STRENGTH PROPERTIES OF CONCRETE REINFORCED WITH POP FIBERS

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CERTIFICATION

This is to certify that this project topic titled “Strength Properties of Concrete Reinforced with Pop Fibers” was undertaken by Aniegboka Chinweike Charles with registration number (NAU/2016224050) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State.

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APPROVAL PAGE

This research work "Strength Properties of Concrete Reinforced with Pop Fibers" has been assessed and approved by department of civil engineering Nnamdi Azikiwe University.

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DEDICATION

This work is dedicated to Almighty God for the gift of life and also for guiding me through school. I also want to dedicate this work to my lovely mother Mrs. Helen Aniegboka who served as a real source of inspiration toward my academic pursuit.

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Special thanks go to Almighty God for giving me the strength to complete this work and also for His guidance and protection throughout my stay in Nnamdi Azikiwe University.

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ABSTRACT

The study was undertaken to evaluate the effect of pop fibers on strength properties of concrete. Pop fiber was added to the concrete in a stepped increase of 2.5% to 10% by weight of the concrete. Tests were conducted to evaluate the strength properties of the concrete reinforced with pop fiber. These tests include: sieve analysis test, specific gravity test, slump test, flexural strength test, split tensile strength test and compressive strength test. Results obtained from sieve analysis test classified the sand and granite as A-2-4 and A-1-b according to AASHTO Soil Classification System, GC (gravel mixed with sand) and SM (sand mixed with clay) according to Unified Soil Classification System. Slump test results revealed that the slump of the concrete decreased from 35mm to 15mm after 10% addition of pop fibers to the concrete, the split tensile strength of the concrete increased from 0% addition of pop fiber to 2.5% addition of pop fiber to the concrete, the flexural strength of the concrete increased from 0% addition of pop fiber to 5% addition of pop fiber to the concrete, the hardened density and compressive strength increased from 0% addition of pop fiber to 5% addition of pop fiber to the concrete. Evaluation of failure mode of both the plain and pop fiber reinforced concrete revealed that failure of the plain concrete occurred due to formation of single cracks while the pop fiber reinforced concrete exhibited more ductile failure mode with greater toughness and residual strength. This study therefore discourage the use of pop fiber beyond 5% in the production of concrete as beyond 5% pop fiber content, reduction in compressive strength of the concrete was observed.

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LIST OF SYMBOL & ABBREVIATION

G_S – Specific Gravity

KF- Kenaf Fiber

AASHTO – American Association of State Highway and Transportation Officials

USCS – Unified Soil Classification System

ASTM – American Society for Testing and Material

BSL – British Standard Light

BSH – British Standard Heavy

D_{10} – Particle Size such that 10% is finer than the Size

D_{30}- Particle Size such that 30% is finer than the Size

D_{60}- Particle Size such that 60% is finer than the Size

C_U – Coefficient of Uniformity

C_C – Coefficient of Curvature

SC – Clayey Sand

SM – Silty Sand

GM – Silty Gravel

GC—Clayey Gravel

GW—Well Graded Gravel

GP—Poorly Graded Gravel

SP—Poorly Graded Sand

SW—Well Graded Sand

CL – Inorganic Clay of Low Plasticity (lean clay)

CH—Inorganic Clay of High Plasticity (fat clay)

ML- Silt of low Plasticity

MH – Silt of High Plasticity

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Concrete is undoubtedly the most widely used construction material in the world, and it is expected to be so in the future (Fook and Yatim, 2015). Concrete is a composite mixture of binding materials (cement), coarse aggregate (gravel), fine aggregate (sand) and water in their correct proportion. Substantial research and development activities have been undertaken in the area of concrete engineering and technology to investigate and discover the characteristics of advanced materials, structure behaviour and applications, and the construction practices of concrete (Fook and Yatim, 2015). Concrete have relatively weak tensile strength and as result, reinforcement of concrete so as to resist tensile forces became necessary.

One of the widely used conventional materials for concrete reinforcement is steel and occasionally, polypropylene and synthetic fibers (Hasan, et al 2015). As the need for these materials is becoming higher and their cost is also rapidly increasing. Steel as one of the conventional materials used for concrete reinforcement have good resistance to tensile forces but are easily corroded when exposed for a long period of time. Therefore, there is a need to explore alternative materials to ensure that the cost of reinforcement is within an affordable limit and the construction purposes.

Natural fibers are prospective reinforcing materials in concrete and their use has been more traditional than technical and can be traced back to earlier civilization (Mulok, et al 2018). The advantages of natural kenaf fiber reinforced concrete (KFRC) included increasing toughness, enhancing cracking behaviour, enhanced durability and improving fatigue and impact resistance have been well presented in the previous research (Elsaid, et al 2011). Modern development of fiber reinforced concrete (FRC) started in the early 1960s. More lightweight synthetic and ductile fiber such as glass fiber was developed. However, production of synthetic fibres (Polypropylene fibres) is costly and consumes high energy in their productions. In substitution for synthetic fibre, natural fibers were introduced. Natural fibers have almost similar properties as synthetic fibre, but it is relatively cheap, and environmentally friendly. Vast researches were conducted to utilize natural fiber as material for concrete reinforcement. Concrete added with fibers, makes it an isotropic and homogeneous material. When concrete cracks, the randomly oriented fibers arrest the crack formation and propagation, thus improve ductility and strength Mulok, et al., (2018).

Al-Oraimi and Seibi (1995) investigated palm leaves fibers reinforced concrete and compared with glass fibers reinforced concrete to study both impact resistance properties. They observed that palm leaves fibers enhanced the mechanical properties and impact resistance of concrete and exhibit comparable response to the glass fibers. Ramakrishna and Sundararajan (2005) studied the concrete impact resistance with some natural fibers such as coir, sisal, jute and hibiscus cannebinus (kenaf). The study found that the coir fiber reinforced concrete has the highest absorbed energy compared to the sisal, jute and kenaf. (Udoeyo and Adetifa 2012) had studied the impact resistance of concrete Kenaf cores with different fiber lengths. The results revealed that by increasing the percentage of Kenaf fibre (KF) in the concrete, the absorbed energy decreased. In addition, the optimum fiber length for high energy absorption is 40 mm.

In other to ensure rational use of earth resources, reduce cost of concrete reinforcement using conventional materials like steel and sometimes synthetic fibers (polypropylene fiber), this study will therefore evaluate the effect of Plaster of paris (kenaf) fiber on strength of concrete.

1.2 Statement of Problem

Concrete is undoubtedly the most widely used construction material in the world, and it is expected to be so in the future (Fook and Yatim, 2015). Concrete used for structural purposes are reinforced using steel and occasionally synthetic fibers (polypropylene). Steel as one of the conventional materials used for concrete reinforcement have good resistance to tensile forces but are easily corroded when exposed for a long period of time and is relatively expensive (Razavi, 2017).

In case of, synthetics fibers it is found that they exhibit high cost of production (Liew, 2008), and not environmentally friendly (Joshi, et al., 2004). Besides, they have adverse effect on human health such as skin and respiration problem (Karnani, et al.,1988). Therefore, the natural fiber reinforced concrete composites is introduced as the sustainable material for structural elements to overcome the problems faced by using synthetics based fibers and also high cost of steel Thompson, et al., (2009).

This study seeks to promote the use of natural fibers as a substitute for steel reinforcement.

1.3 Aim and Objectives of Study

The aim of study is to evaluate the effect of Plaster of Paris (kenaf) fiber on strength of concrete while the objectives are:

1. To determine the feasibility and efficacy of Plaster of paris (kenaf) fiber as a constituent for concrete reinforcement.
2. To investigate the effect of Plaster of Paris (kenaf) fiber on compressive, flexural and split tensile strength of concrete.
3. To ascertain the maximum amount of Plaster of Paris (kenaf) fiber needed for optimum enhancement of strength properties of concrete.

1.4 Scope of Study

The study is basically centered at assessing the strength of Kenaf fiber reinforced concrete. Constituents to be used for the production of concrete such as Portland cement, Fine aggregate (sand), Coarse aggregate (granite) and Kenaf fiber will be subjected to various laboratory testing. The laboratory testing include: Particle size distribution (sieve analysis) test, Specific gravity test Slump (workability) test, Compacted and bulk density test, and to evaluate the effect of Kenaf fiber on strength of concrete, Compressive, Flexural and Split tensile strength test of the hardened concrete will be conducted.

1.5 Significance of Study

The findings obtained from the study on the use of Kenaf fiber as a constituent for concrete reinforcement will be significant in the following ways:

1. Promote the use of Kenaf fiber as constituents for concrete reinforcement thereby rational use of earth resources.
2. Offset cost for production of structural concrete.
3. Promote the use of renewable and environmentally friendly non conventional materials for concrete production.
4. Reduce adverse health effect associated with the production of steel and synthetic fibers (polypropylene).
5. Serve as reference for further study and field construction.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Concrete is undoubtedly the most widely used construction material in the world, and it is expected to be so in the future (Fook and Yatim, 2015). Concrete used for structural purposes is usually reinforced with steel and sometimes synthetic fibers. Substantial energy and adverse health consequence are associated with the production of steel and synthetic fibers. However, natural fibers are readily available, renewable and environmentally friendly and have potential of performing the same function as that shown by conventional concrete materials (steel and synthetic fibers).

This chapter will therefore review relevant literature on the topic of study, present the work of other researchers in the field of science and engineering as they relate to this study which focuses on the investigation of strength of Plaster of Paris (kenaf) fiber reinforced concrete.

2.3 Concrete

It is a composite material that consist essentially of a binding material such as a mixture of Portland cement and water within which are embedded particles or fragments of aggregate usually a combination of fine and coarse aggregate (Graw-Hill, 2003). Gambir, (2004), concrete is a synthetic construction material made by mixing cement, fine aggregate, coarse aggregate and water in the proportions. Each of these components contributes to the strength of concrete. Concrete is by far the most versatile and most widely used construction material (Aderinola, et al. 2020). It can be engineered to satisfy a wide range of performance specification, unlike other building material such as natural stone or steel which generally have to be used as they are.

