribute a decrease in compressive strength of concrete by 37.143N/mm^2 when all other variables are kept constant ($t = -4.063$, $p = 0.001$). On the other hand, water-to-cement ratio increased by one unit in concrete mixtures will result to a decrease in compressive strength by 41.136N/mm^2 conditional on all other variables remaining constant ($t = -8.215$, $p < 0.001$). The beta values of the standardized coefficients indicates that fines in sand upon one standard deviation increment contributes an average decrease of 0.408N/mm^2 to the concrete compressive strength. Water-to-cement ratio also contributes 0.826N/mm^2 decrease on the average to the strength when increased by one standard deviation. It can be noted from equation 4.3 that, water-to-cement ratio contributes the largest effect on concrete compressive strength (Beta = -0.826).

Table 4.13. Regression Coefficients for Compressive Strength after 28 Days Curing of Specimens

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	45.357	3.169		14.313	0.000
Fines (F)	-37.143	9.142	-0.408	-4.063	0.001
Water/Cement Ratio (w/c)	-41.136	5.007	-0.826	-8.215	0.000

R^2 = 84.8% (Adjusted R^2 = 82.8%); F = 41.998, $p < 0.001$

The 91 day compressive strength result of concrete cube specimens are presented in Table 4.14. The trend is as same with the other curing ages.

Table 4.14. Average Compressive Strength after 91 Days Curing

Water/Cement Ratio	Fines (%)	Mass (kg)	Crushing Load (kN)	Compressive Strength (N/mm^2)
0.55	2	8.483	514.4	22.86
	4	8.343	544.1	24.18
	6	8.329	523.9	23.28
	8	8.121	354.8	22.46
	10	8.325	487.3	21.66
	12	8.382	472.5	21.00
0.60	2	8.452	468.5	20.82
	4	8.403	482.5	21.45
	6	8.382	450.0	20.00
	8	8.505	427.1	18.99
	10	8.477	393.0	17.47
	12	8.126	354.8	15.77
0.70	2	8.207	416.1	18.49
	4	8.086	418.0	18.58
	6	8212	412.2	18.32
	8	8.259	366.5	16.29
	10	8.276	345.1	15.34
	12	8.302	336.5	14.96

From Table 4.15, the compressive strength of reinforced concrete correlates strongly but negatively with the percentage of fines in sand and water-to-cement ratio at the 5% level of significance ($r = -0.500$, $p < 0.05$ and $r = -0.783$, $p < 0.001$ respectively).

Table 4.15. Correlation among Compressive Strength, Clay/Silt in Sand and Water-to-Cement Ratio

	Fines (F)	Water/Cement Ratio (w/c)	Compressive Strength (f_{cu})
Fines (F)	1	0.000	-0.500^{a}
Water/Cement Ratio (w/c)		1	-0.783^{b}
Compressive Strength (f_{cu})			1

$^{a}P < 0.05$; $^{b}P < 0.001$

From Table 4.16, the coefficient of multiple determination, R^2 suggests that the explanatory variables can explain about 86.3% of the variations in the compressive strength of concrete (Adjusted R^2 = 84.4%). The ANOVA obtained indicates that the model developed from the analysis is significant for making predictions of compressive strength of concrete after 91 days curing with variable fines content in sand and water-to-cement ratio ($F = 47.119$, $p < 0.001$). The model developed for the relationship is presented in the equation below as:

$$f_{cu,91} = 43.883 - 40.61F - 34.848w/c \qquad \text{(Eqn. 4.4)}$$

where $f_{cu,91}$ is the compressive strength of concrete after 91 days curing, F is the fines percentage in sand and w/c is the water-to-cement ratio.

It is noted from equation 4.4 that, an increase of fines content in sand by one percent will result to a decrease of compressive strength of concrete after 91 days curing by 40.610N/mm^2 whereas an increase in the water-to-cement ratio by one unit (0.01) will cause a decrease of 34.848N/mm^2 on the strength. Meanwhile, as the fines content in sand and water-to-cement ratio increased by one standard deviation, the compressive strength of concrete decreased on the average by 0.500N/mm^2 and 0.783N/mm^2 respectively.

Table 4.16. Regression Coefficients for Compressive Strength after 91 Days Curing of Specimens

	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	43.883	2.695		16.283	0.000
Fines (F)	-40.610	7.775	-0.500	-5.223	0.000
Water/Cement Ratio (w/c)	-34.848	4.259	-0.783	-8.183	0.000

$R^2 = 86.3\%$ (Adjusted $R^2 = 84.4\%$); $F = 47.119$, $p < 0.001$

4.5. Tensile Splitting Results on Cylindrical Specimens

Table 4.17 presents the average test results on cylindrical specimens to ascertain the tensile splitting strength. Refer to Appendix E for the raw data on cylindrical specimens. The trend observed is similar to that of compressive strength. That is, at constant water-to-cement ratio, concrete with 4% fines (clay/silt) in sand had the highest tensile splitting strength after which there was a decline in tensile splitting strength as the content of fines increased beyond 4%. At constant fines (clay/silt) content in sand, tensile splitting strength of concrete decreased with increase in water-to-cement ratio, except for 8% and 10% fines in sand and water-to-cement ratios of 0.55 and 0.60.

