PHYSICAL AND MECHANICAL PROPERTIES OF NORMAL CONCRETE WITH RECYCLED CLAY PRODUCTS AND THE PLASTIC FIBRES AS COARSE AGGREGATES

BRIAN JACKS ODERO

MASTER OF SCIENCE

(Civil and Structural Engineering)

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

2016

Physical and Mechanical Properties of Normal Concrete with Recycled Clay Products and the Plastic Fibres as Coarse Aggregates

Brian Jacks Odero

A Thesis Submitted in Fulfillment for the Degree of Master of Science in Civil and Structural Engineering in the Jomo Kenyatta University of Agriculture and Technology

2016

DECLARATION

This thesis is my original work and, has not been submitted for a degree in any other University.

Signed……………………………………….Date …………………………….

Brian Jacks Odero

This thesis has been submitted for examination with our approval as University Supervisors.

Signed……………………………………….Date …………………………….

Prof. R. N. Mutuku

TUM, KENYA

Signed………………………………………..Date …………………………….

Eng. C. K. Kabubo

JKUAT, KENYA

DEDICATION

This thesis is humbly dedicated to my friends, my beloved family: my parents, my fiancé.

ACKNOWLEDGEMENTS

I am so delighted to seize this opportunity and express my heartfelt gratitude to my supervisors, Prof. R.N. Mutuku and Eng. C.K. Kabubo. They provided me with a lot of expert guidance, valid comments, suggestions, continuous support and untiring efforts in carrying out this research work.

I would like to extend my sincere gratitude to the Jomo Kenyatta University of Agriculture and Technology, Department of Civil, Construction and Environmental Engineering for providing me the platform to undergo my postgraduate studies. I would also like to give my appreciation to the National Commission for Science, Technology and Innovation (NACOSTI) for delivering the financial support required for this research and Structural Engineering Laboratory staffs for their cooperation and assistance while carrying out the various research preparations and tests.

The manual cutting of the plastic bottle fibres and preparation of clay bricks aggregates into the required sizes was not an easy task without the help of casual assistants who helped me a lot to achieve this. I would also like to express my deepest gratitude to friends who gave the encouragement and unconditional support while carrying out this research.

I am greatly indebted to my family, sisters and brothers for their faith in me. Their support, encouragement and advice were invaluable. They gave me due attention and delivered what they can throughout my academic career. They helped me to be where I am today. Beyond all, my usual thank goes to the Almighty God for He is in all that exists.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ANNEXES

ABBREVIATIONS AND ACRONYMS

w/c	water to cement ratio
NCA	Normal coarse aggregate
CB	Clay bricks
PF	Plastic fibres
PET	Polyethylene terephthalate
USA	United States of America
UK	United Kingdom
CCN	City County of Nairobi
NEMA	National Environmental Management Authority
µm	Micrometer (micron)
MPa	Mega Pascal
°C	Degrees celcious
mm/min	millimetre per minute
$	United States dollar
Shs.	Shillings
ppm	parts per million
%	percent
N/mm^2	Newton per square millimeters
kN	kilo Newton
kg/m^3	kilogram per cubic meters
kg	kilogram
tons	tonnes
min	minutes
£	pounds

ABSTRACT

The quantities of clay product wastes in Kenya have been increasing significantly (approx. 45.9 tonnes annually in Nairobi) without consideration for potential reuse or recycling increasing the risk to public health due to the scarcity of land area for dumping. This growing problem can be alleviated if new disposal options other than landfill can be found. Further, increased construction activity and continuous dependence on conventional materials of concrete are leading to scarcity of construction materials. This study aims at establishing the suitability and strength characteristics of clay product aggregates and plastic fibres as replacement for normal coarse aggregate in concrete.

Clay product wastes originate mostly from broken or leftover bricks, whitewares, sanitary and kitchen ware. In this research, clay bricks were used to replace coarse aggregate in concrete, and varied with shredded plastic fibres. First, clay bricks and plastic fibres were prepared and graded in order to assess their suitability as aggregates. Then different concrete mixes were produced by replacing coarse aggregates with clay products and plastic fibres aggregates. The variations of the coarse aggregates were 20, 40, 60, 80 and 100% by weight for clay products and 5, 10 and 15% by volume of plastic fibres in C20 grade concrete.

Different mixes of clay bricks and plastic fibres were prepared and used for making concrete specimens. Slump tests to ascertain the workability of the fresh concrete properties were carried out. Final test samples were cast and cured and their physical and mechanical properties assessed through density, splitting tensile tests, flexural tests, compressive tests and pull out force tests at 7 and 28 days of curing. The effect of plastic fibres and clay bricks aggregates in concrete were studied and analyzed for physical and mechanical properties of the concrete.

The results demonstrate there is great potential of use of waste clay products and plastic fibres as replacement in concrete. The optimum content of these aggregates were found to be 18.7 and 12.7% by weight and volume of clay bricks and plastic fibres, respectively. This resulted to reduction in concrete mechanical strengths by 59.8, 31.5, 44.2 and 31.1% for compressive strength, flexural strength, pull out force and splitting tensile strength respectively compared to control mix. However, the findings of this research are intended for application requiring non-structural applications. These would therefore address issues such as environmental threats caused by wastes and leftovers, introducing them as alternative source of coarse aggregates in concrete, a conservation of natural resources.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Over the years, the building and construction industry has remained the most vibrant and dynamic industry to achieving growth and development in the world (Yannis, 2013). Clients would normally desire to have the most economical development with the highest quality possible. The building and construction industry contributed 4.8 percent of Kenya's Growth Domestic Product (GDP), which rose to Shs. 5.36 trillion in 2014 from Shs. 4.73 trillion in 2013 - representing a nominal growth of 13.3% (KNBS, 2015).

Good and efficient housing that is green and environmentally friendly has become the mantra for our societies; and players in the construction industry are endeavouring to find out how to attain the benefits of sustainable construction without sacrificing aesthetics as well as making it affordable (Yannis, 2013).

In Kenya, the high rate of population growth, estimated at 4.2% per annum (as of 2012), has put a lot of pressure on land use and consequently shooting up the demand for better and cheap accommodation (Yannis, 2013). The rapid growth in population has led to soaring demand for housing in most parts of the country, this has presented a major opportunity for growth as private developers rush to keep up with this demand. Cement consumption increased by 21.8 per cent in 2014 compared to a 6.9 per cent increase in 2013, from 4,266.8 to 5,197 thousand tonnes. This is attributed to an increase in construction works. Wage employment in the sector grew by 10.7 per cent from 129.7 thousand persons in 2013 to 143.6 thousand persons in 2014 (KNBS, 2015).

Cement and aggregates which are the most important constituents used in concrete production, are the vital materials needed in construction industry. This has inevitably led to a continuous and increasing demand of raw materials used for their production. Parallel to the need for the utilization of the natural resources, emerges a growing concern for protecting the environment and a need to preserve natural resources, such as aggregates, by using alternative materials that are either recycled or discarded as a waste (NEMA, 2008).

Concrete is one of the world's most important construction material. The quality and performance of concrete plays a key role for most of the infrastructures including commercial, industrial, residential and military structures, dams, power plants and transportation systems. Concrete is the largest manufactured material in the world and accounts for more than 6 billion metric tonnes of materials annually. In the United States, federal state and local governments have nearly $1.5 trillion dollars in investment in the U.S. civil infrastructure. The worldwide use of concrete materials accounts for nearly 780 billion dollars in annual spending (Naik & Moriconi, 2005).

Concrete strength is greatly affected by the properties of its constituents and the mix design parameters. Because aggregates represent the major constituent of the concrete mix, its properties affect the properties of the final product. Aggregates have been customarily treated as inert filler in concrete. They were originally viewed as a material dispersed throughout the cement paste largely for economic reasons. It is possible, however, to take an opposite view and to look at aggregates as building materials connected into a cohesive whole by means of the cement paste, in a manner similar to masonry construction. In fact aggregate is not truly inert and its physical, thermal, and sometimes chemical properties influence the performance of concrete (Neville, 2011).

There are many disposal ways for solid, liquid and gaseous waste materials which include composting, landfills, incineration, and open burning. This study gives a better way on how to dispose some solid wastes of clay products and plastic fibre materials in a most beneficial way. However, it is important to underline that re-using of wastes is not economically advantageous, due to the high costs of transportation and its effect on the total cost of production (Yadav *et al.*, 2008). Moreover, it is important not to neglect other costs directly particular to the kind of wastes, due, in particular, to the need of measuring gas emission, during firing (Yadav *et al.*, 2008).

Clay is often used in the manufacture of bricks, whitewares, sanitary and kitchenwares. Sanitary wares, as with all other clay products, are produced from natural materials, which generally contain kaolin, china clay, feldspar, potassium, and quartz (Pacheco-Torgal & Jalali, 2010). These are manufactured from such industries like Saj Ceramics along Mombasa road, Eurocon Companies in Industrial estates of Nairobi and Kenya Clay Products Ltd along Thika Super Highway all in Kenya. Roofing tiles products in our markets are sold by companies such as Australian Decra Space and Style, and Dura Roofing Tiles. In Nairobi County, the total solid waste generated due to clay product wastes sums to approximate 45.9 tonnes annually (Syagga, 1992).

The quantities of waste products considered unsuitable for sale and thus rejected depends on the type of installation and the product requirements. Such wastes are considered inert, due to their low capacity for producing contamination. However, dumping constitutes a major disadvantage, producing significant visual impact and environmental degradation.

The construction industry as the end user of almost all the clay product wastes is well poised to solve this environmental problem. Clay products wastes fall under the categories of non-biodegradable materials; there has been renewed interest in developing alternatives of its disposal. One possible solution for this problem is to incorporate clay products into cement-based materials. Waste clay products can be crushed into reduced sizes of 20 mm (maximum aggregate sizes) to produce lightweight concrete, without affecting strength (Kanaka & Raja, 1992).

Plastics on the other hand being part of solid waste products can also be constructively used in concrete technology. Plastics fibres are known to be stable and will neither decay nor degenerate either in water or in soil. However, plastics if burnt release many toxic gases, which are very dangerous for health (Neville, 2011).

Pezzi *et al.* (2006) used plastic material particles incorporated as aggregate in concrete and evaluated the chemical, physical, and mechanical properties. The results showed that the addition of polymeric material in fractions less than 10% in volume does not imply a significant variation of the concrete mechanical features. Ghaly *et al.* (2004) conducted research on plastic chips that were used as partial replacement of coarse aggregates in concrete mixtures. Plastic aggregate replaced 5, 10 and 15% by mass of coarse aggregate. He found out that at w/c ratio of 0.54, the greater the plastic content in the mix, the lower is the compressive strength of concrete by 6.37, 20.37 and 29.28% respectively.

This research attempts to give a contribution to the effective use of clay products and plastics wastes in concrete in order to prevent the ecological and environmental strains they cause, thus limiting the amount of environmental degradations. Nevertheless, researches carried out so far by reusing clay products wastes and plastic fibres in concrete are scarce and have not fully evaluated the physical and mechanical properties of the new concrete, which are key issues.

1.2 Problem statement

Presently, clay product materials are used abundantly in various purposes like flooring, walling and kitchenwares while plastic bottles are used for chemical packages, portable water, etc. As the usage increases, so does the production of these wastes. Plastic has become the most common material since the beginning of the 20th century and modern life is unthinkable without it. NEMA Kenya estimates that only 1% of wastes due to plastics are recycled. Unfortunately, what makes it so useful, such as its durability, light weight and low cost, also makes it problematic when it comes to its end of life phase due to its non-biodegradable nature. The re-use and recycling is minimal. Second, plastic wastes block gutters and drains creating serious storm water problems.

The excessive excavation of quarries for natural aggregates production for construction purpose is becoming a serious environmental problem. Erosion and failure of quarries and damage of structures situated closer to the quarries due to continuous drilling and blasting the bedrocks. The demand for natural aggregates is also quite high in our country owing to rapid infrastructural growth results to depletion of these resources. Therefore, use of the large amount of brick masonry or ceramic waste produced in the country as alternative materials to replace the demand for natural coarse aggregates may provide a significant source of aggregates. In addition it reduces the amount of waste that ends to landfills which becomes an environmental hazard.

Moreover, some countries such as United Kingdom (in the year 2003) are depending on imported aggregates; increasing the import by 10.5% between year 2002 to 2003 to supplement the demand, which is very expensive. This concern leads to a highly growing interest for the use of alternative materials that can replace the natural aggregates. Recycled clay products and plastic fibres aggregate are seen as possible substitutes for conventional natural aggregate in concrete. Therefore, this study sought to establish the physical and mechanical properties of normal concrete with coarse aggregate replaced with recycled clay products and plastic fibres.

1.3 Study justification

Provision of cheaper and affordable housing has been a challenge to the construction industries in Kenya. There has been a growing concern on the high cost and performance of buildings and structures. Concrete being a major component in construction becomes crucial, as the greatest contributor of development. Moreover, it would even be of high application with the increase in industrialization and the development of urbanization. Yet concrete construction so far is mainly based on the use of virgin natural resources.

Malek *et al.* (2006) by visiting a number of local construction sites in Jordan provided an important indication of the percentage of particular construction waste materials accumulated at the sites. The study established that 19% of the total quantity of waste of 1,721.8 tonnes consisted of glass, plastics and concrete. The weights of these materials were estimated to be 35 tonnes of glass, 52 tonnes of plastic and 240 tonnes of concrete. Hence, this waste should be incorporated in a waste management plan.

Recycling waste clay products in concrete construction, from broken and deteriorated materials, would reduce the negative impact on the environment and increase sustainability of aggregate resources. According to NEMA (2008), 225 of the 1,500 tonnes (or 15%) of solid waste collected daily in Nairobi consist of plastics, which makes them available for use as proposed in this research. However, the agency estimates that less than 1% of plastic waste in the country is recycled. Kenya for this case has only four firms that recycle on a large scale, the widely used thin plastic bags known locally as "flimsies" (NEMA, 2008). With recycling being at such a low scale, it then calls for research on other means of getting rid of the potentially harmful waste material.

The production and use of plastics has a range of environmental impacts. Firstly, plastics production requires significant quantities of resources, primarily fossil fuels, both as a raw material and to provide energy for the manufacturing process. It is estimated that 4% of the world's annual oil production is used as a feedstock for plastics production and an additional 3-4% during manufacture (UNEP, 2006).

In addition, plastics manufacture requires other resources such as land and water that produces waste and emissions. The overall environmental impact varies according to the type of plastic and the production method employed.

There has been an increasing significant interest in the development of concrete mixes with clay products and plastic wastes. Besides, recycling clay products and plastic wastes as an aggregate is effective for environmental conservation and economical advantageous for concrete production.

1.3.1 Benefits of recycled clay products

The hard physical structure of these materials and their chemical structure make them a good and suitable choice to be used in concrete (Khaloo, 1995). The benefits of using clay product wastes in construction are three-fold:

(a) They can offer distinct engineering benefits over traditional aggregates.

(b) They can be used as an alternative to primary materials thereby reducing an environmental burden on extraction.

(c) Their use can help to reduce burden of waste disposal (including illegal stockpiling and disposal, such as fly-tipping, with their associated risks) and the impacts on the environment associated with some other uses of these wastes (Pacheco-Torgal & Jalali, 2010).

1.3.2 Advantages of using plastics in concrete

The growth in the use of plastic is due to its beneficial properties, which include (Yadav *et al.*, 2008):

(a) Lighter weight than competing materials reducing fuel consumption during transportation.

(b) Resistance to chemicals, water and impact.

(c) Excellent thermal and electrical insulation properties.

(d) Unique ability to combine with other materials like aluminum foil, paper, adhesives.

(e) Intelligent features, smart materials and smart systems.

(f) Reduction of municipal solid wastes thus reducing use of landfills for disposal.

1.3.3 Disadvantages of plastics

The followings are the main disadvantages of using the plastics in concrete are as follows (Yadav *et al.*, 2008):

(a) Plastics have low bonding properties reducing the compressive, tensile and flexural strength of concrete.

(b) Its melting point is low so that it cannot be used in furnaces because it melts when it comes in contact with the heat at high temperature.

1.3.4 Significance of the research

The use of recycle clay bricks and plastic bottles in concrete would be beneficial players in the industries like NEMA, and the contractors in construction industries. The adoption of the waste materials in construction would help solve environmental threats posed by wastes and leftovers, ultimately leading to the conservation of natural resources.

Concrete made with crushed clay bricks and plastic fibres as aggregate, would contributes to reduction in unit weight. This is useful in the application-requiring non-load bearing lightweight concrete such as concrete partition wall panels used in facades, canal linings, pathways, pavements and so on. The utilization of clay bricks and plastic fibres in concrete has not been fully investigated in Kenya. This research will provide better disposal mechanism to wastes.

On the international scene, the use of these waste products as replacement of concrete aggregates will add to the existing body of knowledge in concrete technology. The research provides the optimum quantity of clay bricks and plastic fibres and mechanical properties of the resulting concrete.

1.4 Objectives

1.4.1 General objective

The general objective is to study the physical and mechanical properties of normal concrete with coarse aggregate replaced with recycled clay products and plastic fibres.

1.4.2 Specific objectives

1) To determine the properties of fresh normal concrete with recycled clay products and plastic fibre as coarse aggregate.

2) To examine the properties of hardened normal concrete with recycled clay products and plastic fibre coarse aggregates.

3) To establish the optimum proportions of clay products and plastic fibre aggregates in normal concrete.

1.5 Hypothesis

Use of a certain optimum amount of recycled clay products and plastic fibres results in concrete with acceptable physical and mechanical strength than that of conventional concrete.

1.6 Scope and limitations

This research addresses the technical and environmental aspects of recycled clay bricks and plastics to replace normal coarse aggregates in concrete of grade C20. Various types of plastics wastes are available in our country such as plastic bags, plastic bottles, heavy weights plastics, the study was limited to the use of light weight plastic bottles. This study concentrated on clay bricks and plastic fibres from low density plastics prepared manually. Due to the financial constraints the study did not focus on the political financial and socio-economic factors of these research materials in concrete which would form the basis for future studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 General properties of concrete

2.1.1 Characteristics of concrete

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues them together (Mindess *et al.*, 2003). In its simplest form, concrete is a mixture of paste and aggregates. The paste, composed of cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete.

2.2 Constituents of concrete

2.2.1 Water

Water is one of the most important elements in concrete production. Water is needed to begin the hydration process by reacting with the cement to produce concrete. There has to be a sufficient amount of water available so that the reaction can take its full course but if too much water is added, this will in fact decrease the strength of the concrete (Neville, 2011). The water-cement ratio is an important concept because other than the recipe for the concrete mix, the amount of water used would also determine its final strength (Khaloo, 1995).

In more details, if too little water is added, there would not be enough water available to finish the reaction, thus some of the cement would harden and bond with other dry cement shortening the hydration process. On the other hand, if too much water is added while the cement is undergoing hydration, the cement would be in a slurry solution thus reducing bonding with aggregates. As a result, when the hydration process is completed, the cement content would still be in a slurry solution and with no strength. The type of water that can be used to mix concrete must be potable which is essentially has neither noticeable taste nor odour. Water containing less than 2000 ppm of total dissolved solids can be used (Khaloo, 1995). In this research, tap water supplied by Thika Municipality Water and Sewerage Company at room temperature was used in all mixes.

2.2.2 Portland cement

The term "Portland" in Portland cement originated in 1824 when an English mason obtained a patent for his product. This was because his cement blend produced concrete that resembled the color of the natural limestone quarried on the Isle of Portland in the English Channel (Mindess *et al.*, 2003).

Cement is a generic name that describes material with adhesive and cohesive properties, which make it capable of bonding mineral fragments into a compact whole. The chemical composition of the cements can be quite diverse but by far the greatest amount of concrete used today is made with Portland cements (Mindess *et al.*, 2003). For this reason, the discussion of cement in this thesis is mainly about the Portland cement.

Cement is a very important part of the concrete; it gives the concrete its strength. Water is the element that is used to begin the hydration reaction where cement reacts with the water to produce a rock-like substance. The reaction is also exothermic, where heat is released in the chemical reactions. For instance large structures like concrete dams, the heat released can pose a potential problem. However, using too much cement in concrete is expensive, and thus aggregates would take the place of cement without reducing its strength and reduce the cost (Mindess *et al.*, 2003).

2.2.3 Aggregates

Aggregates generally occupy 65 to 70% of the volume of concrete and can therefore be expected to have an important influence on its properties (Neville, 2011). They are granular materials derived for the most part from natural rock and sands. Moreover, synthetic materials such as slag and expanded clay or shale are used to some extent, mostly in lightweight concrete.

In addition to their use as economical filler, aggregates generally provide concrete with better dimensional stability and wear resistance. Based on their size, aggregates are divided into coarse and fine fractions. The coarse aggregate fraction is that retained on 4.75 mm sieve while the fine aggregate fraction is that passing the same sieve (Mindess *et al.*, 2003).

2.3 The use of recycled materials in concrete construction

2.3.1 General

Recycling of materials in concrete technology is seen as being essential to reduce the total amount of waste materials going into landfill, especially in the urban areas where land is very scarce. The use of recycled materials is often cheaper for the consumers of the end product. Hence, there is also an economic justification for promoting its use.

Construction is the largest consumer of natural resources. However, the construction industry is also one of the largest generators of waste. Due to the increasing concern of the limited amount of remaining landfill space for disposal, some countries like the UK prompted to introduce the landfill tax and a waste strategy in an attempt to secure behavioral changes and meet new waste targets. This tax, together with the aggregates levy has largely encouraged the use of alternative materials in construction. The aggregate levy in the UK is around £1.60

per tonne and its main objectives are to reduce the demand for primary aggregates and encourage the use of alternatives (Wallis, 2005).

When considering a waste material as a concrete aggregate, three major areas are relevant. These are economy, compatibility with other materials, and the concrete properties. The economical use of waste material depends on the quantity available, the amount of transportation required, the extent of the benefits and the mix design requirements (Mindess *et al.*, 2003).

The use of recycled materials generated from transportation, industrial, municipal and mining processes in transportation facilities is an issue of great importance. Recycled concrete aggregates and slag aggregates are used where appropriate. As the useable sources for natural aggregates for concrete are depleted, utilization of these products also increases (Khaloo, 1995).