According to Stanley and Bond (1999), the oldest concrete discovered dates from around 7000 BC, and was found in 1985 when a bulldozer uncovered a concrete floor during the construction of a road at Yiftah El in southern Galilee, Israel. It was also reported that the Romans also developed the concept of light weight concrete by casting jars into wall arches as well as the use of pumice aggregates. However, though concrete might have existed as early as 7000 BC, the massive use of it might have started around the 19th century.

2.2.1 History of Concrete

The first major concrete users were the Egyptians in around 2,500BC and the Romans from 300BC the Romans found that by mixing pink sand like material which they obtained from Pozzuoli with their normal lime-based concretes they obtained a stronger material. The pink sand turned out to be fine volcanic ash and they had unintentionally produced the first pozzolanic cement. Pozzolanic is any siliceous and aluminous material which possesses little or no cementitious value in itself but will, if finely divided and mixed with water, chemically react with calcium hydroxide to form compounds with cementitious properties.

2.2.2 Structural Benefits of Concrete

Concrete provides so many benefits among which include its low cost when compared to steel. By incorporating waste materials for its production, the cost can significantly reduce hence leading to a significant reduction in the total construction cost. Also, repairing work for concrete is easier and more economical than other construction materials. It is durable and can also be recycled for use in other areas such as a filler material for road construction. Unlike wood, for example, which can rot and decay and is susceptible to natural disaster, concrete requires little or no maintenance and can stand up to the toughest winds, the harshest of weather conditions and resist fire with ease. Concrete can also have a decorative function. Concrete does not burn and therefore provides comprehensive fire protection including life safety, protection of properties and of the environment. Concrete is one of the more sustainable building materials when both the energy consumed during its manufacture and its inherent properties in-use is considered. Concrete's thermal mass can be used to avoid or reduce temperature swings in the building and to eradicate the need for energy guzzling air conditioning systems. Dense, heavyweight concrete provides the highest amount of thermal mass (European Concrete Platform ASBL, 2009). Another important feature of concrete is that it is environmentally friendly. Concrete is one of the best, most natural building materials to use when considering the environmental impact of construction. The use of waste in the production of concrete helps to reduce environmental pollution and also addresses the problem of waste management. Concrete walls and floors are effective storage heaters, absorbing free heat from the sun during the daytime and releasing heat at night. Concrete stores heat in the winter and cools buildings in the summer, creating optimum comfort conditions for the occupants (European Concrete Platform ASBL, 2009). Concrete in buildings provides exceptional levels of security and safety.

2.3 Constituents Used For Production of Concrete.

(Mc Graw-Hill, 2003) stated that the ingredient used for concrete production include cement, fine aggregate (sand), coarse aggregate (granite).

2.3.1 Water

(Shatty, 2000) states that water is an important ingredient of concrete as it actively participate in chemical reaction with cement. Since it help to form the strength giving cement gel. (Nakhil, et al. 2011) stated that water is an essential ingredient as part of mixing water is utilized in the hydration of cement and the balanced water is required for impacting workability to concrete. Thus the quality and quantity of water is required to be given adequate consideration in the production of concrete. (Nakhil, et al. 2011), Also state that water plays a vital role in the strength of concrete as it helps in the following areas:

a) It wet the surface of aggregate as it helps to develop cohesion thereby enabling the cement paste to adhere quickly and satisfactorily to the wet surface of aggregate than to the dry surface.
b) To prepare a plastic mixture of the various ingredient and to impact workability to concrete so as to facilitate placing in the desired position.
c) Water is also needed for hydration of the cementing material to set and harden during the period of curing.

2.3.1.1 Influence of Water Quality on Concrete

(Nakhil, et al. 2011), conducted a research on the impact of water quality on strength properties of concrete using portable water, ground water and sewage water and it was deduced that portable water satisfy the requirement of water to be used for construction work as there was significant resulting increase in the flexural, split tensile and compressive strength of the concrete compared to other source of water. (Tahir, et al. 2020), stated that the quality of water has a significant effect on the strength properties of concrete as treated water produces concrete with comparatively higher strength than groundwater and saline water.

2.3.1.2 Influence of Water-Cement ratio on Concrete

(Shatty, 2000) stated that the water-cement ratio of concrete must lie within practical limit (0.55-0.6) as this determine the strength of concrete. According to (Shatty, 2000) lower cement –water ratio could be used when the concrete is vibrated to achieve higher strength where as higher water-cement ratio is required when the concrete is hand compacted. In other word, the effect of water-cement ratio on strength and durability properties of concrete depends on the type of compaction. But however, regardless of the type of compaction employed during the production of concrete the water-cement ratio falls within the practical limit (0.55-0.6) as any deviation could result to fall in the strength of concrete due to introduction of air voids.

2.3.2 Cement

Cement is one of the essential ingredient of concrete as the compressive strength of concrete largely depends on the quality and quantity of cement as cement is the strength giver that binds the fine aggregate (usually sand or other substitute) and coarse aggregate (gravel, crushed stone) together to form a rigid mass that is capable of sustaining loads. (Chanadan, 2019). Cement grade or cement strength class correspond to the minimum 28 days compressive strength of concrete. Generally, there are three cement grades: grade 33, grade 43 and grade 53 which have a compressive strength of 32.5Mpa, 42.5Mpa and 52.5Mpa respectively. (Chanadan, 2019) stated that in terms of quality of assurance of cement, any cement with a compressive strength of 32.5Mpa would be adjudged as meeting the strength requirement of cement grade 32.5Mpa. During the course of this research work Ordinary Portland Cement (OPC) will be used for the production of concrete. Ordinary Portland Cement (OPC) is cement containing 95%-100% clinker and gypsum and 0%-5% minor additional constituents (Chanadan, 2019).

2.3.3 Fine Aggregate

Fine aggregate plays an important role as it combines with cement in the presence of water increasing the workability and uniformity of concrete (Balamuwgan, and Perumal, 2013). Shatty, (2000). Stated that fine aggregate are important constituents as it gives body to the concrete and also help to reduce shrinkage. Mindness and Young, (1987), Fine aggregate aid in the hydration of cement as it react with cement in the presence of water to form paste. In other word, hydration of cement is largely controlled by the fineness of the aggregate. (Anna, 1994) stated that fine aggregate have the possibility of improving particle parking as they act as fillers both in lean and rich mixes with crushed aggregate.

2.3.4 Coarse Aggregate

Coarse aggregate occupies over 75% of the concrete volume acting as economic filler material. (Ezeldin and Actcin, 1991) compared concrete with the same mix proportion containing four different coarse aggregate types. They concluded that in high strength concrete, higher strength coarse aggregate typically yield higher compressive strength while in normal strength –concrete coarse aggregate has little effect on compressive strength. Some research (Strange and Bryant, 1979) and (Nallathambi, et al. 1984) has shown that there is an increase in fracture toughness with an increase in the sizes of coarse aggregate.

2.4 Chemical Composition of Ordinary Portland Cement (OPC)

The raw materials used in the manufacture of Portland cement consist mainly of lime (Cao), silica (SiO2), alumina (Al2O3) and iron oxide (Fe2O3). The four compounds are usually regarded as the major constituents of cement. They are described in abbreviated form by cement chemists as follows: CaO = C; SiO2 = S; Al2O3 = A; and Fe2O3 = F. Likewise, H2O in hydrated cement is denoted by H, and SO3 by S. In addition to the main compounds listed above, there exist minor compounds, such as MgO, TiO2, Mn2O3, K2O and Na2O; they usually amount to not more than a few per cent of the mass of cement. Two of the minor compounds are of particular interest: the oxides of sodium and potassium, Na2O and K2O, known as the alkalis. They have been found to react with some aggregates, the products of the reaction causing disintegration of the concrete, and have also been observed to affect the rate of the gain of strength of cement (Neville, 2005). The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding. Table 2.1 shows the approximate oxide composition limits of ordinary Portland cement.

Table 2.1 Oxide Composition Limit of Ordinary Portland cement (OPC) (Shetty, 2005).

Oxide	Approximate Percentages
CaO	60-67
SiO2	17-25
AL2O3	3.0-8.0
Fe2O3	0.5-6.0
MgO	0.1-4.0
Alkalis(K2O, N2O)	0.4-1.3
SO3	1.3-3.0

The oxides present in the raw materials when subjected to high clinkering temperature combine with each other to form complex compounds. The identification of the major compounds is largely based on R.H. Bogue's work and hence it is called ―Bogue's Compounds. The four compounds usually regarded as major compounds are tricalcium silicate (C3S), dicalcium silicate (C2S), tricalcium aluminate (C3A) and tetracalciumalumino ferrite (C4AF). Shetty, (2005).The Bogue's formula used in calculating the percentage of the various compounds is given as follows: C3S = 4.07 (CaO) – 7.60 (SiO2) – 6.72 (Al2O3) – 1.43 (Fe2O3) – 2.85 (SO3) C2S = 2.87 (SiO2) – 0.754 (3CaO.SiO2)C3A = 2.65 (Al2O3) – 1.69 (Fe2O3) C4AF= 3.04 (Fe2O3).

2.4.1 Effect of Alkali on the Properties of Cement

Bentz (2006) reported that the addition of the alkalis of lithium, sodium and potassium have each accelerated the early age hydration of cement paste. However what is considered as the critical adverse effect of alkalis in cement is the propagation of alkali-silica reaction (ASR) when the alkali level is beyond the specified maximum. However, Ahmed and Asmaa, (2012) opined that the addition of alkalis has retarded the initial and final setting times of ordinary Portland cement ASTM Type I, while its later age strength was improved. According to Newzealand ready mixed concrete association (NZRMCA, 2004), most alkali in concrete is supplied as sodium (Na) or potassium (K) ions. The other alkali metals may not contribute significantly to ASR damage. The total alkali content of a concrete or cement paste is therefore taken as the sum of the equivalent alkali of the individual constituents given by Na2Oe (%) = Na2O (%) + 0.658 K_2O.