Table 4.17. Average Test Result after 28 Days Curing for Tensile Splitting Strength

Water/Cement Ratio	Fines (%)	Mass (kg)	Crushing Load (kN)	Tensile Splitting Strength (N/mm^2)
0.55	2	12.611	133.7	1.89
	4	12.585	143.3	2.03
	6	12.544	131.0	1.85
	8	12.625	114.1	1.61
	10	12.541	106.7	1.51
	12	12.623	107.0	1.51
0.60	2	12.524	123.3	1.71
	4	12.516	129.7	1.83
	6	12.555	123.9	1.75
	8	12.481	119.4	1.69
	10	12.439	114.4	1.62
	12	12.568	105.8	1.50
0.70	2	12.358	96.9	1.37
	4	12.309	105.4	1.44
	6	12.390	96.9	1.35
	8	12.304	93.6	1.32
	10	12.395	93.6	1.31
	12	12.336	73.0	1.20

Table 4.18 presents the correlational matrix for the study variables which show a negative association between the response and causal variables at the 5% level of significance. Fines (clay/silt) in sand was found to have mild correlation with the tensile splitting strength ($r = -0.485, p < 0.05$) whereas water-to-cement correlated strongly with the tensile splitting strength ($r = -0.775, p < 0.001$).

Table 4.18. Correlation among Tensile Splitting Strength, Clay/Silt and Water-to-Cement Ratio

	Fines (F)	Water/Cement Ratio (w/c)	Compressive Strength (f_{cu})
Fines (F)	1	0.000	-0.485[a]
Water/Cement Ratio (w/c)		1	-0.775[b]
Compressive Strength (f_{cu})			1

[a]$P < 0.05$; [b]$P < 0.001$

Regression analysis computed from the tensile splitting test is presented in Table 4.19. The coefficient of multiple determination, R^2 suggest the content of fines in sand and water-to-cement ratio explains about 83.6% of the variations in the tensile splitting strength of concrete (Adjusted $R^2 = 0.814$). The ANOVA generated indicates significance of the model ($F = 38.191, p < 0.001$) and its adequacy for predicting tensile splitting strength of concrete. However, equation 4.5 as predicted by regression is valid for concrete with 4% fines in sand and beyond. The predicting model as developed is expressed as:

$$f_{ct,28} = 3.532 - 3.195F - 2.798w/c \qquad \text{(Eqn. 4.5)}$$

where $f_{ct,28}$ is the tensile splitting strength after 28 days curing, F is the fines percentage in sand and w/c is the water-to-cement ratio.

It can be deduced from the model that, an increase in fines (clay/silt) content in sand by one percent will result in a decrease of the tensile splitting strength by 3.195N/mm^2 ($t = -4.635, p < 0.001$) conditional on all other variables remaining constant. On the other hand, an increase in water-to-cement ratio by one unit will amount to a decrease of 2.798N/mm^2 ($t = -7.409, p < 0.001$) in the tensile splitting strength of concrete when all other variables remain constant. For one standard deviation in the increment of fines content in sand and water-to-cement ratio, the Beta values shows tensile splitting strength decreased on the average by 0.485N/mm^2 and 0.775N/mm^2 respectively.

Table 4.19. Regression Coefficients for Tensile Splitting Strength of Specimen after 28 Days Curing

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.532	0.239		14.780	0.000
Fines (F)	-3.195	0.689	-0.485	-4.635	0.000
Water/Cement Ratio (w/c)	-2.798	0.378	-0.775	-7.409	0.000

$R^2 = 83.6\%$ (Adjusted $R^2 = 81.4\%$); $F = 38.191$, $p < 0.001$

4.6. Flexural Strength Result of Prism Specimens

The raw data obtained for beam specimens are presented in Appendix F from which the average test results are presented in Table 4.20 showing parameters measured from tested beams which include: crack width, crack load, crack length, ultimate flexural strength of the beams and mode of failure.

Table 4.20. Average Test Results after 28 Days Curing for Flexural Strength

Water/Cement ratio	Fines (%)	Ultimate crack width (mm)	Crack length (mm)	Ultimate crack load (kN)	Flexural Strength (N/mm^2)	Mode of failure
0.55	2	3.44	203	77.4	15.47	Flexure-shear
	4	2.65	218	83.3	16.66	Flexure-shear
	6	1.49	228	76.8	15.37	Flexure-shear
	8	2.26	225	74.4	14.88	Flexure
	10	1.65	218	73.5	14.70	Flexure-shear
	12	2.40	208	68.0	13.59	Flexure-shear
0.60	2	1.90	227	76.0	15.20	Flexure-shear
	4	1.19	245	80.2	16.04	Flexure-shear
	6	1.18	185	73.7	14.74	Flexure-shear
	8	2.94	205	71.0	14.20	Flexure
	10	1.04	242	68.7	13.74	Flexure-shear
	12	1.89	235	67.9	13.58	Flexure-shear
0.70	2	1.66	255	60.5	12.09	Flexure-shear
	4	1.74	235	63.1	12.62	Flexure-shear
	6	1.64	232	62.1	12.42	Flexure-shear
	8	1.27	220	58.9	11.78	Flexure-shear
	10	1.24	208	52.3	10.45	Flexure-shear
	12	1.53	218	50.4	10.09	Flexure-shear