The use of concrete for the disposal of solid wastes has concentrated mostly on aggregates, since they provide the only real potential for using large quantities of waste materials (Mindess *et al.*, 2003). The effect of waste materials on concrete properties must be considered. For example, the lower modulus of elasticity of glass compared to that of good quality rock will lower the elastic modulus of concrete. Crushed recycled concrete has been used as an aggregate, producing concrete with strength and stiffness equal to about two-thirds of that obtained using natural aggregates. These effects would be much more pronounced if low strength, low modulus materials such as clay products and plastic fibres are used. Clay product wastes have been proposed for use in concretes where high resiliency rather than strength are required (Khalaf, 2006).

One of today's major problems and which will continue to do so for foreseeable future is the environmental pollution resulting from industrial wastes and waste living materials.

Particularly among the waste materials in the advancement of civilization are broken and discarded clay products and plastic bottles. The main reason for this is that the amounts of these wastes are increasing due to continuous construction activities of homes and industrial productions (NEMA, 2008). This research therefore uses these wastes as replacement for coarse aggregates.

2.4 Clay products in concrete

2.4.1 Floor tiles

Khaloo (1995) investigated the use of crushed tile as a source of coarse aggregate in concrete. The resulting concrete made with 100% crushed tile as the coarse aggregate had a higher compressive (+2%), tensile (+70%) and flexural (+29%) strengths compared to normal concrete. Ay and Unal (2000) studied the possibility of using ground floor tile as a cement replacement in concrete. He found that grounded waste tiles possessed pozzolanic properties and it is therefore possible to use grounded waste tile as a 35% by weight replacement of cement. In this research, crushed clay bricks were used as replacement of coarse aggregate.

2.4.2 Crushed clay bricks in concrete

Research on use of crushed clay bricks in concrete has been going on for many years. The use of crushed bricks in concrete affects the properties of the resulting concrete to a certain extent depending on the type and origin of bricks. Akhtaruzzaman and Hasnat (1988) first studied the use of crushed bricks as a 100% replacement of coarse natural aggregates in concrete. The resulting concrete had density ranging from 2000 to 2080 kg/m^3 and a compressive strength ranging from 13.8 to 34.5 N/mm^2. He found that the tensile strength of the bricks concrete was higher than that of normal concrete by about 11%. However, modulus of elasticity was found to be 30% less than that of normal concrete.

Khaloo (1995) tried to use crushed clinker (hard burnt) bricks as aggregates in concrete. The resulting concrete had density of about 2100 kg/m^3. The average compressive reduced by 7% while tensile and flexural strengths showed an increase of 2 and 15% respectively for concrete with bricks as coarse aggregate compared to normal concrete. In this research, the waste clay bricks drawn from the sites were prepared and used at various proportions to determine the properties of the resulting concrete mix.

2.5 Plastic fibres

2.5.1 Definition

Plastic is a material that contains one or more organic polymers of large molecular weight, solid in its finished state and at some state while manufacturing or processing into finished articles, can be shaped by its flow. Plastics are typically polymers of high molecular mass, and may contain other substances to improve performance and reduce costs.

Plastics can be separated into two types. The first type is thermoplastics, which can be melted for recycling in the plastic industry. These plastics are polyethylene, polypropylene, polyamide, polyoxymethylene, polytetrafluorethylene and polyethyleneterephthalate. The second type is thermosetting plastic. This plastic melt but the chemical reaction is irreversible because the molecular chains are bonded firmly with meshed crosslink. These plastic types are known as phenolic, melamine, unsaturated polyester, epoxy resin, silicone and polyurethane. At present, these plastic wastes are disposed by either burying or burning. However, these processes are costly (Yadav *et al.*, 2008).

K. Ramadevi and R. Manju (2012) focused on use of non-biodegradable solid waste materials to replace natural ingredients like sand in concrete. In their investigation, 0.5, 1, 2, 4 and 6% volume of sand was replaced by PET bottle fibers for concrete grade C20. The waste PET bottles were collected, shredded into flakes and the ground to make plastic fibers. The density of concrete was found to be reduced for PET fiber reinforced concrete. The study showed that the compressive, split tensile and flexural strength increased by 2% replacement of fibers. Further replacement caused a reduction in strength. This current research used proportion of manually cut plastic fibres from plastic bottles to replace coarse aggregate by volume.

2.5.2 Plastic aggregate as a substitute in concrete

Bayasi and Zeng (1993) studied the effect of polypropylene fibres on the slump of concrete mixes. They did report an increase in inverted slump cone time with the increase in volume fractions of 0.1, 0.3 and 0.5% of plastic fibres. They further found out that for fibre volume fractions less than or equal to 0.3% fibre, effect on fresh mix workability is insignificant and rather inconsistent. However, for fibre volume of 0.5%, fibres adversely affected fresh mix workability evident by the increase in inverted slump measure to 19 mm fibres with a more pronounced effect than 12.7 mm.

Malek *et al.* (2006) investigated the effect of replacing sand with plastics. For a 20% replacement, the slump decreased to 25% of the original slump value with 0% plastic particle content. This decrease in the slump value is due to the shape of plastic particles, i.e., the plastic particles have sharper edges than the fine aggregate. The slump, value at 20% plastic particle content was 58 mm and can be considered acceptable and the mix is workable.

The hardened properties with the addition of the plastic particles led to a reduction in the strength properties. For a 20% replacement, the compressive strength showed a sharp reduction of up to 72% of the original strength. With 5% replacement, the compressive strength showed a 23% reduction (Malek *et al.*, 2006).

Similar behavior, but at a lower effect, was observed in both the splitting and flexural strengths of the tested samples. The strength reduced by 23% and was attributed to strength of plastic particles being lower than that of aggregates. Therefore, both the use of concrete with plastic particles and the percentage of replacement should be controlled, according to the allowable strength of the structural element to be constructed (Malek *et al.*, 2006). In this research the plastic fibres prepared from plastic bottles were used at 0 to 15% by volume to replace NCA and determine properties of the resulting concrete mix.

2.6 Tests on fresh concrete

2.6.1 Workability test

Workability is a measure of the ease with which concrete can be worked on in various processes such as mixing, placing and compaction. It is the amount of energy required to achieve the necessary consistency of concrete such that concrete is easily mixed, placed and compacted. Concrete workability for this research was assessed by slump measure and a steel frustum cone 300 mm high in accordance to BS1881-102, (1983). Common forms of slumps are as shown in Figure 2.1 and the descriptions of slump magnitudes are as given in Table 2.1 (Neville, 2011).

Figure 2.1: Forms of slump

Table 2.1: Description of workability and magnitude of slump

Description of workability	Slump (mm)
No slump	0
Very low	5 - 10
Low	15 - 30
Medium	35 – 75
High	80 - 155
Very high	160 - collapse

2.7 Mechanical characteristics of concrete

The main purpose of measuring the strength of concrete test specimens is to estimate its strength in the actual structure. This estimation gives an indication of the strength of concrete in a structure, which is also dependent on the adequacy of compaction and curing.

2.7.1 Compressive strength

Compressive strength is the capacity of a material to withstand axially directed pushing forces. The strength of the concrete with recycled brick as an aggregate depends on the strength of the original brick. For instance, the use of crushed brick aggregates, obtained from brick with higher initial strength, may exceed the compressive strengths reached using granite aggregate, even allowing for the production of high strength concrete (Gomes & Brito, 2009).

Generally, it is possible to estimate the strength of the concrete with the brick as the coarse aggregate from the strength of the original brick (Gomes & Brito, 2009). This estimation of the compressive strength could be important when recycled bricks from a construction waste are used as an aggregate for a new concrete. In this way, it would be possible to determine whether that brick type, in a particular condition, is suitable for use as the aggregate for a new concrete with demanded strength.

2.7.2 Flexural strength

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The angular shape of the crushed brick and its surface roughness are generally beneficial for a good bond between the aggregates and the cement paste, which could hence increase the flexural strength performances.

In spite of that assumption, flexural strength of the concrete with crushed brick as an aggregate is about 8-15% lower than the one of the ordinary concrete (Gomes & Brito, 2009). During the studies of correlation between flexural and compressive strength of concrete with crushed brick aggregate, it was observed that a decrease in flexural strength has a similar pattern as compressive strength (Guerra *et al.*, 2009).

Choi *et al.* (2005) found out that flexural strength of new composites decreases regularly with the increase in percentages of plastics, in concrete. For 50% replacement of aggregates by plastics, the flexure strength reaches 32.8% of the reference concrete.

2.7.3 Tensile strength

The splitting tensile strength test is used in the design of structural concrete members to evaluate the shear resistance provided by concrete and to determine the development length of the steel reinforcement. The test is rather simple to perform, does not require other equipment than that needed for the compression test, and gives an approximately similar value of the “true” tensile strength of concrete (Neville, 2011).

Some aspects regarding the tensile strength of lightweight concrete and aggregates were studied by Holm (1994). He showed that shear, bond strength between aggregate and cement paste, and crack resistance are related to tensile strength that is, in turn, dependent upon tensile strength of the coarse aggregate and cement paste phases and the degree to which the two phases are securely bonded.

Al-Manaseer and Dalal (1997) studied the effect of plastic aggregates on the splitting tensile strength of concrete. The study concluded that the splitting tensile strength decrease with the increase in plastic aggregates percentage (the splitting tensile was found to decrease by 17% for concrete containing 10% of plastic aggregates). It was also observed that the splitting failure of concrete with specimens containing plastic aggregate did not exhibit typical brittle failure as in the case of conventional concrete. The splitting tensile failure was more of a gradual failure as for specimens tested in compression load.

2.7.4 Pull-out test

The pull-out test is used to determine the overall development length of concrete reinforcement.

$$U=\frac{f_s A_s}{P_o L} \tag{2.1}$$

Where, U is the bond stress

f_s is the stress in the reinforcing bar

A_s is the nominal cross-sectional area of the bar

P_o is the nominal perimeter of the bar

L is the length of embedment of the bar

Martin (1982) used pull-out testing on deformed bars using cube specimens of size 250 mm with a certain length of the bars debonded to yield a bond length equal to five times bar diameter. Jiang *et al.* (1984) developed a new type of specimen which consisted of a reinforcing bar split longitudinally into two halves and embedded in the opposite sides of the prism cross-section rather than concentric with the prism. Effect of bar diameter, confinement and strength of concrete on the bond behaviour of bar hooks in exterior beam-column joints has been reported (Soroushian, 1988). The bond strength decreases as the bar diameter increases. The post-peak bond-slip response was not influenced by the bar diameter (Soroushian & Choi,1989). Specific literature on the effect of crushed clay bricks and plastic fibres are still insufficient therefore, this study would seek to investigate using standard procedures.

2.7.5 Modulus of elasticity

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. Correia *et al.* (2006) found out that increasing the percentage of substitution of natural aggregate with crushed brick aggregate results in decrease of the modulus of elasticity. The moduli of elasticity of concrete with crushed brick as an aggregate is about 30-40% lower than that of normal concrete.

Debieb F. and Kenai S. (2008) found that the modulus of elasticity of fine, coarse and both fine and coarse crushed bricks concrete is lower by upto 30%, 40% and 50% as compared to the modulus of elasticity of a natural aggregates concrete. Ghaly *et al.* (2004) concluded that by replacing 5, 10, and 15% by mass of coarse aggregate with plastic content, the moduli of elasticity decreases by 7.8, 10.9 and 15.6% respectively for w/c ratio of 0.54.

2.8 Summary

It is apparent from the reviews that a number of researchers have found potential of using clay brick materials in concrete. For instance, Akhtaruzzaman and Hasnat (1988) replaced NCA with 100% of crushed bricks in concrete, the concrete density was between 2000-2080 kg/m^3. Gomes and Brito (2009) tested the flexural strength of the concrete with crushed brick and obtained strengths that were between 8-15% lower than normal concrete. Khaloo (1995) used crushed bricks as aggregates in concrete. The resulting concrete had density of about 2100 kg/m^3 while compressive, tensile and flexural strengths were -7%, +2% and +15% of the normal concrete.

Studies have also shown that plastics can be used as replacement by small proportions of sand in concrete. Malek *et al.* (2006) replaced sand with 20% plastics, the slump and compressive strength decreased by 25 and 72% of the control mix. Al-Manaseer and Dalal (1997) studied the effect of plastic aggregates on the splitting tensile strength and found that by replacing upto 10% of sand there was a decrease of 17% for resulting concrete. Ghaly *et al.* (2004) showed reduced compressive strength of concrete by 6.37, 20.37 and 29.28% partially replacing plastic chips 5, 10 and 15% respectively by mass of coarse aggregate.

However, the researches cited have not fully investigated physical and mechanical properties of concrete where coarse aggregates are replaced with clay bricks and plastic fibres. Previous researches reviewed have not ascertained the optimum quantities of these aggregates in concrete mix.

This research aimed to produce concrete replacing crushed clay bricks and plastic fibres manually prepared from locally available wastes in concrete. The research determined the workability, compressive strength and density variation, tensile split strength, pull out force and flexural strength for concrete replacing NCA with clay bricks and plastic fibres. It also sought to determine the optimum quantities and combined effect of these material used under same condition and their influence on concrete mix.

2.9 Conceptual framework

Figure 2.2 shows the conceptual framework of the research.

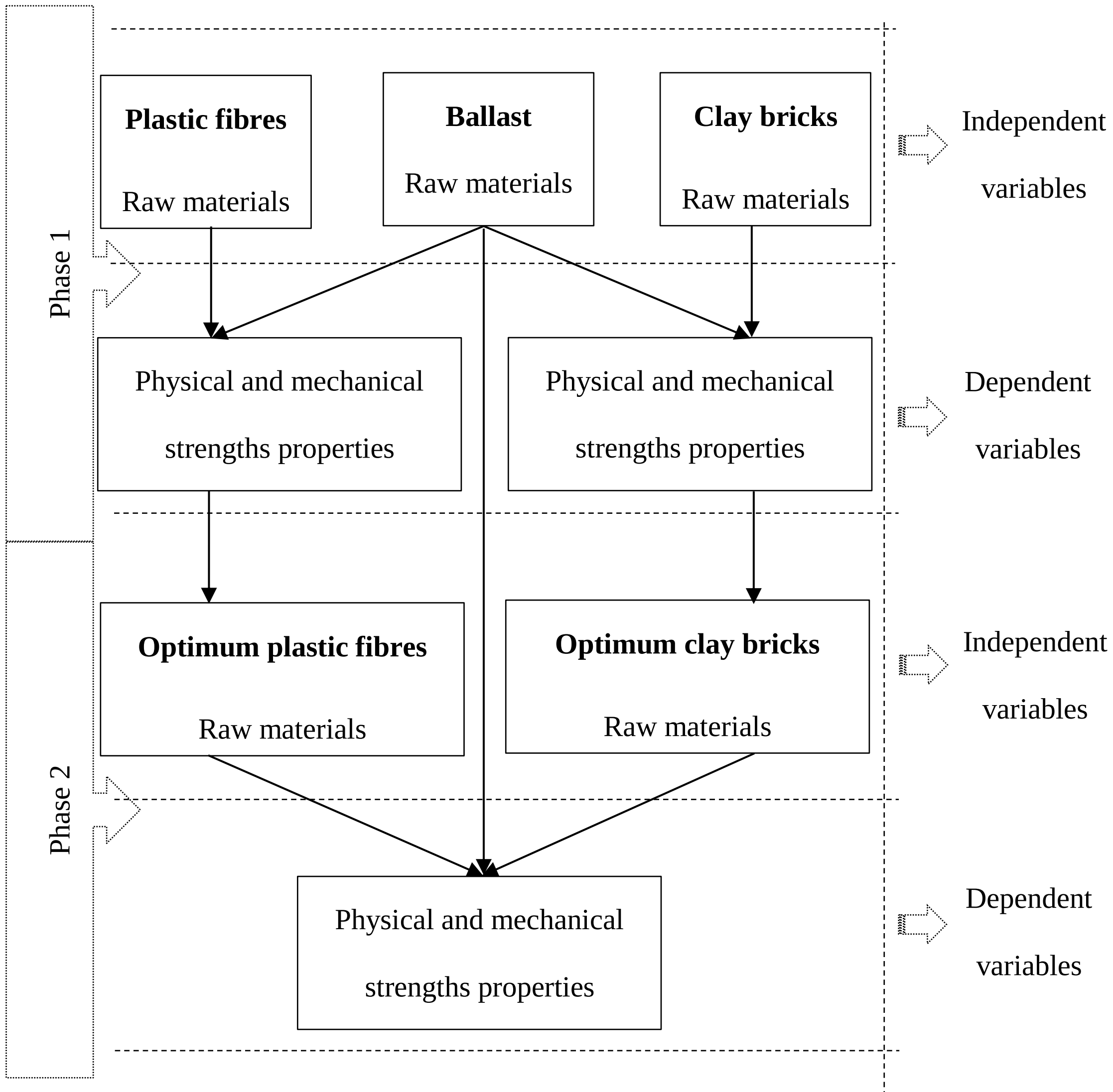


Figure 2.2: The conceptual framework

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials preparation and properties

3.1.1 General

All materials used in this study were locally sourced; the concrete mixes composed of fine aggregate (river sand), normal coarse aggregate, clay bricks aggregate, plastic fibres, cement and water. The various procedures to ascertain the fresh and harden properties of the concrete are given in this chapter.

3.1.2 Cement

The cement used was pozzolanic cement of grade 32.5N (Mombasa cement) conforming to BS12 (1996). This cement was used for this research and was sourced from a local hardware based in Juja. In this study cement type is not a variable hence was obtained from one source. Care was taken to ensure that the cement of same company and same grade was used throughout the investigation. Tests that were conducted on cement were consistency tests, setting tests, soundness tests to ascertain its quality for use in this study.

3.1.3 Fine aggregate

Those fractions from 150 microns to 4.75 mm are termed as fine aggregate. The fine aggregate sample used in this study was purchased from local sand suppliers at Juja Kiambu County sourced from Masinga river. The river sand was washed and screened to eliminate deleterious materials and over size particles. To investigate its properties and suitability for the application in this research, the following tests were carried out.

a) Sieve analysis for fine aggregate and fineness modulus

Sieve analysis is a procedure for the determination of particle size distribution of aggregates using a series of square or round meshes starting with the largest sieve size to pan. This test was performed and used to determine the grading and fineness modulus of fine aggregate (BS 812-103.1, 1985). Well graded ordinary river sand locally available were used.

Sieving was achieved through hand shaking for a minimum of 2 minutes or when no more particles could pass through a certain sieve. The FM of fine aggregates, which is the cumulative weight of aggregate retained and divided by 100, the formula given as equation (3.1).

$$\text{Fineness modulus (F.M)}=\frac{\Sigma \text{ cumulative coarser}}{100}\% \qquad (3.1)$$

b) Specific gravity and water absorption

About 500g of air-dry sand sample passing 5.0 mm sieve and retained on 0.075 mm sieve was washed thoroughly in distilled water to remove all materials finer than 0.075 mm test sieve. The washed sample was then transferred into a shallow tray and fully submerged in water for 24 hours. Water was then carefully drained from the sample by decantation. The wetted aggregates were then exposed to air currents and stirred at frequent intervals in order to evaporate surface moisture completely. Then the mass of the saturated and surface-dry (SSD) aggregates was taken (C).

The aggregates were then placed in a specific gravity bottle and distilled water was poured into it until it was full. Entrapped air was eliminated by rotating the bottle on its side, the hole in the apex of the cone being covered with a finger. The outer surface of specific gravity bottle was wiped and weighed (A). The contents of the bottle were transferred into a tray. The bottle was then refilled with distilled water to the same level and its mass determined (B). The sample was then placed in a tray and dried in an oven at a temperature of 100ºC to 110ºC for 24±0.5 hours, cooled and weighed (D). The procedure was repeated two more times for the purpose of averaging the results. The values of specific gravity and water absorption were obtained from the following calculations:

Specific gravity on SSD condition $= \frac{C}{C-(A-B)}$ (3.2)

Specific gravity on oven dry condition $= \frac{D}{C-(A-B)}$ (3.3)

Apparent specific gravity on oven dry material $= \frac{D}{D-(A-B)}$ (3.4)

Water absorption $= \frac{C-D}{D}$ % (3.5)

c) Moisture content

The moisture content of the fine aggregates was determined in accordance to BS 812-109 (1990). The measuring container was cleaned and dried and weighed to the nearest 0.1g (m_1). The sample of 500g was placed in the container using scoop and weighed (m_2). The container with the test portion was placed in the oven to dry at 105^{0}C for a minimum of 12 hours. After drying the container and the content was weighed again (m_3). The moisture content of the fine aggregate was calculated using the following formula:

Moisture content, w $= \frac{m_2-m_3}{m_3-m_1}$ % (3.6)

d) Silt content of fine aggregate

The silt content tests for fine aggregate (sand) were done in accordance to the BS 812 (1990) standard. It is recommended to wash the sand or reject if the silt content exceeds a value of 6% (Neville, 2011).

3.1.4 Coarse aggregate

The size of coarse aggregate used in this research was between 4.75-19mm. Crushed stones available in the local market were collected to be used as natural aggregates. The natural coarse aggregates from crushed basalt rock, conforming to BS 882 (1992) was used. Well-burnt bricks of well-shaped and reddish in colour were collected and then crushed in the laboratory for making brick aggregates. Clay bricks were obtained from Kenya Clay Products Ltd waste piles used in this research. The bricks were crushed manually to the same sizes range 4.75-19mm conforming to those of natural coarse aggregate.

The physical properties like particle size distribution, specific gravity, bulk density, flakiness index and fineness modulus were determined. Where possible or otherwise large pieces were crushed again to smaller sizes and sieved until the grading of the aggregates complied with the grading limits set out in BS882 (1992). It was observed after crushing that the particles of clay brick aggregates have rougher surfaces and sharper intersecting angles as shown in Plate 3.1.