Where: Na2Oe is the total equivalent alkali in the form of Na2O from various constituents (cement, aggregates, water and admixture). Na2O is the percentage of sodium oxide from varioius constituent materials K2O is the percentage of potassium oxide from varioius constituent materials. ASTM C-150 has restricted the total alkali content in concrete to 0.6% by mass of the cement or 3kg/m3 of concrete where there is tendency of alkali-silica reactivity (ASR). In a research conducted by Reddy et al. (2011), in which the effect of potassium chloride (KCl) on Ordinary Portland cement(OPC) concrete was investigated, it has been reported that both compressive and tensile strength of the concrete increases with an increase in KCl concentration. Meanwhile, initial and final setting times were both retarded with the addition of KCl in the mixing water when compared with the control specimen. Halaweh, (2006) carried out a detailed study on the effect of alkalis and sulphates on Portland cement. He concluded that the addition of alkalis influences the rate of hydration, decreases strength development but increases the porosity of the microstructure of According to Susan (2012), the scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that are derived from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. These signals include secondary electrons (that produce SEM images), backscattered electrons (BSE), diffracted backscattered electrons (EBSD that are used to determine crystal structures and orientations of minerals), photons (characteristic X-rays that are used for elemental analysis and continuum X-rays), visible light (cathodoluminescence) and heat.

2.5 Properties of Ordinary Portland Cement

2.5.1 Fineness of cement

As hydration take place at the surface of the cement, it is the surface area of the cement particles which provide the material available for hydration. The rate of hydration is controlled by fineness of the cement. For a rapid rate of hydration, a higher fineness is necessary. (Anna, 1994) Investigated the effect of fineness of cement and eventually came up with the following observation:

i. Higher fineness require higher grinding (High cost implication)
ii. Finer cement deteriorate faster upon exposure to atmosphere
iii. Finer cement are very sensitive to alkali-aggregate reaction
iv. Finer cement require more gypsum for proper hydration
v. Finer cement requires more water.

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence fastens the development of strength. Fineness of cement is determined by permeability. For example in the blaine air permeability method, a known volume of air is passed through cement. The time is recorded and the specific surface is calculated by a formula. Fineness is expressed in terms of specific surface of the cement (Cm^2/gr). For OPC specific surface area is 2600-3000 Cm^2/gr. This test is conducted as per BS EN196-6:1995.

2.5.2 Setting Time of Cement

Setting time refers to a change from liquid state to solid state. During setting time, cement paste acquire some strength (Gartener, et al. 1989). The water content has a marked effect on time of setting. In acceptance test for cement, the water content is regulated by bringing the paste to a standard condition of wetness and this is referred to as “normal consistency”. Normal consistency of OPC ranges from 20-30% by weight of concrete. Vicat apparatus is used to determine normal consistency. Normal consistency is that condition for which the penetration of a standard weighed plunger into the paste is 10mm in 30sec. In practice, the terms initial set and final set are used to describe arbitrary chosen time of setting. Initial set indicates the beginning of a noticeable stiffening and final set may be regarded as the start of hardening (or complete loss of plasticity). It is the also the period between the time water is added to cement and time at which 1 mm square section needle fails to penetrate the cement paste, placed in the Vicat'smould 5 mm to 7 mm from the bottom of the mould. Final setting time is that time period between the time water is added to cement and the time at which 1 mm needle makes an impression on the paste in the mould but 5 mm attachment does not make any impression. The setting time test is carried out using the Vicat apparatus as per BS-EN 196 part3 (1995). The results of the test should comply with the requirements of BS-EN 197 part1 (2000), which recommend a minimum of 60 minutes and a maximum of 10 hours as the initial and final setting times of ordinary Portland cement respectively. (Gartener, et al. 1989) summarized the factors affecting setting time as:

i. Temperature and Humidity.
ii. Amount of water
iii. Chemical composition of cement
iv. Fineness of cement (the finer the cement, the faster the setting)

Marthong, (2012), investigated that the addition of saw dust ash in OPC grade 42.5 had increased the initial and final setting times. This was attributed to the low rate of hydration in the paste containing the saw dust ash.

2.5.3 Soundness of Cement.

Soundness is referred to as the volume stability of cement paste. The cement paste should not undergo large changes in volume after it has set. Free CaO and MgO may result in unsound cement (Chanadan, 2019). Upon hydration, C and M (calcium and magnesium) will form CH and MH with volume increase thus cracking. (Gartener, et al. 1983), since unsoundness is not apparent until several months or years, it is necessary to provide an accelerated method for its determination which include:

i. Lechatelier Method where only free CaO can be determined.
ii. Autoclave Method where both free CaO and MgO can be determined.

In the soundness test a specimen of hardened cement paste is boiled for a fixed time so that any tendency to expand is sped up and can be detected. Soundness means the ability to resist volume expansion. For ordinary Portland cement, BS-EN 197 part1 (2000) has specified a maximum expansion of 10mm. The work of Chowdhury et al., (2015) indicated that the soundness of cement was improved with the addition of saw dust ash as partial replacement. In the research, cement was replaced by the ash within the range of 5% to 30% and the soundness was found to increase with an increase in the ash content.

2.5.4 Strength of Cement and it's effect on Concrete.

Strength test are not carried out on neat cement paste because it is very difficult to form this paste due to cohesive property of cement. Strength test are carried out on cement mortar prepared by standard gradation (1 part cement + 3 part sand + ½ part water). The strength of cement is tested through compression, direct tension or flexure tests. According to BS-EN 196 part1 (1995), prisms of size 40mmx40mmx160mm are cast of a cement sand mortar produced using 1:3 mix ratio. The test prisms are tested for compressive strength at 2days and 28 days. According to BS 5826, cement mortar is classified into M4, M6, and M12 with compressive strengths of 4N/mm2, 6N/mm2, and 12N/mm2 respectively at 28 days. BS EN 998 part 2 (2003) had also provided similar compressive strength.

(Chandan, 2019) Investigated on the effect of grade of cement on compressive strength of concrete where it was reported that the compressive strength is largely dependent on the grade of cement as cement grade 52.5 produces comparatively higher compressive strength than cement grade 42.5 and 32.5 respectively. Similar observation was also confirmed by (Gideon, et al. 2015).

2.5.5 Hydration of Ordinay Portland Cement (OPC)

It is the chemical reaction of cement with water. As the water comes into contact with cement particles, hydration reactions start immediately at the surface of the particles. (Gartener, et al. 1989). Although hydrate such as C-H are formed, process of hydration is a complex one and results in reorganization of the constituents of original compound to form new hydrated compounds. (Gartener, et al. 1989) states that at any stage of hydration, the hardened cement paste (HCP) consist of:

1. Hydrate of various compounds referred to collectively as Gel.
2. Crystals of calcium hydroxide (CH)
3. Some minor hydrate compound
4. Unhydrated cement
5. Residue of water filled spaces-pores.

(Jenings, et al. 1983) opined that upon hydration, C_3S, C_2S and CH are formed which become an integral part of the hydration products. CH does not contribute very much to the strength of Portland cement. According to (Jenning, and Ghosh, 1983) C_3S having a faster rate of reaction accompanied by greater heat of hydration develops early strength of the paste. On the other hand, C_2S hydrates and hardens slowly so results in less heat generation and develops most of the ultimate strength. (Gartener, et al. 1989) summarized hydration process as:

1. Immediately after mixing with water
2. Reaction occurs around particles referred to as early stiffening.
3. Accompanied by formation of skeletal structure referred to as first hardening
4. Gel infilling known as later hardening.

2.6 Plaster of Paris (Kenaf) Fiber

Kenaf fiber (Hibiscus cannabinus L.) comes from a plant named ‘Kenaf’ which is a plant in the Malvaceae family, is in the genus Hibiscus and is probably native to southern Asia although its exact natural origin is unknown. Kenaf denoted as industrial kenaf due to of its great interest for the production of industrial raw materials. Kenaf is a warm season annual fiber crop closely related to cotton and jute. The other names of kenaf are Ambary, Bimli, Deccan Hemp, Ambari Hemp, and Bimlipatum Jute Edeerozey, et al., (2007). It is comparatively commercially available and economically cheap amongst other natural fiber reinforcing material Saba, et al., (2015). Kenaf has been studied as a potential replacement for the diminishing tobacco farming industry in the south-eastern United States. Kenaf is a hardy, strong and tough plant with a fibrous stalk, resistant to insect damage and requires relatively fewer amount of or no pesticides Saba, et al., (2015). Kenaf has a single, straight and branchless stalk. Kenaf stalk consists of two types of fiber, an inner woody core and outer fibrous bast around the core. Bast is a coarser fiber in the outer layer while core fiber is a finer fiber in the core. Kenaf grows quickly and rise to heights of 4-5 m and 25-35 mm in diameter in a 4-5 month growing season.

Historically, kenaf has been used as a cordage crop to produce twine, rope, and sackcloth. The reason why there are very high interests in kenaf cultivation in recent years are because kenaf has the ability to absorb nitrogen and phosphorus included in the soil and also can accumulate carbon dioxide at a high rate Aji, et al., (2009).

2.6.1 Surface Treatment of Plaster of Paris (Kenaf)

The efficiency of the fiber-reinforced composites depends on the fiber-matrix interface and the ability to transfer stress from the matrix to the fiber Elsaid, et al., (2011). However, the drawbacks in natural fibers like high moisture absorption lead to their low mechanical properties and poor fiber-matrix adhesion in composites, and limit their applications. Hence natural fibers need to be treated by physical and chemical methods to change their structural properties and improve its mechanical properties. Various chemical treatments have been used by many researchers in the past. The literature results show that the alkali treatment is a commonly used method to clean and modify the fiber surface and enhance interfacial adhesion between a natural fiber and a polymeric matrix (Mohanty, et al., 2006: Edeerozy, et al., 2007). Mohanty, et al. (2005) reported that fibers are treated with NaOH to remove lignin, pectin, wax substances, and natural oils that cover the surface of the fiber cell wall. Sgriccia et al., (2008) confirmed that the alkali treatment removed the hemicellulose from the fiber. Mwaikambo and Ansell [9] have treated hemp, jute, msisal, and kapok fibers with various concentrations of NaOH solution. They found that 6% was the optimum concentration in terms of cleaning and fiber bundle surfaces and with high tensile strength. Besides that, from the findings of Edeerozey, et al. (2007), when the NaOH concentration was increased to 9%, the tensile strength of fibers exhibited a significant decrease. The intensity of 9% NaOH was too strong and might cause to damage the fibres, thus resulting in lower tensile strength. He also noted that 6% NaOH yields the optimum concentration of NaOH for the chemical treatment.

