EFFECTS OF PARTIAL REPLACEMENT OF SAND WITH SAWDUST AND FISH SCALES ON THE PROPERTIES OF CONCRETE BLOCKS

TIMOTHY ONGINO OLUCHIRI

MASTER OF SCIENCE

(Civil Engineering)

JOMO KENYATTA UNIVERSITY OF

AGRICULTURE AND TECHNOLOGY

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Effects of Partial Replacement of Sand with Sawdust and Fish Scales on the Properties of Concrete Blocks

Timothy Ongino Oluchiri

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DECLARATION

This thesis is the original work and has not been presented for a degree in any other University

Signature …………………………………….Date……………………………………

Timothy Ongino Oluchiri

This thesis has been submitted for the examination with our approval as University supervisors

Signature …………………………………….Date……………………………………

Prof (Eng.), Walter O. Oyawa, PhD

JKUAT, Kenya

Signature …………………………………….Date……………………………………

Mr Mathew Winja

JKUAT, Kenya

DEDICATION

This thesis is dedicated to my parents, wife and children who have committed most of their moral and financial resources for the success of this work.

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ABBREVIATIONS AND ACRONYMS

A.C.I	-	American Concrete Institute
A.S.T.M	-	American Society for Testing and Materials
B.S	-	British Standards
CAHF	-	Centre for Affordable Housing Finance in Africa
HOFINET	-	Housing Finance Information Network
KEBS	-	Kenya Bureau of Statistics
L.V.E.M.P	-	Lake Victoria Environmental Management Program
ML&FD	-	Ministry of Livestock & Fisheries Development
SFB	**-**	Sawdust fish scales blend
UN	-	United Nations
W/C	-	Water Cement ratio

ABSTRACT

This study investigated the potential use of sawdust and fish scales as aggregates in partial replacement of sand in the manufacture of masonry blocks. Both sawdust and fish scales are by-products of industrial processes and are considered to be organic waste materials. The methodology used in this study comprised of analyzing the physical properties and compressive strength of the samples. The blocks were manufactured by replacing sand by sawdust and crushed fish scales combined in the following ratios of 5%, 10%, 15% and 20% . Both sawdust and crushed fish scales were subjected to a pre-treatment process that involved washing and sun drying them for 24 hrs to remove all impurities and moisture content in them. In the case of fish scales grinding had to be done. Then they were mixed with lime to allow for compatibility with the cement matrix at 5% proportion. Tests for the compressive strength for the masonry blocks were done on the 7th, 14th, 21st and 28th days. The compressive strength of the blended masonry blocks was found to be 15.7N/mm^2 at the age of 28 days which was found to be the optimum replacement level after replacement of 5%. The production of masonry with a replacement of up to 5% fine aggregates for the sawdust blend was found to be viable. This research therefore aims to assist the construction industry to achieve low cost housing by use of cost effective and environmentally friendly materials.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Kenya's constitution recognizes housing as a basic human right. Despite the advances made in the construction sector, there remains a significant deficit in housing supply; There are 1.85 million housing units of backlog (Centre of Affordable Housing in Africa Yearbook, 2015).Considering that the urban population grew between 2009 and 2014 the urban population grew at an average rate of 4.4% per annum and that the average urban household size is 3.4 persons, Kenya needs 132000 housing units per annum to meet urban population growth. If production remains at 50,000 units a year as put by the Ministry in charge of housing in 2011, a recurrent shortfall of about 82,000 units is added to the existing deficit annually (Centre For Affordable Housing Finance in Africa Yearbook, 2015).

Table 1.1: Status of housing in Kenya

Housing Requirements and deficit	Units
Current Housing Stock	8, 738,097
Current Housing Deficit (2015)	1.85 million
Annual Housing Demand	132,000
Owner Occupied Units (2009)	17.71% of the Total
Mortgage-To-GDP Ratio (2014)	3.53 %(2013)

Sources; Compass 2015, Housing Finance Information Network (HOFINET) 2015, Centre for Affordable Housing Finance in Africa (CAHF) 2015**.**

The most widely used building material in concrete production is the natural sand, mined from the river beds. However its availability for making concrete is becoming a problem due to its scarcity and the excessive and non-scientific methods used in mining it from the river beds, which lowers the water- table (Oyedepo et al., 2014).Worldwide, consumption of sand as fine aggregates in concrete production is very high and several developing countries have encountered some strains in the supply of natural sand in order to meet the increasing needs of infrastructural development in recent years (Divakar et al., 2012).In their study, Brahim et al.(2013) noted that there is growing scarcity of river sand which has led to some countries to ban sand harvesting from rivers for ecological reasons. In Kenya, the demand for these natural aggregates and specifically sand and ballast has been rising due to the rapid development of housing and infrastructure. Owing to the rapid housing development in the 47 newly established counties, there is bound to be a high consumption of concrete as the devolved governments come into effect in accordance with the Constitution of Kenya.

Plate 1.1: Non-scientific methods of mining sand pose a threat to environment. (Source: Standard Newspaper May 2016).

Accumulation of unmanaged wastes especially in developing countries has led to environmental concerns over the state of pollution. To minimize the negative environmental impact caused by the concrete industry and promote environmental sustainability of the industry the use of wastes from industries for concrete making is considered as an alternative solution. This would help to prevent excessive usage of natural raw materials such as sand and ballast. Some of these materials are agricultural or industrial wastes which include sawdust, concrete debris, fly ash, coconut shells among others (Ganiron Jr., 2014).Wide availability of solid fish wastes and wood saw dust make these materials suitable and dependable alternatives for aggregates in concrete productions (Shafigh et al., 2014).

1.2 Statement of the Problem

Building materials are said to constitute the single largest input in the construction of housing and other buildings accounting for about 70 to 80 percent of the total value of a building (journal of African countries on building materials and technologies. 1998 vol 3, vol no 4) Concrete which is a primary construction material is a combination of cement, fine and coarse aggregate and water, mixed in a particular proportion to get a particular strength. The cement and water react together chemically to form a paste, which bonds the aggregate particles together. The construction sector relies heavily on their conventional materials for the production of concrete. But the high and increasing cost of these materials has greatly hampered the development of housing and other infrastructural facilities in Kenya. It is the growing concerns of resource depletion and global pollution that has challenged many researchers and engineers to seek alternative options and hence develop new materials and technologies that rely on renewable resources (Oyedepo et al., 2014). These new materials include the use of agricultural and industrial waste materials in building and construction industry. Many of these by-products are used as aggregates for production of lightweight concrete. It is therefore, important that building materials are made available in sufficient quantities and at affordable cost. However, the materials available on the market, in most developing countries are either prohibitively expensive or are in scarce supply. Concrete is a primary construction material of modern age and over 13 billion metric tons being used every year Koteng (2013).In Kenya the demand for natural aggregates more specifically sand, has been rising tremendously due to rapid development of housing and other infrastructure works.

Quite recently, several large infrastructure projects have been launched in several counties indicating that consumption of sand, ballast and cement is set to rise in the coming years Koteng (2013). High cost of building materials has affected many Kenyans who engage in cutting corners to achieve building production leading to collapse of these buildings.

According to Turgut and Algin (2007), accumulation of unmanaged waste especially in developing countries has resulted in increased environmental concerns. Recycling of such waste as building materials appears to be a viable solution not only to such pollution problem but also to economic design of buildings. The use of waste materials in construction industry contributes to natural resources conservation and environmental protection. The main advantages of waste materials include preservation of virgin raw materials; re-use of waste and energy as well the development of sustainable concrete and construction of eco-friendly buildings (Bechio et al., 2009).

1.3 Objectives of the Study

1.3.1 General Objective

To investigate the performance of concrete blocks manufactured with a blend of sawdust, fish scales and sand aggregates.

1.3.2 Specific Objectives

i. To determine physical properties of crushed fish scales and sawdust.
ii. To determine the effect of partial replacement of sand with sawdust, fish scales aggregates on the properties of fresh and hardened concrete.
iii. To establish the properties of concrete blocks made with blended aggregates.

1.4 Research questions

i. What are the material properties of crushed fish scales and sawdust?

ii. What is the effect of partial replacement of sand with blended sawdust and fish scale aggregates on properties of fresh and hardened concrete?

iii. What properties do concrete blocks manufactured from blended sawdust and fish scales display?

1.5 Scope

The study covered effects of partial replacement of sand with sawdust and fish scales on the properties of concrete (blocks)**.** Also, fresh and hardened properties of C25 concrete as an optimum grade made with partial replacement of sand with sawdust and fish scales aggregate as part of fine aggregate.

1.6 Limitations of the study

Variations in type of cement, sawdust and fish scales could have resulted in different results. However, these variations were not considered as much concentration was based on concrete commonly used as structural concrete.

1.7 Justification of the study

Building materials have been cited as the main contributing factor in rising cost of housing in Kenya and worldwide. Heavy reliance and increased consumption of conventional concrete materials have led to depletion of the materials and uncontrolled quarrying activities and pollution of the environment.

The increased cost of sand and concrete products have also contributed to rapid growth of slums and sub-standard buildings as many developers tend to cut costs and avoid using established construction procedures and practices. In view of these challenges, this study paves way for recognition and acceptance of using industrial waste materials such as saw dust waste and solid fish scales as partial substitutes for sand for block manufacture in low cost housing construction.

Plate 1.2: Informal settlements in Kenya (October 20th 2015, Mathare slum, Daily Nation)

The use of river sand as fine aggregates has caused significant problems in the mining areas. Given that sand acts as a safe aquifer for water flowing below and through it, its removal results in destruction of underground aquifers and loss of safe water, sand scooping also adversely affects surface water quality and quantity and damages the aquatic ecosystem. Haulage of sand by heavy trucks causes environmental degradation by accelerating soil erosion and affecting soil stability in the mining areas. It also causes pollution of environment.

Sawdust and fish scales from solid fish wastes are least used as fine aggregates in Kenya. Use of these materials which are often discarded as waste product from industrial processes will enhance environmental conservation in two ways; by eliminating river sand harvesting and providing better use of industrial wastes of sawdust and fish scale wastes which are usually dumped in the water and landfills.

1.8 Significance of the Study

This study aims to provide solutions to the challenges facing the building and construction industry. New innovative methods and materials for building houses are being explored. These materials include waste materials such as sawdust and fish scales and which are also environmentally friendly, cost effective and available locally.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Research work has generally been carried out on all the proposed alternative materials with a view of utilizing the materials in construction. Studies on the alternative materials have however been done in different parts of the world. For instance, much of the data on laterite concrete is as a result of studies that have been carried out by researchers in Nigeria (Udoeyo et al., 2006; Osunade et al., 1994: Ata et al., 2005) while studies on quarry dust have been extensively done in India and Australia (Babu et al., 1997; Nagaraj et al., 1996; Narasimahan et al., 1999). Up to date, there are generally no guidelines for practical application of the proposed alternative materials.

The use of lightweight concrete has gained acceptance and popularity worldwide in the recent years in the construction industry (Oyawa et al., 2012. Hassan et al., 2012 noted that lightweight concrete is very versatile and popular material for construction and offers a range of technical, economic and environmental enhancing and preservation advantages.

2.2 Lightweight Concretes

Lightweight aggregate concrete can be produced using a variety of lightweight aggregates that originate from natural materials like sawdust, rice husks, bagasse, volcanic pumice and thermal treatment of natural materials like clay, slate or shale. It can also be manufactured from industrial by products like slag. The benefits of using lightweight aggregate concrete include reduction in dead loads, environmental sustainability, reduction in formwork and propping hence making savings in transport and handling of the materials.

2.3 Use of Sawdust Wastes in concrete production

Sawdust is a by-product of milling, drilling, sanding or otherwise pulverizing wood with machine based sewing that consists of fine particles of wood chips. Sawdust refers to the tiny-sized and purely wood waste produced by sawing of wood. The size of sawdust particles depends on the kind of wood from which the sawdust is obtained and also on the size of the saw teeth (Afuwape, 1983). Other industrial wastes include pulverized fuel ash, palm kernel shells, slag, fly ash which are produced from milling stations, thermal power station, waste treatment plants (Olutoge et al., 2010). Determined physical properties of rice husk ash, sawdust and palm kernel shells densities. Sawdust is a highly valuable material having different particle sizes, chemical composition, density and color (Raridragajah et al., 2001). It is principally composed of cellulose, hemicellulose lignin and extractives (Osei et al., 2016).Sawdust is considered an industrial waste in timber milling industries which constitutes a nuisance to both health and environment when not properly managed. Some of these waste include sawdust, pulverized fuel ash, palm kernel shells, slag, which are produced from milling stations, thermal power station, waste treatment plants (Olutoge et al., 2010). He determined the physical properties of vice husk ash, sawdust and palm kernel shells densities.