Plate 3.1: Normal coarse aggregate and clay bricks aggregate

a) Particle size distribution

The result of sieve analysis carried out as per BS 812-103.1 (1985) for crushed clay bricks aggregate and normal coarse aggregates. The FM of coarse aggregates was calculated from formula given as equation (3.7).

$$\text{Fineness modulus (F.M)} = \frac{\Sigma \text{ cumulative coarser}}{100} \% \tag{3.7}$$

b) Specific gravity and water absorption

About 1 kg sample of air dried coarse aggregates passing 19 mm sieve but retained on 4.75 mm sieve was obtained through quartering. It was then weighed on a weighing balance and thoroughly washed to remove finer particle and dust and soaked for 24hours. The specimen was then removed from water, shaken off and rolled in a large absorbent cloth until visible films of water were removed. Large particles were wiped individually and mass of saturated and surface-dry (SSD) aggregates was determined (Ws). The sample was then placed in a wire basket and totally immersed then measured using a double beam balance of capacity 5 kg x 0.5 g and recorded (Ww). The basket was then removed from water and allowed to drain before transferring the aggregates into a tray and oven dried at a temperature of 105-110^{0}C for 24 hours. The samples were then removed from the oven, cooled and its mass determined (Wd). The procedure was repeated two more times. The values of specific gravity and water absorption were obtained from the following calculations:

$$\text{Specific gravity on SSD} = \frac{W_s}{W_s - W_w} \tag{3.8}$$

$$\text{Specific gravity on oven dry condition} = \frac{W_d}{W_s - W_w} \tag{3.9}$$

$$\text{Water absorption} = \frac{W_s - W_d}{W_d} \% \tag{3.10}$$

c) **Flakiness index**

The flakiness index tests on clay bricks and ballast were conducted according to BS 812-105.1 (1989).

3.1.5 Plastic fibres

Polyethylene terephthalate (PET) plastic water bottles were collected from piles of waste plastics at Dandora dumpsite in Nairobi, Kenya. This dumpsite is one of the largest and long serving sites for most of the domestic, commercial and industrial waste in Nairobi County as shown in Plate 3.2. The waste plastic bottles were obtained by picking up. They were thoroughly cleaned before use to ensure that the debris and other forms of impurities that could alter the hydration and bonding of cement water paste are removed.

At the laboratory, polyethylene terephthalate (PET) plastic water bottles were then shredded manually with scissors into widths and lengths between 4.75-19mm aggregate sizes as shown in Plate 3.3 and Annexes A (iv) and (v). The plastic fibres samples were then sieved to ensure that they fit in the limit sieve size requirements of 4.75-19mm. The shape and weight of the plastic fibres particles used in this study prevented a sieve analysis from being applicable since the particles were very light (about 4 times lighter than NCA) and have irregular shapes characterized with shape corners.

Plate 3.2: Piles of waste plastic bottles at Dandora dumpsite in Nairobi, Kenya

(a) Whole bottles (b) Cut bottles

Plate 3.3: Hand cut plastic fibres from plastic bottles

Determination of density

About 500g sample of air dried plastic fibres was obtained through quartering. It was then weighed on a weighing balance and thoroughly washed to remove finer particle and dust and soaked for 24 hours. The mass of surface-dry plastic fibres was determined (Ws). The sample was then placed in a wire basket having openings of not more than 3mm and completely immersed in distilled water. The basket was closed to prevent the plastics from floating on water surface then gently immersed while ensuring no entrapped air on the surface. The mass of the sample while totally immersed was measured using a double beam balance of capacity 5 kg x 0.5 g and recorded (Ww). The procedure was repeated three times. The value of specific gravity was obtained using the formula below:

$$\text{Specific gravity} = \frac{W_s}{W_s - W_w} \qquad (3.11)$$

3.2 Testing machine

A universal testing machine (UTM) as shown in Plate 3.4, also known as a universal tester is used to test the tensile stress and compressive of materials. The machine has load carrying capacity of 500kN and 1500kN as maximum tensile and compression load respectively and load cell of 500kN. It has precision and repeatability: ± 1% of read value. The machine has a hydraulic selector allows to select the tensile or the compression test as Frame No.1 and Frame No.2 respectively. Both frames have upper heads fixed while lower head movable up and down. The machine was operated at speed of 0.4kN/sec.

The UTM has the following components; (a) Load frame - the two strong supports for the machine, (b) Load cell - A force transducer or other means of measuring the load, (c) Cross head - A movable crosshead (crosshead) is controlled to move up or down. The available UTM at the labs had fixed upper head while the lower head free to move up and down. The lower head moves at a constant speed, (d) Control panel - This is a machine that is used to detect and register the loads and deformations to structures via connecting wires. The readings are displayed through the small screen along with the channel through which the connections are made.

Well-cured samples were wiped to remove excess moisture from the surface of the specimen before placing in testing machine. Frame No. 1 was used for pull out test while No. 2 used for tensile, compressive and flexural strength tests.

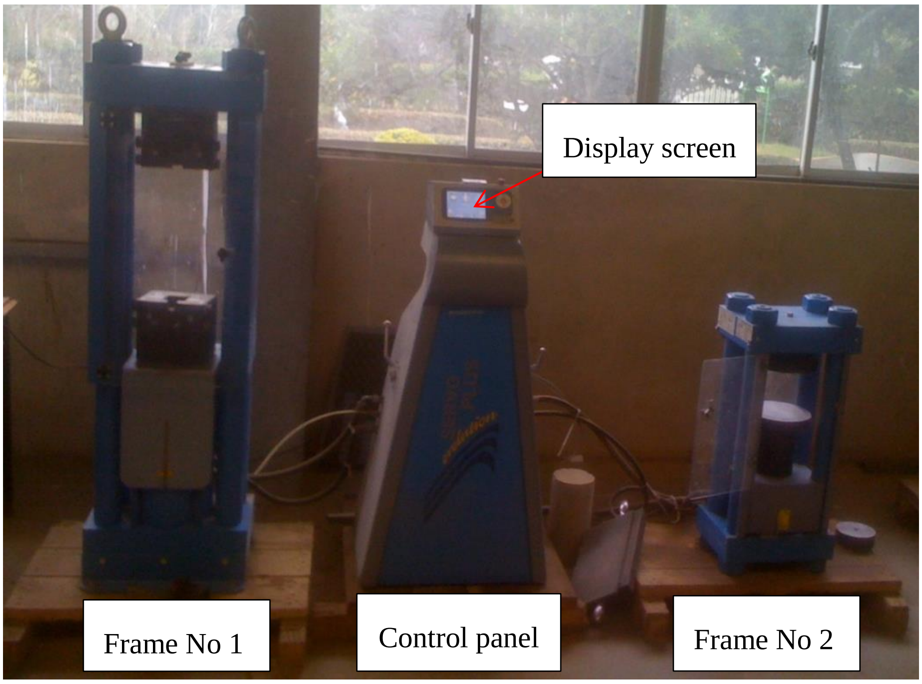


Plate 3.4: Universal testing machine for concrete tests

3.3 Selection of concrete mix proportions and trial mix

3.3.1 Concrete mix design

The mix proportion for grade C20 concrete was determined in accordance to BRE (1997), concrete mix design as shown in Appendix A, and the summary of the materials required for making the samples are as given in Table 3.1.

Table 3.1: Summary of mix design

Quantities	Cement (kg/m^3)	Water (kg/m^3)	Fine agg. (kg/m^3)	Coarse agg. (kg/m^3)
per m^3 (to nearest 5 kg)	309	170	646	1255
per trial mix of 0.003375 m^3 ratio	1.043	0.574	2.181	4.234
Ratio	1	0.55	2.09	4.06

3.3.2 Trial mix

Before proceeding to the preparation of the mix proportions, trial mixes were prepared for each of the concrete mixes replacing NCA with clay bricks and plastic fibres. After calculating the proportion required per cubic meter of concrete, the volume of mix, which was required to make cubes of size 150mm. The batch weights of the trial mix were obtained by multiplying the weights of the mix with the proportion of the constituent materials. The mixing of concrete was done according to the BS 1881-125 (1986) procedures given in laboratory guidelines.

First, fine and coarse aggregates were mixed with some proportion of water added to allow for absorption. Cement was then added and mixed with the aggregates while adding the remaining water until sufficient workability was achieved.

(a) Fresh concrete

The slump test was conducted to determine the workability of fresh concrete. Concrete was placed and compacted in three layers by a tamping rod, each layer given 25 strokes, in a firmly held slump cone. The design slump that was targeted was between 10 to 30mm for control mix.

(b) Hardened concrete

Concrete densities and compressive strength tests were conducted on the cubes at the age of 7 days to monitor strength variation due to replacements of NCA with clay bricks and plastic fibres.

3.3.3 Theoretical nomenclature

Each individual test was given a unique name. The naming method of samples in this research was adopted as shown in Figure 3.4. The first term designate concrete mix. Replacement of coarse aggregate with clay brick aggregate was denoted by the second term. The third and last term denotes plastic fibres and replacement of coarse aggregate with plastic fibres, respectively, such as M100-P0, M100-P5, M80-P0.

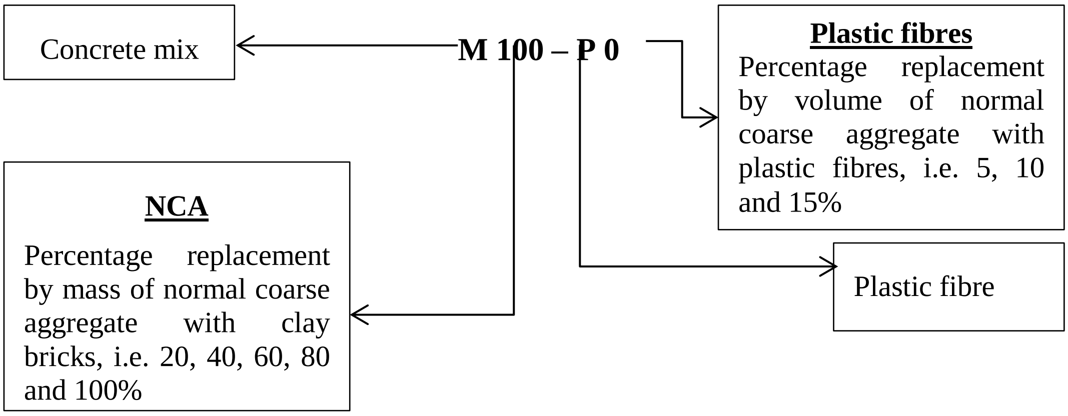


Figure 3.1: Test specimen nomenclature

3.4 Material batching and concrete mix preparation

Saturated surface dry aggregates were used for the concrete mixes in this research. The batching process was done by weight of cement, water and aggregates. Replacement of clay bricks was done by mass at interval of 20% while that of plastic fibres done volume at interval of 5 upto 15% of normal coarse aggregate. Tables 3.2 and 3.3 outline the mix proportions by mass of each batch concrete cube 150 x 150 x 150 mm. The mix was prepared by manual process using metallic tray while maintaining consistency and repeatability of various mixes in the laboratory as shown in Plate 3.5.

Plate 3.5: Manual concrete mixing using spade and tray

The mix proportions of the basic ingredients, i.e., cement, water, and fine aggregate, were kept constant while normal coarse aggregate, clay bricks and plastic fibres varied in different proportions for all samples. Cubes of size 150 mm, cylinders with 100 mm diameter and 200 mm height and prisms of size 100 x 100 x 500 mm were prepared. The slump test was conducted immediately on fresh concrete to determine the workability. The samples were demoulded after 24 hours from casting time and kept in water tank for 7 and 28 days curing.

Table 3.2: Batch mix proportions for concrete with clay bricks

S/No.	Cement (kg)	Water (kg)	FA (kg)	NCA (kg)	Clay bricks (kg)	Ratio by mass (CB: NCA)	W/C ratio
M100-P0	1.043	0.574	2.181	4.234	_ (0%)	_	0.55
M80-P0	1.043	0.574	2.181	3.387	0.847 (20%)	1:4	0.55
M60-P0	1.043	0.574	2.181	2.540	1.694 (40%)	1:1.5	0.55
M40-P0	1.043	0.574	2.181	1.694	2.540 (60%)	1:0.67	0.55
M20-P0	1.043	0.574	2.181	0.847	3.387 (80%)	1:0.25	0.55
M0-P0	1.043	0.574	2.181	_	4.234 (100%)	_	0.55

Table 3.3: Batch mix proportions for concrete with plastic fibres

S/No.	Cement (kg)	Water (kg)	FA (kg)	NCA (kg)	Plastic fibres (kg)	Ratio (PF: NCA)	W/C ratio
M100-P0	1.043	0.574	2.181	4.234	_ (0%)	_	0.55
M100-P5	1.043	0.574	2.181	4.180	0.054 (5%)	1:77.4	0.55
M100-P10	1.043	0.574	2.181	4.126	0.108 (10%)	1:38.2	0.55
M100-P15	1.043	0.574	2.181	4.072	0.162 (15%)	1:25.1	0.55

3.5 Casting and curing

All the concrete samples prepared in this research were cast following procedures described in various standards as discussed above for compressive strength, split tensile strength, pull-out force and flexural strength tests BS 1881-108 (1983). The samples were composed of control mix, clay bricks and plastic fibres replaced in concrete mix. These were then demoulded after 24 hours and taken to curing tank BS 1881-111 (1983) as shown in Plate 3.6.

Plate 3.6: Samples curing process in water tank

3.6 Tests on fresh concrete

3.6.1 Workability test

Concrete workability was measured in accordance to BS 1881-102 (1983). The objective of the test was to determine slump of fresh concrete mix.

The apparatus used were;

- A standard mould which is a frustum of a cone complying with BS 1881 – 102 (1983).
- A standard flat base plate preferably steel.
- A standard tamping rod.
- Standard graduated steel rule from 0 to 300mm at 5mm intervals.
- A scoop approximately 100mm wide.

The procedure of the test involved cleaning and oiling the inside surfaces of the mould to prevent sticking of fresh concrete on the surfaces of the mould. It was then placed on the base plate and held. The mould was filled in three equal layers and each layer was tamped 25 times with a standard 16 mm diameter steel tamping rod. Surplus concrete above the top edge of the mould was struck off with the tamping rod. The slump measure was used to measure the original height with the cone included.

The cone was then slowly lifted and removed leaving the moulded concrete unsupported. The amount by which the concrete sample slumps was measured and recorded. Plate 3.7 gives pictorial view of how the concrete slump were obtained for this research.

Plate 3.7: Concrete slump measurement

3.7 Test for hardened concrete

The following tests and mathematical equations were applied to obtain the densities and mechanical strengths of hardened concrete.

3.7.1 Concrete density

Density (ρ) is the mass of a unit volume of hardened concrete expressed in kilograms per cubic metre. The determination of densities of hardened concrete cubes were done at 7 and 28 days of curing. The masses of samples were taken by electric weighing balance shown in Plate 3.8. Concrete densities were determined as per the guidance of standards (BS 1881-114, 1983). The dry concrete density, ρ, of cube specimen calculated using equation (3.12).

$$\rho = \frac{m}{V}\ \text{kg/m}^3 \qquad (3.12)$$

Where, m is the mass of the as-received specimen in air (in kg);

V is the volume of the specimen calculated from its dimensions (in m^3);

Equipment: weighing balance with an accuracy of 0.1 % of the mass.

Plate 3.8: Electrical weighing balance

3.7.2 Compressive strength test

This test was carried out in accordance to BS 1881-116 (1983) in which cube specimens of size 150 x 150 x 150 mm of hardened concrete were used. The testing was done on Universal Testing Machine (UTM) of 300 tonnes capacity that has the facility to control the rate of loading with a control valve as given in Plate 3.9.

Compressive strengths of hardened concrete cubes were determined at 7 and 28 days of curing. Concrete standard test was based on 28 days strength as per BS1881-116 (1983). The maximum load applied to the cube at failure was noted, the results expressed to the nearest 0.5 N/mm^2. Compressive strength, f_c, of cube specimen calculated using equation (3.13).

$$f_c = \frac{P}{A_c} \text{ N/mm}^2 \tag{3.13}$$

Where, f_c is the compressive strength (in newtons per square millimetres)

P is maximum load at failure (in newtons)

A_c is the cross sectional area of the specimen on which the compressive force acts, calculated from the designated size of the specimen (in square millimetres).

Plate 3.9: Compressive strength testing machine and control machine

3.7.3 Splitting tensile strength

This test was done following procedures and standards prescribe in BS 1881-117 (1983). Split tensile test was carried out on a cylinder to determine the horizontal tensile stress to evaluate the shear resistance provided by concrete. The split tensile strengths of hardened concrete cylinders were determined at 7 and 28 days of curing.

Cylinders measuring 200 mm height and 100 mm diameter were used. The cylinder sample was placed with its axis horizontal between the patens of a universal testing machine with the load being increased gradually until failure as given, Plate 3.10. The split tensile strength, f_{sp}, of the concrete cylinder specimen calculated using equation (3.14).

$$f_{sp} = \frac{2P}{\pi LD} \text{ N/mm}^2 \qquad (3.14)$$

Where, f_{sp} is the split tensile strength (in newtons per square millimetres)

P is load at failure (in newtons)

L is length of the specimen (in millimetres)

D is diameter of the specimen (in millimetres)

Plate 3.10: Splitting tensile testing setup

3.7.4 Flexural strength test

The British standard, BS 1881-118 (1983) specifies the method for the determination of the flexural strength of specimens of concrete beams of size 100 x 100 x 500 mm. Flexural strengths of hardened concrete beams were determined at 28 days of curing. The bearing surface of support and rollers were wiped, cleared and any loose sand or other material was removed. The beams were then tested on a span of 450 mm and 100 mm wide specimen by applying two equal loads placed at two points as shown in Figures 3.2 and Plate 3.11. The flexural strength, f_b, of the concrete prism specimen calculated using equation (3.15).

$$f_b = \frac{P_{max} L}{bh^2} \text{ N/mm}^2 \quad (3.15)$$

Where, f_b is the flexural strength (in newtons per square millimetres)

P_{max} is maximum load on the beam (in newtons)

L is distance between two supports under the test beam (in millimetres)

b and h are width and height of cross section of the beam at the point of failure (in millimetres), respectively.

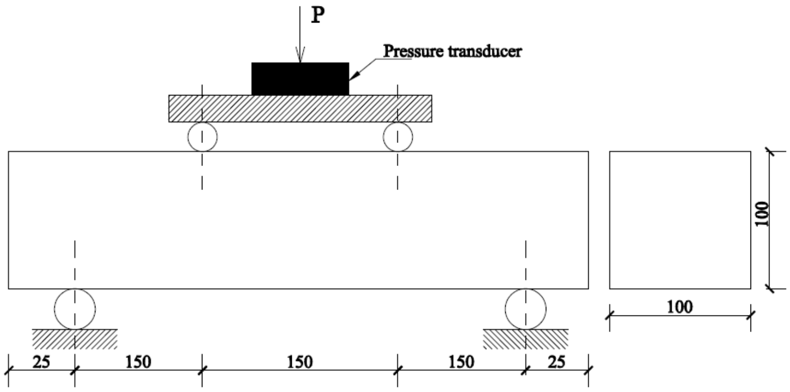


Figure 3.2: Two-point bending test specimen geometry and loading

Plate 3.11: Flexural strength test setup

3.7.5 Pull-out test

The tests were done in accordance to BS 1881-207 (1992). The detailed schematic of the pull-out test setup is given as in Figures 3.3 and Plate 3.12. Pull out forces of hardened concrete cube samples were determined at 28 days of curing. The load was applied at a rate of 2 kN/sec and distributed on the specimen surface by a square steel plate of size 200 x 200 x 10 mm thick. The plate has circular hole 20 mm diameter to allow steel bar pass through. The test was performed by holding the concrete block fixed and pulling on the free end of the reinforcement until failure occurs by either bond slip or material failure. The steel bar was gripped rigidly on the actuator side such that the top section of the concrete cylinder was pressed against bearing steel Plate. During loading, the steel bar was being pulled moving down.

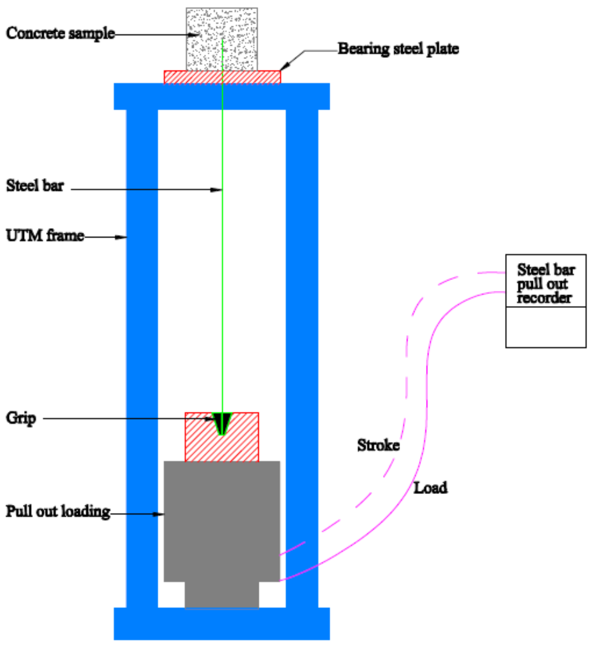


Figure 3.3: Schematic layout of pull out test setup

Plate 3.12: Pull-out load test setup

The pull out force was determined for hardened concrete by measuring the force required to pull an embedded 10 mm diameter square twisted steel bar inserted into fresh concrete mix specimen. The force was achieved from ultimate bondage between steel bar and concrete mix. Bond stress can also be calculated for embedded bar length corresponding to maximum pull out load and it can be regarded as the bond strength or the ultimate bond as shown in equation (3.16). For uniform bond, the bond stress τ_b can be expressed as:

$$\tau_b = \frac{P_{max}}{\pi LD} \text{ N/mm}^2 \tag{3.16}$$

Where, P_{max} is maximum pull out load (in newtons)

D is diameter of the bar (in millimetre)

L is embedded bar length (in millimetre)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter focuses on the results of materials properties, physical and mechanical properties of crushed clay bricks and plastic fibres replaced as well as combined effect of the two aggregates in concrete mix. Each test was conducted three times and the averaged results determined for all the samples.

4.2 Materials properties

4.2.1 Cement

Tests conducted on cement were: consistency tests, setting tests, soundness tests to ascertain its quality for use in this study as shown in Table 4.1.