2.7 Natural Fibrous Concrete

According to ACI 544.1R-82, (1982) fibrous concrete (FC) is defined as concrete made with hydraulic

Hydraulic cement, containing fine or fine and coarse aggregate and discontinuous discrete fibers. The fibers can be made from natural material or manufactured product. Fibrous concrete can be considered as material relatively short continuous fiber are randomly distributed throughout the matrix in order to overcome the problems brought about by the low tensile strength and strain capacity of a plain concrete mix. The properties of natural fibrous concrete are dependent on several numbers of factors including the type, length, and volume of fibers used. Previous research indicated that the fiber volume fraction required to provide significant improvement in the mechanical properties of cement composites was approximately 3% (Rancines and Pama, 1978). The study of jute fibrous concrete indicates that in general, compressive strength is not significantly affected by the additional of fibers, while tensile and flexural strength and toughness are all substantially increased Elsaid, et al., (2011).

Combining natural fiber with other resources provides a strategy for producing advanced composite materials that take advantage of the properties of both types of resources. The use of fibers in concrete was found to increase concrete strength and durability, and also to enhance the bond between fibers and matrix (cement binder) thus increasing the efficiency of fiber reinforcement Elsaid, et al., (2011). Plain concrete is generally weak and brittle in tension compared to its capacity in compression, fiber reinforcing is a practical mean developed for a better control of the tensile performance as well as the tensile post-cracking and post-yield behaviors of concrete. Reinforcement by short and small diameter fibers to some extend can overcome these deficiencies. The randomly distributed fibers provide the material with significantly improved tensile strength, ductility, and toughness characteristics (Sen and Reddy, 2011).

2.7.1 Review of Works Natural Fibrous Reinforced Concrete

Several studies on the effect of Plaster of Paris (kenaf) fiber on mechanical properties of concrete have been conducted. Elsaid et al., (2011) investigated that KFRC generally exhibits more distributed cracking and higher toughness than plain concrete. They also found that cracking behaviour enhances the durability of concrete at relatively low cost compared to other types of fibers. They established that the optimum mixture proportions of KFRC are of 1.2% and 2.4% fiber contents.

Ngo et al., (2014) to investigate the effects of the addition of natural fibres (Kenaf and Oil Palm Fruit Bunch) on the mechanical properties of reinforced polymer composites. They found that tested composites showed improvement by adding natural fiber as reinforcement in both tensile and flexural strength.

Moses et al., (2015) investigated the compressive strength properties of kenaf fiber composite mortar with Fiber contents of 1%, 2% and 3 %. It is observed that the compressive strength decreased with increasing fiber volume and length. However, there was an increase in compressive strength of between 0.21% - 22.3% for composite mortar containing 1-3% volume of fiber with 10mm fiber length.

Hafizah et al., (2014) presented the experimental results of a series of tensile test conducted on continuous kenaf fiber with different types of thermoset resin. It is found that composites performance increased gradually with every increment of fiber volume fraction. Flexural properties of beams under static and cyclic loading conditions and behaviour of beam-column joints under cyclic loading have been carried out and it is concluded that rural fibers including coir and sugarcane natural fibers exhibit better performance than conventional concrete. Hence the past research activities on natural fibrous concrete focused on mechanical strength and microstructural studies at 28 days curing period only (Ramakrishana and Sundararajan, 2005: Sivaraja and Kandasamy, 2010: Savastano and Warden, 2005).

Hasan, et al., (2015) carried out an investigation into the suitability of Kenaf fiber to produce structural concrete. Concrete produced with kenaf fiber reinforced concrete (KFRC) with fiber volume contents are increasing 0%, 1%, 3% and 5% in the mix proportions. The concrete fresh properties consisting slump and density were determined in the laboratory. The compressive strength, compacting factor test, modulus of rupture, surface strength, and direct shear test of Kenaf fiber reinforced concrete specimens are investigated and compared to the properties of conventional concrete specimens. The experimental results indicate that the mechanical properties (Compressive and tensile strength) of Kenaf fiber reinforced concrete decrease with addition of kenaf fiber content. It was also observed that the addition of the fiber depressed the ultimate load of the concrete for compressive strength, modulus of rupture and direct shear test.

However, kenaf fiber concrete enhanced the toughness and ductility behaviour of the concrete compared with the conventional concrete.

Fook and Yatim, (2015) conducted a study on mechanical properties of kenaf fiber reinforced concrete with different fiber content and fiber length. Compressive strength, splitting tensile strength, and flexural strength of Kenaf fiber reinforced concrete (KFRC) were determined experimentally and the properties of plain concrete were used as a reference (control). The influence of five fiber contents (0.5%, 0.75%, 1.0%, 1.5%, and 2.0%) by volume of concrete and two fiber lengths (25 mm and 50 mm) added to the KFRC were investigated. The results indicate that the workability of Kenaf fiber reinforced concrete (KFRC) reduced compared to plain concrete. In terms of mechanical properties of Kenaf fiber reinforced concrete (KFRC), results revealed that compressive strength decreased with increase in fiber content. However, the study also observed that by adding appropriate fiber content and fiber length in concrete, the flexural strength and indirect tensile strength of concrete can increase and at the same time, the Kenaf fiber reinforced concrete (KFRC) can have compressive strength similar to that of plain concrete. Further, Kenaf fiber reinforced concrete (KFRC) generally exhibits more resistance to cracking and toughness than the plain concrete.

CHAPTER THREE

MATERIALS AND METHODS

These chapter present relevant materials and methods employed to accomplish the research goal. The method of collection, storage and preparation of samples before testing were clearly stated. All laboratory testing such as Particle Size Distribution test, Specific Gravity, Slump test, Compressive, Flexural and Split tensile strength test were conducted at Laboratory unit of Department of Civil Engineering, Nnamdi Azikiwe University, Awka Anambra State. Below are detailed description of Materials and Methods adopted in obtaining results.

3.1 Collection and Preparation of Materials

3.1.1 Cement

Ordinary Portland cement (Dangote cement) was used for the experimental study. This cement is designated as OPC. The cement was purchased at Onitsha Market in Anambra State. Upon purchase, the cement was conveyed to school laboratory where it was kept in a cool dry place preparatory for various laboratory testing. The cement sample satisfy the requirement for use as one of the major component of concrete in that, it was not caked or baked through visual inspection and quick setting time. Relevant laboratory test performed on the cement was soundness and fineness test.

3.1.2 Water

The water sample used for this experiment was collected within the school environment. The water sample passed all the necessary requirement for use as ingredient of concrete based on the fact that it is colourless, devoid of suspended solid particles, contains infinitesimal trace of dissolved solid particles with no trace of turbidity after being subjected to laboratory testing. The water was collected in three gallons (25 litre each).

3.1.3 Fine Aggregate (Sand)

Sand sample used in producing the concrete was obtained from a construction site situated at Nnamdi Azikiwe University Campus. The sand was sieved through 5.0mm test sieve before it was added to the concrete mix to ensure uniformity of particle size and also to remove impurities. After sieving, the aggregate were air-dried to a saturated state of an aggregate. Sieve analysis of the aggregate was conducted according to the ASTM C136 (2006). The sample passed the necessary requirement for use as ingredient of concrete based on the fact that it is gritty with particle sizes visible to the naked eyes, physical properties of the sand samples were determined prior to its incorporation into the concrete.

3.1.4 Coarse Aggregate (Crushed Granite)

Granite samples designated as GT was procured from Reynolds Construction Company (popularly known as RCC) at 9th mile in Enugu State. After procurement, the granite samples were conveyed to the laboratory unit of Department of Civil Engineering Nnamdi Azikiwe University Awka Anambra State where the index properties of the aggregate were determined. The granite sample was sieved before adding to the concrete so as to ensure uniformity of particle size and to remove impurities. Sieve analysis of the aggregate was conducted according to the ASTM C136 (2006). The granite sample passed all the necessary physical test in that, it has high crushing strength, it is relatively large in size (within range of 4.75mm to 20mm) and is a representative of granite (chippings) in color.

3.1.5 Plaster of Paris (Kenaf) Fiber

Plaster of Paris (Kenaf) fiber used for the experimental study was purchased from a building material vendor at Onitsha market in Anambra State. Upon purchase, the fiber was conveyed to the school laboratory where it was subjected to various laboratory testing. The water absorption ratio of the fiber was determined in accordance with ASTM D570-98 (2010).The fiber was kept in a safe place devoid of contamination before laboratory testing. Plaster of Paris fiber used for the experiment was added to the concrete mix in a stepped increase of 5% up to 30% by volume of the concrete mix.

Plate 3.1: Plaster of Paris (Kenaf) Fiber used for the study

3.2 Laboratory Testing

This section presents the experimental procedure and laboratory tests that were adopted for the project work. The tests conducted was conducted for all the constituents of concrete and this include: Sieve analysis test, Specific gravity test, Water absorption test, Compacted and bulk density test, Slump (workability) test of fresh concrete, Compressive, Flexural and Split tensile strength test of hardened concrete were carried out at Nnamdi Azikiwe University Civil Engineering Laboratory located inside the school campus. Below is a detailed description of test procedures and apparatus.

3.2.1 Particle Size Distribution (Sieve Analysis)

Sieve analysis is a procedure used to assess the particle size distribution of a granular material (sand, gravel). The size distribution is often of critical importance to the behaviour of the material during use. Sieve analysis can performed on any type of non-organic or organic granular material including sand, crushed rock, clay, granite, feldspar and a wide range of manufactured powders, grains and seed down to minimum size depending on the exact method. The standard grain size analysis test determines the relative proportion of different grain sizes as they are distributed among certain size ranges.

The particle size distribution (PSD) or sieve analysis were perform for coarse aggregate (granite), fine aggregate (sand) and additive (quarry dust) in order to determine the grading of each material in accordance with BS 812-103 (1990).