In East Africa, fish processing industries comprise an important segment of the economy where over thirty fish processing industries are located along the shores of Lake Victoria employing thousands of people (LVFO, 2007).

In an investigation on the use of sawdust as sand replacement to produce a low cost and lightweight material for use in construction, (Adebaku et al., 2012) found out that at 10% sawdust replacement, both the production costs and weight reduced by 10%. (Usman et al., 2012) found out that the strength of concrete reduced with sawdust as fine aggregate due to its higher rate of water absorption and the optimum replacement was 25%. Olutuge (2010) investigated the suitability of Palm Kernel shells and sawdust on replacement of crushed coarse aggregates and sand respectively in production of concrete. (Bechio et al., 2009) observed that an increase in wood aggregate content reduced the weight of concrete by decreasing its density, while compressive strength test indicated that the mechanical properties dropped with a decrease in density. Sawdust has scarcely been used in concrete production for at least 40 years (Saed, 2013). Although, seriously limited by its low compressive strength, sawdust concrete can be made to perform well in certain floor and wall applications (Haithan, 2013).

Dry sawdust concrete weighs only 30% as much as normal weight concrete and its insulating properties approximate those of wood (Taokil et al., 2011). Sawdust concrete is also called a nailing concrete because nails and screws can be driven into it and will hold firmly with proper cement to sawdust ratio, It is not flammable and can therefore be used for manufacturing precast units for use in certain floor and wall application (Haithan, 2013). However due to the organic nature of sawdust and the presence of harmful soluble carbohydrates tannins, waxes and resins in wood, hydration of cement is affected (Vaickellions et al., 2006; Al- Numan et al., 1996). Sugars in concentrations as low as 0.03 – 0.15% in cement retard the setting time and affect the strength of the cement (Numan et al., 1996). It has been found that Alkaline medium dissolves much more (about 5-10 times) woods extractives than water (Vaickelionis et al., 2006). Under the influence of alkaline medium hemicellulose disintegrate to the soluble sugars. It has also been found that along with sugars starches and tannins can inhibit cement setting and therefore pretreating sawdust by soaking in water and washing it without the addition of alkali material will not extract all the harmful substances.

Plate 2.1: sawdust waste

Shortcoming of sawdust concrete includes presence of organic solute components that affects the setting and its strength. Variations of moisture content causes volume changes in concrete and hence concrete has to undergo pre-treatment processes that includes boiling the sawdust in water containing hydrated lime in order to dissolve all soluble organic components (Haithan, 2013).

Table 2.1: Chemical characteristics of sawdust aggregates

Constituents	Percentage by weight
Si O_2	87
Al2O_3	2.5
Fe2O_3	2.0
Mg O	0.24
C_9 O	3.50
Loss of ignition (LO)	4.76

Analyzed by Kumar et al., 2004

In this investigation on the use of sawdust in concrete, A.C.I shows pre-treatment of sawdust which consisted of two phases. Phase 1 involves eliminating the retarding effect of the extractable substances in sawdust on setting and hardening of concrete. Sawdust was boiled in water containing 20% hydrated lime for an hour and ferrous sulphate was added, the sawdust was then washed and residues of the extracts and lime removed by alternate soaking and removing them from water. The sawdust was then dried and placed in water proof bags (AC) (Guide for structural lightweight concrete, 1994)

In his research on strength of concrete by partial replacement of sand with saw dust, K. mbiga and P. Menaakish confirmed that as the percentage of saw dust content increases in the mix, the compressive strength decreases

A cube manufactured with 10% replacement levels show that the sow dust replacement did not appear to have significant effect on the compressive strength of the concrete cubes. The water /cement ratio increases as the percentage of saw dust decreases.

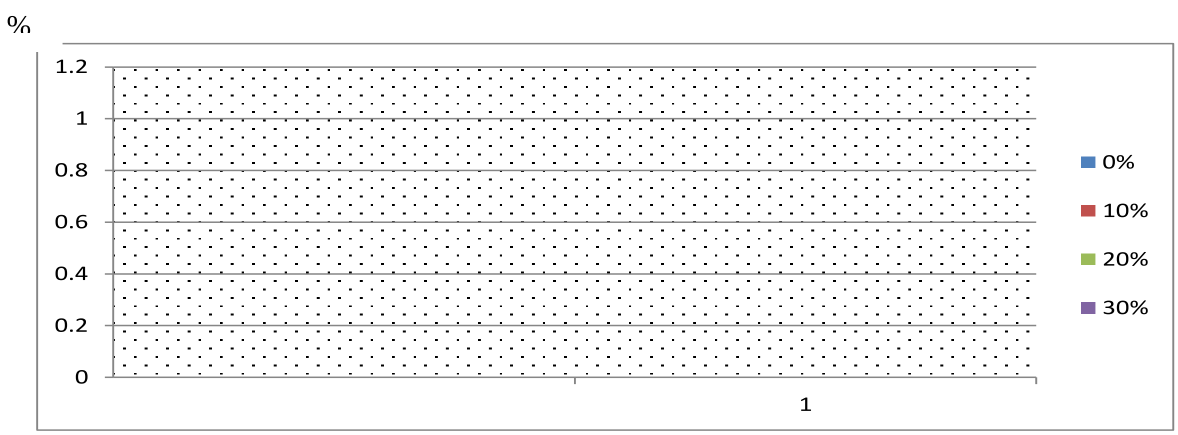


Figure 2.1: Variation of Weight of cubes in N/MM2 for 7 days against increase in SFB aggregates.

Figure 2.2: Variation of Weight of cubes in N/MM2 for 28 days against increased levels of SFB aggregates.

Source; International journal of Advanced Engineering Research and Studies

(Ambiga et al., 2014) study concluded that to achieve a better result in the use of saw dust as aggregate material for concrete production the % replacement of sand should not be more than 10%. In their study on engineering properties of sawdust concrete for block making, (Raundraragah et al., 2013) noted that batching sequence influenced the type of concrete produced by sawdust. His sawdust concrete block consisted of Portland cement, fly ash with low calcium natural sand and sawdust from pine wood. Calcium chloride used to accelerate the setting while lime was employed to increase the alkalinity.

(Adebakin et al., 2012) made the following observations on sawdust as a mixture in production of low cost and light weight hollow sand concrete blocks:-

> That the volume of sawdust required to meet the replacement percentage required made proper mixing very tedious. The increase in replacement level also increases the water – cement ration.

The attempt at replacing 50% replacement of sand with sawdust was not successful as bonding was poor.

The presence of tannin in sawdust acts as a retarder, adversely affecting the block strength.

With increased percentage of sawdust content in the concrete mix the less the compressive strength. But with blocks manufactured with 10% replacement level the sawdust replacement appeared to have a significant effect on the sand concrete blocks. The water cement ration increases as the percentage of sawdust increases.

At 10% sawdust replacement there is about 10% reduction in weight and 3% reduction in production cost.

Adebakin et al. (2012) concluded that to achieve a better result the use of sawdust for block production, the percentage replacement level of sand should not be more than 10%.

Table 2.2: Percentage Replacement levels and water/ Binder ration.

Replacement level (%)		**Water /Binder Ratio**
100% sand	0% Saw dust	0.50
90% sand	5% sawdust	0.54
80% sand	10% Sawdust	0.55
70% sand	30% sawdust	0.56
60% sand	40% sawdust	0.57

Source: American journal of Scientific and industrial research: 2013

2.4 Use of fish scales waste in concrete production

The processing of fish involves stunning, slim removal beheading, washing, scaling, gutting, cutting of fish meat ones, separation and steaks and fillets. Industrial fish processing industries in Kenya generate large amounts of waste residues which if not properly utilized or managed can lead to environmental pollution and health problems. Fish processing residues include scales, viscera, fish scraps and protein material. According to the UN report of 1997, Kenya produces 30 to 40% of the total production of fish waste from over thirty processing industries located along the Lake Victoria. Research done by (Muyodi et al., 2004) also indicates that fish processing industries along the shores of Lake Victoria generate tones of solid wastes. The prospects of generating value added products from fish wastes will encourage factories to utilize these wastes productively before discharge. Research studies done by (Kassaveti et el., 2008) indicates that there is great potential of using fish wastes for production of products such as cosmetics, pharmaceutical and biochemical products.

Table 2.3: List of Fish Processing Companies, Capacities utilized and Location

Name of the Companies	Location	Fish species	Installed capacity per day/metric tones	Utilized capacity per day
W.E Tilley (M) Ltd	Nairobi	Nile Perch	60	35
East African Sea-foods Ltd	Kisumu	Nile Perch	40	22
Afro-Meat Ltd	Kisumu	Nile Perch	30	5
Prinsal Enterprises	Migori	Nile Perch	30	20
Peche Foods	Kisumu	Nile Perch	15	7
Capital Fish (K) Ltd	Homabay	Nile Perch	50	20
Fish Processors (2000) Ltd	Kisumu	Nile Perch	25	7
Samaki (2000) Ltd	Nairobi	Nile Perch	25	7
Wananchi Marine Products Ltd	Mombasa	Tuna	100	70
Trans Africa Fisheries Ltd	Mombasa	Octopus, Lobsters, Cuttlefish, Squids	29	22
Sea Harvest Kenya Limited	Mombasa	Octopus, Lobsters, Cuttlefish, Squids	5	3
Banner Distribution Ltd	Malindi	Lobsters	10	1
Crustacean Processors	Mombasa	Lobsters	0.5	0.2
M.V. Alpha Manyara	Mombasa	Prawns	2	0.3
M.V Alpha Serengeti	Mombasa	Prawns	2	0.3
M.V Alpha Amboseli	Mombasa	Prawns	2	0.3
M.V Venture II	Mombasa	Prawns	2	0.3

Source: Department of fisheries Ministry of Livestock and Fisheries Development, 2003.

Worldwide fish industry wastes are an important contaminant having an impact on the environment and the recovery of value added products from these residues constitutes an important waste reduction strategy for the industry (Gumisiriza et al., 2009). Analysis of the waste carried out using standard methods established that annual solid waste and waste water generation was estimated at 36,000 tonnes and 1,838,000m^3 respectively (Gumisiriza et al., 2009)

The applications of fish scales as aggregates in concrete production with engineering potential and economic advantage. Each type of waste has certain physical and chemical properties, which may be suitable in concrete production.

2.5 Mechanical properties of fish scales

The physical and chemical properties of fish scales that have lately generated a lot of interest among researchers. In his study Menuer (1984) found out that collagen fiber in fish scales have high potential in strength development because of their high tensile strength (90 mpa). Scales vary in size, shape structure and extent and this is useful property, in this research finding found out that most fish scales are 200- 300mm and consists of hard outer bony layer, supported by a softer cross- line of collagen fibers. (Deju et al., 2011), further indicate that fish scales display combinations of flexibility, strength resistance to penetration and lightweight characteristics that could be useful in construction related activities.

Plate 2.2: solid fish waste

2.6 Using fish scales as aggregate

Collagen is the most abundant component of fish scales and as a biomaterial, it has good biocompatibility and can be degraded into physiologically well tolerated compounds. In nature primary purpose of fish scales is to provide external protection and the large diversity of fish species about results in fish scales of varying sizes, shapes, structures and compositions(**www.innovativemagazines.com**).There is large potential for using fish scales, an abundantly available (waste) material, as sources of both nature-derived collagen and novel applications etc.,

2.7 Pre-treatment of organic materials

Ganiron et al., (2013) while developing sawdust concrete which consists of cement, sand, sawdust and water to give a slump of between 25-51 mm. a slump of 25-50mm is recommended by Neville(pg7).Pre-treatment of sawdust prevents rotting as it is organic. Pre-treatment helps to neutralize the material to prevent reaction that world adversely affect concrete during hydration and setting. Pre-treatment- washing, clearing, drying and addition of calcium chloride during manufacture. (Ganiron et al., 2013).Dry density of 650-1600kg/m^3 and have a compression strength of 30N/mm^3 and splitting strength of 25N/mm^2. (Ganiron et al., 2013)

2.8 Summary of the review and literature gap

Research studies on sawdust sand cement concrete have been extensively been carried out by various researchers worldwide and a significant number from Nigeria (Olutunge, 2010; Oyedepo, 2014). Locally, there have been limited researches carried out on utilization of sawdust waste and grounded scales from fish as main or partial substitute for block or brick production. Reports of success attained with sawdust sand cement concrete vary from country to country but there is agreement on the nature of problems encountered in using sawdust to modify the properties of concrete. This study is therefore an attempt to resolve some of the problems encountered when using sawdust aggregate as main or partial aggregates is masonry block production

Extensive research work has generally been carried out on natural organic material with the view of establishing their viability as a construction material. Such studies have been done in different parts of the world. For instance, much of the data on sawdust concrete is as a result of studies that have been carried out by researchers in Nigeria (Olutuge et al,. 2010; Afuwape, 1983; Udoeye et al,. 2002) and in India (Ambika et al,. 2015; Ganiron, Jr. 2014; Kumar et al,. 2004). There are however limited studies on concrete utilizing natural organic waste such as saw dust, rice husks and bagasse which have been carried out in Kenya. Odera (2015) has carried out studies on saw dust concrete with good results. Studies on fish scales by Meuner et al,. (1984) and Zhu et al. (2011) indicate that there is great potential in using crushed and powdered fish scales as aggregate materials.