It can be noted from Table 4.21 that the crack width most often reduced as the water-to-cement ratio increased for each content of fines (clay/silt) in sand. On the average, the crack width reduced from 2.71mm to 2.03mm (about 25% crack width reduction) and 1.76mm (about 35% crack width reduction) for 0.55, 0.60 and 0.70w/c respectively. This explains that more water content is able to mix the concrete constituents well given better interfacial bonding resulting in less crack width before failure occurs. The highest flexural strength was recorded in the specimen with 4% fines content in sand whereas the least occurred in the 12% fines content for all three water-to-cement ratios. Most of the specimens failed in the flexural and shear mode which propagated a little above the neutral axis in most cases. Again, no bonding failure occurred since none of the beams had a horizontal crack at the level of reinforcement. The crack length as measured occurred in the central one-third of all the tested beams except beam specimen with 6% fines and 0.6w/c. Thus, with a beam length of 600mm, the central one-third length of the beams will range between 200mm and 400mm measured from one face end. Meanwhile, the crack length measured from one face end ranged from 203mm to 255mm which within the central one-third length of the beam with only one which was 185mm.

Table 4.21. Correlation among Flexural Strength, Clay/Silt in Sand and Water-to-Cement Ratio

	Fines (F)	Water/Cement Ratio (w/c)	Flexural Strength (fc_f)
Fines (F)	1	0.000	-0.436^a
Water/Cement Ratio (w/c)		1	-0.846^b
Flexural Strength (f_{cf})			1

$^a P < 0.05$; $^b P < 0.001$

The correlation among the flexural strength of reinforced concrete with water-to-cement ratio and fines content in sand is presented in Table 4.21 which indicates a significant relationship at the 5% level of significance. The results in Table 4.21 show that, flexural strength of concrete has negative relation with the content of fines in sand and the water-to-cement ratio used in the concrete. This means that as the explanatory variables increased, the flexural strength decreased. As the flexural strength of reinforced concrete had mild association with the fines content in sand ($r = -0.436$, $p < 0.05$), it had a strong association with the water-to-cement ratio ($r = -0.846$, $p < 0.001$) on the other hand.

Table 4.22. Regression Coefficients for Flexural Strength after 28 Days Curing of Specimens

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	30.485	1.456		20.940	0.000
Fines (F)	-23.076	4.200	-0.436	-5.494	0.000
Water/Cement Ratio (w/c)	-24.507	2.300	-0.846	-10.653	0.000

$R^2 = 90.5\%$ (Adjusted $R^2 = 89.3\%$); $F = 71.841$, $p < 0.001$

Table 4.22 shows regression analysis for the relationship among the variables of which fines (clay/silt) content in sand and water-to-cement ratio which explains about 90.5% of the variations in the flexural strength of reinforced concrete (Adjusted $R^2 = 89.3$) keeping all other variables constant. The ANOVA obtained indicates the model developed is significant for predicting the 28-day flexural strength of reinforced concrete ($F = 71.841$, $p < 0.001$). Hence the predicting model for the flexural strength is given in equation 4.6 as:

$$f_{cf,28} = 30.485 - 23.076F - 24.507w/c \qquad \text{(Eqn. 4.6)}$$

where $f_{cf,28}$ is the flexural strength of reinforced concrete after 28 days curing, F is fines percentage in sand and w/c is water-to-cement ratio. The equation 4.6 is valid for concrete beam with 4% fines in sand and beyond.

Equation 4.6 suggests that flexural strength of reinforced concrete will decrease by 23.076N/mm^2 ($t = -5.494$, $p < 0.001$) and 24.507N/mm^2 ($t = -10.653$, $p < 0.001$) when the fines content in sand and water-to-cement ratio are increased by one unit respectively. From Table 4.22, an increase of fines content in sand and water-to-cement ratio by one standard deviation will cause a decrease of 0.436N/mm^2 and 0.846N/mm^2 on the average in the flexural strength of reinforced concrete respectively. This explains that, water-to-cement ratio in the model contributes the highest (about 84.6%) effect on the flexural strength of reinforced concrete.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

This chapter discusses the major findings made from the study in line with the research objectives and compared to literature.

5.2 Workability of Concrete

Consistency of concrete is a very important parameter for measuring the properties of fresh concrete. The study result shows that workability of concrete decreased as the content of fines in sand increased at constant water-to-cement ratio which is in agreement with literature (MacGingley & Choo, 1990; IPRF, 2005; Esmail, 2009; Cemex, 2013; Cho, 2013; Mallikarjuna et al., 2013; Ngugi et al., 2014; Iyappan & Manu, 2015). This was so because solid materials finer than 75µm (clay/silt) have larger surface area which increases water demand to produce concrete of desired consistency (Ahmed & Ahmed, 1989). In all, concrete mix with 0.70w/c produces better slumps which were within the range of medium slumps (52mm to 95mm) with the exception of concrete with 10% and 12% clay/silt content (having 49mm and 47mm slump respectively) belonging to low slump. Slump difference for concrete with 2% fines content in sand with the successive 4% fines content for 0.55w/c had the highest percentage reduction (40% decrease) whereas slump difference for 0.70w/c between 10% and 12% fines content had the lowest percentage reduction (4.1% decrease).