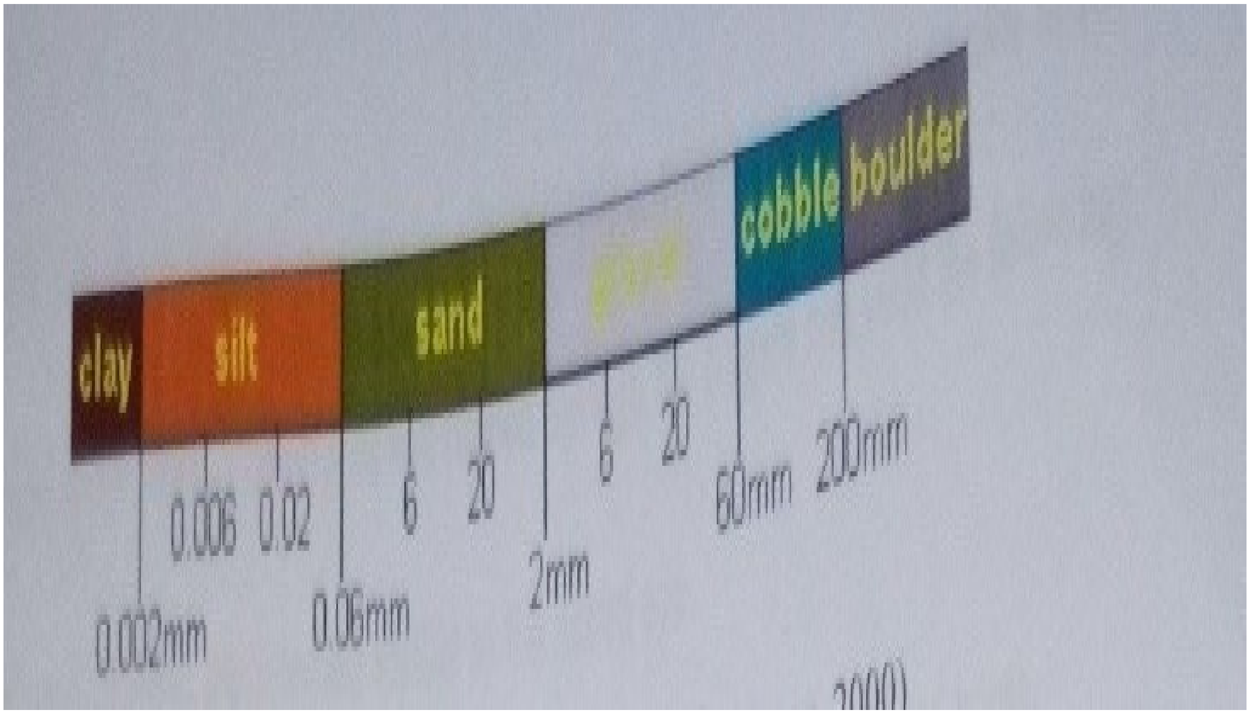

Plate 3.2 Ranges for grain Sizes of different Soil type (Atkinson, 2000).

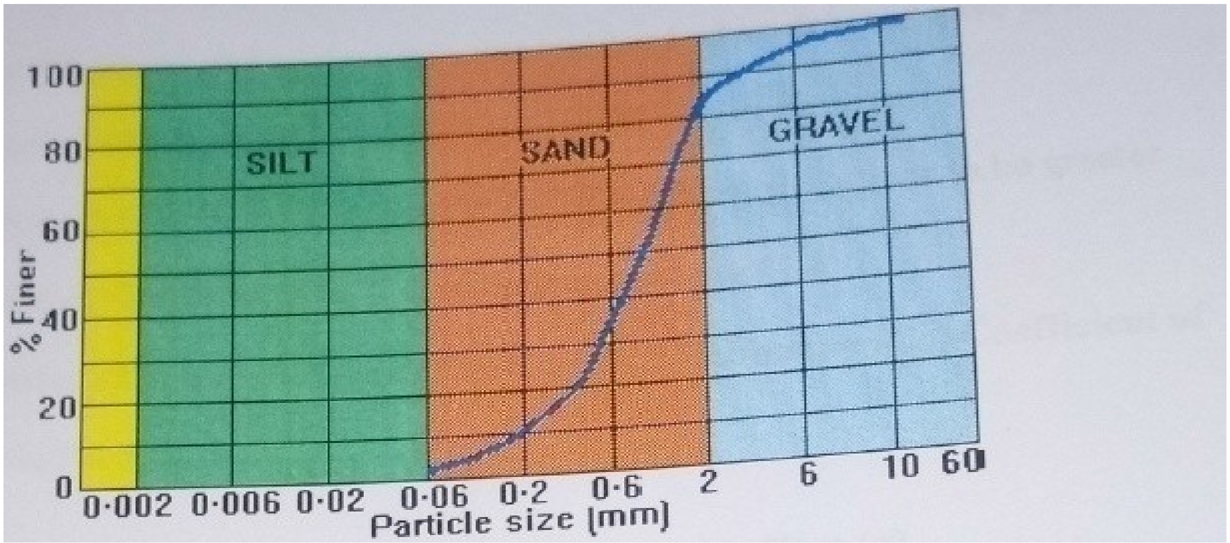

Plate 3.3 Grading Curve Ranges for Different Soil Types (Atkinson, 2000).

For a soil to be well graded the value of coefficient of uniformity (Cu) has to be greater than 4 and 6 for gravel and sand respectively, while the Coefficient of Curvature (C_v) should be in the range of 1 to 3.

The apparatus needed for this experiment is listed below:

1. Stack of sieves including pan and cover.
2. Mechanical sieve shaker.
3. Weighing balance of 0.01g sensitivity.
4. Hand brush
5. Mortar and pestle (Used for crushing if the sample is conglomerated or lumped)
6. Thermostatically controlled Oven (With temperature of about $80^{O}C$-$110^{O}C$).
7. Masking tape for identification of sample.
8. Exercise book and pen for recording of result.
9. The calculation for attaining Coefficient of uniformity and Coefficient of curvature are outlined below.

Percentage retained (%) = $\frac{mass\, of\, soil\, retai\, ned \in the\, sieve\,(g)}{total\, mass\, of\, soil\, sample\,(g)} \times 100$

Cumulative percentage retained = $\sum Percentage\, retained\,(\%)$

Cumulative Percentage Finer (%) = 100-Cummulative percentage retained.

Coefficient of Curvature = $\frac{D\,60}{\underset{¿}{D\,10}\,¿}$

Coefficient of Uniformity = $\frac{(D\,30)\,2}{D\,10 \times D\,60}$

Where

D10= particle size such that 10% of the soil is finer than the size

D30= particle size such that 30% of the soil is finer than the size.

D60= particle size such that 60% of the soil is finer than the size**.**

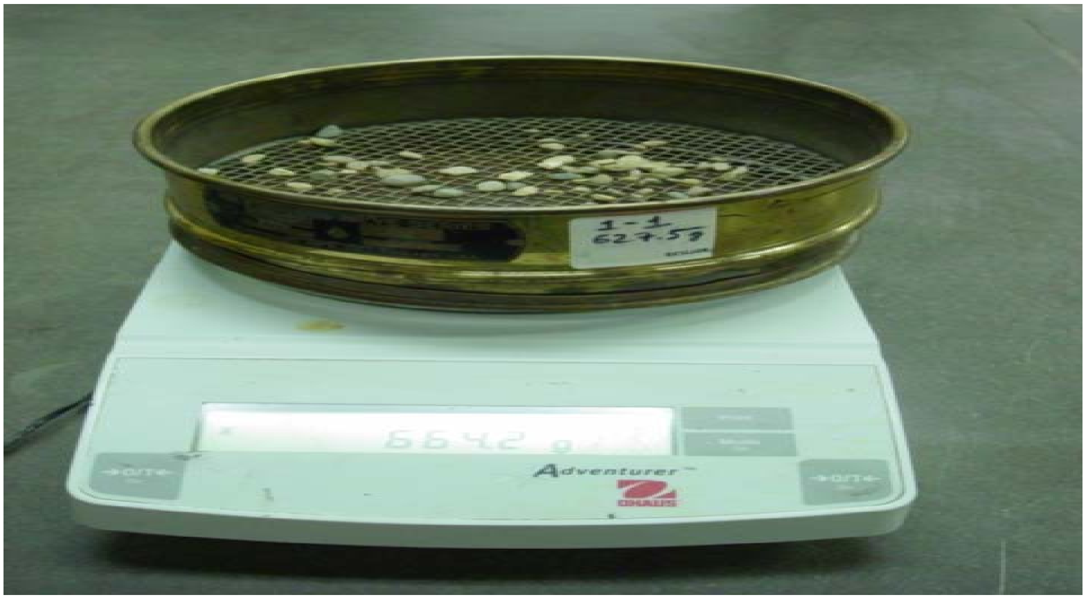

Plate 3.4 Apparatus for Particle Size Distribution Test.

Plate 3.5 Apparatus for Particle Size Distribution Test (Sieve Analysis).

Test Procedure

1. Clean properly the stack of sieves to be used for the experiment using hand brush.
2. Weigh about 500g of air-dried soil sample on a weighing balance.
3. Pour the weighed soil sample into 75um sieve and wash under a steady supply of water until clear water start coming out from the sieve after passing through the soil sample.

4. After washing pour the washed soil sample into a pre-weighed plate and dry it inside the thermostatically controlled oven at a controlled temperature of 80-110^{O}C for 16-24hrs.
5. Remove the sample from the oven and determine it weight (net weight) by deducting the weight of plate from the weight of plate and soil.
6. Arrange the stacks of sieve in the ascending order, place in a mechanical sieve shaker, and thereafter pour the sample and connect the shaker for about 10-15 minute.
7. Disconnect the sieve shaker and determine the mass retained on each of the sieve sizes.
8. Determine the percentage retained, Cumulative percentage retained and Cumulative percentage finer.
9. Plot the graph of sieve Cumulative percentage finer against sieve sizes.
10. Determine D10, D30 and D60 from the plotted graph.
11. Determine the Coefficient of Curvature and Coefficient of Uniformity and classify the soil using the American Association of State Highway and Transportation Official (AASHTO) and Unified Soil Classification System (USCS) respectively.

Plate 3.6: Weighing of Samples Retained on the Sieve

3.2.2 Specific Gravity for Fine Aggregate

Specific gravity is the ratio of mass of unit volume of soil at a stated temperature to mass of equal volume of gas-free distilled water at the same temperature (Krishna, 2002). Also as defined by (Braja, 2006), Specific gravity can be defined as the ratio of unit weight of a material to unit weight of water. The specific gravity of soil solids is often needed for various calculations in soil mechanics. It can be determined accurately in the soil laboratory.