Table 4.1: Properties of cement

Sr/No.	Properties of cement	Results	Requirements as per BS 12 (1996)
1	Specific gravity	3.15	3.10-3.15
2	Standard consistency (%)	33	30-35
3	Initial setting time (min)	80	30 (minimum)
4	Final setting time (min)	257	600 (maximum)
5	Compressive strength (28 days in N/mm^2)	33.7	32.5 (minimum)

4.2.2 Fine aggregate

a) Sieve analysis for fine aggregate and fineness modulus

The findings were computed as in Appendix B, Table B1 and graphically presented in Figure 4.1. From the figure, the sand used for this research was well-graded pattern.

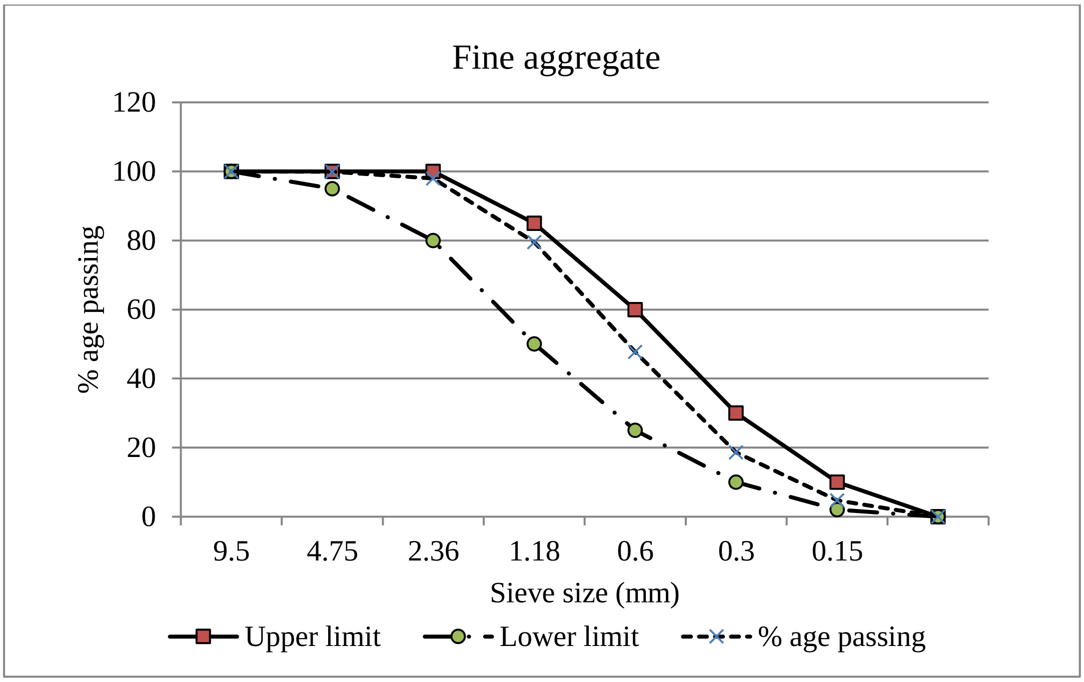


Figure 4.1: Result of sieve analysis for fine aggregates

From the test results, the cumulative percentage of retained materials given by:

Total cumulative percentage retained = 0+0.1+2+20.5+52.3+81.4+95.3 = 251.6

$$\text{Fineness modulus}=\frac{251.6}{100}=2.52$$

b) Specific gravity and absorption capacity of fine aggregate

The following are average results found for the fine aggregate sample from the experiments done for this research as shown in Appendix B, Table B2.

Bulk specific gravity	=2.45
Bulk specific gravity (SSD basis)	=2.51
Apparent specific gravity	=2.61
Absorption capacity	=2.53%

c) Moisture content of fine aggregate

The moisture content of the fine aggregate sample used in this study was tested at different times prior to mixing and it was found to be 0.45%.

d) Silt content of fine aggregate

The silt content of sand used in this research had an average silt content of 2.56% and this was therefore within the acceptable range, less than 6%.

Table 4.2: Silt content analysis for fine aggregate

Parameter	Sand		
	Trial 1	**Trial 2**	**Trial 3**
Weight of sample (g)…………W1	500	500	500
Weight of tray (g)	2469	2467	2502
Weight of tray + sample (g)	2956.5	2954	2990
Oven dry weight (g)……….…W2	487.5	487	488
Silt content (%)	2.56	2.67	2.46

4.2.3 Normal coarse aggregate

The physical properties like particle size distribution, specific gravity, bulk density, flakiness index and fineness modulus were determined.

a) Sieve analysis for coarse aggregate and fineness modulus

The sieve analysis findings were computed as in Appendix B, Table B3 and B4 and graphically presented in Figure 4.2 and 4.3. From the figures, both natural and clay bricks aggregates used for this research showed uniform-grading pattern.

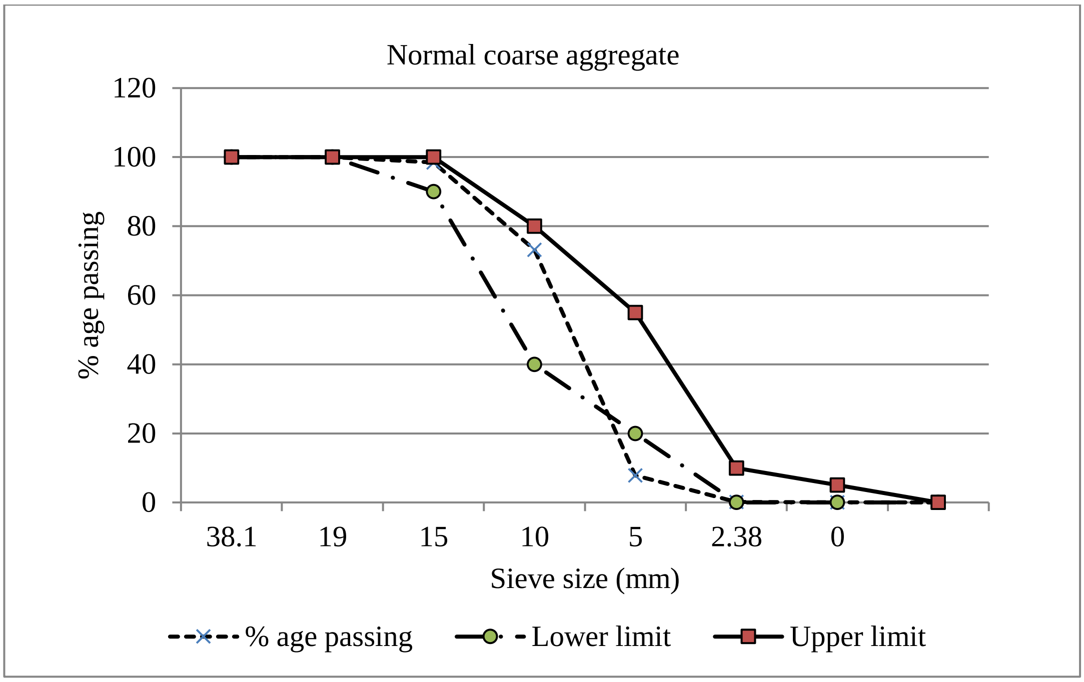


Figure 4.2: Result of sieve analysis of normal coarse aggregates

From the test results, the cumulative percentage of retained materials given by:

Total cumulative percentage retained = 0+0.7+22.73+95.48+99.95 = 218.9

$$\text{Fineness modulus}=\frac{218.9}{100}=2.19$$

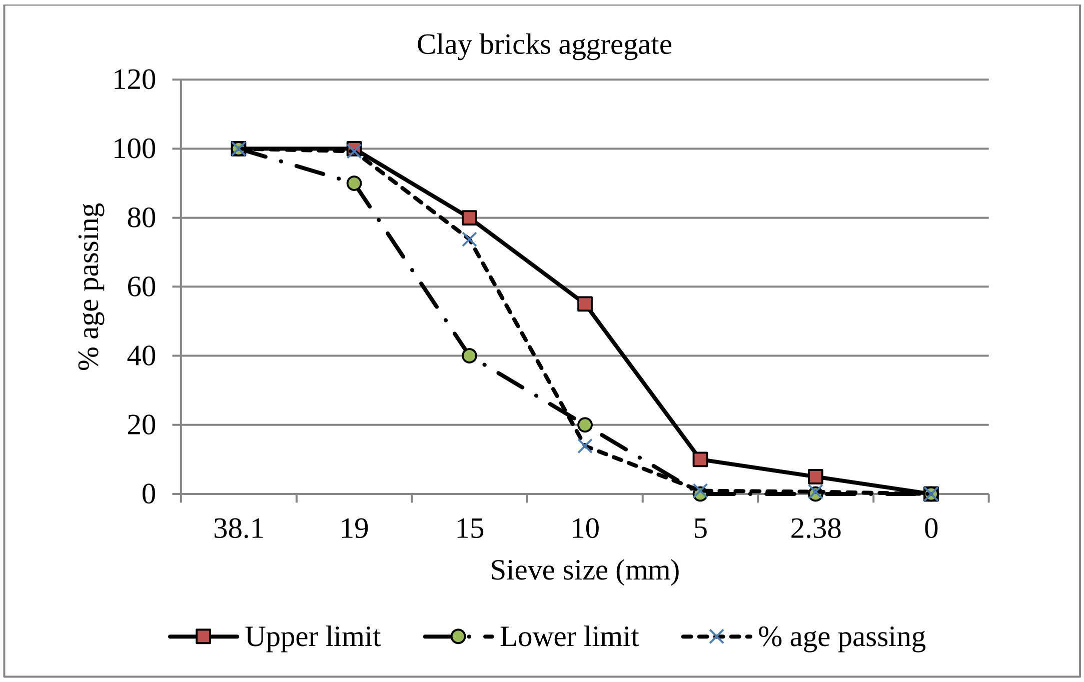


Figure 4.3: Result of sieve analysis of clay bricks aggregates

From the test results, the cumulative percentage of retained materials given by:

Total cumulative percentage retained = 0+0.78+26.2+86.13+99.05 = 212.15

$$\text{Fineness modulus}=\frac{212.2}{100}=2.12$$

b) Specific gravity and water absorption

The specific gravity test result of ballast and crushed clay bricks were summarized as shown in Table 4.3 from Appendix B, Table B5 and B6.

Table 4.3: Specific densities of coarse aggregates

Parameters	Normal coarse aggregate	Crushed clay bricks
Bulk specific gravity	2.53	2.86
Bulk specific gravity (SSD basis)	2.52	2.1
Apparent specific gravity	2.45	1.82
Absorption capacity (%)	2.71	14.95

d) Flakiness index

The results are as shown in Appendix B, Table B7 and B8. Flakiness index of normal coarse aggregate and crushed clay bricks were 37.9% and 39.3%. Thus, the clay bricks are flakier than normal aggregates and this would probably reduce the workability of concrete. The overall results of clay bricks flakiness index are lower than 40% limit, which means the clay bricks is suitable to be used as coarse aggregate.

4.2.4 Plastic fibres

Plastic fibres were tested on the various properties as shown in Table 4.4, for physical and mechanical properties.

Table 4.4: The physical and mechanical properties of plastic fibres

Properties	**Plastic fibres**
Specific gravity	0.8
Water absorption 24 hours (%)	<0.2
Density (kg/m^3)	625
Colour	Different colours
Shape of particles	Angular

4.3 Trial mix results

The comprehensive trial mixes result and analysis for various replacements of clay bricks and plastic fibres in concrete are represented in Appendix C. Tables 4.5 and 4.6 gives the summary of results for densities and compressive strength for the trial mix.

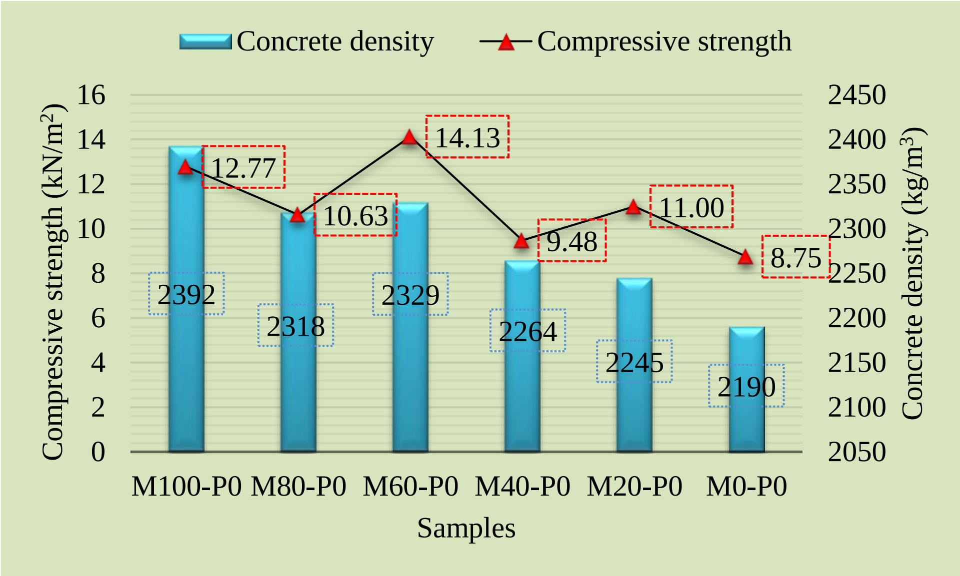


Figure 4.4: Compressive strength and densities for concrete with clay bricks (trial mixes)

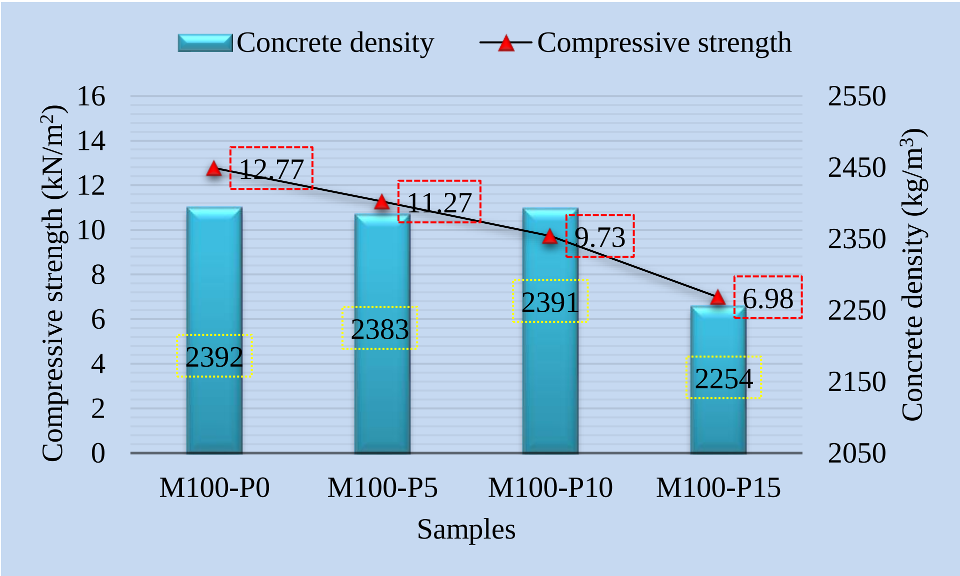


Figure 4.5: Compressive strength and densities for concrete with plastic fibres (trial mixes)

4.4 Slump test

Results for the slump values for fresh concrete are listed in Tables 4.7 and 4.8. The types of slump, which are either zero, true, shear or collapsed were recorded as observed.

4.4.1 Effect of crushed clay bricks aggregates on concrete slump

The results of the slump values for concrete with clay bricks are given in Table 4.7. The results show that slump reduced by 35.3 (M80-P0), 52.9 (M60-P0), 17.6 (M20-P0) and 70.6% (M0-P0) and increased by 141(M40-P0) from reference concrete (M100-P0).

Table 4.7: Slump results for concrete with varying proportions of clay bricks

Sr/No.	Specimen	Clay bricks (%)	Slump (mm)	Variation (%)
1	M100-P0	0	17	-
2	M80-P0	20	11	-35.3
3	M60-P0	40	8	-52.9
4	M40-P0	60	41	141
5	M20-P0	80	14	-17.6
6	M0-P0	100	5	-70.6

The reduction in slump was attributed to water absorption rate of crushed clay bricks which is higher than that of normal coarse aggregate for the same water/cement ratio 0.55. There was a systematic increase in water demand with increase in the content of clay bricks aggregates. The higher the percentages of clay bricks aggregate, the more the water absorption rate and this resulted in lower slump value. High absorption rate and angular shape of clay bricks affected workability of resulting concrete mix, a finding supported by Dina, (2011).

The porous nature of clay aggregates resulted in medium to high rapid water absorption hence if the aggregate used was dry at mixing time, it rapidly absorbed water leading to harsh mixes which are less workable and almost crumbled at M40-P0 and M20-P0.

4.4.2 Effect of plastic fibres on concrete slump

The results of the slump values for concrete with plastic fibres are given in Table 4.8. The results showed that slump values were 17, 29, 55 and 78 mm for samples M100-P0 (control), M100-P5, M100-P10 and M100-P15, respectively. There was an increase of slump with increasing amount of plastic fibres in concrete mix. At 5 and 10% the mix was fairly workable while the concrete failed at 15% (with shear slump of 78 mm) of plastic fibres replacement, an indication of high percentage quantity of fibres in the mix. The general increase in the slump value was likely due to the shape and smooth surface of plastic fibres, i.e., the fibres have sharp edges and smooth surface than normal coarse aggregate.

Table 4.8: Slump results for concrete with varying proportions of plastic fibres content

Sr/No.	Specimen	Plastic fibres (%)	Slump (mm)	Variation (%)
1	M100-P0	0	17	-
2	M100-P5	5	29	70.6
3	M100-P10	10	55	152.9
4	M100-P15	15	78	288.2

4.5 Density of concrete

The concrete density values for this study were measured from the concrete cube samples after 7 and 28 days curing. The overall results of the concrete density for 7 and 28 days tests for clay bricks and plastic fibres in concrete are presented in Appendix C, Table C1 and C2 respectively. This section highlights the behaviour of clay bricks and plastic fibres on concrete density.

4.5.1 Effect of clay bricks aggregates on concrete dry density

Figure 4.4 gives the bar chart represents the trend development of concrete density of variation of NCA and crushed clay bricks. From the 28 day results shown in Figure 4.4, reduction of concrete density of 15.6, 15, 14.6, 11.5 and 10% was observed for samples M20-P0, M40-P0, M60-P0 and M80-P0, respectively, all compared with the reference concrete mix M100-P0.

Reduction in the densities was mostly due to increase in replacement of coarse aggregates with clay bricks in the concrete. The bricks have low specific gravity, 2.17, as compared to that of normal coarse aggregates, 2.84, contributing to decrease in the concrete density. Dina (2011) also found out that the reduced density of the product is due to the reduced specific density of clay bricks compared to natural aggregates. The clay bricks were almost 24% lighter than the normal coarse aggregate and therefore it was expected that the mass density of the mix be significantly lower.

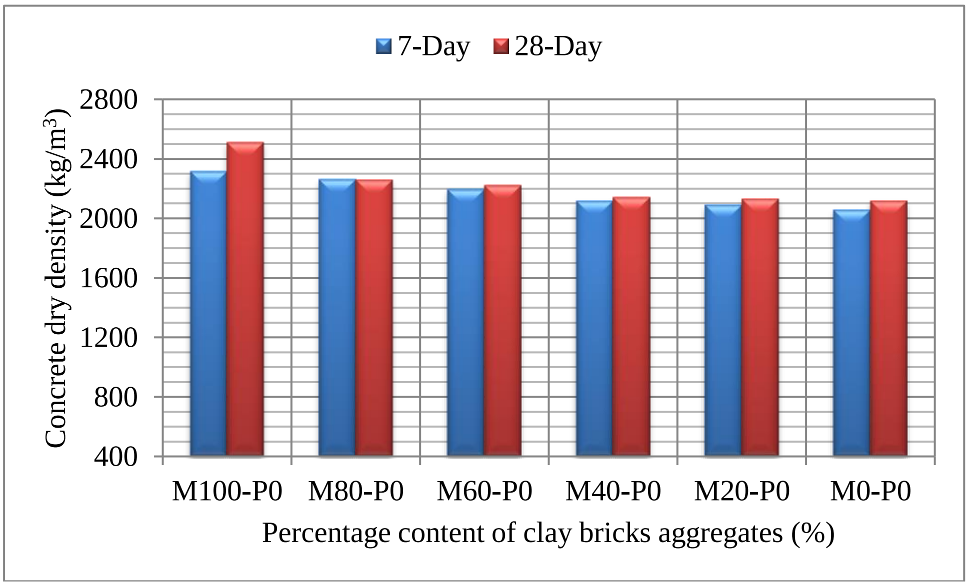


Figure 4.6: Concrete dry density with varying contents of clay bricks aggregates

4.5.2 Effect of plastic fibres on concrete dry density

Figure 4.5 gives the bar chart represents the trend development of concrete density of variation of NCA and plastic fibres. From the 28 day results shown in Figure 4.5, reduction of concrete density of 10, 12.3 and 13.5% was observed for samples M100-P5, M100-P10 and M100-P15, respectively, all compared with the reference concrete mix M100-P0.

The density of plastic fibres and normal coarse aggregate were found to be 625 kg/m^3 and 2650 kg/m^3 respectively. The plastic fibres are 4.24 times lighter than NCA leading to reduction of densities of concrete mix.