At constant fines percentage in sand, the workability of concrete was found to increase with an increase in the water-to-cement ratio which again conforms to literature

(Alawode & Idowu, 2011; Chen, 2012; Apebo et al., 2013; Cemex, 2013). The increase in slump with an increase in water-to-cement ratio was attributed to excessive water dispersing concrete constituents after the initial demand for mixing concrete has been consumed. This resulted in making the concrete soft for transporting, placing and compaction.

From the predicting model (Wc = -141.905 – 235.714F + 310.476w/c), workability for the optimum fines (4%) and 0.55w/c will result in a slump value of 19mm as against the observed slump of 15mm. Meanwhile, making an interpolation for 4% fines and 0.57w/c will be Wc = -141.905 – 235.714(0.04) + 310.476(0.57) which is 25.64mm (≈26mm) belonging to low slump.

5.3 Compressive Strength

Generally, the experimental results from the study showed that the compressive strength of cube specimens made of 1:2:4 mix proportion using cement class of 32.5R did not meet the specified concrete strength class of C20/25 recommended for structural works by the BS 8110-1:1997 (BSI, 2005). This revelation confirms earlier investigations as reported by Adewole, Ajagbe and Arasi (2015) and Boateng (2015). From the study results, the compressive strength of concrete decreased with an increase in water-to-cement ratio with 0.55w/c threshold for all curing ages which is in agreement with literature (Druta, 2003; Li, 2004; Alawode & Idowu, 2011; Olusola et al., 2012; Apebo et al., 2013; Mallikarjuna et al. 2013; Adom-Asamoah et al., 2014) in most cases of constant fines (clay/silt) content in sand. This may be as a result of less bridging of the calcium-silicate-hydrate of cement hydration due to greater dispersion caused by high amount of water content in the mix.

In agreement with literature, compressive strength increased to highest strength for 4% fines content beyond which it decreased at constant water-to-cement ratio (Seeni, Selvamony, Kannan & Ravikumar, 2012; Cho, 2013; Dammo et al., 2014; Iyappan & Manu, 2015). This means some amount of fines in sand (4%) is desirable for optimum compressive strength of concrete. Impliedly, an appreciable amount of fines in sand aids the strength development of concrete since in reality most natural sand contains some amount of fines in them (Abdullahi, 2006). These fines fill the pores of the medium or normal sand which in turn bonds well with the coarse aggregates (stone) used in concrete. Meanwhile, with excessive fines content in sand used for mixing concrete, lower compressive strength are obtained because the fines absorb most of the mixing water. This result in inadequate water content for the hydration of cement (Neville, 1996; Wisconsin., 2007) thereby weakening the strength of concrete.

5.3.1 Predicting model for compressive strength of concrete

Various regression models were developed for predicting the strength of concrete after 7, 28 and 91 days curing of concrete with varying fines (clay/silt) content in sand and water-to-cement ratio. The 28-day compressive strength is discussed in this chapter of the study since concrete strength are normally determined by the 28-day strength by various standard codes. The regression equation developed suggests a significant model for prediction valid for sand containing 4% fines and beyond ($F = 41.998$, $p < 0.001$) where predicted values of compressive strength can be well found within the set of actual values obtained in the study. For example, using the equation $f_{cu,28} = 45.357 – 37.143F – 41.136w/c$ with $R^2 = 84.8\%$ to predict the compressive strength of concrete with optimum percentage of fines in sand and water-to-cement ratio of 4% and 0.55w/c respectively will be $f_{cu,28} = 45.357 – 37.143 (0.04) – 41.136 (0.55)$ which is 21.25N/mm^2. The residual measure in the example for the average compressive strength observed (21.69N/mm^2) is 0.44N/mm^2 representing 2.03% error in the prediction.

By interpolation, it is deduced that predicting compressive strength of concrete that has slump not less than 25mm for 1:2:4 mix proportion should have maximum allowable limits of 4% fines (clay/silt) content and water-to-cement ratio of 0.57 which will result in a 28-day compressive strength of concrete as 20.42N/mm^2. The water-to-cement ratio used for this prediction was deduced from the predicting model for concrete slumps (workability).

5.4 Tensile Splitting Strength

There was similar trend of the tensile splitting strength to the compressive strength of concrete results. Thus, tensile splitting strength increased to 4% fines content in sand beyond which it decreased at constant water-to-cement ratio. Impliedly, maximum tensile splitting strength was observed for concrete with 4% fines (clay/silt) content in sand which agrees with the findings of Iyappan and Manu (2015). On the other hand, at constant fines except for 8% and 10% content, tensile splitting strength decreased with an increase in water-to-cement ratio agreeing with literature (Li, 2004; Mallikarjuna et al., 2013). Using the predicting equation $f_{ct,28} = 3.532 – 3.195F – 2.798w/c$ with the predicted optimum variables (4% fines in sand and 0.55w/c) will result to tensile splitting strength of

$1.87 N/mm^2$ as against the observed strength of $2.03 N/mm^2$. The residual observed in this example was $0.16 N/mm^2$ representing 7.9%.