The apparatus employed for this experiment includes:

1. Density bottle of 50ml capacity and a stopper.
2. Desiccator containing anhydrous silica gel.
3. Thermostatically controlled oven with temperature of about 80-110^{O}C.
4. Weighing balance of 0.01g sensitivity.
5. Mantle heater.
6. Plastic wash bottle.
7. Distilled water.
8. Funnel
9. Thin glass rod for stirring.
10. 425um Sieve.
11. Dry piece of cloth for cleaning.
12. Masking tape for identification of sample.
13. Exercise book and pen for recording of result.

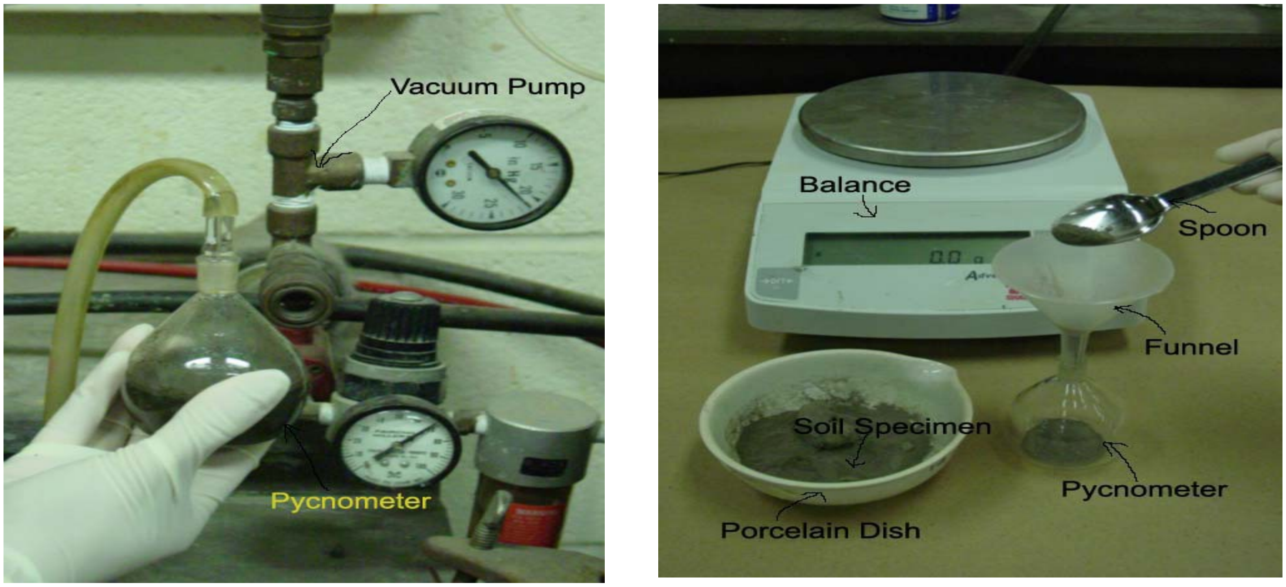

Plate 3.7: Apparatus used for Specific Gravity Test

3.2.3 Specific Gravity Test for Coarse Aggregate (Granite)

The specific gravity of aggregate is defined as the ratio of aggregate to the weight of equal volume of water. The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Aggregate having low specific gravity is generally weaker than those with high specific gravity. This property helps in general identification of aggregate.

Apparatus Used

1. Wire mesh Bucket or perforated container of convenient sizes with thin wire hangers for suspending it from a balance.
2. Pycnometer of 1000ml.
3. Set up consisting of container for filling water and suspending the wire basket in it and airtight container of capacity similar to that of a bucket, a shallow tray, two dry absorbent clothes.

Test Procedure

1. About 2 kg of aggregate sample is taken, washed to remove fines and then placed in the wire basket. The wire basket is then immersed in water, which is at a temperature of 22^0C to 32^0C.

2. Immediately after immersion the entrapped air is removed from the sample by lifting the basket 2mm above the base of the tank and allowing it to drop, 25 times at a rate of about one drop per second.

3. The basket, with aggregate are kept completely immersed in water for a period of 24 ± 0.5 hour.

4. The basket and aggregate are weighed while suspended in water, which is at a temperature of 22^0Cto 32^0C.

5. The basket and aggregates are removed from water and dried with dry absorbent cloth.

6. The surface dried aggregates are also weighed.

7. The aggregate is placed in a shallow tray and heated to about 110^0C in the oven for 24 hours. Later, it is cooled in an airtight container and weighed.

3.2.4 Compressive Strength Test of Hardened Concrete Cube

The test method covers determination of compressive strength of cubic concrete specimens. It consists of applying a compressive axial load to molded cubes at a rate which is within a prescribed range until failure occurs.

The Apparatus Used includes:

1. **Testing Machine -** The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.
2. **Cube Moulds -** The mould shall be of 150 mm size conforming to IS: 10086-1982.
3. Weights and weighing device
4. Tools and containers for mixing,
5. Tamper (square in cross section)

Test Procedure

1. **Sampling of Materials -** Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.

2. **Proportioning -** The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.

3. **Weighing -** The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

4. **Mixing Concrete -** The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

5. **Mould -** Test specimens cubical in shape shall be 150mm × 150mm × 150mm .If the largest nominal size of the aggregate does not exceed 20mm, 10omm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter.

6. **Compacting -** The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

7**. Curing -** The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27°± 2°C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients.

8. **Placing the Specimen in the Testing Machine -** The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression plates.

9. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom

10. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.

11. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.

12**.** The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted.

The compressive strength of concrete cube is computed as follows:

Compressive Strength (N/mm^2) = $\frac{Applied\ load\ (N)}{Area\ of\ Cube\ (mm \times mm)}$

Where applied load (N) = Force

Now conversion of applied load from Ton force to KN or N.

1 Ton force = 10kN or 10,000N.

For 220kN = 220× 1000 = 220,000N

Area of cube = 150mm×150mm = 22,500mm^2

Compressive Strength = $\frac{220,000\,N}{22,500\,mm2}$ = 9.78N/mm^2

Plate 3.8: Universal Testing Machine for Compressive Strength Test

Plate 3.9: Arrangement of Kenaf Fiber used for Production of Concrete Cubes

3.2.5 Slump (Workability) Test

Slump test is used to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work. This test was conducted according to standard as stated in BS 1881 part 102, (1983).

The procedures are as follows:

1. Clean the internal surface of the mold and apply oil.
2. Place the mold on a smooth horizontal non- porous base plate.
3. Fill the mold with the prepared concrete mix in 4 approximately equal layers.
4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mold. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mold and the base plate.
7. Raise the mold from the concrete immediately and slowly in vertical direction.
8. Measure the slump as the difference between the height of the mold and that of height point of the specimen being tested.

Calculation

Slump = Height of the slump cone – Height of the unsupported concrete.

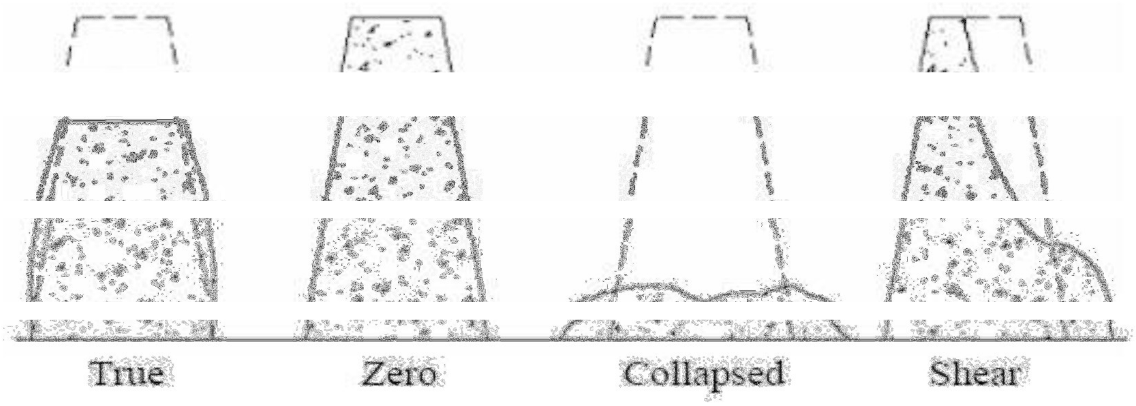

Figure 3.1: Types of Concrete Slump Test Results.

1. True Slump – True slump is the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cone has been removed as shown above. In a true concrete just subsides shortly and more or less maintain the mould shape. This type of slump is most desirable and represents the reliable condition to get an idea about the workability of concrete.
2. Zero Slump – Zero slump is the indication of very low water-cement ratio, which results in dry mixes. This type of concrete is generally used for road construction. In this slump, the concrete maintains the actual shape of the mould as it is said to be stiff, consistent and almost non-workable.
3. Collapsed Slump – In the case, fresh concrete collapses completely. This is an indication that the water-cement ratio is too high, i.e. concrete mix is too wet or it is a high workability mix, for which a slump test is not appropriate.
4. Shear Slump – In this case, one-half of the cone slide down in an inclined plane, this slump indicates lack of cohesion in the concrete mix. Shear slump may occur in case of a harsh mix.

Plate 3.10: Apparatus used for Slump Test

3.2.6 Flexural Strength Test of Hardened Concrete

Age at Test - Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. Where it may be necessary to obtain the early strengths, tests may be made at the ages of 24 hours ±½ hour and 72 hours ± 2 hours. The ages shall be calculated from the time of the addition of water to the dry ingredients.

Number of Specimens - At least three specimens, preferably from different batches, shall be made for testing at each selected age.

Apparatus

Testing Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.

Beam Moulds - The beam moulds shall conform to IS: 10086-1982. The standard size shall be 150mm × 150mm × 700mm. Alternatively, if the largest nominal size of the aggregate does not exceed 19 mm, specimens 100mm × 100mm × 500mm may be used.
Weights and weighing device, Tools and containers for mixing, Tamper (square in cross section).