2.8 The conceptual framework

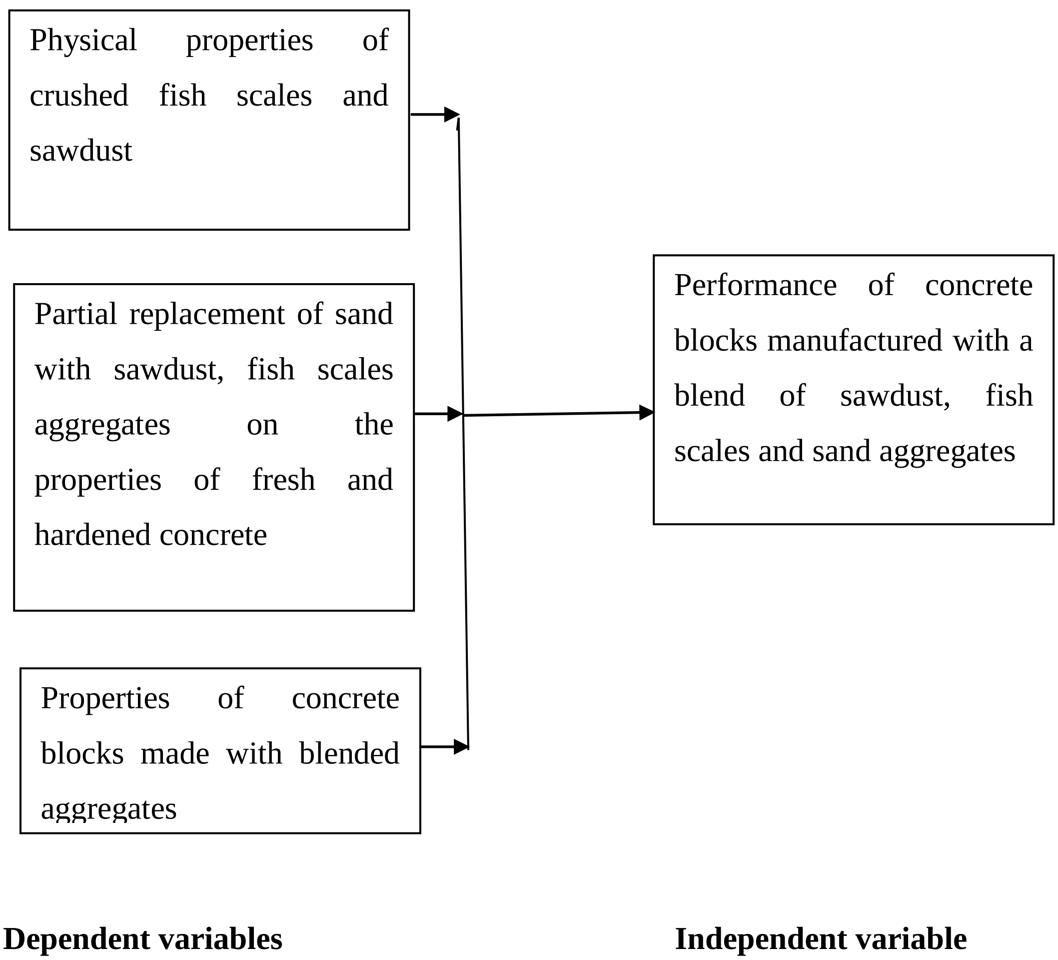


Figure 2.3: Conceptual framework

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The chapter consists of the research design, materials sampling and preparations (aggregates, sawdust, grounded fish scales, cement and lime.) water, determination of physical properties of sand fish scales and sawdust, determination of workability of fresh concrete and determination of hardened concrete

The objective of the research is to utilize organic waste as partial substitutes of sand in the production of lightweight concrete. The research explores the use of both sawdust and crushed and grounded fish scales in concrete production. This was done by carrying out tests on the materials and comparing them against normal concrete. Four types of aggregates were investigated in this research. sand; sawdust and fish scales and blended sawdust and fish scales.

3.2 Research Design

Experimental study design was employed which involved laboratory testing of the materials. Different samples of concrete mixes having varying amounts of sawdust, sand and crushed fish scales were subjected to appropriate tests to determine their physical properties and the optimum replacement levels for production of concrete and lightweight concrete blocks. Adjustment of ratios depending on the replacement done. Here the replacement is for sand or fine aggregates by blended sawdust ranging between 5% to 20%.

3.3 Materials Preparation

3.3.1 Aggregates

Aggregates are inert particles that are normally bound together by a cementing agent. The main characteristics of aggregates that influence the strength, durability and workability of concrete are cleanliness, grading, hardness and the shape. Both natural organic aggregate sawdust and grounded fish scales and inorganic natural aggregates i.e. sand blended for production of lightweight masonry blocks.

3.3.1.1 River sand Fine Aggregate

The fine aggregate used is river sand obtained from river Nzoia. The sand was free from any visible impurities and conformed to the requirements of BS 882 (1992) grading for fine aggregates.

Plate 3.1: River sand

3.3.1.2 Sawdust

The sawdust was sourced from sawmills and furniture markets in Kakamega town. It consisted of different wood species including Eucalyptus (hard wood) and pine trees (soft wood) which are widely used in furniture making in town. The sawdust was collected in plastic bags and sun dried for 24 hours to expel all moisture. To ensure uniform drying, they were thoroughly agitated, then stored in airtight and waterproof bags.

Plate 3.2: Saw Dust particles

Drying of sawdust and fish scale

Both sawdust and fish scales were air dried by spreading the samples on suitable size trays. They were stirred to ensure uniform drying. They were again subjected to oven drying to expel all moisture within them and they were thoroughly mixed by use of a rifler to achieve homogeneous mixture. They were then kept in water proof bags to avoid contamination and absorption of moisture present in the air.

Pre-treatment process of sawdust and fish scales

Phase 1. To eliminate or reduce the retarding effect of organic substances in sawdust and fish scales, water was boiled with 10 percent of hydrated lime. Washing of sawdust and fish scales was done with clean water to remove all extracts of organic substances in the two materials.

Phase 2. Consisted of washing the residues of extracts and lime by alternate soaking and removing them from ordinary water

Phase 3. Consisted of drying them under sunlight conditions by spreading them on trays and agitating them to ensure uniform drying and expansion of all moisture in them

Phase 4. Consisted of putting them in water proof bags to avoid contamination and absorption of moisture present in the air atmosphere.

3.3.1.3 Grounded Fish Scales (Course Aggregate)

Fish scales were obtained from the fish processing factories in Kisumu town and around the lake region. Before being used, the scales were subjected to a pre-treatment process that involved washing them to remove oduor smell, sun drying for 24 hours and then grinding to various sizes. They were then placed in airtight and water proof bags to avoid contamination and absorption of moisture from the air.

Plate 3.3: Dried and grounded fish scales

3.3.2 Cement and Lime

The cement used for this research was the commercially available Ordinary Portland cement of 42.5 grades and conforming to Kenya Bureau of Standards (KEBS).

Plate 3.4: Cement

3.3.3 Water

Portable water free from any visible impurities was used for this experiment.

3.4 Material batching and mixing of concrete

3.4.1 Batching

Batching of materials for concrete was done by volume due to differences of specific densities of the aggregate. Batching was done with water-cement ratio of 0.65. The water cement ratio was increased by 0.8 to make it workable. The addition of sawdust-fish scale to concrete was done by 5%increment up to 20% by volume of the fine aggregate. In total twenty (20) concrete cubes of sizes 150mm*150mm*150mm were made after batching and mechanical mixing.

Plate 3.5: Batched material

Batching was done by volume due to remarkable differences in specific gravity of materials.

Plate 3.6: Concrete Cubes made from blended saw dust

The moulds were cleaned and oiled in order to enable them to demould the hardened concrete cubes and cylinders after setting. The concrete materials were filled in the moulds in layers and placed on the vibrating table for proper compaction.

Both cubes and cylinders were left in the open for 24 hours before being placed into the curing tank where they underwent wet curing.

3.4.2 Mixing of fresh concrete

The concrete was mixed using the concrete batch mixer. The mixer was loaded with the material quantities beginning with coarse aggregates at the bottom followed by a layer of sand and finally a layer of cement. In the care of the 2nd, 3rd and 4th mixes, a proportion of modified and blended sawdust and fish scales equal to the volume occupied by the quantity of sand to be replaced was added uniformly over the sand layer before adding cement. This was done by filling a container of known weight with the quantity of sand to be replaced. The level of sand in the container was marked. The same container was then filled with sawdust blended with fish scales (SFB) to the level marked before determining the amount of blended sawdust to be used as replacement. The mixer was then closed and contents mixed for five minutes to form a homogeneous dry mix. Water was then added and distributed evenly over the mix as the mixer was rotated until the concrete was mixed properly. The concrete workability was determined before casting into moulds.

3.5 Material tests

3.5.1 Physical properties of aggregates

3.5.1.1 Sieve analysis

This test was performed to determine the percentage of different grain sizes contained within the specific materials. The sieve analysis test involves dividing a sample of aggregate into fractions which contain particles between specific size limits, these being the openings of standard sieves. Gradation test was carried out using sieves to the requirements of BS812: Part 1; 1975. This was done for all the fine and coarse aggregates used in this study. Then the grading curves for the samples were plotted in the logarithmic chart.

3.5.2. Moisture content

Moisture content represents the water in excess of saturated surface dry state.

The weight of surface dried fines were determined for each sample and recorded as W_1. They were then placed in an oven at 105^0C for 24 hours. After being removed from the oven, their weight were determined and recorded as W_2. The moisture content is determined as a percentage by the formula below:

$$\frac{(W_1-W_2)}{W_2}$$

3.5.3 Water absorption test

Water absorption tests were determined for the aggregates were carried out in accordance with the specifications in BS812; Part 2:1975. Water absorption in these samples were determined by measuring the increase in weight of an oven dried sample when placed in water for 24 hours. The ratio of the increased weight to the weight of the dried sample expressed as a percentage is defined as the water absorption. It can be used to predict concrete durability to resist corrosion. Absorption capacity is a measure of the porosity of aggregate.

3.5.4 Density tests

The apparent and bulk densities for the fine aggregates were determined. The apparent specific gravity is defined as the ratio of the weight of the aggregates dried in an oven at 100 to 110°C for 24 hours to the weight of water occupying a volume equal to that of the solid including the impermeable pores (Neville, 1981). The apparent specific gravity test was carried out according to the standard procedure, required by BS812 part 2 of 1996. The bulk density tests were carried out on the materials under two different states i.e. the loose and the compacted states after oven drying them.

3.5.5 Workability of fresh concrete

3.5.5.1 Slump Test

This test was carried out under the Standard procedure outlined by BS 1881:1990. Slump is a measure of workability of concrete. lt helped to check hour to hour batch to batch variation in materials that are fed into the mixing machine. Increase of this value guides to know about the moisture content of the aggregate i.e. increase in slump means increase in moisture content of constituent materials. Decrease in this value helps to control the grading of aggregates. Workability is also influenced by the water cement ration in the concrete which also has an influence on the strength of the concrete obtained.

3.5.5.2 Compaction Factor Test

This test is carried out to determine the amount of work necessary to achieve full compaction of the concrete mixes. The compaction factor test measures the degree of compaction resulting from the applications of a standard amount of work.

$$\text{Compaction Factor (C.F)} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

3.5.6 Determination of hardened concrete

3.5.6.1 Uniaxial Compressive strength

Uniaxial compressive strength test was carried out for all the mixes after curing period in accordance withBS881: Part III 1983 and ASTM C39.

The test on compressive strength was done in accordance with BS881: Part III 1983. Compressive strength is a measure of the concretes ability to resist loads. The 28th day strength is taken as the characteristic strength of the concrete. To check on the development in strength, the concrete compressive strength was determined at 7,14 and

21 days. The apparatus used was the Universal Testing Machine and the weighing balance.