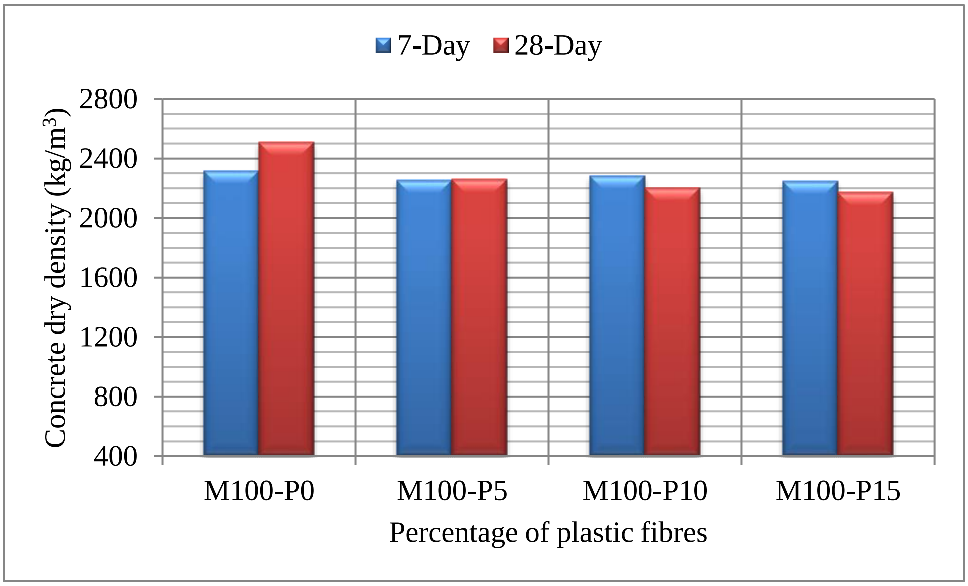


Figure 4.7: Concrete dry density with varying contents of plastic fibres

4.6 Compressive strength

Cubical specimens of size 150 mm were cast for conducting compressive strength for each concrete mix. The overall results of the compressive strength for 7 and 28 days tests for clay bricks and plastic fibres in concrete are presented in Appendix D, Table D1, D2, D3 and D4. The compressive strength of any mix was taken as the average of the strength of three cubes. Plate 4.1 shows hardened concrete sample after failure under the compressive loading test.

Plate 4.1: Failure of concrete cube tested for compressive strength

4.6.1 Effect of clay bricks aggregate on compressive strength

Figure 4.6 illustrates the trend of strength development of concrete specimens with different proportions of clay bricks prepared for 7 and 28 days. The results show the control specimen, M100-P0, having the highest strength of 17.92 N/mm^2 while sample, marked M0-P0, with least strength of 11.35 N/mm^2. From the results, a reduction in compressive strength of 8.1, 17, 32.6, 35.4 and 36.7% were obtained for M80-P0, M60-P0, M40-P0, M20-P0 and M0-P0, respectively, all compared to control mix (M100-P0).

Concrete containing crushed bricks had a relatively reduced strength than normal aggregate concrete. This is due to the higher water absorption of crushed brick aggregates compared to natural aggregates finding also supported by Zakaria M. and Cabrera JG. (1996). Debieb and Kenai (2008) found that the compressive strength decreased by 35% when coarse aggregates were fully substituted by crushed bricks the findings were because of increased water absorption of crushed bricks aggregates. The strength drop with the clay bricks aggregates mix could also be attributed to factors such as density, size interlocking and rigidity of these aggregates.

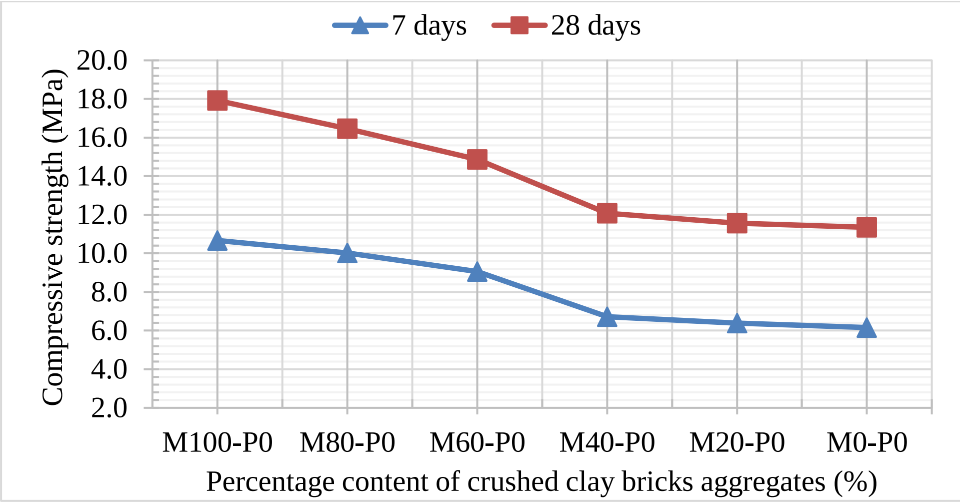


Figure 4.8: Concrete compressive strength for varying proportions of clay bricks

4.6.2 Optimal clay bricks aggregate in concrete mix

Summary of 28 days compressive strength of concrete is given in and Figure 4.7, mathematical non-linear regression method was followed to determine the optimum content of crushed clay bricks as coarse aggregate in the mix. Least square linear regression shows the relationship as given by equation (4.1), to predict the compressive strength of concrete with varying percentages of crushed clay bricks for the strength-range studied as shown in Figure 4.7.

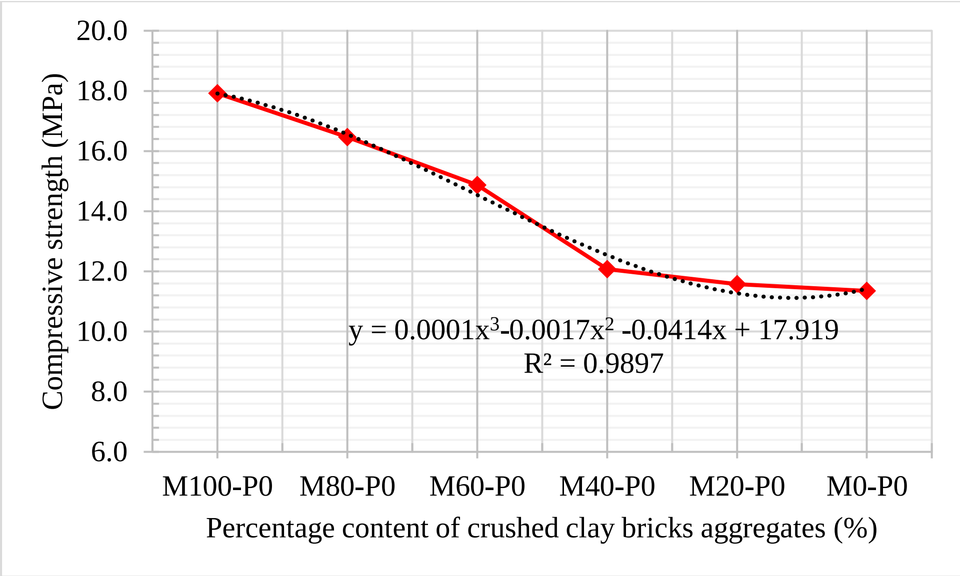


Figure 4.9: Compressive strength of concrete vs. % of clay brick at 28 days

From the graph, the relationship between compressive strength and quantity of clay bricks in concrete was obtained as:

$$y=0.0001x^3-0.0017x^2-0.0414x+17.919$$

$$\frac{dy}{dx}=0.0003x^2-0.0034x-0.0414=0$$

$$x=\frac{0.0034 \pm (0.0034^2+4x0.0003x0.0414)^{0.5}}{2x0.0003}$$

$$x = 18.71\%$$

$$f_c=0.0001x^3-0.0017x^2-0.0414x+17.919 \qquad (4.1)$$

Where f_c is the compressive strength in N/mm^2 and x is the percentage of crushed clay brick.

The optimum quantity of clay bricks in concrete was determine by linear regression analysis. The optimum was at the point at which maximum quantities of clay bricks provided consistent strength with the prediction equation for compressive strength. From the analysis, the optimum quantity was estimated to be 18.7% (marked as M81.3), and the corresponding compressive strength of 16.20 N/mm^2. Veera Raddy (2010) also carried out investigation of ceramic scraps replacement in concrete. He concluded that ceramic scrap can be partially used to replace conventional coarse aggregates in the range between 10 to 20%, without affecting its structural strength.

4.6.3 Effect of plastic fibres on compressive strength

Figure 4.8 gives the trend development of concrete specimens with different proportion of plastic fibres prepared for 7 and 28 days. The results show control specimen, M100-P0, having the highest strength of 17.92 N/mm^2 while sample, marked M100-P15, with least strength of 9.11 N/mm^2.

The control sample compared against concrete with plastic fibres shows a reduction in compressive strength of 34, 45.8 and 49.2% for samples M100-P5, M100-P10 and M100-P15 respectively as given in Figure 4.8. It was observed that as the quantities of plastic fibres increase the compressive strength reduced.

This trend could be attributed to the decrease in adhesive strength between the surface of the fibres and the cement paste. An almost similar reduction of 70% were by Choi *et al.* (2005) and Marzouk *et al.* (2007). The plastic fibres aggregate have smooth surfaces and also form voids in concrete, hence resulting to decrease in compressive strength as the plastic fibres content increase.

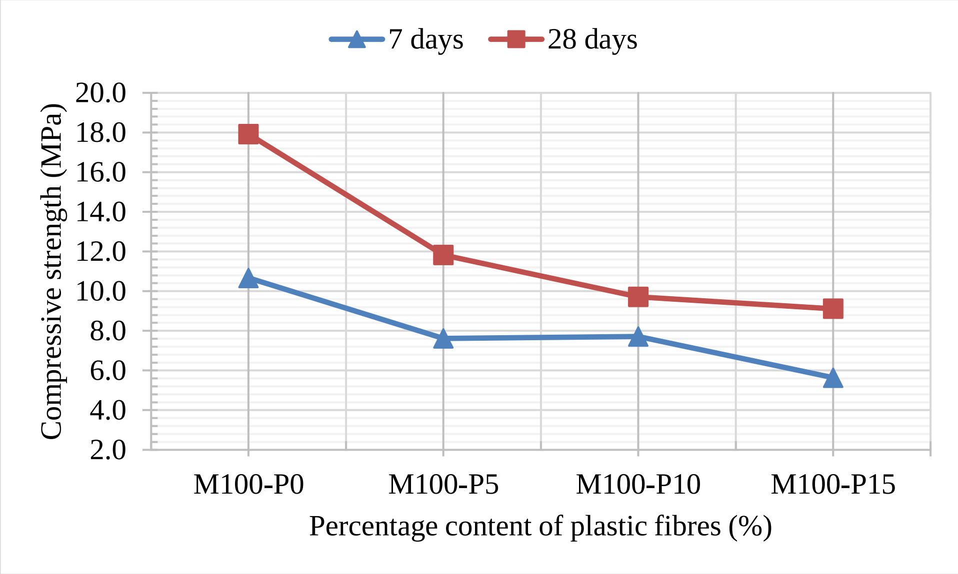


Figure 4.10: Concrete compressive strength with varying proportions of plastic fibres

4.6.4 Optimal plastic fibres contents in concrete mix

Summary of 28 days compressive strength of concrete is given in and Figure 4.9, mathematical non-linear regression method was followed to determine the optimum content of plastic fibres as coarse aggregate in the mix. Least square linear regression shows the relationship as given by equation (4.2), to predict the compressive strength of concrete with varying percentages of plastic fibres for the strength-range studied as shown in Figure 4.9.

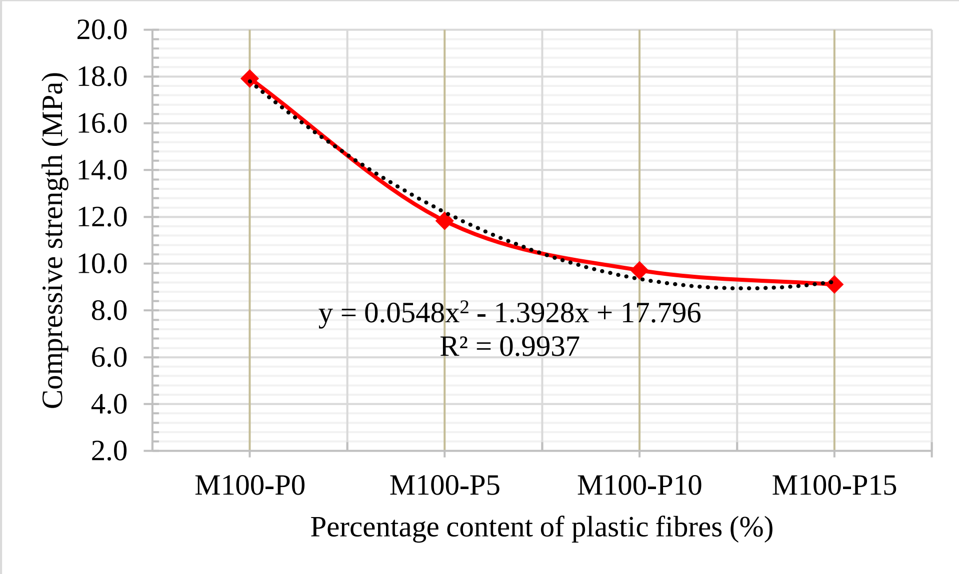


Figure 4.11: Compressive strength of concrete vs. plastic fibres at 28 days

From the graph, the relationship between compressive strength and quantity of plastic fibres in concrete was obtained as:

$$y=0.0548x^2-1.3928x+17.796$$

$$\frac{dy}{dx}=0.1096x-1.3928=0$$

$$x=\frac{1.3928}{0.1096}$$

$$x = 12.7\%$$

$$f_c=0.0548x^2-1.3928x+17.796 \quad (4.2)$$

Where f_c is the compressive strength in N/mm^2 and x is the percentage of plastic fibres.

The optimum quantity of plastic fibres in concrete was determine by linear regression analysis. Optimum was at the point at which maximum quantities of plastic fibres provided consistent strength with the prediction equation for compressive strength. From the analysis, the optimum quantity was estimated to be 12.7% (marked as P12.7), and the corresponding compressive strength of 8.95 N/mm^2.

4.7 Tensile strength

Cylindrical specimens of size 100 mm diameters and 200 mm height were cast for conducting splitting tensile strength for each concrete mix. Overall results and analysis of the split tensile strength for 7 and 28 days tests for clay bricks and plastic fibres in concrete are presented in Appendix D, Table D5 and D6 respectively. The tensile strength of any mix was taken as the average of the strength of cylindrical samples. Plate 4.2 shows split tensile specimen test set up and failed sample after failure mode.

Plate 4.2: Splitting tensile sample test setup and failure mode

4.7.1 Effect of clay bricks on split tensile strength

The results and trend of split tensile strength development tested for concrete were as shown in Figure 4.10 for 7 and 28 days. The results show control specimen, M100-P0, having the highest strength of 1.48 N/mm^2 while sample, marked M0-P0, with least strength of 0.90 N/mm^2.

The graph shown in Figure 4.10 illustrates the variation of the split tensile strength of specimens with different replacement percentage of normal coarse aggregates. From the results, a reduction in split tensile strength of 4.1, 10.8, 28.4, 26.4 and 39.2% were obtained for M80-P0, M60-P0, M40-P0, M20-P0 and M0-P0, respectively, all compared to control mix (M100-P0).

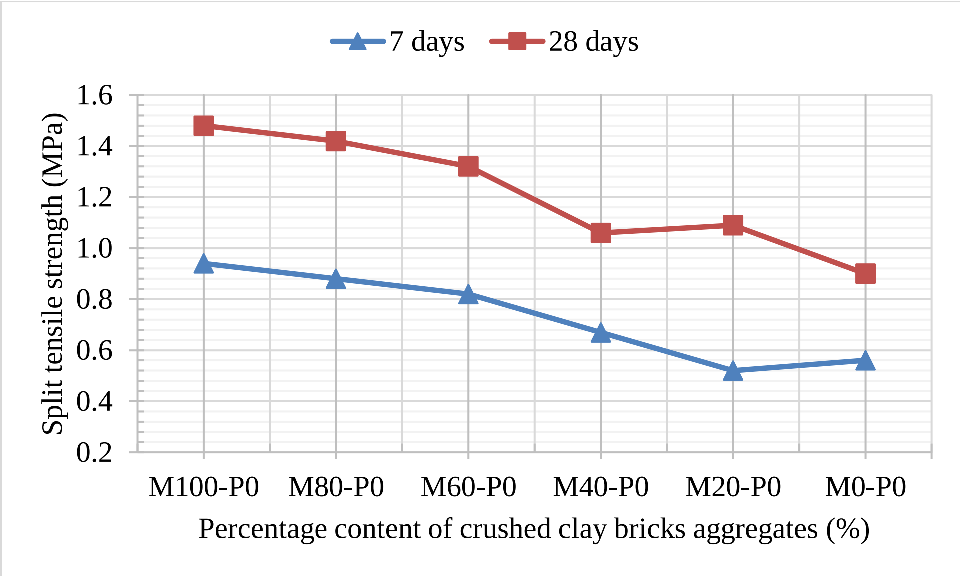


Figure 4.12: Concrete split tensile strength with varying proportions of clay bricks

The splitting tensile strength of the concrete with clay bricks was lower than that of normal concrete, and this was attributed to poor bond strength between cement paste and clay brick particles. Besides, pores in concrete due to voids in crushed clay bricks are much more than conventional concrete.

4.7.2 Split tensile strength and compressive strength for concrete with clay bricks

Split tensile strength results can be predicted where compression strength of clay bricks aggregates of C20 concrete is determined using equation (4.3), generated. Appendix D, Table D7 detail the analysis of 28 days compressive strength and split tensile strength for concrete with different portions of clay bricks replacing NCA in the mix. Figure 4.11 shows the logarithmic relationship between split tensile strength and compressive strength of concrete mix with clay bricks.

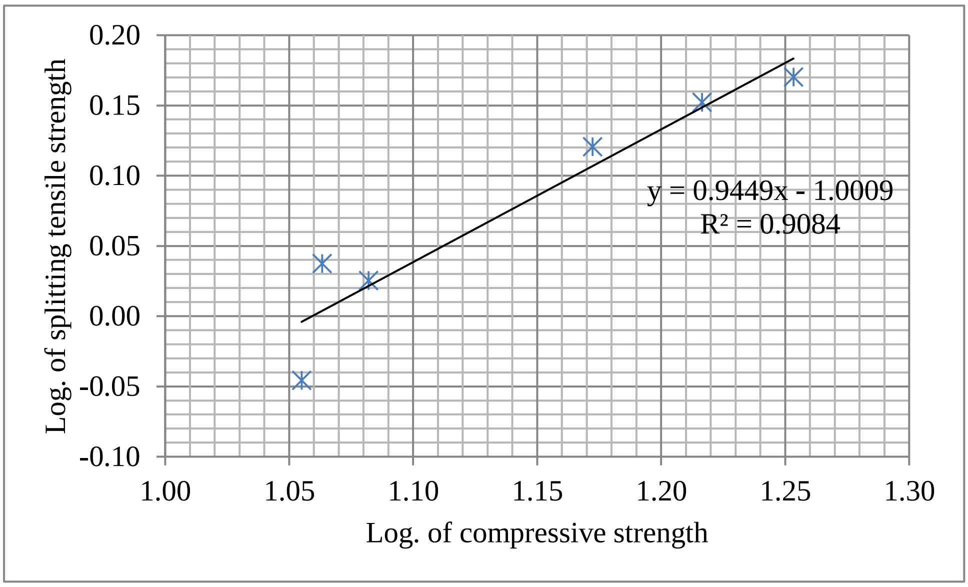


Figure 4.13: Logarithmic relationship between split tensile strength and compressive strength of concrete with clay bricks contents

From the graph, the relationship between splitting tensile and compressive strength of concrete where coarse aggregate was replaced with clay bricks, was found as:

$$f_{sp}=k(f_c)^n$$

$$\log(f_{sp})=n\log(f_c)+\log k \equiv y=0.9449x-1.0009$$

$$\log k=-1.0009 \Rightarrow k=\text{antilog}(-1.0009)=0.0998$$

$$\therefore n=0.9449 \text{ and } k=0.0998$$

$$f_{sp}=0.0998(f_c)^{0.9449} \quad (4.3)$$

Where f_{sp} is the split tensile strength and f_c is the compressive strength.

A study on lightweight aggregate by Oluokun (1991) suggested the expression between tensile strength and compressive strength of concrete as shown in equation (4.4). the difference between the coefficients could be attributed to the mode of crushing of aggregates and inclusion of clay bricks aggregates in concrete. Tensile strength of concrete is more sensitive to inadequate curing than the compressive strength possibly because of the effects on non-uniform shrinkage (Neville, 2011).

$$f_t=0.2f_c^{0.7} \tag{4.4}$$

Where f_t is the tensile strength and f_c is the compressive strength.

4.7.3 Effect of plastic fibres on split tensile strength

Figure 4.12 shows the split tensile of strength development of concrete specimens made with different proportion of plastic fibres at 7 and 28 days of curing. The results show control specimen, M100-P0, having the highest strength of 1.48 N/mm^2 while sample, marked M100-P15, with least strength of 0.92 N/mm^2.

The control sample compared with concrete with plastic fibres shows a decreasing trend in tensile strength of 14.2, 25.7 and 37.8% for samples M100-P5, M100-P10 and M100-P15, respectively, as shown in the figure. This trend could be attributed to the decrease in adhesive strength between the surface of the fibres and the cement paste. Due to this, smooth surfaces of plastic fibres aggregate would form voids in concrete, which results in decrease of tensile strength of the concrete.

It was also observed that upon splitting, the plastic fibres seemed to hold the two parts of the concrete specimen together although the specimen had technically failed; this is also consistent with observations of the cube compression specimen failure. Concrete with plastic fiber contents was gradual and did not break easily into two pieces like control specimens.