Test Procedure

1. Sampling of Materials - Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.

2. Proportioning - The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.

3. Weighing - The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.
4. Mixing Concrete - The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

5. Mould - The standard size shall be 150mm × 150mm × 700mm. Alternatively, if the largest nominal size of the aggregate does not exceed 19 mm, specimens 100mm × 100mm × 500mm may be used.

6. Compacting - The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

7. Curing - The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients.

8. Placing the Specimen in the Testing Machine - The bearing surfaces of the supporting and loading rollers shall be wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers.

The specimen shall then be placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould, along two lines spaced 20.0 or 13.3 cm apart.

10. The axis of the specimen shall be carefully aligned with the axis of the loading device. No packing shall be used between the bearing surfaces of the specimen and the rollers.

11. The load shall be applied without shock and increasing continuously at a rate such that the extreme fiber stress increases at approximately 7 kg/sq cm/min, that is, at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens.

12. The load shall be increased until the specimen fails, and the maximum load applied to the specimen during the test shall be recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure shall be noted.

3.2.9 Split Tensile Strength of Hardened Concrete

Split tensile Strength test is a mechanical test conducted on concrete to determine the maximum load that can be applied to concrete cubes before rupture. Concrete tensile strength is the ability of the concrete to resist tensile force or stress applied to it. The tensile strength of concrete is measured by the split cylinder test of concrete method.

Apparatus Used

Testing Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.

Cylinders -The cylindrical mould shall be of 150mm diameter and 300mm height conforming to IS: 10086-1982.

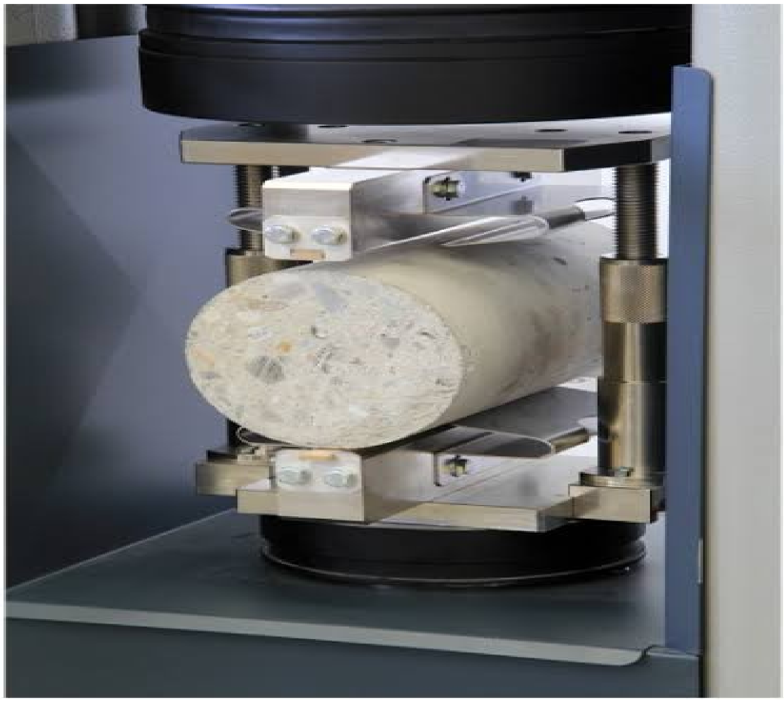

Plate 3.11: Split Tensile Strength Test Machine

Procedure

1. **Sampling of Materials -** Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.

2. **Proportioning -** The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.

3. **Weighing -** The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

4. **Mixing Concrete -** The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

5. **Mould -** The cylindrical mould shall be of 150mm diameter and 300mm height conforming to IS: 10086-1982.

6. **Compacting -** The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

7. **Curing -** The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°C for 24hours ± ½hour from the time of addition of water to the dry ingredients.

8. **Placing the Specimen in the Testing Machine -** The bearing surfaces of the supporting and loading rollers shall be wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers.

9. Two bearings strips of nominal (1/8 in i.e 3.175mm) thick plywood, free of imperfections, approximately (25mm) wide, and of length equal to or slightly longer than that of the specimen should be provided for each specimen.

10. The bearing strips are placed between the specimen and both upper and lower bearing blocks of the testing machine or between the specimen and the supplemental bars or plates.

11. Draw diametric lines an each end of the specimen using a suitable device that will ensure that they are in the same axial plane. Center one of the plywood strips along the center of the lower bearing block.

12. Place the specimen on the plywood strip and align so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip.

13. Place a second plywood strip lengthwise on the cylinder, centered on the lines marked on the ends of the cylinder. Apply the load continuously and without shock, at a constant rate within, the range of 689 to 1380kPa/min splitting tensile stress until failure of the specimen

14. Record the maximum applied load indicated by the testing machine at failure. Note the type of failure and appearance of fracture.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents key findings relevant in evaluating the effect of pop fibers on strength properties of concrete. These findings are presented below:

4.1 Results

Table 4.0: Physical Properties of Concrete Components Employed in the Research

Properties	**GT**	**SD**
Specific Gravity	**2.61**	**2.55**
Coefficient of Uniformity (Cu)	**1.42**	**-----------**
Coefficient of Curvature (Cc)	**0.8**	**-------**
Percentage Passing Sieve Size 0.075mm	**------------**	**22.36**
Percentage Passing Sieve Size 4.75mm	**1.63**	**----------**
AASHTO Classification System	**A-1-b**	**A-2-4**
Unified Soil Classification System	**GC**	**SM**

Table 4.1: Slump Test Result for Concrete at varying percentages of Pop Fibers

Percentage Replacement of Pop Fibers (%)	**Height of Slump Cone (mm)**	**Height of Collapse (mm)**	**Slump Value at 0.55w/c ratio (mm)**	**Slump Type**
0	**300**	**265**	**35**	**True Slump**
2.5	**300**	**270**	**30**	**True Slump**
5	**300**	**275**	**25**	**True Slump**
7.5	**300**	**278**	**22**	**True Slump**
10	**300**	**285**	**15**	**True Slump**

Table 4.2: Average Density Results for Concrete produced at varying percentages of Pop Fibers

Percentages of Pop Fibers (%)	**Average Density (kg/m^3)**
0	**2343**
2.5	**2394**
5	**2434**
7.5	**2393**
10	**2358**

Table 4.3: Average Density Results for Concrete produced at varying intervals of Curing Days

Curing Days (Age)	**Average Density (kg/m^3)**
7	**2330**
14	**2393**
21	**2430**

Table 4.4: Average Compressive Strength Results for Concrete produced at varying percentages of Pop Fibers

Percentages of Pop Fibers (%)	**Average Compressive Strength (N/mm^2)**
0	**23.45**
2.5	**23.54**
5	**23.72**
7.5	**23.39**
10	**22.80**

Table 4.5: Average Compressive Results for Concrete produced at varying intervals of Curing Days

Curing Days (Age)	**Average Compressive Strength (N/mm^2)**
7	**22.96**
21	**23.36**
28	**24.02**

Table 4.6: Average Flexural Strength Results for Concrete produced at varying percentages of Pop Fibers

Percentages of Pop Fibers (%)	**Average Flexural Strength (N/mm^2)**
0	**12.32**
2.5	**12.49**
5	**12.54**
7.5	**11.75**
10	**11.37**

Table 4.7: Average Flexural Strength Results for Concrete produced at varying intervals of Curing Days

Curing Days (Age)	**Average Flexural Strength (N/mm^2)**
7	**11.72**
28	**12.47**

Table 4.8: Average Split Tensile Strength Results for Concrete produced at varying percentages of Pop Fibers

Percentages of Pop Fibers (%)	Average Split Tensile Strength (N/mm^2)
0	7.27
2.5	7.45
5	6.74
7.5	6.21
10	5.87

Table 4.9: Average Split Tensile Strength Results for Concrete produced at varying intervals of Curing Days

Curing Days (Age)	Average Flexural Strength (N/mm^2)
7	6.38
28	7.03

4.2 Analysis of Results

4.2.1 Specific Gravity

Figure 4.0 shows the specific gravity values obtained for granite and sand respectively. Comparative deduction revealed that granite sample with a specific gravity of 2.61 recorded the highest specific gravity value. The specific gravity of the aggregate samples tested was greater than 2.4 and as a result, they are classified as normal weight aggregate. The classification was done in accordance with the specification given by Popovics, (2014) on weight classification of aggregate based on their respective specific gravity values. Popovics, (2014) stated that aggregate with specific gravity value less than 2.4 are classified as light weight aggregate while aggregate with specific gravity value exceeding 2.4 are classified as normal weight aggregate which correlate with the result obtained by the study. The range of specific gravity values (2.55 - 2.61) obtained by the study for sand and granite satisfied ASTM D854-14 requirements which state that the specific gravity of aggregate used for concrete production should lie between 2.55

to 2.9 and therefore, the result obtained justifies the use of this aggregates for the study. This finding is consistent with the works of Apeh and Ogunbode, (2012).