The cubes were removed from the curing tank and allowed to drain before being weighed and their masses recorded. The dimensions of the cubes were determined to check if there was any distortion in shape. Each cube was then place centrally on the Universal Testing Machine and subjected to loading upon failure the load applied was determined from the appropriate scale and recorded.

3.5.6.2 Split Tensile strength test.

The tensile strength is one of the basic and important properties of concrete. Concrete is not usually expected to resist direct tension because of its low tensile strength and briffle nature. The determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The splitting tensile strength test was performed in accordance with ASTM C496ten cylinders after the curing period. Failure of the load applied was determined from the appropriate scale and recorded.

Plate 3.7: Picture of the Universal Testing Machine and cubes after failure

Plate 3.8: concrete cubes after failure on compression loading

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Material properties

In this Chapter, the Physical properties of the aggregates used in this study are evaluated. The properties have been found to influences the behavior of concrete. These include; particle size analysis or gradation, water absorption, moisture content and density tests. These tests were determined in accordance with the requirements of BS 882 1992.

a) Gradation and fineness modulus (FM)

The grading curve was plotted percentage passing against the sieve sizes, on a semi log graph together with the upper and lower limits of the zone II envelope as shown in the figures 4.1, 4.2 and 4.3 both sand and sawdust grading curves were found to be within the zone II envelope. This shows that sand and sawdust were suitable for use in designing the concrete mixes as provided for in BS 882:1992. It was observed that the curve for the grounded fish scales fell outside the envelope thus requiring blending with sawdust and sand to ensure that it is within the range required for use in this experiment. The fineness modulus (FM) of sand, sawdust and fish scales is 2.88, 2.70 and 3.09 respectively. The higher the FM the coarser the fine aggregates.

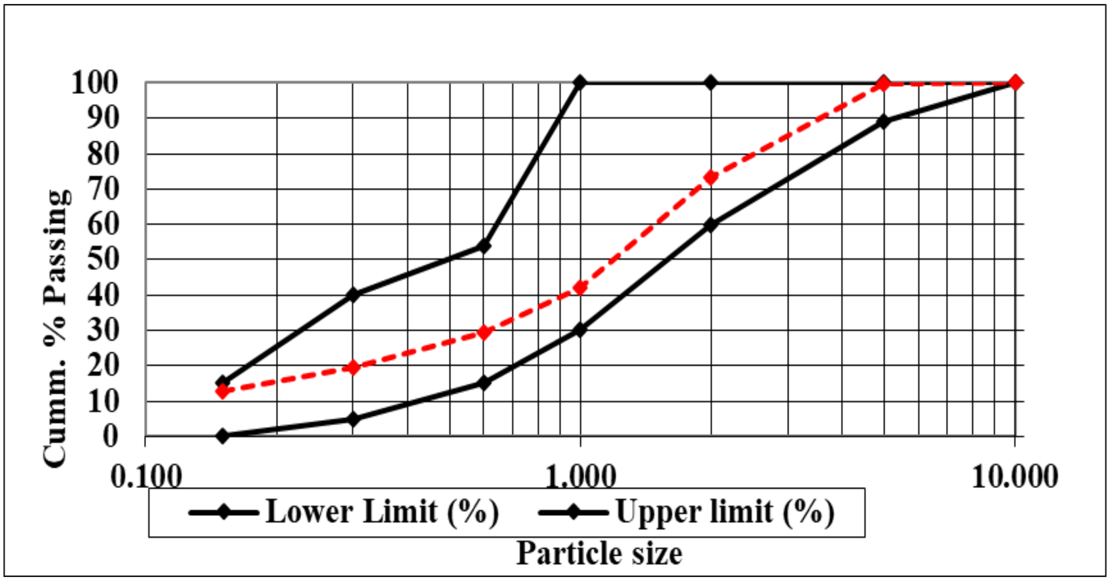


Figure 4.1: grading curve for fine aggregates i.e. sand

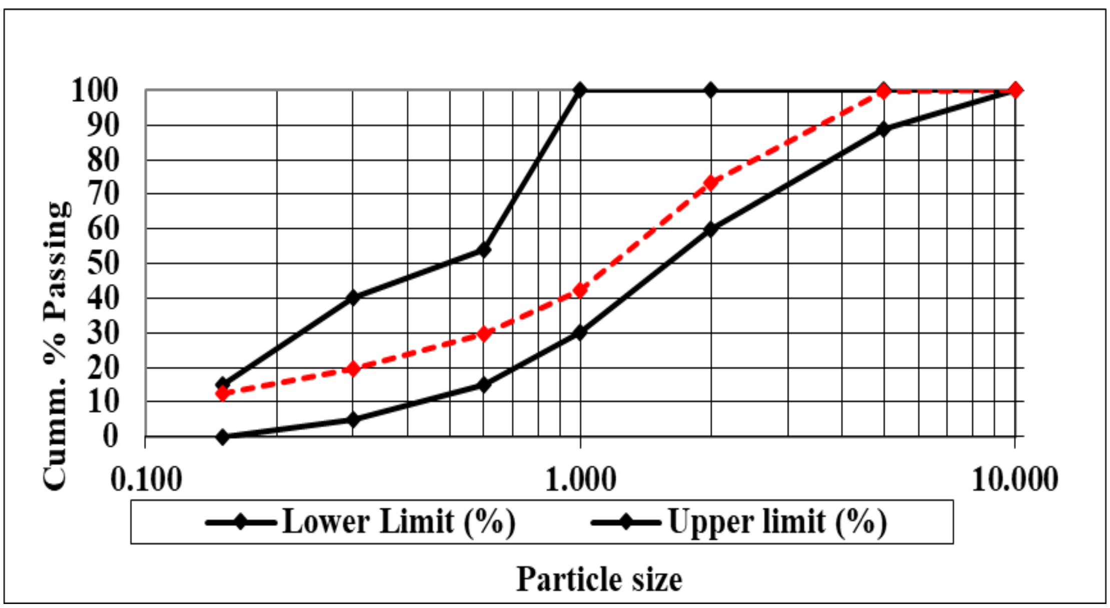


Figure 4.2: Grading curve for fish scales

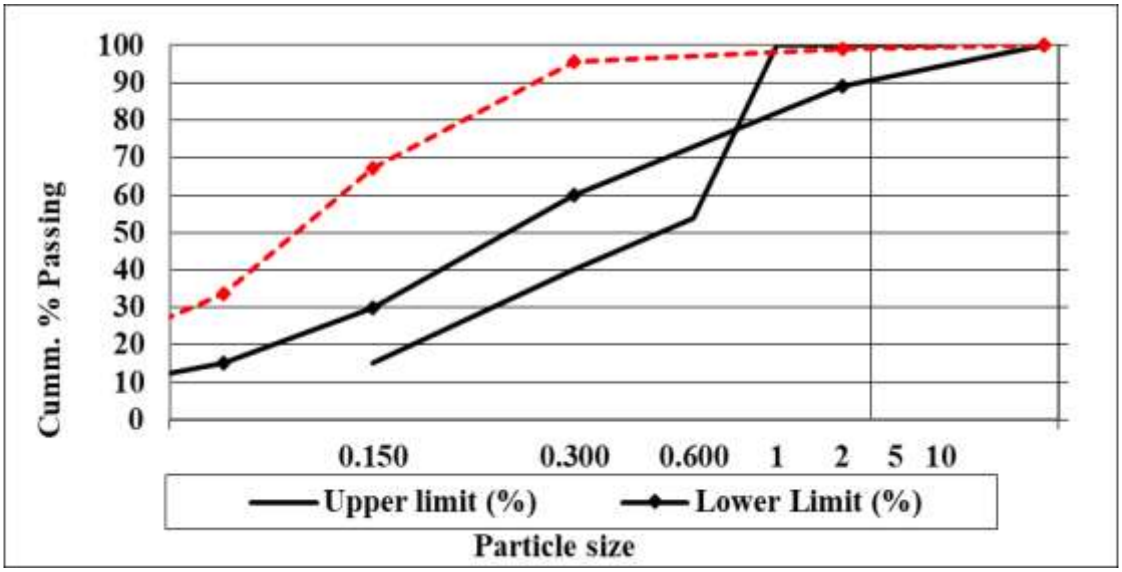


Figure 4.3: Grading curve for sawdust

Table 4.1: Specific gravity, water absorption, moisture content and density values

S/N	Parameter	Value for sand	Value of Sawdust	Value of ground fish scales	Value of coarse aggregates
1	Specific Gravity	2.85	0.37	0.25	2.80
2	Water absorption	1.80	2.50	1.25	
3	Fineness modulus	2.88	3.09	2.70	
4	Moisture content	4.23	25.58	3.50	1.55
5	Loose Bulk	0.74	0.08	0.0075	0.81
6	Density compacted bulk density	0.85	0.25	0.15	0.89

4.1.1 Basic Material Properties

4.1.1.1 Specific gravity

The computed values of specific gravity, water absorption and density of sand, sawdust and fish scales are tabulated as shown in the table 4.1 above. The apparent specific gravity for sand, sawdust and grounded fish scales are 2.85, 0.37 and 0.25 respectively. The specific gravities for sand and fish scales were found to be much lower than for sand.

4.1.1.2 Water Absorption

The absorption value for the materials was obtained by measuring the increase in weight of the oven-dried samples when immersed in water for 24hrs. Table 4.1 above indicates that the absorption values for sawdust are higher than in sand and fish scales. This can be attributed to the nature of the sawdust used. The value of water absorption obtained for river sand, that is 1.8 is within the proposed limits according to Neville (2007) for commonly used aggregates. Ground scales from Tilapia fish has been found to have the lowest absorption value because of the nature and structure of scales. Therefore the high water absorption of the sawdust limits its use as fine aggregate unless it is blended with another form of aggregate. In this study, sawdust is blended with ground fish scales to improve its water absorption properties.

4.1.1.3 Relative Densities

Both the bulk and specific relative densities of the aggregates were determined both in loose and dense states. The values for these densities are as indicated in the table 4.1 above. Dry densities values of 0.37 and .025 place sawdust and fish scales in the category of lightweight aggregates while the specific gravity of sand and gravel place them in the category of common groups of rocks whose gravities are in the range of 2.62 to 3.00. It also shows that the bulk densities of river sand, sawdust and ground fish scales in their loose states are 0.74, 0.08 and 0.075 respectively. In their compacted states, these densities are higher because of the less void spaces in them. The loose state with the results reported by other researchers (Abubakar et al., 2013). Ground fish scales were mixed with the sawdust in dry states and increase sawdust properties in order to produce concrete with desirable engineering properties. Sand was nearly twice as dense as sawdust and fish scales blended concrete obtained would be expected to be less dense compared to the conventional concrete.

4.2 Effect of FSB aggregates on workability of fresh concrete

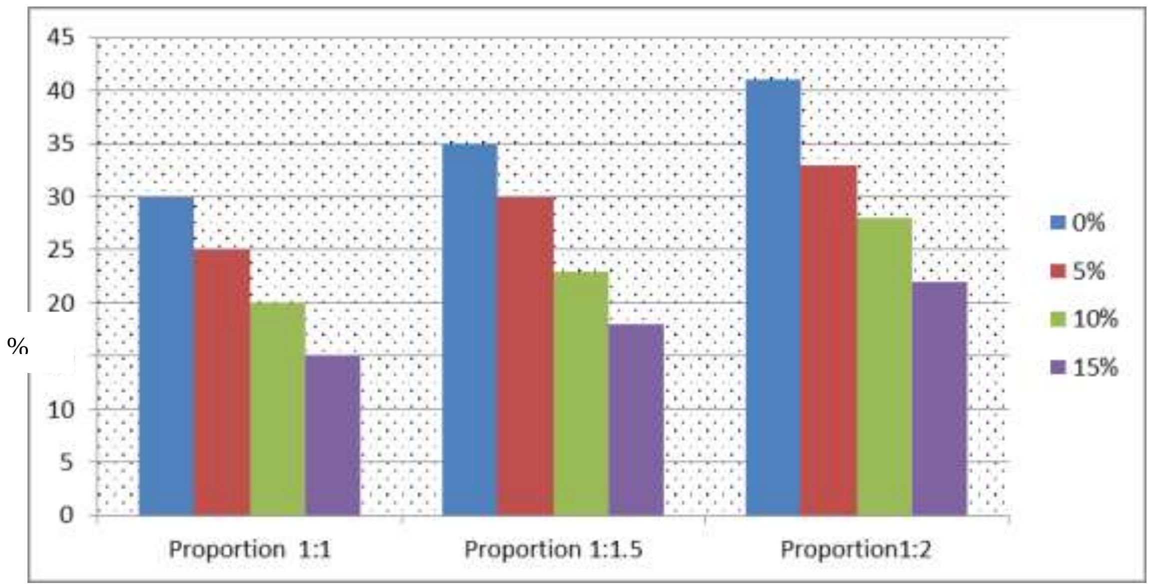


Figure 4.4: Variation in slump for different proportions of SFB

The results of the slump tests have been presented in the table 4.2 and figure 4.5 above. The results of the slump tests carried out to determine the workability of fresh concrete with varying SFB aggregates as partial replacement of sand at 0.65 water cement ratio as reported in figure 4.4 above. The workability of concrete was observed to increase initially as the percentage of SFB content increased. The value of 34 mm was obtained but this dropped to 26 and 18 mm respectively with the addition of SFB as partial replacement of sand. The decrease in workability of concrete to 10%, 15% and 20%

SFB can be attributed to difficulties in achieving a mix at 0.65 water cement ratio due to increase in surface area as well as high water absorption of SFB introduced into the concrete cubes. This trend in the slump test was confirmed by the compacting factor test (CFT), see figure 4.6 below. The results showed an initial increase in CFT test which however reduced drastically with SFB proportions. The results also imply that more effort will be required to place, compact and finish the freshly mixed concrete. Decreased workability levels cold partly be attributed to SFB levels.