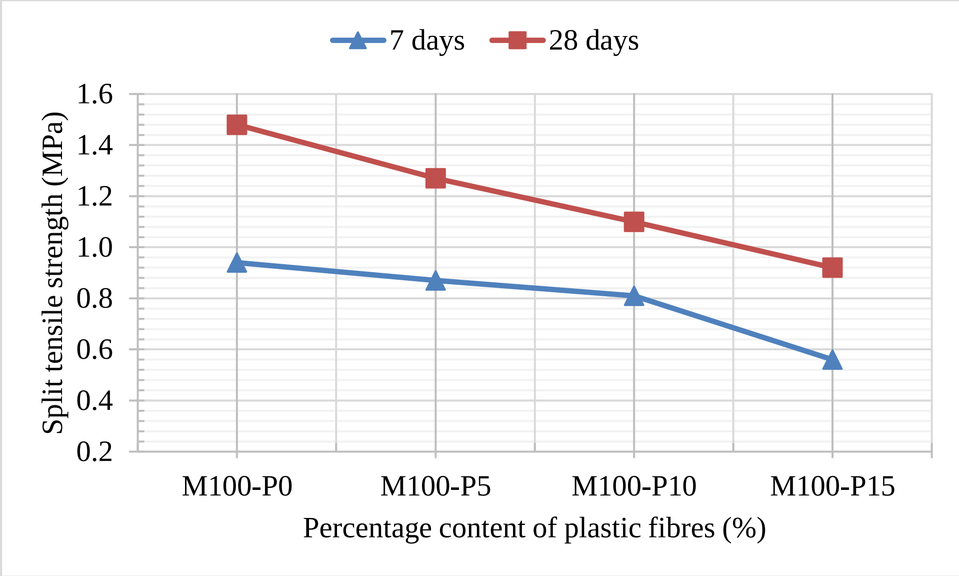


Figure 4.14: Concrete split tensile strength with varying proportions of plastic fibres

There was a decreasing trend in tensile strength development. This reduction was because of increased stress between the aggregates leading to segregation from cement paste. There was inadequate bond between plastic fibre and cement paste; their interface would therefore experience micro cracks, due to lose bonding between the two materials.

4.7.4 Split tensile strength and compressive strength for concrete with plastic fibres

Split tensile strength results can be predicted where compression strength of plastic fibres for C20 concrete can be determined using equation (4.5), generated. Appendix D, Table D8 details the analysis of 28 days compressive strength and split tensile strength for concrete with different portions of plastic fibres replacing NCA in the mix. Figure 4.13, gives the logarithmic relationship between splitting tensile and compressive strengths for concrete mix with plastic fibres.

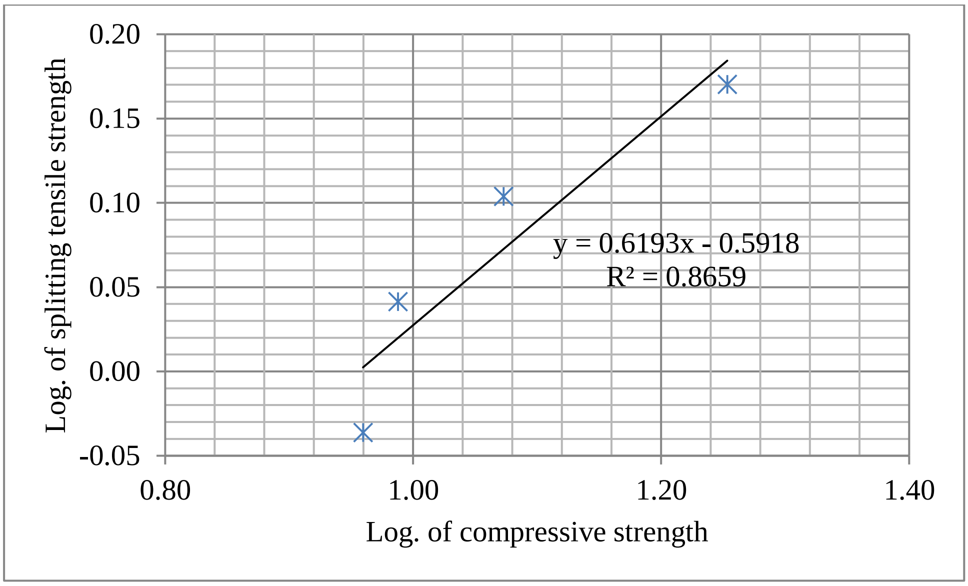


Figure 4.15: Logarithmic relationship between split tensile strength and compressive strength of concrete with plastic fibres contents

From the graph, the relationship between splitting tensile and compressive strength of concrete where coarse aggregate was replaced with plastic fibres, was found as:

$$f_{sp}=k(f_c)^n$$

$$\log (f_{sp})=n \log (f_c)+\log k \equiv y= 0.6193x-0.5918$$

$$\log k = -0.5918 \Rightarrow k = \text{antilog} (-0.5918) = 0.256$$

$$\therefore n = 0.6193 \text{ and } k = 0.256$$

$$f_{sp}=0.256(f_c)^{0.6193} \quad (4.5)$$

Where f_{sp} is the split tensile strength and f_c is the compressive strength.

4.8 Flexural strength

Cuboid specimens of size 100 x 100 x 500 mm were cast for conducting flexural strength for each concrete mix. Comprehensive results and analysis of the flexural strength for samples at

28 days tests for clay bricks and plastic fibres in concrete are presented in Appendix D, Table D9 and D10 respectively. The flexural strength of any mix was taken as the average of the strength of the samples. Plate 4.3 shows how the specimen was set up and failure after the test.

Plate 4.3: Set up of flexure beam and final failure under flexural strength.

4.8.1 Effect of crushed clay bricks on flexural strength

The test results for flexure on beams are graphically represented as shown in Figure 4.14. This is an illustration of flexural strength development of concrete specimens with different proportion of clay bricks for 28 days. The results show control specimen, M100-P0, having the highest strength of 2.89 N/mm^2 while sample, marked M0-P0, with least strength of 1.65 N/mm^2.

Figure 4.14 illustrates the variation of the flexural strength of specimens with different replacement percentage of normal coarse aggregates. From the results, a reduction in flexural strength of 11.1, 29.4, 31.1, 35.3 and 42.9% were obtained for M80-P0, M60-P0, M40-P0, M20-P0 and M0-P0, respectively, all compared to control mix (M100-P0).

Almost similar results, Debieb and Kenai (2008) found that the flexural strength decreased by 33% when coarse aggregates were fully substituted by crushed bricks the findings were because of increased water absorption, permeability and shrinkage of crushed brick aggregate concrete were significantly greater than those of the natural aggregate concrete. This reduction in flexural strength was attributed to the structural weakness of clay bricks aggregates although considered as marginal.

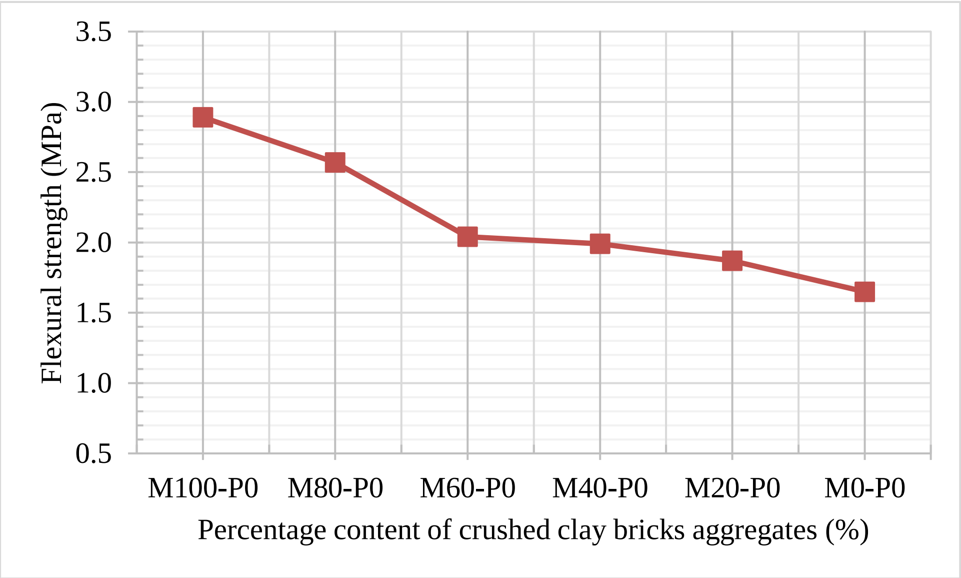


Figure 4.16: Concrete flexural strength with varying proportions of clay bricks

4.8.2 Flexural strength and compressive strength for concrete with clay bricks

Flexural strength results can be predicted where compression strength of clay bricks for C20 concrete can be determined using equation (4.6) generated. Appendix D, Table D11 details the analysis of 28 days compressive strength and flexural strength for concrete with different portions of clay bricks replacing NCA in the mix. Figure 4.15, gives the logarithmic relationship between flexural and compressive strengths for concrete mix with clay bricks.

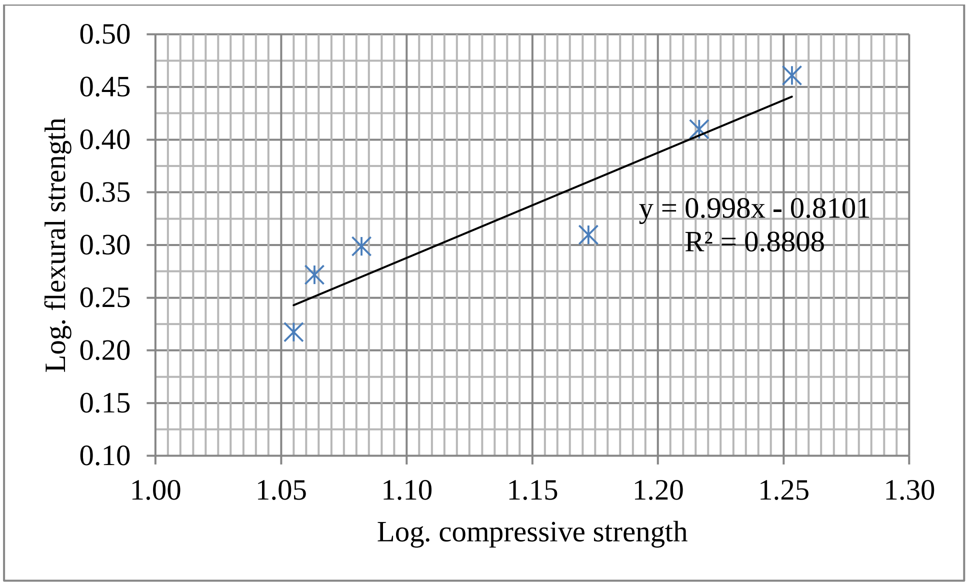


Figure 4.17: Logarithmic relationship between flexural strength and compressive strength of concrete with clay bricks contents

From the graph, the relationship between flexural and compressive strength of concrete where coarse aggregate was replaced with clay bricks, was found as:

$$f_{fs}=k(f_c)^n$$

$$\log(f_{fs})=n\log(f_c)+\log k \equiv y=0.998x-0.8101$$

$$\log k = -0.8101 \Rightarrow k = \text{antilog}(-0.8101) = 0.1548$$

$$\therefore n = 0.998 \text{ and } k = 0.1548$$

$$f_{fs}=0.1548(f_c)^{0.9449} \tag{4.6}$$

Where f_{fs} is the flexural strength and f_c is the compressive strength.

4.8.3 Effect of plastic fibres on flexural strength

The results for flexural strength tested for concrete were presented as shown in Figure 4.16 for concrete specimens with different proportion of plastic fibres at 28 days. The results show control specimen, M100-P0, having the highest strength of 2.89 N/mm^2 while sample, marked M100-P15, with least strength of 1.81 N/mm^2.

The graph shown in Figure 4.16 illustrates the variation of the flexural strength of specimens with different percentage replacement of normal coarse aggregates with plastic fibres. The control sample compared with concrete with plastic fibres shows a decreasing trend in flexural strength of 37, 29.4 and 37.4% for samples M100-P5, M100-P10 and M100-P15, respectively. The trend in Figure 4.16 was attributed to decrease in adhesive strength between the surface of plastic fibres and the cement paste. Apparently, the cracking strength and ultimate strength of beams with plastic fibres are sensitive to the content of fibres. This trend could be attributed to the decrease in adhesive strength between the surface of the fibres and the cement paste. However, the flexural strengths of the waste plastic concrete composites compared similarly with those of previous research by Pezzi *et al.* (2005) and Marzouk *et al.* (2007).

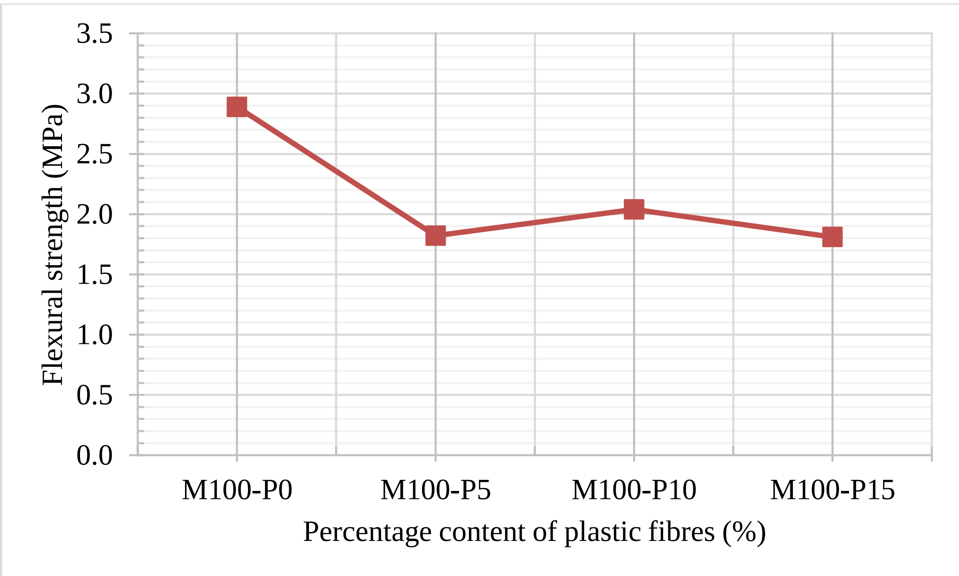


Figure 4.18: Concrete flexural strength with varying proportions of plastic fibres

4.8.4 Flexural strength and compressive strength for concrete with plastic fibres

Flexural strength results can be predicted where compression strength of plastic fibres for C20 concrete can be determined using equation (4.7) generated. Appendix D, Table D12 details the analysis of 28 days compressive strength and flexural strength for concrete with different portions of plastic fibres replacing NCA in the mix. Figure 4.17, gives the logarithmic relationship between flexural and compressive strengths for concrete mix with plastic fibres.

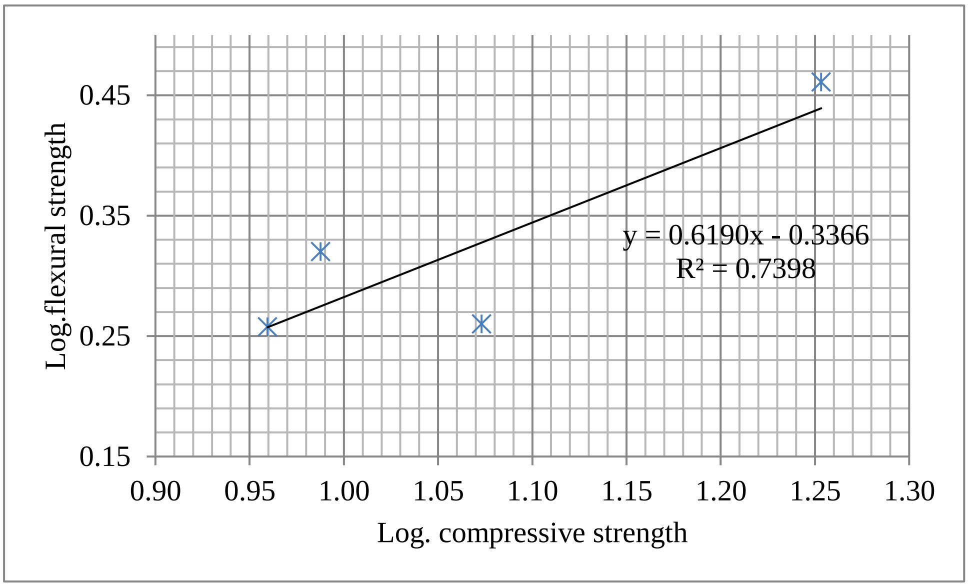


Figure 4.19: Logarithmic relationship between flexural strength and compressive strength of concrete with plastic fibres contents

From the graph, the relationship between flexural and compressive strength of concrete where coarse aggregate was replaced with plastic fibres, was found as:

$$f_{fs}=k(f_c)^n$$

$$\log(f_{fs})=n\log(f_c)+\log k \equiv y= 0.6190x-0.3366$$

$$\log k = -0.3366 \Rightarrow k = \text{antilog}(-0.3366) = 0.4607$$

$$\therefore n = 0.619 \text{ and } k = 0.4607$$

$$f_{fs}=0.4607(f_c)^{0.619} \quad (4.7)$$

Where f_{fs} is the flexural strength and f_c is the compressive strength.

4.9 Pull out force

The comprehensive results and analysis of the pull out force for samples at 28 days tests for clay bricks and plastic fibres in concrete are presented in Appendix D, Table D9 and D10 respectively. The pull out force of any mix was taken as the average of the test samples. Figure 4.18 and 4.20 shows how the specimen was placed and failure after the test. Plates 4.4 and 4.5 show the photos of experimental setup and failure mode of the specimen after the test.

Plate 4.4: Pull out testing apparatus and procedure

Plate 4.5: Illustration of pull out test specimens after failure

4.9.1 Effect of clay bricks aggregate on pull out force

The results for pull out force tested for concrete were as shown in Figure 4.18, for concrete specimens with different proportion of clay bricks prepared for 28 days. The results show control specimen, M100-P0, having the load capacity of 14.92 kN while sample, marked M20-P0, with least load of 9.36 kN.

Reduction in pull out force of 11.1, 16.3, 21.2, 37.3 and 17.1% were obtained for M80-P0, M60-P0, M40-P0, M20-P0 and M0-P0, respectively, all compared to control mix, M100-P0. Due to angular shape and porous nature of the clay bricks, the cement paste gets absorbed through the pores leaving less paste to provide adequate bond strength between steel bar and the concrete. Hence the pull out force of the bar reduces with the increase of clay bricks. At 80% replacement of coarse aggregates with clay bricks, (M20-P0), there was sharp reduction since the quantity of coarse aggregate were greater than cement paste and fine aggregate hence insufficient bonding between steel and resulting concrete.

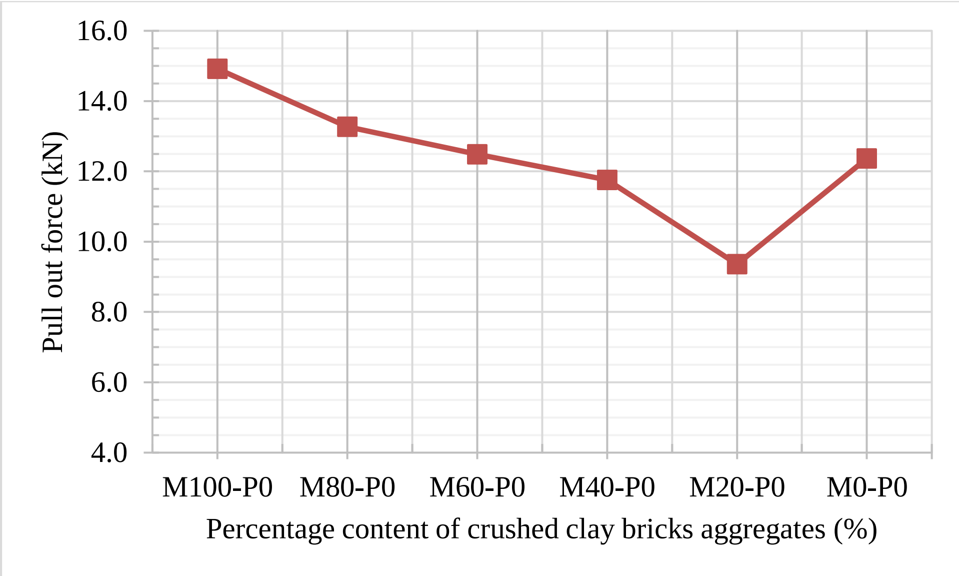


Figure 4.20: Concrete pull out force with varying proportions of clay bricks

4.9.2 Pull out force and compressive strength of concrete with clay bricks

Pull out force results can be predicted where compression strength of clay bricks for C20 concrete can be determine using equation (4.8) generated. Appendix D, Table D13 details the analysis of 28 days compressive strength and pull out force for concrete with different portions of clay bricks replacing NCA in the mix. Figure 4.19, gives the logarithmic relationship between pull out force and compressive strengths for concrete mix with clay bricks.

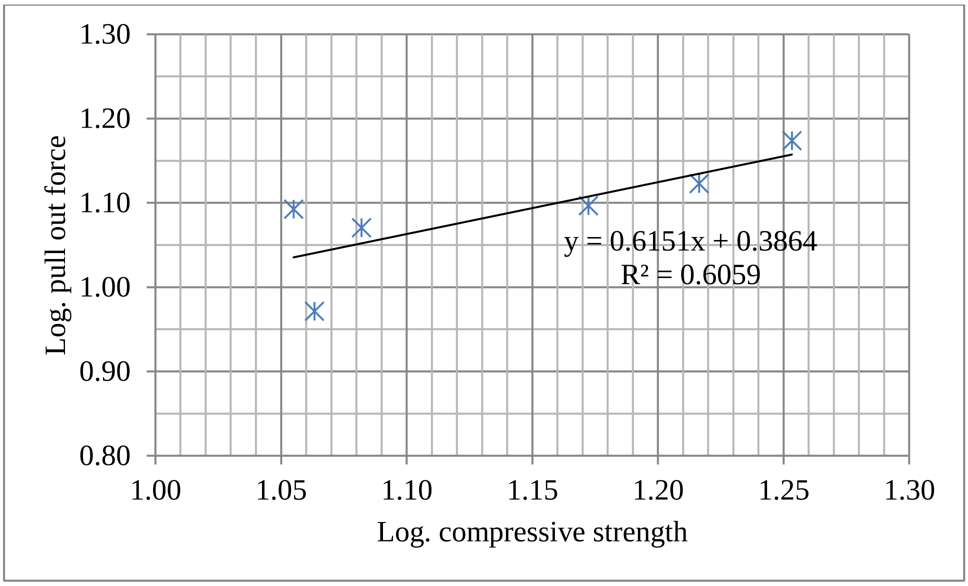


Figure 4.21: Logarithmic relationship between pull out force and compressive strength of concrete with clay bricks contents

From the graph, the relationship between pull out force and compressive strength of concrete where coarse aggregate was replaced with clay bricks, was found as:

$$f_{pf}=k(f_c)^n$$

$$\log (f_{pf})=n \log (f_c)+\log k \equiv y= 0.6151x+0.3864$$

$$\log k = 0.3864 \Rightarrow k = \text{antilog}\,(0.3864) = 2.434$$

$$\therefore n = 0.6151 \text{ and } k = 2.434$$

$$f_{pf}=2.434(f_c)^{0.6151} \qquad (4.8)$$

Where f_{pf} is the pull out force and f_c is the compressive strength.