5.5 Flexural Strength

The flexural strength of reinforced concrete at constant fines content in sand decreased with an increase in water-to-cement ratio which supports existing literature (Neville, 1996; Mallikarjuna et al., 2013). Meanwhile, the flexural strength increased to 4% fines (clay/silt) content in sand beyond which it decreased at constant water-to-cement ratio. This agrees with literature that, there is little demand of water to hydrate the cement responsible for the development of strength in the concrete (Neville, 1996). As the fines (clay/silt) content increases in the sand, more water is demanded for producing workable concrete which may make it easier to fail under load. That is, the interfacial bonding of the aggregate is less strong since much of the sand will be too fine to bond the coarse aggregate well and dispersion of cement hydrates by more water in the mix.

The predicted equation ($f_{cf,28} = 30.485 – 23.076F – 24.507w/c$, $R^2 = 0.905$) was found to be valid for concrete beam with 4% fines in sand and beyond. By interpolation, making prediction of the 28-day flexural strength of reinforced concrete from the model for 4% fines content in sand and 0.57w/c for 1:2:4 mix will be $15.59 N/mm^2$. Meanwhile, the flexural strength based on the optimum percentage of fines (clay/silt) in sand and water-to-cement ratio of 4% and 0.55w/c respectively will give a predicted strength of $16.08 N/mm^2$ as against the observed strength of $16.66 N/mm^2$. This results in a residual of $0.58 N/mm^2$ representing 3.5% of error in the prediction.

CHAPTER SIX

6.0 SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1. Introduction

The aim of the study was to determine the effect of fines (clay/silt) in sand and water-to-cement ratio on concrete properties. In line with that, this chapter of the study summarizes the results obtained from the study based on the objectives set out. It includes highlights on findings, conclusions drawn in accordance with the objectives and the recommendations for addressing the developments and for future studies.

6.2. Summary of Findings

The study results reveal the following findings as tied to the study objectives:

1. The higher the fines (clay/silt) content in sand, the lower the slump value thereby making the workability of fresh concrete poorer whereas higher water-to-cement ratio increases the workability (slump) of concrete with a predicting equation as $Wc = -141.905 - 235.714F + 310.476w/c$.
2. The percentage of fines content in sand and water-to-cement ratio negatively affects the compressive strength of concrete. A model developed for predicting compressive strength after 7, 28 and 91 days based on the study result which are valid for concrete with 4% fines in sand and beyond is given as:

   $f_{cu,7} = 27.142 - 30.581F - 18.964w/c$, $R^2 = 0.727$;

   $f_{cu,28} = 45.357 - 37.143F - 41.136w/c$, $R^2 = 0.848$; and

$f_{cu,91} = 43.883 - 40.61F - 34.848w/c$, $R^2 = 0.863$ respectively.

3. The percentage of fines content in sand and water-to-cement ratio negatively affects the tensile splitting strength of concrete. A predicting model from the study result is given as $f_{ct,28} = 3.532 - 3.195F - 2.798w/c$, $R^2 = 0.836$.
4. The flexural strength of reinforced concrete was negatively affected by the percentage of fines content in sand and water-to-cement ratio used for producing the concrete with a predicting model as $f_{cf,28} = 30.485 - 23.076F - 24.507w/c$, $R^2 = 0.905$.

6.3. Conclusions

It is concluded based on the study findings that:

1. Higher water-to-cement ratios increase workability (slump) of concrete while higher fines% in sand decrease the workability of concrete.
2. The maximum water-to-cement ratio for achieving concrete class C20 using 1:2:4 mix proportion of concrete should not go beyond 0.57.
3. The maximum fines content in sand for making concrete should be 4%.
4. When water-to-cement ratio and fines content in sand increase, the compressive strength of concrete decreases.
5. The tensile splitting strength of concrete decreases as the percentage of fines in sand and water-to-cement ratio increases.
6. Increment of water-to-cement ratio and fines content in sand decreases the flexural strength of reinforced concrete.

6.4. Recommendations

It is recommended based on the study that:

1. Fines (clay/silt) content in sand should be checked by concrete producers before determining the concrete mix proportion.
2. Sand with fines above 4% should only be used for producing concrete when remedies like sand washing or cement increment is adopted.
3. Cement content should always be increased anytime water content is increased above the initial water-to-cement ratio adopted during concrete production.
4. An extensive study should be conducted using different samples of sand across the regions of Ghana to affirm or determine the allowable percentage of fines (clay/silt) in sand in Ghana.
5. The chemical and biological elements of sand fines (clay/silt) should be investigated to determine their influence on concrete properties.