Table 4.2: Compacting Factor Test Results

% Replacement	**W/C Ratio**	**Weight of partially compacted concrete (A)**	**Weight of fully compacted concrete B (g)**	**Compactive factor A/B**
0	0.65	12.50	13.70	0.912
5	0.65	12.60	12.80	0.98
10	0.65	9.45	11.20	0.78
15	0.65	8.46	9.90	0.73
20	0.65	7.68	8.94	0.72

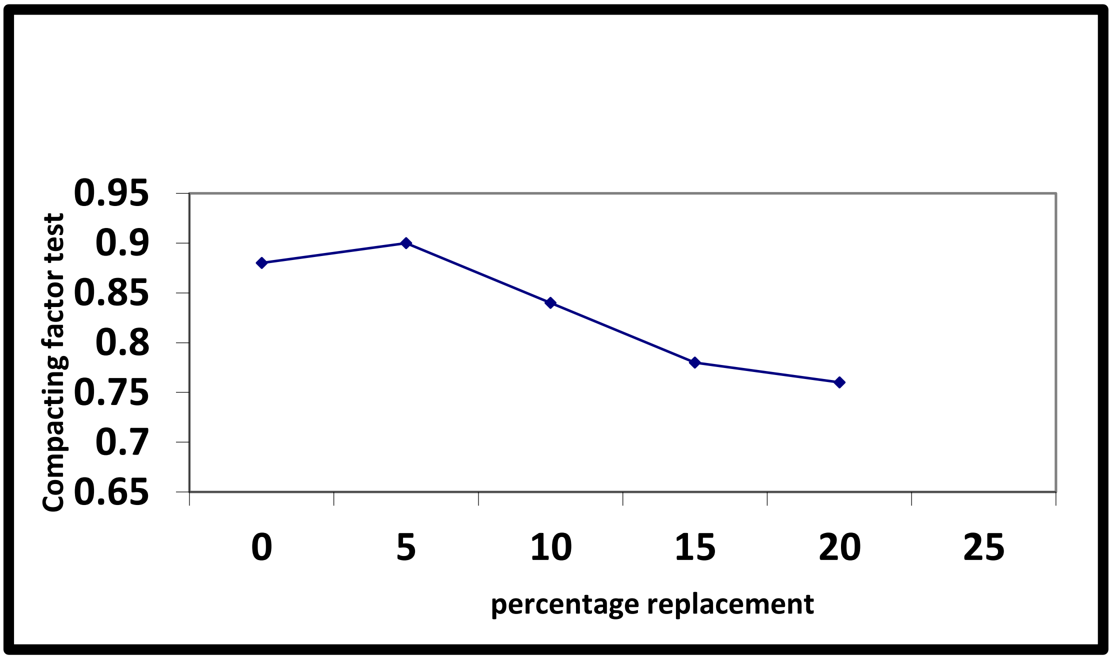


Figure 4.5: Compacting factor as a function of percentage replacement

4.3 The effect of varying SFB aggregates on compressive and tensile strength of concrete blocks

4.3.1 Compressive Strength Results

Table 4.3: Compressive strength Development (1:1:1)

%SFB	7-day compressive strength	28-day compressive strength	% 7day strength to 28 day strength
0%	7.7	12.3	62%
5%	10.3	14.7	70%
10%	8.1	10.8	75%
15%	6.7	9.1	73%

Figure above shows the various 7 and 28 day compressive strengths. The results show some slight increase in compressive strength in addition of 5% SFB content. However the compressive strength decreased with continued addition of SFB content at 10% and 15% additions.

The values of 7.7N/mm^2, 10.3N/mm^2, 8.1N/mm^2 and 6.7N/mm^2 were obtained for compressive strengths with 0%, 5%, 10% and 15% sawdust as partial replacements. The compressive strength at 5% replacement was slightly higher than the control concrete. This can be attributed to concrete obtained being denser than the reference concrete as it had an average density of 2149.0kg/m^3 compared to 2144.0kg/m^3.

This increase in density may have been caused by the fine particles of SFB particles and sand which filled all the voids within the concrete mix.

The table above shows the variations of concrete compressive strength of various concrete mixes after 28 days of curing. It can be observed that there is an increase in compressive strength with 5% replacement of SFB. Values ranging from 12.3N/mm^2 for control to 14.7N/mm^2, 10.8N/mm^2 and 9.1N/mm^2 were recorded for cubes with 5%, 10%, and 15% SFB replacement respectively. At 28 days the control concrete had the highest strength. The increase in strength after 28days was due to the fact that strength development in concrete is a function of the cement hydration process which takes place slowly. This is clearly observed in the case of the control mixes. However the overall reduction in strength in all the concrete classes as the SFB content increased could be attributed to the following reasons:-

First is high void content in concrete mixes resulting from the low workability as the concrete of SFB content increased. The low workability made it difficult to achieve proper compaction of the concrete during molding.

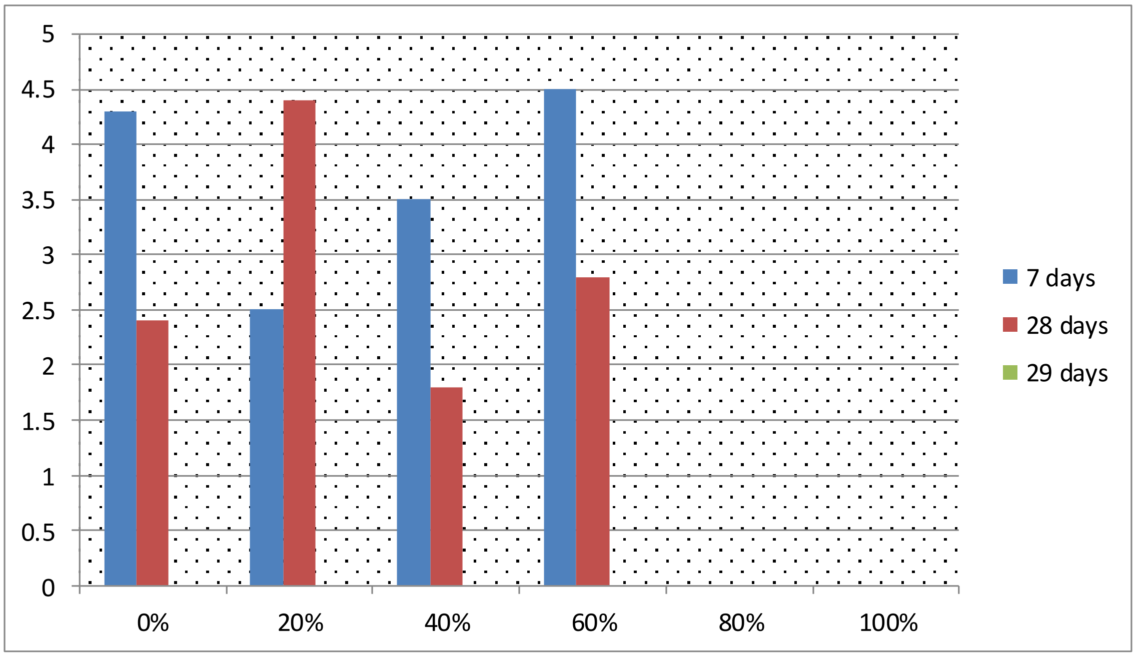
Secondly SFB is hygroscopic hence when it absorbs water, if experiences volumetric changes which results in internal stresses within the concrete mix. This could have resulted in poor bonding between the SFB particles and the cement paste. The concrete mixes with 5%, 10% and 15% SFB replacement of sand exhibited 28 day strength in excess of 5N/mm2 which is the minimum strength required for lightweight concrete bricks.

The figure also shows that the trend of strength development was varying between the developments concrete classes. The control concrete had achieved 62.5% of its 28 day compressive strength by the 7^{th} day of curing. The concrete mixes with 5% and 10% SFB content showed considerable early strength development attaining 70%, 75% and 73% respectively of their 28 day compressive strength. From this it can be observed that the presence of SFB in concrete affected the rate of strength development.

Considering that concrete strength development is a function of hydration of the cement SFB must have been impending this reaction.

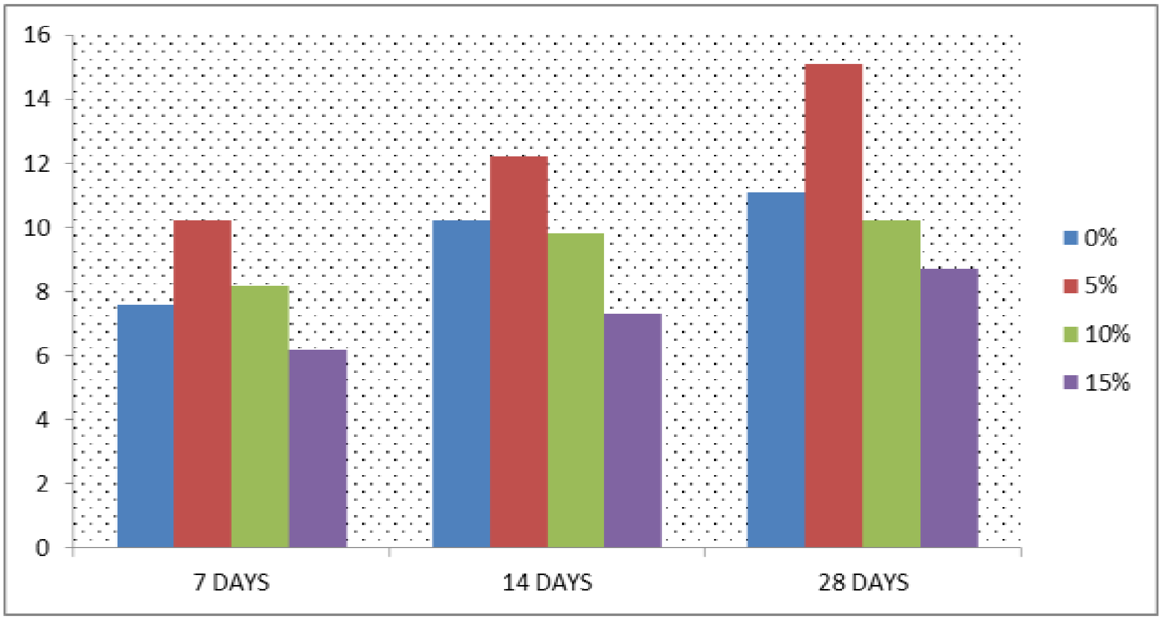
The compressive strength values showed a variation of compressive strength of concrete with replacement levels of SFB content. From the figures shown, the compressive strength of concrete initially increased to a peak value of about 5% replacement level. However as the percentage replacement increases to 10%, 15% and 20% there is reduction in compressive strength to less than 7.3N/mm^2. This was evident at all the three ages of testing i.e. 14, 21 and 28 days after curing. The maximum compressive strength attained at the age of 28 days was 15.7N/mm at a replacement value of 5%, the slump of wet concrete was at average of 35 for the water/cement ratio of 0.65.