4.9.3 Effect of plastic fibres aggregate on pull out force

From the results as presented in Figure 4.20, for pull-out force development of concrete specimens with different proportion of plastic fibres specimen, M100-P0, have the highest force of 14.92 kN while sample, marked M100-P15, with least force of 9.07 kN.

The pull out force at 28 days of the samples slightly shows and increases of 0.13% for sample M100-P5, and takes a decreasing trend of 29.2 and 39.2% for M100-P10 and M100-P15 samples respectively from control specimen. From observation of the concrete mix, the cement paste and plastic fibres did not properly mix with the increase of fibres leading to formation of a weak bond with the steel bar, thus causing the failure of concrete to occur at stresses lower than for control mix. The reductions could be attributed to the lack of adhesion at the boundaries of the plastic fibres in concrete.

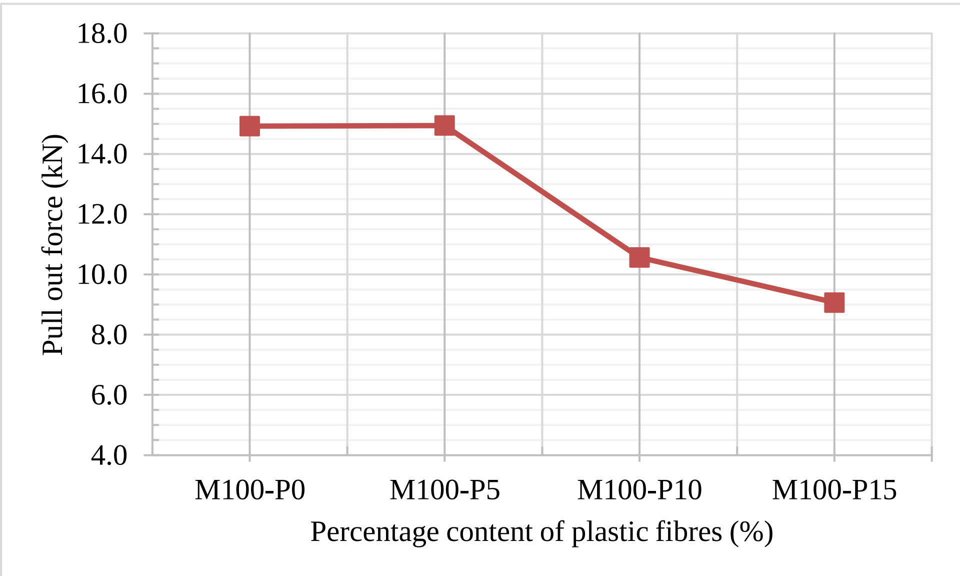


Figure 4.22: Concrete pull out force with varying proportions of plastic fibres

4.9.4 Pull out force and compressive strength of concrete with plastic fibres

Pull out force results can be predicted where compression strength of plastic fibres for C20 concrete can be found using equation (4.9) generated. Appendix D, Table D14 details the analysis of 28 days compressive strength and pull out force for concrete with different portions of plastic fibres replacing NCA in the mix. Figure 4.21, gives the logarithmic relationship between pull out force and compressive strengths for concrete mix with plastic fibres.

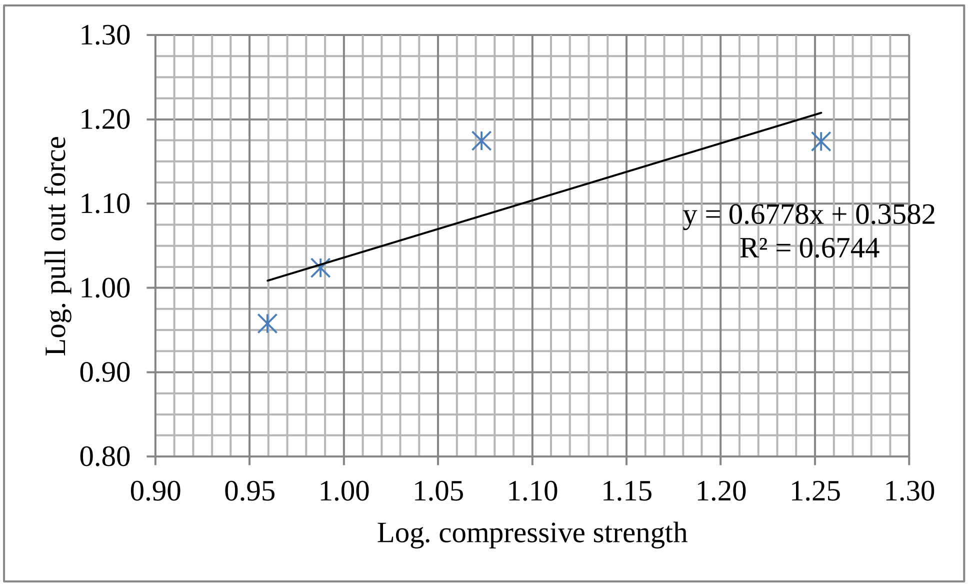


Figure 4.23: Logarithmic relationship between pull out force and compressive strength of concrete with plastic fibres contents

From the graph, the relationship between pull out force and compressive strength of concrete where coarse aggregate was replaced with plastic fibres, was found as:

$$f_{pf}=k(f_c)^n$$

$$\log (f_{pf})=n \log (f_c)+\log k \equiv y= 0.6778x+0.3582$$

$$\log k = 0.3582 \Rightarrow k = \text{antilog } (0.3582) = 2.2814$$

$$\therefore n = 0.6151 \text{ and } k = 2.2814$$

$$f_{pf}=2.2814(f_c)^{0.6778} \quad (4.9)$$

Where f_{pf} is the pull out force and f_c is the compressive strength.

4.10 Mechanical properties of concrete mix with optimal aggregate contents

This stage entails tests aimed at evaluating the effect of combined optimum materials at 28 days of curing. The combined mix composed of coarse aggregate where NCA was partially replaced with 18.7% of crushed clay bricks and 12.7% of plastic fibres, specimens marked as M81.3-P12.7. Compressive strength, pull out force, splitting strength and flexural strength tests were performed using standard procedures as discussed in chapter 3.

4.10.1 Compressive strength

The 28 days test were performed as provided in BS 1881-116 (1983) the results summarized as in Table 4.9. Results for M100-P0 are as give from Appendix D, Table D4. The compressive strength of combined results optimum clay brick and plastic fibres gives average of 7.20 N/mm^2 a reduction of 59.8% as compared to control mix (M100-P0). Packing of the aggregates greatly reduced with the two combined, resulting to less bonding. The clay bricks absorb more water and cement paste leaving less paste for strength development.

Table 4.9: Compressive strength of concrete with optimum aggregate contents

Sr/No.	Sample	Trials	Compressive strength (N/mm^2)
1	M100-P0	1	17.90
		2	17.90
		3	17.97
		Average	**17.92**
2	M81.3-P12.7	1	7.15
		2	6.88
		3	7.59
		Average	**7.21**

4.10.2 Flexural strength

As from the previous sections, three flexural beam samples of the optimum ingredients for test materials (clay bricks and plastic fibres) for combined mix. The 28 days test were performed as provided in BS 1881-118 (1983) the results summarized as in Table 4.10. Results for M100-P0 are as give from Appendix D, Table D9.

The combined mix considerably results to a decrease in flexural strength of 1.98 N/mm^2 representing a reduction of 31.5% compared to the control concrete mix. The reduction of the flexural strength was attributed to reduced packing of the aggregates (clay bricks and plastic fibres). Clay bricks adsorbed water and cement paste resulting to weak concrete for the beams to withstand flexure actions.

Table 4.10: Flexural strength of concrete with optimum aggregate contents

Sr/No.	Sample	Trials	Flexural strength (N/mm^2)
1	M100-P0	1	2.85
		2	2.97
		3	2.83
		Average	**2.89**
2	M81.3-P12.7	1	1.93
		2	1.87
		3	2.15
		Average	**1.98**

4.10.3 Pull out force

Table 4.11 gives the comparative pull out results for the specimen after 28 days of curing. The pull out force showed average results of 8.32 kN that represents a reduction of about 44.2% of from control mix. Results for M100-P0 are as give from Appendix D, Table D9. This is still within the expected limit 8-20 kN for 10 mm diameter steel bar as provided for in BS1881-207 (1992).

The combination of clay bricks and plastic fibres in concrete results to great reduction of bond strength between the steel bar and concrete. The failure of concrete was by slip. Clay bricks have high water demand which resulted in less formation of cement paste for bond development hence the reduction of pull out force.

Table 4.11: Pull out force of concrete with optimum aggregate contents

Sr/No.	Sample	Trials	Pull out force (kN)
1	M100-P0	1	15.19
		2	14.89
		3	14.68
		Average	**14.92**
2	M81.3-P12.7	1	8.80
		2	6.53
		3	9.64
		Average	**8.32**

4.10.4 Splitting strength

As from the previous sections, three cylindrical samples of the optimum ingredients for test materials (clay bricks and plastic fibres) in combined mix. The 28 days test method was done as in BS1881-111 (1983). The procedure was followed for specimen sizes 100 mm diameter and 200 mm length loaded until failure.

From Table 4.12, the average results were found to be 1.02 N/mm^2 representing a reduction of 31.1% from reference concrete mix. Results for M100-P0 are as given in Appendix D, Table D5. Clay bricks have high water absorption rate hence forming a weak cement paste; the plastic fibres have smooth surfaces resulting in weak adhesion with other materials in the concrete mix. This could have caused the reduction in the tensile strength of the new concrete.

Table 4.12: Split tensile strength of concrete with optimum aggregate contents

Sr/No.	Sample	Trials	Split tensile strength (N/mm^2)
1	M100-P0	1	1.46
		2	1.69
		3	1.30
		Average	**1.48**
2	M81.3-P12.7	1	1.06
		2	0.95
		3	1.04
		Average	**1.02**

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Fresh concrete properties

1) The introduction of crushed clay bricks into concrete reduced the workability by 35.3, 52.9, 17.6 and 70.6% from reference concrete mix for M80-P0, M60-P0, M20-P0 and M0-P0, respectively and an increased by 141 for M40-P0. The concrete slump collapsed at M40-P0 (60% replacement with clay bricks). The reduction of the workability was attributed to increase in water absorption of the clay bricks leaving less cement paste in concrete mix.
2) The replacement of plastic fibres in concrete resulted to a general increase in slump by 70.6, 152.9 and 288.2% from reference concrete mix for M100-P5, M100-P10 and M100-P15, respectively. But at 10 and 15% replacement of plastic fibres the slump sheared. The increased slump was most likely due to the smooth surface nature of the plastic fibres in the concrete.

5.1.2 Hardened concrete properties

1) A reduction in concrete densities of up to 15.6% was observed when 100% by mass of the NCA was replaced by clay bricks aggregate in sample M0-P0. An almost similar trend of reduction in density of concrete with plastic fibres was observed, where 15% replacement of coarse aggregate with plastic fibres showed upto 13.5% reduction. The low specific gravity of the clay bricks and plastic fibres as compared to the natural coarse aggregates produced a decrease in the density of the concrete. Clay bricks and plastic fibres are nearly two and four times respectively lighter than

the conventional normal coarse aggregate and hence it could be expected that the density of the mix would be relatively lower.

2) From the test results, total replacement of NCA with clay bricks (by 100%) leads to reduction in concrete mechanical strengths by 36.7, 39.2, 17.1 and 42.9% for compressive strength, tensile strength, pull out force and flexural strength respectively. This reduction was generally attributed to the nature of clay bricks aggregates which had high water absorption hence less cement paste formed to provide adequate bond in concrete.
3) For concrete with plastic fibres, the test results showed that addition of the fibres resulted in a significant reduction in concrete strengths compared to the control. For coarse aggregate replaced with plastic fibres upto 15%, the strength properties decreased for compressive strength, indirect tensile strength, pull out force and flexural strength by 49.2, 37.8, 39.2 and 37.3% respectively, compared with control samples. The reason for the strength reduction were attributed to reduction in quantity of solid load carrying material and lack of adhesion at the boundaries of plastic fibres, smooth surface and formation of voids in the concrete mix.

5.1.3 Optimum content of coarse aggregate

1) The optimum quantities of crushed clay bricks and plastic fibres aggregates were found to be 18.7% and 12.7% respectively as determined by regression analysis. The optimum values are the maximum quantities of clay bricks and plastic fibres aggregates replaced in normal concrete without adversely affecting its physical and mechanical properties.
2) The replacement of the coarse aggregates with optimum quantities to determine the effect of combined effects of clay bricks and plastic fibres in concrete resulted in

reduction of concrete strength by 59.8, 31.5, 44.2 and 31.1% for compressive strength, flexural strength, pull out force and splitting tensile strength respectively compared to control mix. The reduction in the strengths were attributed to the improper combination of the aggregates leading to formation of weak bond between them.

5.2 Recommendations

1) The research has shown concrete with crushed clay bricks and plastic fibres contributes to reduction in unit weight. This would provide a viable alternative to normal weight concrete for applications in areas such as partition wall panels, facades thus reducing weight of the building and reduction in sizes of bases and columns.
2) From the research findings, the 28day compressive strengths results for concrete with clay bricks and plastic fibres were generally between 11.35-17.92kN/m^2. This falls within 9-18kN/m^2 required for lightweight concretes Neville (2011). Therefore, concrete with clay bricks and plastic fibres would be recommended for application in areas requiring non-structural concrete such as ground floor slab, precast concrete, kerbs, channels, canal linings, pathways and foot paths.

5.3 Areas requiring further research

1) The long-term performance of these mixes for period beyond 28 days was not investigated in the present study. The effect on the long term should be determined.
2) The study focused on clay bricks and plastic fibres aggregates of size between 19-4.75mm as replacement of normal coarse aggregates in concrete. The effect of smaller sizes less than 4.75mm of these aggregates as replacement of fine aggregate in concrete, needs to be investigated.

REFERENCES

Akhtaruzzaman & Hasnat A. (1983). Properties of concrete using crushed brick as aggregate. *Concrete International*, *5*(2), 58-63.

Al-Manaseer A. A & Dalal T. R. (1997). Concrete containing plastic aggregates. *Concrete International*, 47-52.

Ay N. & Ünal M. (2000). The use of waste ground ceramic in cement production. *Cement and Concrete Research, 30*, 497-499.

Bayasi Z. & Zeng J. (1993). Properties of polypropylene fibre reinforced concrete. *ACI Material Journal, 90*(6), 605-610.

British Research Establishment. (1997). *Design of normal concrete mixes* (2nd ed.). London: Garston Watford WD2 7JR.

BS 12. (1996). *Specification for portland cement.* London: British Standard Institution.

BS 1881-102. (1983). *Method for determination of slump.* London: British Standard Institution.

BS 1881-108. (1983). *Casting concrete samples.* London: British Standard Institution.

BS 1881-111. (1983). *Method of normal curing of test specimens (20 °C method).* London: British Standard Institution.

BS 1881-114. (1983). *Methods for determination of density of hardened concrete.* London: British Standard Institution.

BS 1881-116. (1983). *Method for determination of compressive strength.* London: British Standard Institution.

BS 1881-117. (1983). *Method for determination of tensile splitting strength.* London: British Standard Institution.

BS 1881-118. (1983). *Method for determination of flexural strength.* London: British Standard Institution.

BS 1881-125 . (1986). *Method for mixing and sampling fresh concrete in laboratory.* London: British Standard Institution.

BS 1881-207. (1992). *Determination of pull out force.* London: British Standard Institution.

BS 812. (1990). *Determination of silt content.* London: British Standard Institution.

BS 812-103.1. (1985). *Method for determination of particle size distribution of aggregate - Sieve tests.* London: British Standard Institution.

BS 812-105.1. (1989). *Determination of aggregate particle shape (flakiness index).* London: British Standard Institution.

BS 812-105.2. (1990). *Determination of aggregate particle shape (elongation index).* London: British Standard Institution.

BS 882. (1992). *Specification for aggregates from natural sources for concrete.* London: British Standard Institution.

Choi Y. W., Moon D. J., Chung J. S. & Cho S. K. (2005). Effects of waste PET bottles aggregate on properties on concrete. *Cement and Concrete Research, 35,* 776-781.

Correia J. R., De Britto J. & Pereira A. S. (2006). Effects on concrete durability of using recycled ceramic aggregates. *Materials and Structures, 39*, 169-177.

Debieb F. & Kenai S. (2008). The use of coarse and crushed bricks as aggregate in concrete. *Construction and Building Materials, 22,* 886-893.

Dina M. Sadek. (2011). Physico-mechanical properties of solid cement bricks containing recycled aggregates. *Journal of Advanced Research (2012), 3,* 253–260.

Ghaly F., Ashraf M. & Michael S., Gill A. M. (2004). Compression and Deformation Performance of Concrete Containing Postconsumer Plastics. *Journals of Materials in Civil Engineering, 16*(4), 289-296.

Gomes M. & De Brito J. (2009). Structural concrete with incorporation of coarse recycled concrete and ceramic aggregates: Durability performance. *Materials and Structures, 42*(5), 663-675.

Guerra I., Vivar I., Llamas B., Juan A. & Moran J. (2009). Eco-efficient concretes: The effects of using recycled ceramic material from sanitary installations on the mechanical properties of concrete. *Waste Management, 29*, 643-646.

Holm T. A. (1994). Lightweight Concrete and Aggregates. *Standard Technical Publication 169C*.

Jiang D. H., Shah S. P. & Andonian A. T. (1984). Study of the transfer of tensile forces by bond. *ACI Journal, 24*(81), 251-258.

Kanaka Sabai V. & Raja Shekaran A. (1992). Ceramic insulator scraps as Light Weight Concrete. *National Conference on Cement and Building Materials from Industrial Wastes*, (pp. 8-15).

Kenya National Bureau of Statistics. (2015). *Economic Survey Report.* Retrieved from http://www.knbs.or.ke.

Khalaf F. M. (2006). Using crushed clay brick as aggregate in concrete. *Journal of Materials in Civil Engineering, 18*(4), 518–526.

Khaloo A. R. (1995). Crushed tile coarse aggregate concrete. *Cement and Concrete Aggregate, 17*(2), 119-125.

Malek Batayneh, Iqbal Marie & Ibrahim Asi. (2007). Use of selected waste materials in concrete mixes. *Waste Management, 27*, 1870–1876. Retrieved from http://www.elsevier.com/locate/wasman.

Martin H. (1982). Bond performance of ribbed bars (Pull-Out Test). Influence of Concrete Composition and Consistency. *Proceeding of the International Conference on Bond in Concrete* (pp. 289-299). Scotland: Paisley.

Marzouk O. Y., Dheilly R. M. & Queneudec M. (2007). Valorization of post-consumer waste plastics in cementitious concrete composites. *Waste management, 27,* 310-318.

Naik T. R. & Moriconi G. (2005). *Environmental-friendly durable Concrete made with Recycled materials for Sustainable Concrete Construction.* University of Wisconsin, Milwaukee.

NEMA. (2008). *The ban on the manufacture, importation and distribution of plastic carrier.* National Environment Management Authority-Kenya. Retrieved January 9, 2009, from http://www.nema.go.ke/index.php?option=com_content&task=view&id=208&Itemid=159

Neville A. M. (2011). *Properties of Concrete* (5th ed.). United Kingdom, Edinburgh: Prentice Hall.

Oluokun F. A. (1991). Prediction of concrete tensile strength from compressive strength evaluation of existing relations for normal weight concrete. *ACI Materials Journal, 88*(3), 302-309.

Pacheco-Torgal F. & Jalali S. (2010). Reusing ceramic wastes in concrete. *Construction and Building Materials, 24*, 832–838.

Pezzi L., De Lice P., Vuono D., Chiappetta F. & Nastro A. (2006). Concrete products with waste's material (bottle, glass, plate). *Materials Science Forum, 514-516*(2), 1753-1757.

Ramadevi K. & Manju R. (2012). Experimental investigation on the properties of concrete with Plastic PET (bottle) fibers as fine aggregates. *International Journal of Emerging Technology and Advanced Engineering, 2*(6), 42-46.

Sidney Mindess, Young J. F. & David Darwin. (2003). *Concrete* (2nd ed.). New Jersey: Prentice hall.

Soroushian P. & Choi K. B. (1989). Local bond of deformed bars with different diameters in confined concrete. *ACI Structural Journal, 86*(2), 217-222.

Soroushian P. (1988). Pull out behavior of hooked bars in exterior beam-column connections. *ACI Structural Journal, 85*, 269-276.

Syagga P. (1992). Problems of Solid Waste Management in Urban Residential Areas in Kenya. In Malombe (Ed.), *African Research Network for Urban Management (ARNUM) Workshop.* Nairobi-Kenya: CCN.

UNEP. (2006). United Nations Environmental Programme. *United nations Framework Conference on Climate Change (UNFCCC) meeting in Nairobi, 7 November 2006.*

Veera Reddy M. (2010). Investigations on stone dust and ceramic scrap as aggregate replacement in concrete. *International Journal of Civil and Structural Engineering, 1*(3).

Wallis M. J. (2005). Re-use of Tires in Port, Coastal and River Engineering. *Sustainable*.

Yadav Ishwar Singh, Maneek Kumar & Shweta Goyal. (2008). *Laboratory Investigations Of The Properties Of Concrete containing Recycled Plastic Aggregates.* M. Tech Thesis, Thapar University.

Yannis Arvanitis. (2013). African Housing Dynamics: Lesson from Kenyan Market. *AEB, 4.*

Zakaria M. & Cabrera J. G. (1996). Performance and durability of concrete made with demolition waste and artificial fly ash-clay aggregates. *Waste Manage 1996, 16*(1-3), 151–158.