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APPENDICES

Appendix A. Some Cases of Building Collapses in Ghana

S/N	*Location of Building*	*Type of Building*	*Date*	*Deaths/Injuries*
1	Cantonments, Accra	Four (4) story building under construction	July, 2015	3 died
2	Apatrapa, Kumasi	Five (5) story building under construction	June, 2015	No casualty
3	Kropo, Kumasi	Five (5) story building under construction	June, 2015	No casualty
4	Cantonments, Accra	Residential building under construction	December, 2014	1 died, 12 injured
5	Nii Boi Town, Accra	Six (6) story building under construction	March, 2014	1 died, some injured
6	Krofrom, Kumasi	Three (3) story building, residential	April, 2013	3 died, 5 injured
7	Achimota, Accra	Five (5) story building, shopping mall	November, 2012	14 died, 27 injured
8	Apatrapa, Kumasi	Uncompleted story building	2012	None reported
9	Kasoa, Central Region	Public toilet	2012	1 died, 2 injured
10	Ayomso, Brong Ahafo Region	Residential	2012	2 died, 2 injured
11	Kato near Berekum B/A	Residential	2011	2 died, 3 injured
12	Sawla	Residential	2011	4 died
13	Dormaa Ahenkro, B/A	Two (2) story building under construction	January, 2011	2 died, 3 injured
14	Spintex Road, Tema	Four (4) story building	June, 2010	2 – 6 injured
15	Dompoase-Aprabo	Residential	2010	2 died, 2 injured
16	Baatsona, Accra	Faculty construction	2010	2 died, 6 injured
17	Wa Upper West Region	Residential	2010	5 died, 4 injured
18	Takwa, Western Region	Five (5) story hotel building under construction	January, 2010	3 died
19	Zenu, Ashaiman	Two (2) story building	October, 2009	4 died
20	Accra	Two (2) court complex	2009	None reported
21	Kejetia, Kumasi	Two (2) story building	August, 2008	No casualty, Properties damaged
22	Danyame, Kumasi	Two (2) story building under construction	March, 2008	1 died
23	Asafo, Kumasi	Four (4) story building under construction	December, 2006	No casualty reported
24	Accra	Four (4) story building uncompleted	December, 2002	No casualty
25	Madina, Accra	Three (3) story building under construction	April, 2002	2 persons missing, 16 injured

(Source: Adu, 2015; Daily Guide Ghana, 2014; Danso & Boateng, 2013; Gomda, 2015; GhISEP, 2012)

Appendix B. Test Results at 7 Days Curing of Cubes for Compressive Test

S/N	Sample	Mass (kg)	Crushing Load (kN)	Compressive Strength (N/mm^2)	Average Strength (N/mm^2)
2A	1	8.209	330.3	14.68	15.73
	2	8.434	368.4	16.37	
	3	8.531	363.3	16.14	
2B	1	8.573	313.7	13.94	14.16
	2	8.551	311.0	13.82	
	3	8.611	331.2	14.72	
2C	1	8.321	267.2	11.87	12.08
	2	8.156	263.7	11.72	
	3	8.164	284.7	12.65	
4A	1	7.972	399.8	17.77	18.00
	2	8.395	437.9	19.46	
	3	8.431	377.4	16.77	
4B	1	8.463	357.2	15.88	15.62
	2	8.265	348.2	15.47	
	3	8.191	348.8	15.50	
4C	1	8.178	278.2	12.36	12.47
	2	8.318	270.8	12.04	
	3	8.041	292.4	13.00	
6A	1	8.146	379.9	16.88	16.11
	2	8.105	344.4	15.31	
	3	8.097	362.9	16.13	
6B	1	8.369	280.6	12.47	12.98
	2	8.376	313.9	13.95	
	3	8.367	281.8	12.52	
6C	1	8.203	277.6	12.34	12.30
	2	8.241	282.5	12.55	
	3	7.949	270.3	12.01	
8A	1	8.027	316.1	14.05	13.90
	2	8.408	294.8	13.10	
	3	8.404	327.7	14.56	
8B	1	8.298	292.7	13.01	12.12
	2	8.542	248.3	11.03	
	3	8.567	277.4	12.33	
8C	1	8.312	271.3	12.06	12.06
	2	8.219	273.8	12.17	
	3	8.267	268.8	11.95	
10A	1	8.545	306.9	13.64	12.91
	2	8.166	299.0	13.29	
	3	8.273	265.3	11.79	
10B	1	8.503	268.0	11.91	12.09
	2	8.529	302.2	13.43	
	3	8.459	246.2	10.94	
10C	1	8.205	228.1	10.14	11.37
	2	8.309	307.3	13.66	
	3	8.020	232.2	10.32	
12A	1	8.191	263.9	11.73	12.88
	2	8.215	291.6	12.96	
	3	8.541	313.7	13.94	
12B	1	8.005	261.6	11.63	11.61
	2	8.063	281.9	12.53	
	3	8.006	240.0	10.67	
12C	1	8.300	262.5	11.67	11.13
	2	8.336	244.9	10.88	