At low replacement levels of river sand with SFB, the fine aggregates introduced in the concrete mixture has the effect of filling the small void spaces in the concrete with high amounts of blended sawdust have low workability which consequently affects the compaction of the concrete. The compaction of concrete has great influence on compressive strength of concrete (Neville, 1993). The low values of the compressive strength of the SFB used in this investigation could also be attributed to the fact that SFB contain some substances which tend to reduce the hydration of cement and hence the development of strength. Furthermore the low strength values could be due to the air that is trapped in the mortar in which is known to cause a reduction in strength values could be due to the air that is trapped in the mortar mix which is known to cause a reduction in strength values. The compressive strength values obtained at 5% replacement was found to conform to the minimum requirement of 17N/mm^2 for lightweight concrete blocks after 28 days of curing. Using SFB in proportion of 5% replacement of fine aggregate is found to be suitable for strength and density of proportions of lightweight and non-structural blocks.

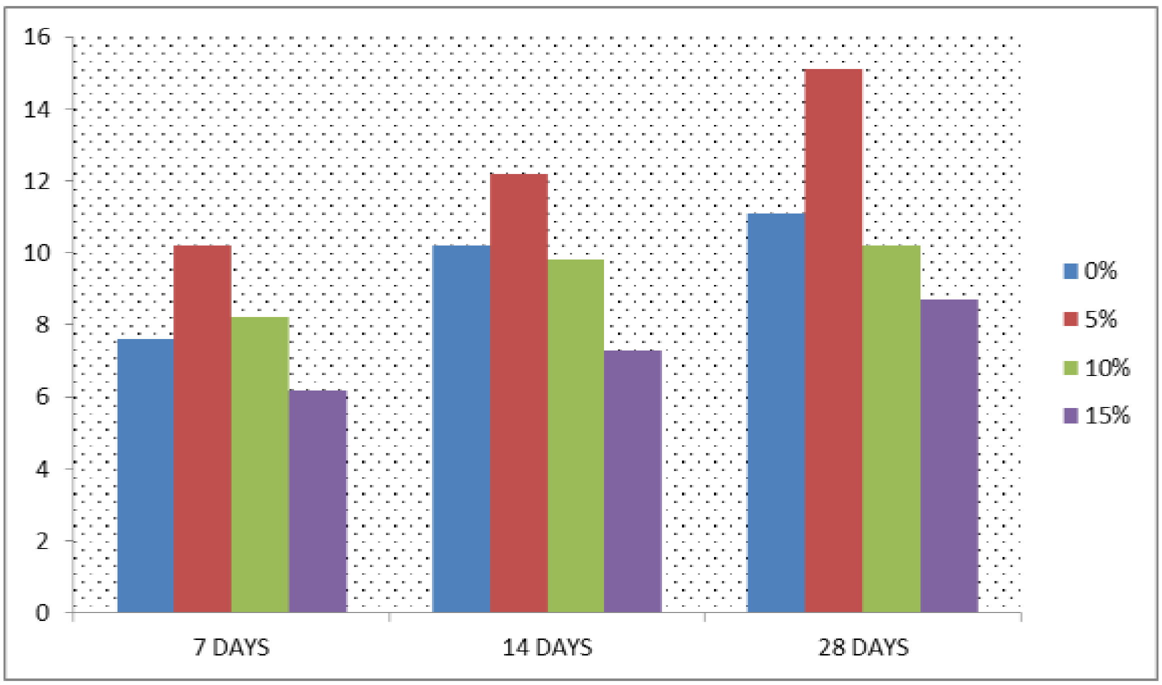


Comprehensive Strength Values in KN against % replacement of sand with SFB aggregates (A)

Figures 4.6 A.BC: Comprehensive Strength Values in KN against % replacement of sand with SFB aggregates



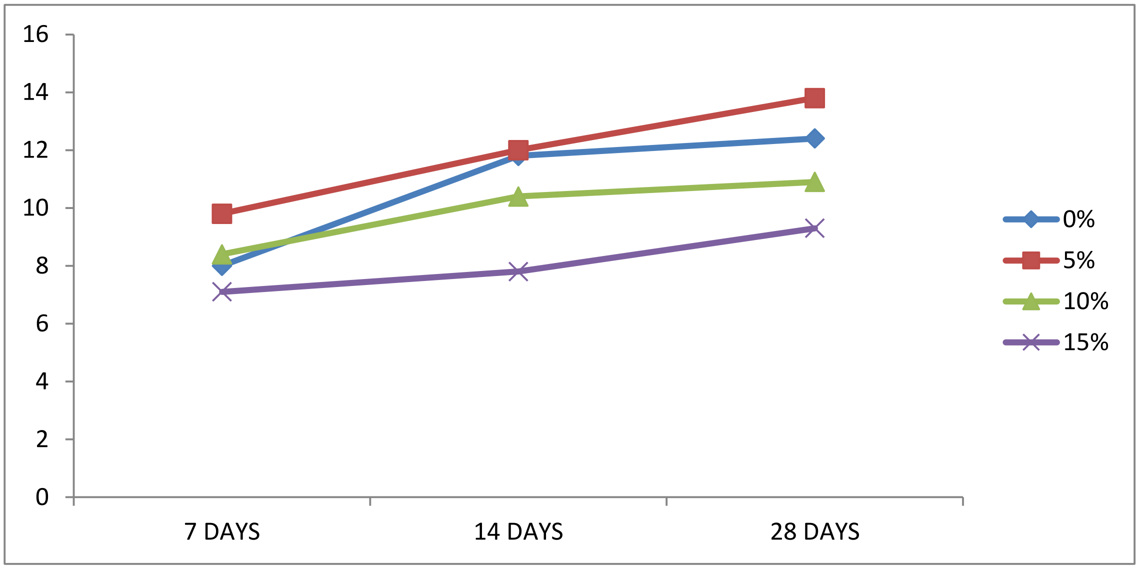
Comprehensive Strength Values in KN against % replacement of sand with SFB aggregates (B).



%

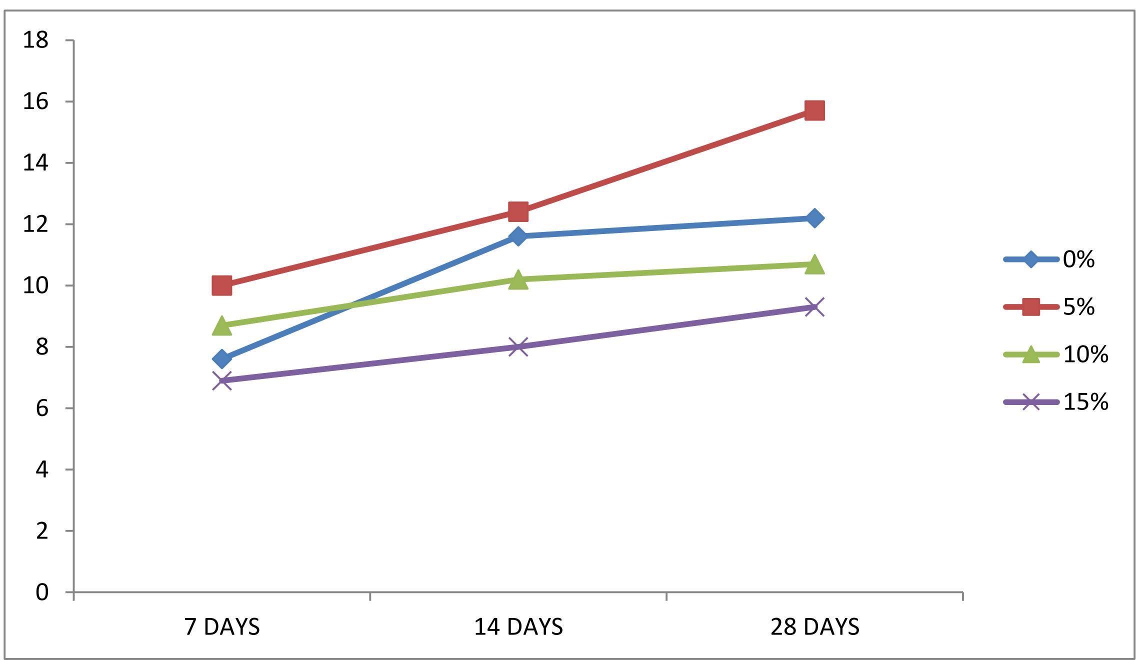
Comprehensive Strength Values in KN against % replacement of sand with SFB aggregates (C)

%

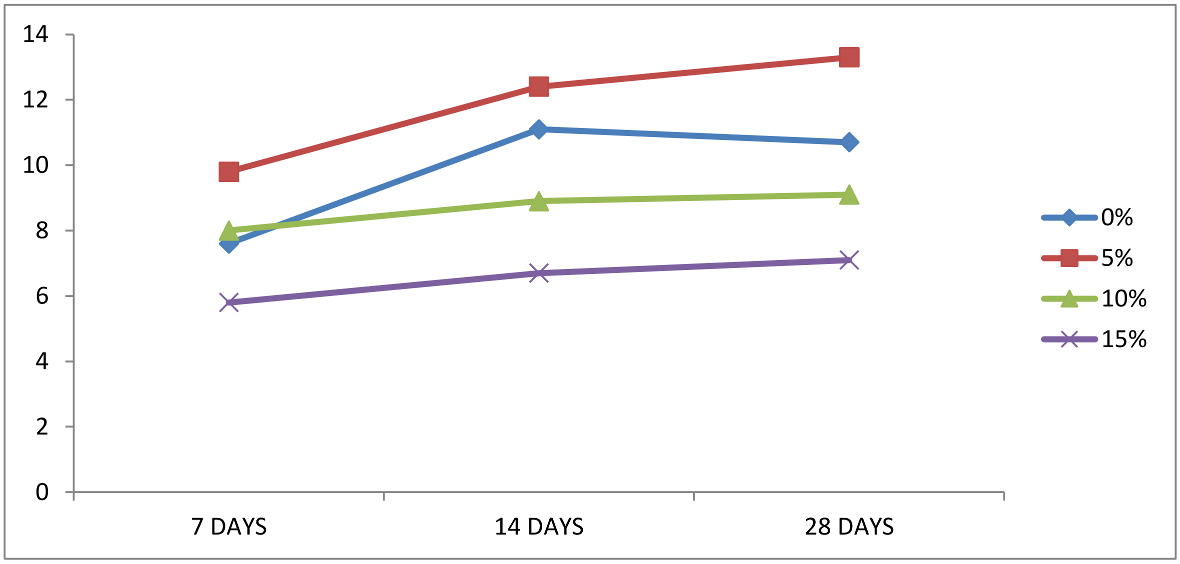


Proportion 1:1:1 (sample A)

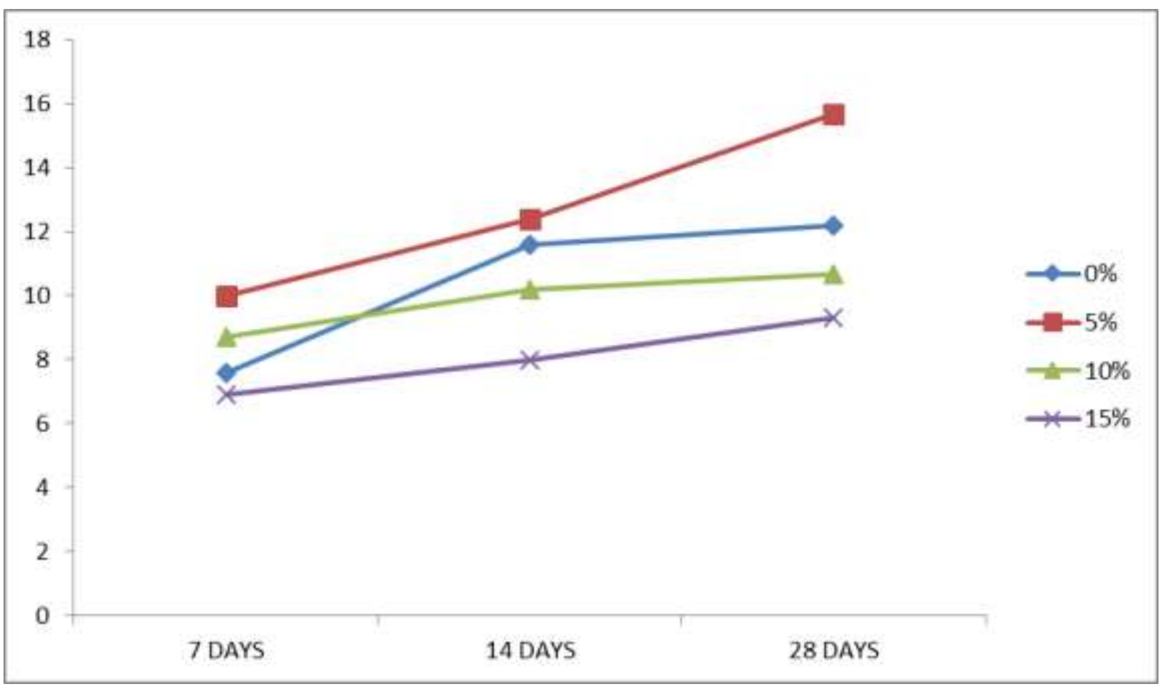
Figure 4.7A,B,C, D, E &F: Effect of replacement of sand with SFB Proportion.