APPENDICES

Appendix A: Concrete mix design

Stage	Item	Reference	Values		
1.0	**Selection of target w/c ratio.**				
1.1	Characteristic strength	Specified	20	N/mm^2	at 28 days
			Proportion defective		5%
1.2	Standard deviation (σ)	Figure 3	N/mm^2	or no data	$8N/mm^2$
1.3	Margin		M=kσ	k= 1.64	$13.12N/mm^2$
1.4	Target mean strength	fc= fck+M	20	13.12	$33.12N/mm^2$
1.5	Cement Type	specified	OPC		
1.6	Aggregate type		fine uncrushed	coarse crushed	
1.7	Free water/cement ratio	Table 2 & 4	0.59		
1.8	Maximum free water/cement ratio	specified	0.55	Use lower value	
2.0	**Selection of free water content**				
2.1	Slump	specified			10-30mm
2.2	Max. aggregate size	specified			20mm
2.3	***Free-water content***	Table 3			**170.0**
3.0	**Determination of cement content**				
3.1	Cement content	[Free water ÷(w/c)]			**309**
3.2	Maximum cement content	specified			_ kg/m3
3.3	Modified Free W/C				**0.55**
3.4	***Minimum Cement Content***	specified			290
4.0	**Determination of total aggregate**				
4.1	Relative density of aggregate (SSD)				2.63
4.2	concrete density	Figure 5			2380

Continued…

4.3	***Total aggregate content***	[=concrete density - water content -cement content]			1901
5.0	**Selection of fine and coarse aggregate content**				
5.1	Grading of fine aggregate	BS 882	%passing 0.6mm	Zone 2	48%
5.2	Proportion of fine aggregate	Figure 6		30-37%	34%
5.3	***Fine aggregate content***	[=Aggregate content x 34%]		646	**646**
5.4	***Coarse aggregate content***	[=Aggregate content - fine aggregate content]			**1255**

Appendix B: Materials properties

Table B1: Sieve analysis test for fine aggregate (sand)

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve and retained (gm)	Wt. retained (gm)	% age retained	Cumul. retained	% age passing
9.5	586	586	0	0.00	0.00	100.00
4.75	567	576	9	1.80	1.80	98.20
2.36	521	535	14	2.80	4.60	95.40
1.18	529	586	57	11.40	16.00	84.00
0.6	506	719	213	42.60	58.60	41.40
0.3	478	627	149	29.80	88.40	11.60
0.15	462	512	50	10.00	98.40	1.60
Pan	423	431	8	1.60	100.00	0.00
Total			500.00	100.00	367.80	432.20

Table B2: Determination for specific gravity and water absorption for fine aggregates

Parameter	Sand		
	Trial 1	Trial 2	Trial 3
Weight of jar+sample+water…....…...A	1718.00	1719.00	1722.00
Weight of jar+water…………..............B	1420.00	1419.00	1417.00
Weight of saturated surface dry sample.C	500.00	500.00	500.00
Weight of oven dried sample	2969.5	2961.5	2922
Weight of container	2482.5	2474	2433.5

Continued…

Weight of oven dried sample…...........…D	487	487.5	488.5
Specific gravity on an oven dried basis	2.41	2.44	2.51
Specific gravity on a saturated & surface dried basis	2.48	2.50	2.56
Apparent specific gravity	2.58	2.60	2.66
Water absorption (% dry mass)	2.67%	2.56%	2.35%

Table B3: Sieve analysis test for normal coarse aggregate

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve and retained (gm)	Wt. retained (gm)	% age retained	Cumul. retained	% age passing
38.1	517	517	0	0.00	0.00	100.00
19	570	584	14	0.70	0.70	99.30
15	569.5	1010	440.5	22.03	22.73	77.28
10	519	1974	1455	72.75	95.48	4.53
5	468	557.5	89.5	4.48	99.95	0.05
2.38	463	463	0	0.00	99.95	0.05
Pan	381.5	382.5	1	0.05	100.00	0.00

Table B4: Sieve analysis test for clay bricks aggregate

Sieve size (mm)	Wt. of sieve (gm)	Wt. of sieve and retained (gm)	Wt. retained (gm)	% age retained	Cumul. retained	% age passing
38.1	528	528	0	0.00	0.00	100.00
19	587	602.5	15.5	0.78	0.78	99.23
15	568	1076.5	508.5	25.43	26.20	73.80
10	493	1691.5	1198.5	59.93	86.13	13.88
5	483.5	742	258.5	12.93	99.05	0.95
2.38	386.5	392	5.5	0.28	99.33	0.67
Pan	302	315.5	13.5	0.68	100.00	0.00
Total			2000	100.00		

Table B5: Determination for specific gravity and water absorption for NCA

Parameter	Natural coarse aggregates		
	Trial 1	Trial 2	Trial 3
Weight of wire basket (g)…………......................……a	433.0	438.5	438.5
Weight of wire basket + aggregate (g)…….…………...b	2433.0	2438.5	2438.5
Weight of aggregate in water (g)………..….…(a+b)Ww	1207.0	1207.0	1204.5
Weight of saturated surface dry sample (g)………....Ws	2000	2000	2000
Weight of oven dried sample (g)………………...…..Wd	1938.0	1951.0	1953.0
Sp. gravity on an oven dried basis	2.50	2.54	2.55
Specific gravity on saturated surface dry basis	2.52	2.52	2.51
Absolute dry specific gravity	2.44	2.46	2.46
Water absorption	3.20%	2.51%	2.41%

Table B6: Determination for specific gravity and water absorption for clay bricks aggregates

Parameter	Clay bricks aggregates		
	Trial 1	Trial 2	Trial 3
Weight of wire basket (g)…..………................……a	438.5	474.0	468.5
Weight of wire basket+ aggregate (g)....…….…….…...b	2433.0	2438.5	2438.5
Weight of aggregate in water (g)...…………(a+b)Ww	1044.5	1047	1045.5
Weight of saturated surface dry sample (g).............Ws	2000	2000	2000
Weight of oven dried sample………...…….……..Wd	1737.5	1734	1746.5
Sp. gravity on an oven dried basis	2.84	2.85	2.88
Specific gravity on saturated surface dry basis	2.09	2.10	2.10
Absolute dry specific gravity	1.82	1.82	1.83
Water absorption	15%	15.34%	14.51%

Table B7: Flakiness index of natural coarse aggregates

Sieve size (mm)		Wt. retained (gm)	% age retained	Weight of flaky particles (gm)	Individual flakiness index (%)	Weighted flakiness index (%)
Passing	Retained					
19	15	21	1.05	5	23.81	0.25
15	12.5	423	21.15	148.5	35.11	7.43
12.5	9.5	1240	62.00	428.5	42.62	21.43
9.5	4.75	314.5	15.73	176	62.32	8.80
4.75	pan	1.5	0.08	0	0.00	0.00
		2000				37.90

Table B8: Flakiness index of clay bricks aggregates

Sieve size (mm)		Wt. retained (gm)	% age retained	Weight of flaky particles (gm)	Individual flakiness index (%)	Weighted flakiness index (%)
Passing	Retained					
19	15	15.5	0.78	3	19.35	0.15
15	12.5	508.5	25.43	146	29.89	7.30
12.5	9.5	1198.5	59.93	463	48.98	23.15
9.5	4.75	258.5	12.93	180	75.44	9.00
4.75	pan	19	0.95	0	0.00	0.00
		2000				39.60

Appendix C: Trial mix

Table C1: Trial mix proportions and trial analysis

Quantities	Cement (kg)	Water (kg)	Fine agg. (kg)	Coarse agg. (kg)
Per m^3 (to nearest 5 kg)	336	185	635	1233
Per trial mix of 0.005 m^3	1.682	0.925	3.177	6.167
Ratio	1	0.55	1.89	3.67

Table C2: Slump test results of the trial mix.

Plastic fibres	Slump (mm)						
	Grade	M100	M80	M60	M40	M20	M0
P0	C20	10.00	8.00	5.00	3.50	4.00	2.50
P5	C20	12.00	9.00	7.00	4.00	6.00	3.00
P10	C20	14.00	11.00	8.00	5.00	7.50	3.50
P15	C20	16.00	14.00	10.00	7.00	9.00	5.00

Table C3: Concrete density for trial samples.

Plastic fibres	7 Days concrete density (kg/m^3)						
	Grade	M100	M80	M60	M40	M20	M0
P0	C20	2392.15	2317.93	2329.04	2264.30	2244.59	2190.37
P5	C20	2382.67	2378.81	2330.37	2276.00	2257.63	2188.00
P10	C20	2390.52	2331.85	2302.22	2251.26	2252.89	2188.00
P15	C20	2253.63	2198.67	2221.33	2202.52	2044.59	2099.41

Table C4: Compressive strength for trial samples

Plastic fibres	7 Days compressive strength (kN/m^2)						
	Grade	M100	M80	M60	M40	M20	M0
P0	C20	12.77	10.63	14.13	9.48	11.00	8.75
P5	C20	11.27	8.78	8.46	9.55	9.58	8.12
P10	C20	9.73	8.36	8.31	7.55	8.05	6.31
P15	C20	6.98	6.06	7.81	6.33	5.28	6.06

Appendix D: Final test results

Table D1: 7 days compressive strength and dry density of concrete mix with clay bricks aggregates

Sample No.	Specimen	% of clay bricks aggregate	Weight (gm)	Compressive strength (kN/m^2)	Density (kg/m^3)
1	M100-P0	0	8400	10.41	2489
2			7819	11.02	2317
3			7802	10.59	2312
Average			8007	10.67	2372
1	M80-P0	20	7640	10.09	2264
2			7635	9.20	2262
3			7645	10.47	2265
Average			7640	9.92	2264
1	M60-P0	40	7411	9.38	2196
2			8100	8.99	2400
3			7410	8.82	2196
Average			7640	9.06	2264
1	M40-P0	60	7116	6.57	2108
2			7171	6.60	2125
3			7164	7.00	2123
Average			7150	6.72	2119
1	M20-P0	80	7122	7.35	2110
2			7035	6.40	2084
3			7081	6.80	2098
Average			7079	6.85	2098
1	M0-P0	100	6968	7.07	2065
2			7522	6.90	2229
3			6938	7.07	2056
Average			7143	7.01	2116

Table D2: 28 days compressive strength and dry density of concrete mix with clay bricks aggregates

Sample No.	Specimen	% of clay bricks aggregate	Weight (gm)	Compressive strength (kN/m^2)	Density (kg/m^3)
1	M100-P0	0	8521	17.90	2525
2			8494	17.90	2517
3			8405	17.97	2490
Average			8473	17.92	2511
1	M80-P0	20	7574	16.59	2244
2			7687	16.35	2278
3			7619	16.43	2257
Average			7627	16.46	2260
1	M60-P0	40	7503	15.23	2223
2			7493	14.41	2220
3			7501	14.97	2223
Average			7499	14.87	2222
1	M40-P0	60	7296	12.10	2162
2			7231	11.54	2143
3			7215	12.59	2138
Average			7247	12.08	2147
1	M20-P0	80	7193	11.83	2131
2			7176	11.71	2126
3			7218	11.18	2139
Average			7196	11.57	2132
1	M0-P0	100	7150	11.42	2119
2			7160	11.05	2121
3			7144	11.57	2117
Average			7151	11.35	2119

Table D3: 7 days compressive strength and dry density of concrete mix with plastic fibres

Sample No.	Specimen	% of plastic fibres	Weight (gm)	Compressive strength (kN/m^2)	Density (kg/m^3)
1	M100-P0	0	8400	10.41	2489
2			7819	11.02	2317
3			7802	10.59	2312
Average			8007	10.67	2372
1	M100-P5	5	7648	7.72	2266
2			7595	7.56	2250
3			7584	7.59	2247
Average			7609	7.62	2255
1	M100-P10	10	7701	7.02	2282
2			7699	7.73	2281
3			7724	8.37	2289
Average			7708	7.71	2284
1	M100-P15	15	7588	4.71	2248
2			7545	6.19	2236
3			7604	6.02	2253
Average			7579	5.64	2246

Table D4: 28 days compressive strength and dry density of concrete mix with plastic fibres

Sample No.	Specimen	% of plastic fibres	Weight (gm)	Compressive strength (kN/m^2)	Density (kg/m^3)
1	M100-P0	0	8521	17.90	2525
2			8494	17.90	2517
3			8405	17.97	2490
Average			8473	17.92	2511

Continued…

1	M100-P5	5	7631	12.28	2261
2			7680	11.64	2276
3			7619	11.79	2257
Average			7643	11.90	2265
1	M100-P10	10	7482	11.01	2217
2			7416	10.03	2197
3			7406	11.11	2194
Average			7435	10.72	2203
1	M100-P15	15	7342	8.42	2175
2			7355	8.05	2179
3			7294	7.86	2161
Average			7330	8.11	2172

Table D5: 7 and 28 days split tensile strength of concrete mix with clay bricks aggregates

Sample No.	Specimen	% of clay bricks aggregate	Split tensile strength (kN/m^2)	
			7 days	28 days
1	M100-P0	0	0.97	1.16
2			0.91	1.69
3			0.95	1.30
Average			0.94	1.38
1	M80-P0	20	1.04	1.37
2			0.71	1.53
3			0.90	1.23
Average			0.88	1.38
1	M60-P0	40	9.38	1.41
2			8.99	1.18
3			0.82	1.37
Average			6.40	1.32

Continued…

1	M40-P0	60	0.73	1.05
2			0.60	0.92
3			0.67	1.21
Average			0.67	1.06
1	M20-P0	80	0.48	1.13
2			0.53	0.87
3			0.55	1.27
Average			0.52	1.09
1	M0-P0	100	0.52	1.03
2			0.67	0.87
3			0.48	0.81
Average			0.56	0.90

Table D6: 7 and 28 days split tensile strength of concrete mix with plastic fibres

Sample No.	Specimen	% of plastic fibres	Split tensile strength (kN/m^2)	
			7 days	28 days
1	M100-P0	0	0.97	1.16
2			0.91	1.69
3			0.95	1.30
Average			0.94	1.38
1	M100-P5	5	0.76	1.45
2			0.69	1.03
3			0.61	1.35
Average			0.69	1.27
1	M100-P10	10	0.70	1.19
2			0.89	0.95
3			0.85	1.16
Average			0.81	1.10

Continued…

1	M100-P15	15	0.57	0.80
2			0.62	1.13
3			0.49	0.82
Average			0.56	0.92

Table D7: Relationship between compressive and split tensile strength of concrete with different portions of clay bricks aggregates in the mix.

No.	Mix	Clay bricks (%)	28 days strength (kN/m^2)		Log. sp. tens. strength	Log. comp. strength
			Split tensile strength	Compressive strength		
1	M100-P0	0	1.48	17.92	0.1703	1.2533
2	M80-P0	20	1.42	16.46	0.1523	1.2164
3	M60-P0	40	1.32	14.87	0.1206	1.1723
4	M40-P0	60	1.06	12.08	0.0253	1.0821
5	M20-P0	80	1.09	11.57	0.0374	1.0633
6	M0-P0	100	0.92	11.35	-0.0362	1.0550

Table D8: Relationship between compressive and split tensile strength of concrete with different portions of plastic fibres in the mix.

No.	Mix	Plastic fibres (%)	28 days strength (kN/m^2)		Log. sp. tens. strength	Log. comp. strength
			Split tensile strength	Compressive strength		
1	M100-P0	0	1.48	17.92	0.1703	1.2533
2	M100-P5	5	1.27	11.83	0.1038	1.0730
3	M100-P10	10	1.10	9.72	0.0414	0.9877
4	M100-P15	15	0.92	9.11	-0.0362	0.9595

Table D9: 28 days flexural strength and pull out force of concrete mix with clay bricks aggregates

Sample No.	Specimen	% of clay bricks aggregate	Flexural strength (kN/m^2)	Pull out force (kN)
1	M100-P0	0	2.85	15.19
2			2.97	14.89
3			2.83	14.68
Average			2.89	14.92
1	M80-P0	20	2.54	11.26
2			2.68	13.95
3			2.48	14.61
Average			2.57	13.27
1	M60-P0	40	1.91	12.84
2			2.21	11.54
3			2.01	13.08
Average			2.04	12.49
1	M40-P0	60	2.12	11.05
2			1.99	12.59
3			1.87	11.65
Average			1.99	11.76
1	M20-P0	80	1.92	9.89
2			1.81	9.73
3			1.88	8.44
Average			1.87	9.36
1	M0-P0	100	1.56	12.59
2			1.68	11.69
3			1.73	12.84
Average			1.65	12.37

Table D10: 28 days flexural strength and pull out force of concrete mix with plastic fibres

Sample No.	Specimen	% of plastic fibres	Flexural strength (kN/m^2)	Pull out force (kN)
1	M100-P0	0	2.85	15.19
2			2.97	14.89
3			2.83	14.68
Average			2.89	14.92
1	M100-P5	5	1.75	15.36
2			1.83	14.78
3			1.86	14.69
Average			1.82	14.94
1	M100-P10	10	2.08	11.22
2			2.26	10.30
3			1.93	10.15
Average			2.09	10.56
1	M100-P15	15	1.99	8.94
2			1.64	8.63
3			1.80	9.63
Average			1.81	9.07

Table D11: Relationship between compressive and flexural strength of concrete with different portions of clay bricks aggregates in the mix.

			28 days strength (kN/m^2)			
No.	Mix	Clay bricks (%)	Flexure strength	Comp. strength	Log. flex. strength	Log. comp. strength
1	M100-P0	0	2.89	17.92	0.4609	1.2533
2	M80-P0	20	2.57	16.46	0.4099	1.2164
3	M60-P0	40	2.04	14.87	0.3096	1.1723
4	M40-P0	60	1.99	12.08	0.2989	1.0821
5	M20-P0	80	1.87	11.57	0.2718	1.0633
6	M0-P0	100	1.65	11.35	0.2175	1.0550

Table D12: Relationship between compressive and flexural strength of concrete with different portions of plastic fibres in the mix.

No.	Mix	Plastic fibres (%)	28 days strength (kN/m^2)		Log. flex. strength	Log. comp. strength
			Flexure strength	Comp. strength		
1	M100-P0	0	2.89	17.92	0.4609	1.2533
2	M100-P5	5	1.82	11.83	0.2601	1.0730
3	M100-P10	10	2.09	9.72	0.3201	0.9877
4	M100-P15	15	1.81	9.11	0.2577	0.9595

Table D13: Relationship between compressive and pull out force of concrete with different portions of clay bricks aggregates in the mix.

No.	Mix	Clay bricks (%)	28 days strength		Log. pull out force	Log. comp. strength
			Pull out force (kN)	Comp. strength (kN/m^2)		
1	M100-P0	0	14.92	17.92	1.1738	1.2533
2	M80-P0	20	13.27	16.46	1.1229	1.2164
3	M60-P0	40	12.49	14.87	1.0966	1.1723
4	M40-P0	60	11.76	12.08	1.0704	1.0821
5	M20-P0	80	9.36	11.57	0.9713	1.0633
6	M0-P0	100	12.37	11.35	1.0924	1.0550

Table D14: Relationship between compressive and pull out force of concrete with different portions of plastic fibres in the mix.

No.	Mix	Plastic fibres (%)	28 days strength		Log pull out force	Log. comp. strength
			Pull out force (kN)	Comp. strength (kN/m^2)		
1	M100-P0	0	14.92	17.92	1.1738	1.2533
2	M100-P5	5	14.94	11.83	1.1744	1.0730
3	M100-P10	10	10.56	9.72	1.0237	0.9877
4	M100-P15	15	9.07	9.11	0.9576	0.9595

ANNEXES

Annexes A: Material properties tests

(i). Determination of water absorption and specific density of coarse aggregates

(ii). Weight measuring of normal coarse aggregates for sieve analysis test

(iii). Procedure to determining water absorption and specific density of fine aggregates

(iv). Sieve analysis test for the test samples (clay bricks aggregates and plastic fibres)

(v). Test results of test samples (clay brick aggregates and plastic fibres) after sieve analysis test.

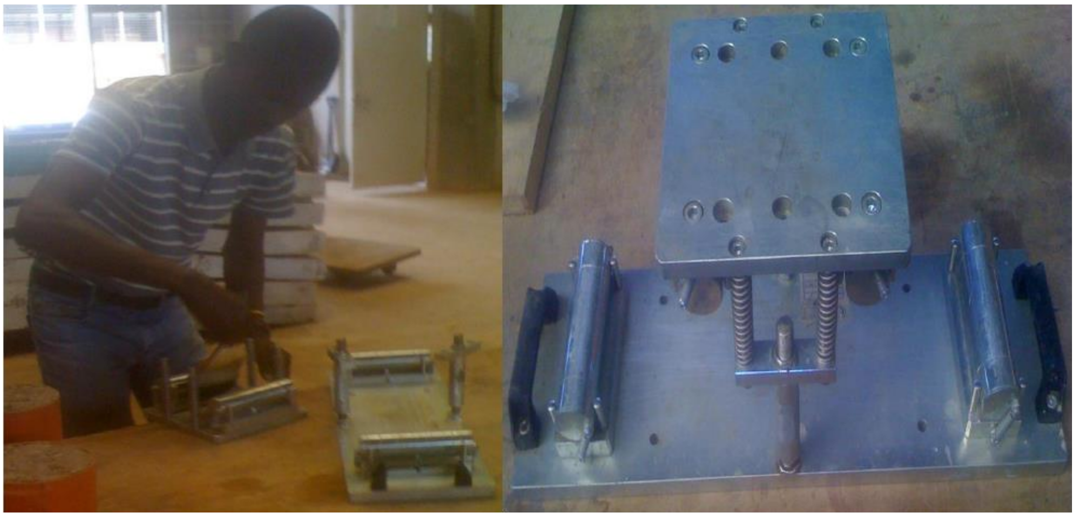
(vi). Preparation of plastic fibres to achieve size between 4.75-19mm to be used in this study

Annexes B: Samples preparation and tests

(i). Concrete cubes the preparation

(ii). Pullout samples preparation

(iii). Pullout system setup, tested samples and typical failure mode



(iv). Preparation for the beam support setup before flexure test

(v). Preparation for the beam support setup before test

(vi). Preparation for the beam support setup before test

(vii). Test samples at 7 and 28 day.

(viii). Concrete cube with plastic fibres and clay bricks aggregates after failure

(ix). Universal testing machine and control machine