	3	8.277	243.9	10.84	

Appendix C. Test Results at 28 Days Curing of Cubes for Compressive Strength

S/N	Sample	Mass (kg)	Crushing Load (kN)	Compressive Strength (N/mm^2)	Average Strength (N/mm^2)
	1	7.978	475.2	21.12	20.83
2A	2	8.242	459.3	20.41	
	3	8.259	471.6	20.96	
	1	8.492	430.1	19.12	18.96
2B	2	8.278	454.8	20.21	
	3	8.390	395.1	17.56	
	1	8.251	307.4	13.66	14.68
2C	2	8.090	355.5	15.80	
	3	8.331	328.1	14.58	
	1	8.420	490.2	21.79	21.69
4A	2	8.472	455.0	20.22	
	3	8.466	578.8	23.06	
	1	8.620	468.6	20.82	19.93
4B	2	8.181	438.5	19.49	
	3	8.526	438.4	19.48	
	1	8.118	375.8	16.70	16.05
4C	2	8.072	361.9	16.08	
	3	8.187	346.1	15.38	
	1	8.371	477.4	21.22	21.25
6A	2	8.484	490.4	21.79	
	3	8.659	466.9	20.95	
	1	8.291	437.2	19.43	19.57
6B	2	8.196	435.5	19.36	
	3	8.249	448.0	19.91	
	1	8.314	322.4	14.33	15.06
6C	2	8.385	321.4	14.29	
	3	8.351	372.4	16.55	
	1	8.117	448.4	19.93	12.80
8A	2	8.206	469.8	20.88	
	3	8.286	485.5	21.58	
	1	8.466	354.4	15.75	15.78
8B	2	8.297	318.5	14.16	
	3	8.300	392.2	17.43	
	1	8.189	352.3	15.66	14.04
8C	2	8.332	303.5	13.49	
	3	8.270	291.5	12.96	
	1	8.194	439.5	19.54	20.38
10A	2	8.253	475.2	21.12	
	3	8.333	460.7	20.47	
	1	8.546	321.3	14.28	15.77
10B	2	8.377	371.5	16.51	
	3	8.481	371.7	16.52	
	1	8.434	333.2	14.81	13.49
10C	2	8.249	309.8	13.77	
	3	8.193	267.6	11.89	
	1	8.222	453.8	20.17	19.32
12A	2	8.303	441.1	19.60	
	3	8.426	409.0	18.18	
	1	8.114	282.0	12.54	13.23

12B	2	8.056	314.3	13.97	
	3	8.118	296.6	13.18	
12C	1	8.325	297.7	13.23	12.19
	2	8.416	271.1	12.05	
	3	8.298	254.3	11.30	

Appendix D. Test Results at 91 Days Curing of Cubes for Compressive Strength

S/N	Sample	Mass (kg)	Crushing Load (kN)	Compressive Strength (N/mm^2)	Average Strength (N/mm^2)
2A	1	8.474	481.3	21.39	22.86
	2	8.433	530.9	23.59	
	3	8.543	531.2	23.61	
2B	1	8.393	465.1	20.67	20.82
	2	8.422	507.6	22.56	
	3	8.540	432.7	19.23	
2C	1	8.163	428.6	19.05	18.49
	2	8.322	406.5	18.07	
	3	8.135	413.2	18.36	
4A	1	8.405	538.8	23.95	24.18
	2	8.358	553.7	24.61	
	3	8.266	539.8	23.99	
4B	1	8.433	466.3	20.73	21.45
	2	8.365	496.5	22.07	
	3	8.410	484.8	21.55	
4C	1	8.073	419.3	18.63	18.58
	2	8.134	412.0	18.31	
	3	8.050	422.8	18.79	
6A	1	8.389	484.6	21.54	23.28
	2	8.329	539.2	23.96	
	3	8.269	548.0	24.35	
6B	1	8.420	490.3	21.79	20.00
	2	8.395	484.9	21.55	
	3	8.332	374.7	16.65	
6C	1	8.295	389.9	17.33	18.32
	2	8.232	414.7	18.43	
	3	8.109	431.9	19.20	
8A	1	8.188	505.2	22.47	22.46
	2	8.090	532.6	23.67	
	3	8.084	477.8	21.24	
8B	1	8.428	452.9	20.13	18.99
	2	8.608	407.5	18.11	
	3	8.478	421.3	18.73	
8C	1	8.255	370.6	16.47	16.29
	2	8.353	356.4	15.84	
	3	8.168	372.6	16.56	
10A	1	8.308	468.2	20.81	21.66
	2	8.368	526.4	23.40	
	3	8.299	467.4	20.77	
10B	1	8.455	417.8	18.57	17.47
	2	8.555	364.2	16.19	
	3	8.420	397.1	17.65	
10C	1	8.351	367.0	16.31	15.34
	2	8.211	336.0	14.93	
	3	8.266	332.3	14.77	

	1	8.454	435.8	19.37	21.00
12A	2	8.438	494.6	21.98	
	3	8.254	486.9	21.64	
	1	8.197	368.9	16.39	15.77
12B	2	8.116	333.2	14.81	
	3	8.066	362.2	16.10	
	1	8.412	334.8	14.88	14.96
12C	2	8.248	373.9	16.62	
	3	8.247	300.9	13.38	

Appendix E. Test Results at 28 Days Curing of Cylinders for Split Tensile Strength