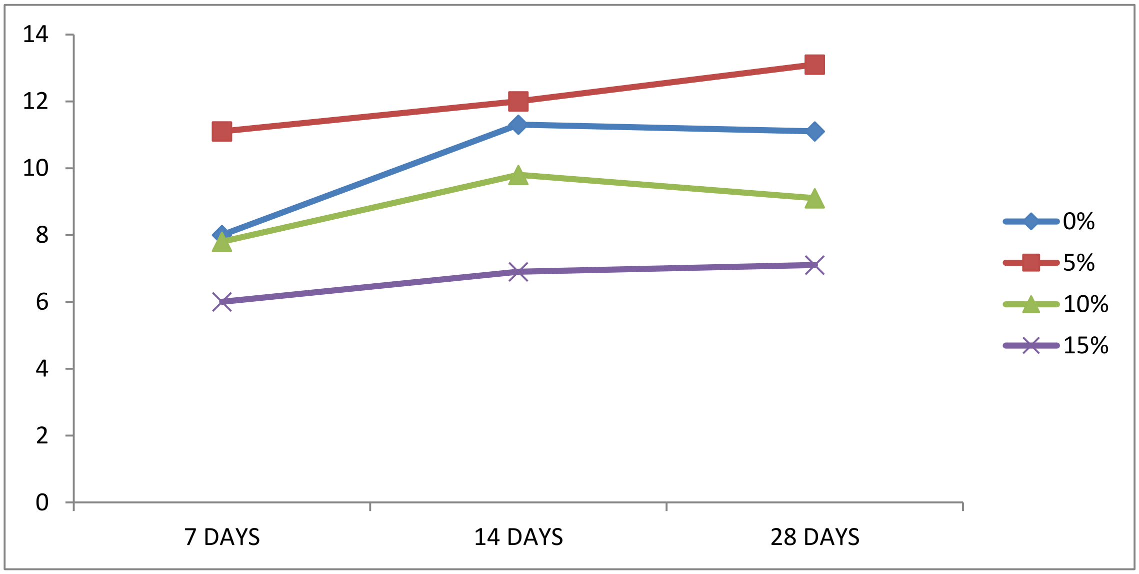
Proportion 1:1:1 (sample B)



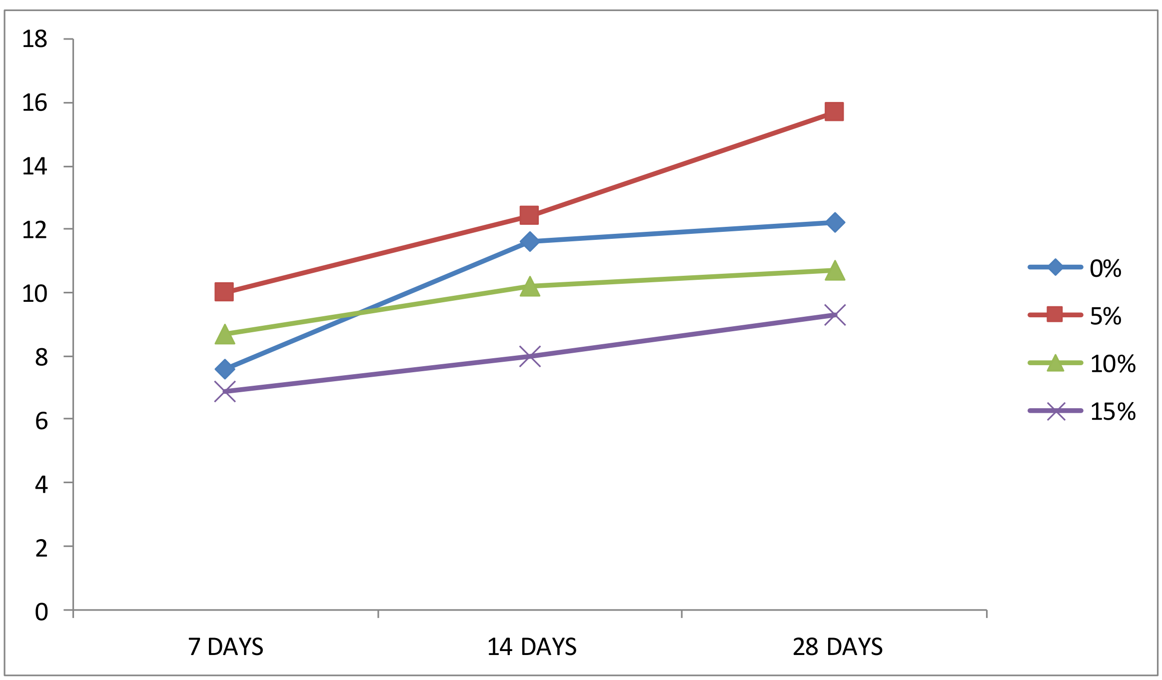
Proportion 1:1.5:1.5 (C)



Proportion 1:1.5:1.5 (D)



Proportion 1:2:2 (E)



Proportion 1:2:2 (F)

4.4 The effect of varying SFB content on Tensile Splitting Strength

Table 4.4: Tensile Splitting Strength results

% SFB	Cylinder label	Weight cylinder (Kg)	Load applied (KN)	Tensile strength (N/MM^2)	Average tensile strength(N/MM^2)
0	KAK/01	13.4	176	2.47	2.445
	KK/02	12.8	172	2.42	
5	KK/03	13.6	168	2.54	2.555
	KK/04	13.6	168	2.56	
10	KK/05	12.9	167	2.20	2.22
	KK/06	12.8	166	2.24	
15	KK/07	12.6	164	2.22	2.21
	KK/08	12.4	163	2.20	
20	KK/09	12.3	160	2.00	1.90
	KK/10	12.2	160	1.80	

Tensile splitting strength results

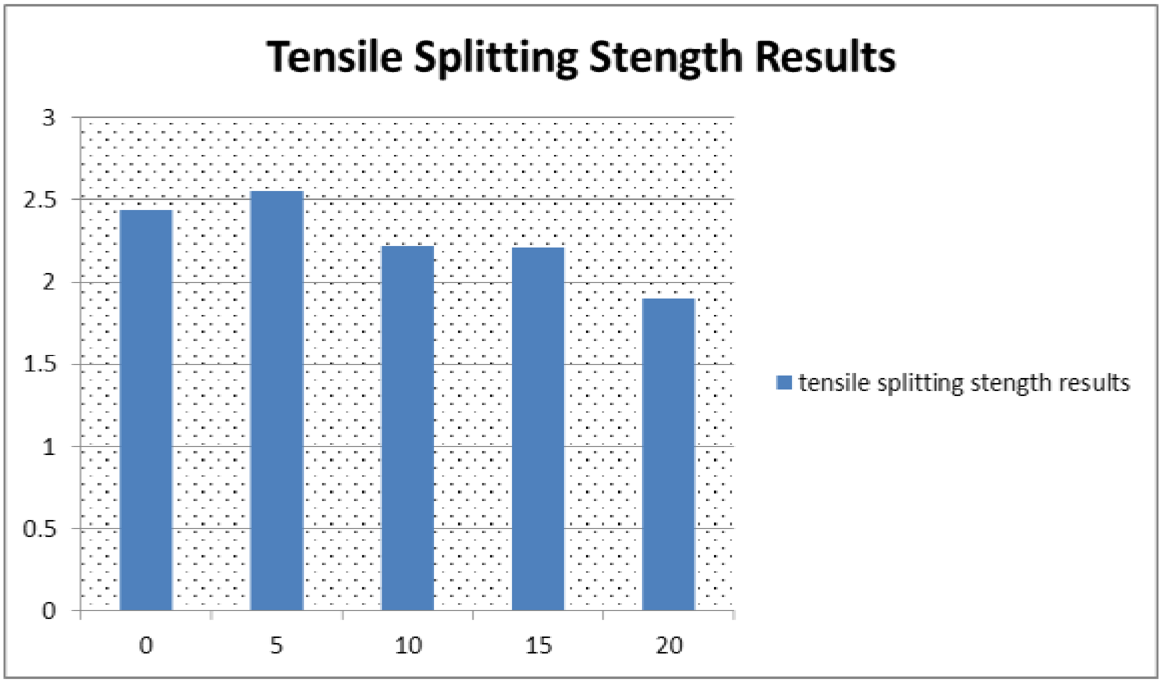


Figure 4.8: variation of Tensile Splitting Strength with increase in SFB proportions

Split tensile strength $T = \frac{2P}{\pi DL}$

Where P= Load applied until failure

D= Diameter of the cylinder

L= Height of the cylinder

The effect of varying SFB content on Tensile splitting strength results on varying SFB content is presented in the table 4.5 and figure 4.7 above. From the figures it is observed that at 5% SFB ratio the tensile strength attained a value of 2.55 N/MM^2. But beyond this value there was decreased levels on tensile strength as SFB proportions increased. At subsequent SFB proportions I.e. 10%, 15% and 20% the strengths attained were

2.22N/MM^2, 2.21N/MM^2 and 1.90N/MM^2. This reduction in tensile strength could be attributed to poor bonding between the SFB particles and the cement paste due to moisture movement.

4.5 The effect of varying SFB on density of the concrete

Table 4.5: The effect of varying SFB on density of the concrete

% volume mix of SFB proportion	**Density of blocks after 7 days**	**Density of blocks after 14 days**	**Density of blocks after 28 days**
0%	2112.0	2142.0	2144.0
5%	2114.5	2145.0	2149.0
10%	1637.0	1710.0	1714.0
15%	1386.0	1483.0	1449.0

The table shows the results of the average density of concrete blocks specimen obtained from varying proportions of SFB after replacement of sand. The density of the control mix (0%) increased from 2112kg/m^3 at 7 days to 2144.0kg/m^3 at 28 days. The density at 5% replacement of sand with SFB increased from 2114.5kg/m3 at 7 days to 2149.0kg/m3 at 28 days, while at 10% replacement the density increased from 1637.0kg/m^3 at 7 days to 1714.0kg/m^3 at 28 days. Similarly at 15% replacement the density increased from 1386.0kg/m3 at 7 days to 14490.0kg/m^3 at 28 days.

Except for 5% replacement at all ages the density of concrete blocks decreased as the percentage replacement of sand by SFB increased. This could be attributed to the low density of SFB compared to sand and the hygroscopic nature of SFB. However all the densities exceeded the 1350.0kg/m^3 which is the maximum density required for lightweight concrete blocks.