S/N	Sample	Mass (kg)	Crushing Load (kN)	Tensile Splitting Strength (N/mm^2)	Average Strength (N/mm^2)
	1	12.540	131.2	1.86	1.89
2A	2	12.620	135.9	1.92	
	3	12.610	133.6	1.89	
	1	12.496	121.9	1.72	1.71
2B	2	12.605	122.2	1.73	
	3	12.487	118.9	1.68	
	1	12.299	97.4	1.38	1.37
2C	2	12.381	108.3	1.53	
	3	12.394	85.0	1.20	
	1	12.601	142.0	2.01	2.03
4A	2	12.581	144.6	2.05	
	3	12.574	143.2	2.03	
	1	12.506	129.6	1.83	1.83
4B	2	12.605	123.7	1.75	
	3	12.436	135.8	1.92	
	1	12.316	102.5	1.45	1.44
4C	2	12.280	96.6	1.37	
	3	12.332	106.0	1.50	
	1	12.561	124.0	1.75	1.85
6A	2	12.534	137.6	1.95	
	3	12.538	131.5	1.86	
	1	12.537	126.7	1.79	1.75
6B	2	12.593	118.2	1.67	
	3	12.535	126.7	1.79	
	1	12.396	86.9	1.23	1.35
6C	2	12.416	102.9	1.46	
	3	12.358	96.1	1.36	
	1	12.619	118.9	1.68	1.61
8A	2	12.600	108.6	1.54	
	3	12.655	114.9	1.62	
	1	12.494	114.5	1.62	1.69
8B	2	12.495	123.2	1.74	
	3	12.455	120.4	1.70	
	1	12.312	91.9	1.30	1.32
8C	2	12.389	99.7	1.41	
	3	12.210	89.3	1.26	
	1	12.521	110.7	1.57	1.51
10A	2	12.561	106.7	1.51	
	3	12.541	102.5	1.45	
	1	12.487	118.8	1.68	1.62
10B	2	12.424	114.7	1.62	

	3	12.405	109.6	1.55	
	1	12.401	94.9	1.34	1.31
10C	2	12.343	86.1	1.22	
	3	12.441	97.1	1.37	
	1	12.596	104.8	1.48	1.51
12A	2	12.599	103.2	1.46	
	3	12.673	112.4	1.59	
	1	12.536	101.8	1.44	1.50
12B	2	12.576	110.3	1.56	
	3	12.593	105.4	1.49	
	1	12.369	90.5	1.28	1.20
12C	2	12.358	83.4	1.18	
	3	12.280	81.5	1.15	

Appendix F. Test Results at 28 Days Curing of Beams for Flexural Strength

S/N	Sample	Crack Width (mm)	Crack Length (mm)	Crack Load (kN)	Flexural Strength (N/mm^2)	Average Strength (N/mm^2)
	1	3.19	215	78.15	15.63	15.47
2A	2	3.93	220	77.36	15.47	
	3	3.21	175	76.55	15.31	
	1	1.39	255	74.45	14.89	15.20
2B	2	1.84	260	76.55	15.31	
	3	2.47	165	77.00	15.40	
	1	1.74	265	60.35	12.07	12.09
2C	2	1.05	255	61.30	12.26	
	3	2.20	245	59.70	11.94	
	1	3.65	205	82.25	16.45	16.66
4A	2	2.99	205	83.29	16.66	
	3	1.31	245	84.35	16.87	
	1	1.17	225	79.65	15.93	16.04
4B	2	1.51	285	85.20	17.04	
	3	0.88	225	75.75	15.15	
	1	1.61	185	59.65	11.93	12.62
4C	2	2.20	265	63.95	12.79	
	3	1.41	255	65.70	13.14	
	1	1.90	225	74.80	14.96	15.37
6A	2	1.30	285	76.84	15.37	
	3	1.26	175	78.90	15.78	
	1	1.65	225	69.95	13.99	14.74
6B	2	0.95	125	73.71	14.74	
	3	0.93	205	77.45	15.49	
	1	1.36	195	62.00	12.40	12.42
6C	2	2.69	255	62.05	12.41	
	3	0.87	245	62.25	12.45	
	1	1.58	205	74.55	14.91	14.88
8A	2	2.90	205	74.35	14.87	
	3	2.31	265	74.37	14.87	
	1	3.62	195	69.90	13.98	14.20
8B	2	2.59	215	72.10	14.42	
	3	2.62	205	70.98	14.20	
	1	1.06	215	58.85	11.77	11.78
8C	2	1.82	225	58.90	11.78	
	3	0.92	220	58.95	11.79	
	1	1.61	225	73.65	14.73	14.70

10A	2	1.47	245	73.45	14.69	
	3	1.88	185	73.40	14.68	
	1	0.29	215	64.20	12.84	13.74
10B	2	1.52	225	68.65	13.73	
	3	1.30	285	73.25	14.65	
	1	1.03	165	49.25	9.85	10.45
10C	2	1.77	225	52.30	10.46	
	3	0.93	235	55.20	11.04	
	1	2.33	195	67.80	13.56	13.59
12A	2	2.47	215	68.00	13.60	
	3	2.40	215	68.05	13.61	
	1	2.73	255	67.75	13.55	13.58
12B	2	2.61	225	68.05	13.61	
	3	0.33	225	67.92	13.58	
	1	1.01	185	51.95	10.39	10.09
12C	2	3.23	265	50.35	10.07	
	3	0.35	215	49.05	9.81	