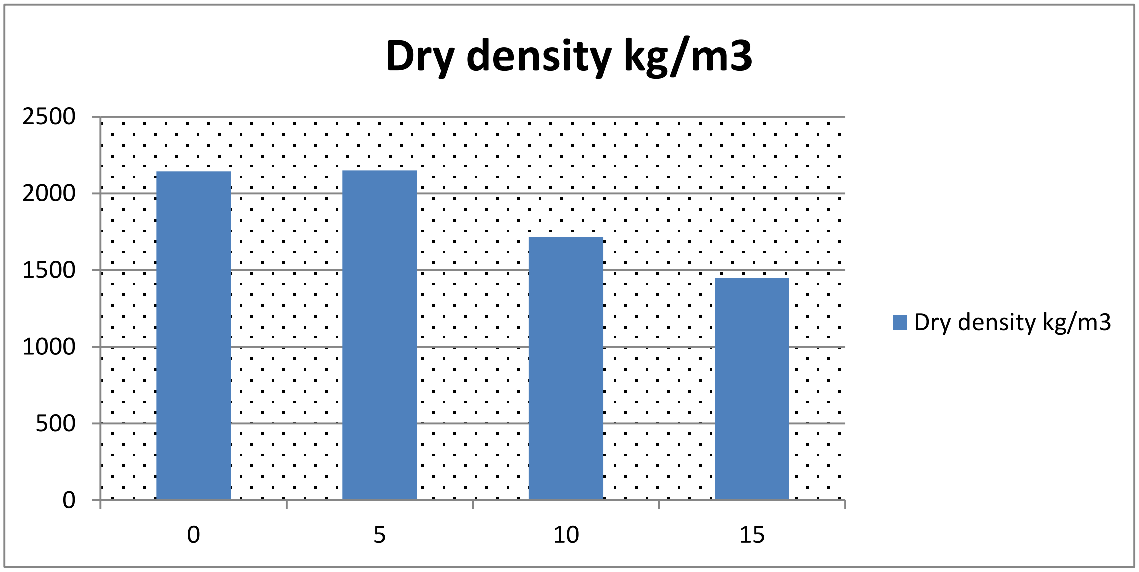


Figure 4.9: dry density on %SFB

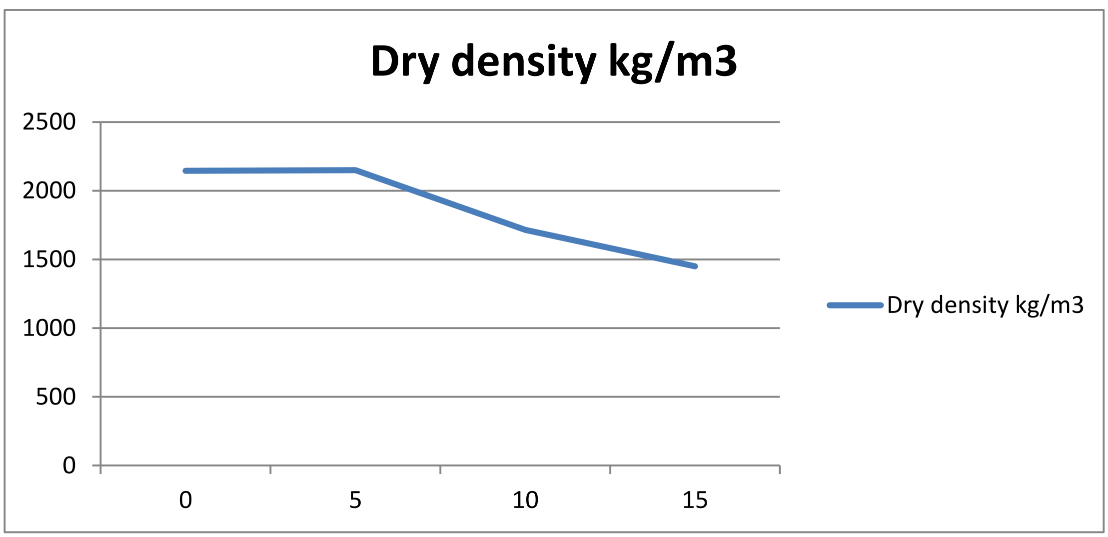


Figure 4.10: dry density on %SFB

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The findings of this research study demonstrated great potential in the use of sawdust and ground fish scales which are generally considered to be waste products to be useful in production of concrete blocks. Through a pre-treatment process involving lime application, proper blending and mixing, sun-drying and grinding of the fishscales, the physical properties of sawdust and fishscales were greatly enhanced thus providing good workability results.

The study further established that as the proportions of sawdust and fishscales blend content increased the concrete mix became less workable indicating that water to cement ratio needed to be increased from 0.55 to 0.65 to make the mix more workable.

The study also established that the optimum replacement level of sand with sawdust and fishscale blend content was 5%. Beyond this, the SFB blocks produced could not meet the minimum stregth requirements.The comprehensive strength generally increased with curing period. However, for partial replacement beyond 5% the strength levels decreased.

5.2 Recommendation

This study attempted to ensure that important infrastructure on alternative building materials was obtained. However there are other aspects which were not evaluated although they may affect the overall performance of the material.

Therefore the following recommendations are proposed;-

a) In order to recycle and make our wastes useful especially in civil engineering, there is need to encourage researchers to take up research courses on these wastes to determine their engineering properties and where they can be used best. E.g. recycled waste use in civil engineering.

b) Once cement is dosed with fine aggregates replaced with Sawdust and fish scales, good workability is achieved and early strength developments of concrete are achieved. This is possible at maximum water cement ratio of 0.6. This mix can be used for lightly loaded beams like lintels and slabs in buildings.
c) There is also need to develop codes or guiding standards on the use of various wastes like blue sawdust and fish scales in concrete. Once developed, there will be reduced cost of construction due to use of readily available wastes and solve the problem of environmental degradation.
d) Further studies should be carried out on concrete blocks made from the saw dust and fish scales SFB blocks to determine the effects of flexible behavior.
e) There is need for further research on the performance of concrete blocks for structural performance.
f) Further investigation is needed to study the influence of rising water reducing admixture to limit the water content of SFB concrete blocks. Any reduction in water content without affecting the workability will help to increase the strength and reduce the drying shrinkage of SFB blocks.
g) Further investigation to study the moisture volumetric changes of SFB blocks is essential especially when the SFB blocks are subjected to external exposure.

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APPENDICES

pressive Strength Test

SAWDUST + FISHSCALES	AGE (DAYS)	CUBE LABEL	CUBE DIMENSION			VOLUME	WEIGHT	DENSITY	MAX LOAD	STRENGTH	AVERAGE DENSITY	MEAN
			LENGTH	WIDTH	HEIGHT							
0%	7	KK/25	150	150	150	3375	7110	2107	170	7.6	2112.0	7.7
		KK/26	150	150	150	3375	7145	2117	175	7.8		
5%	7	KK/27	150	150	150	3375	6760	2113	230	10.2	2114.5	10.3
		KK/28	150	150	150	3375	6805	2116	235	10.4		
10%	7	KK/29	150	150	150	3375	5535	1640	185	8.2	1631.0	8.1
		KK/30	150	150	150	3375	5475	1622	180	8.0		
15%	7	KK/31	150	150	150	3375	4650	1378	140	6.2	1386.0	6.3
		KK/32	150	150	150	3375	4700	1393	145	6.4		

1:1:1 STRENGTH TEST:

SAWDUST + FISHSCALES	AGE (DAYS)	CUBE LABEL	CUBE DIMENSION			VOLUME	WEIGHT	DENSITY	MAX LOAD	STRENGTH	AVERAGE DENSITY	MEAN
			LENGTH	WIDTH	HEIGHT							
0%	14	KK/9	150	150	150	3375	7220	2139	260	11.6	2142.0	11.7
		KK/10	150	150	150	3375	7240	2145	265	11.8		
5%	14	KK/11	150	150	150	3375	6900	2144	280	12.4	2145.5	12.2
		KK/12	150	150	150	3375	6875	2157	270	12.0		
10%	14	KK/13	150	150	150	3375	5760	1707	230	10.2	1710.0	10.3
		KK/14	150	150	150	3375	5780	1713	235	10.4		
15%	14	KK/15	150	150	150	3375	5010	1484	180	8.0	1483.0	7.9
		KK/16	150	150	150	3375	5000	1481	175	7.8		

1:1:1 STRENGTH TEST:

SAWDUST + FISHSCALES	AGE (DAYS)	CUBE LABEL	CUBE DIMENSION			VOLUME	WEIGHT	DENSITY	MAX LOAD	STRENGTH	AVERAGE DENSITY	MEAN
			LENGTH	WIDTH	HEIGHT							
0%	28	KK/17	150	150	150	3375	7240	2145	275	12.2	2144.0	12.3
		KK/18	150	150	150	3375	7230	2142	280	12.4		
5%	28	KK/19	150	150	150	3375	6915	2149	355	15.7	2149.0	14.7
		KK/20	150	150	150	3375	6880	2149	310	13.8		
10%	28	KK/21	150	150	150	3375	5765	1708	240	10.7	1714.0	10.8
		KK/22	150	150	150	3375	5800	1719	245	10.9		
15%	28	KK/23	150	150	150	3375	4906	1454	210	9.3	1449.0	9.1
		KK/24	150	150	150	3375	4870	1443	200	8.9		

1:1.5:1.5 STRENGTH TEST

SAWDUST + FISHSCALES	AGE (DAYS)	CUBE LABEL	CUBE DIMENSION			VOLUME	WEIGHT	DENSITY	MAX LOAD	STRENGTH	AVERAGE DENSITY	MEAN
			LENGTH	WIDTH	HEIGHT							
0%	7	KK/43	150	150	150	3375	7110	2107	170	7.6	2109.0	7.3
		KK/44	150	150	150	3375	7125	2111	180	8.0		
5%	7	KK/45	150	150	150	3375	6710	2108	220	9.8	2113.5	10.05
		KK/46	150	150	150	3375	6780	2119	250	11.1		
10%	7	KK/47	150	150	150	3375	5500	1630	180	8.0	1630.0	7.9
		KK/48	150	150	150	3375	5500	1630	175	7.8		
15%	7	KK/49	150	150	150	3375	4620	1369	130	5.8	1377.0	5.9
		KK/50	150	150	150	3375	4670	1384	135	6.0		

1:1.5:1.5 STRENGTH TEST

SAWDUST + FISHSCALES	AGE (DAYS)	CUBE LABEL	CUBE DIMENSION			VOLUME	WEIGHT	DENSITY	MAX LOAD	STRENGTH	AVERAGE DENSITY	MEAN
			LENGTH	WIDTH	HEIGHT							
0%	14	KK/33	150	150	150	3375	7220	2139	230	10.2	2142.0	10.1
		KK/34	150	150	150	3375	7240	2145	225	10.0		
5%	14	KK/35	150	150	150	3375	6860	2144	275	12.2	2143.5	12.1
		KK/36	150	150	150	3375	6860	2143	270	12.0		
10%	14	KK/37	150	150	150	3375	5700	1689	220	9.8	1692.0	9.4
		KK/38	150	150	150	3375	5720	1695	225	10.0		
15%	14	KK/39	150	150	150	3375	5010	1473	165	7.3	1467.0	7.75
		KK/40	150	150	150	3375	5000	1461	155	7.9		

1:1.5:1.5 STRENGTH TEST

SAWDUST + FISHSCALES	AGE (DAYS)	CUBE LABEL	CUBE DIMENSION			VOLUME	WEIGHT	DENSITY	MAX LOAD	STRENGTH	AVERAGE DENSITY	MEAN
			LENGTH	WIDTH	HEIGHT							
0%	28	KK/41	150	150	150	3375	7260	2145	250	11.1	2144.0	12.75
		KK/42	150	150	150	3375	7200	2142	235	10.4		
5%	28	KK/43	150	150	150	3375	6900	2149	355	15.1	2149.0	14.2
		KK/44	150	150	150	3375	6870	2149	340	13.3		
10%	28	KK/45	150	150	150	3375	5710	1692	300	10.2	1714.0	10.45
		KK/46	150	150	150	3375	5735	1699	240	10.7		
15%	28	KK/47	150	150	150	3375	4850	1437	185	8.7	1449.0	8.35
		KK/48	150	150	150	3375	4805	1424	180	8.0		

1:2:2 STRENGTH TEST

SAWDUST + FISHSCALES	AGE (DAYS)	CUBE LABEL	CUBE DIMENSION			VOLUME	WEIGHT	DENSITY	MAX LOAD	STRENGTH	AVERAGE DENSITY	MEAN
			LENGTH	WIDTH	HEIGHT							
0%	14	KK/51	150	150	150	3375	7170	2124	250	11.1	2129.0	11.2
		KK/52	150	150	150	3375	7200	2133	255	11.3		
5%	14	KK/53	150	150	150	3375	6840	2137	280	12.4	2131.0	12.2
		KK/54	150	150	150	3375	6800	2125	270	12.0		
10%	14	KK/55	150	150	150	3375	5690	1686	200	8.9	1691.0	9.35
		KK/56	150	150	150	3375	5720	1695	220	9.8		
15%	14	KK/57	150	150	150	3375	4920	1458	150	6.7	1463.0	6.8
		KK/58	150	150	150	3375	4950	1467	155	6.9		

1:2:2 STRENGTH TEST

SAWDUST + FISHSCALES	AGE (DAYS)	CUBE LABEL	CUBE DIMENSION			VOLUME	WEIGHT	DENSITY	MAX LOAD	STRENGTH	AVERAGE DENSITY	MEAN
			LENGTH	WIDTH	HEIGHT							
0%	28	KK/59	150	150	150	3375	7255	2150	240	10.7	2152.0	10.9
		KK/60	150	150	150	3375	7270	2154	250	11.1		
5%	28	KK/61	150	150	150	3375	6860	2155	300	13.3	2157.0	13.2
		KK/62	150	150	150	3375	6840	2159	295	13.1		
10%	28	KK/63	150	150	150	3375	5700	1689	205	9.1	1690.0	9.1
		KK/64	150	150	150	3375	5705	1690	205	9.1		
15%	28	KK/65	150	150	150	3375	4805	1424	160	7.1	1437.0	7.2
		KK/66	150	150	150	3375	4860	1440	165	7.3		

Appendix II: SFB results on slump

SFB	Slump (Mm) For Proportion 1:1	Slump (Mm) For Proportion 1:1.5	Slump (Mm) For Proportion 1:2	Mean
0%	30	35	41	35
5%	35	35	33	34
10%	25	25	28	26
15%	15	18	22	18