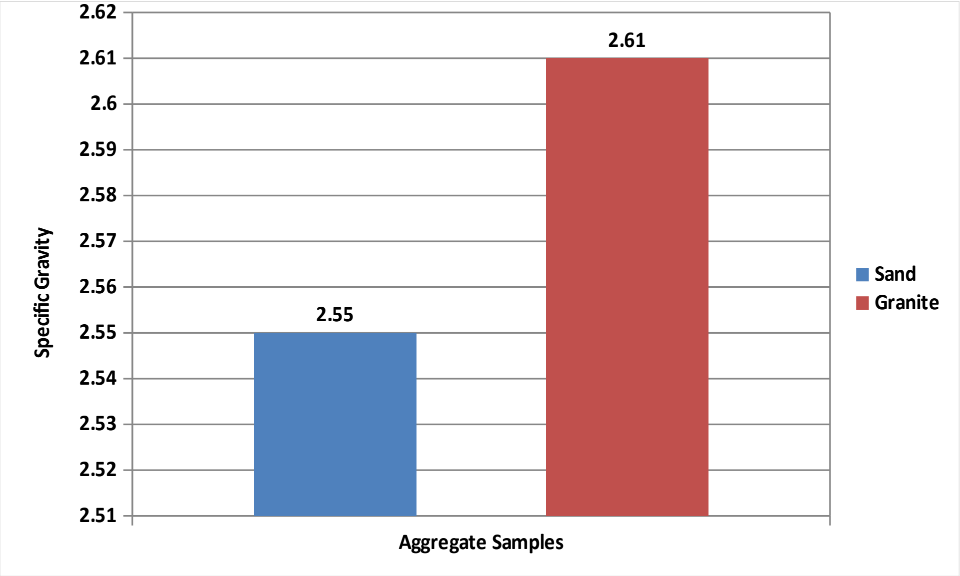

Figure 4.0: Specific Gravity of Sand and Granite

4.2.2 Sieve Analysis

Figure 4.1 is a semi logarithmic plot of the particle size distribution of granite, sand and samples respectively. Results obtained revealed that the percentage passing through sieve size 4.75mm for GT was 0.16, coefficient of uniformity and curvature were 1.42 and 0.82 and according to AASHTO classification system, the granite sample was classified as A-1-b and Clayey gravel (SC) according to unified soil classification system. The percentage passing through sieve size 0.075mm for sand was 22.36 and as a result, sand are classified as A-2-4 according to AASHTO Classification System, Silty sand (SM) according to unified soil Classification System. The shape parameters (coefficient of uniformity and coefficient of curvature) for sand samples cannot be obtained from the graph and as a result, gradation of sand samples cannot be ascertained.

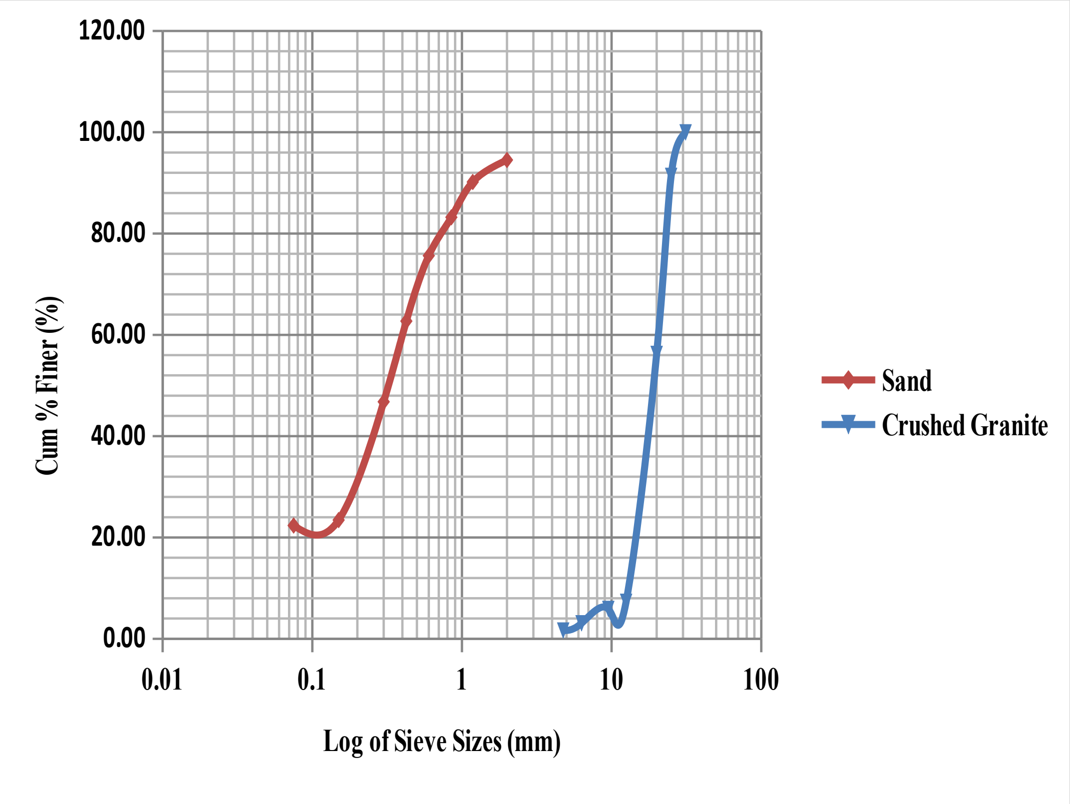

Figure 4.1: Particle Size Distribution Curve for Sand and Granite

4.2.3 Slump (Workability)

Figure 4.2 and Table 4.2 shows the slump test result for both the plain and pop fiber reinforced concrete. The slum value of both the plain and pop fiber reinforced concrete ranged from 15-35mm. On addition of pop fiber to the concrete, it was observed that the slump of the concrete decreased from 35mm to 15mm after 10% addition of pop fiber to the fresh concrete. The decrease in slump could be attributed to the high water absorption capacity of Pop fibers. As more water is absorbed by the fiber during mixing, the water content required for hydration of cement is reduced which invariably reduces the workability of the fresh concrete. However, it was observed that the slump type formed by both the plain and pop fiber reinforced concrete were true slump since their slump value does not exceed 40mm.

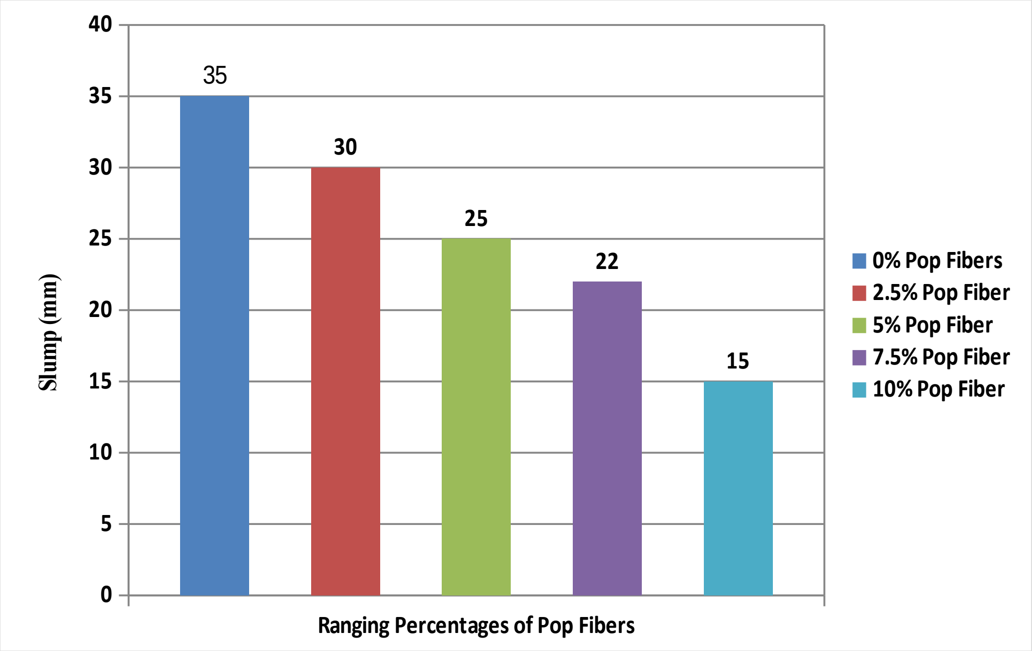

Figure 4.3: Graph Showing the Slump of the Fresh Concrete at Varying Percentages of Pop Fiber

4.2.4 Compressive Strength

Figure 4.4 and 4.5 shows the compressive strength of plain and pop fiber reinforced concrete. Results obtained revealed that the compressive strength of the hardened concrete increased with curing age for both plain and pop fiber reinforced concrete. It was also observed that on addition of varying percentages of pop fiber ranging from 2.5% to 10% to the concrete, the compressive strength of the concrete increased from 2.5% pop fiber content to 5% pop fiber content beyond 5% pop fiber content, the compressive strength decreased. A Sharp decline in compressive strength was observed at 10% addition of the pop fiber to the concrete. The decline in compressive strength of the hardened concrete on addition of high content of pop fibers to the concrete could be attributed to the low density of the fibers and slump of the fresh concrete produced by addition of pop fibers. The high water absorption capacity of the fibers is also responsible for decline in compressive strength as more water is absorbed by the fiber while mixing thereby reducing the water content required for hydration process of cement with water. High fiber content increases the agglomeration in concrete making the concrete more porous, thereby reducing its strength. The finding obtained is in agreement with the works of Lam and Yatin, (2015) and Azzim and Yatim, (2018).

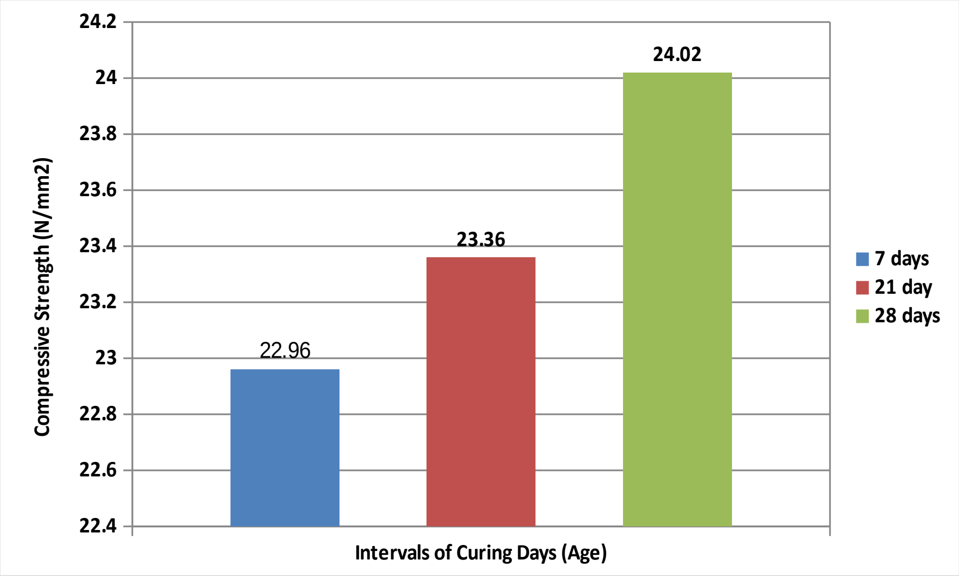

Figure 4.4: Graph of Compressive Strength against Curing Days

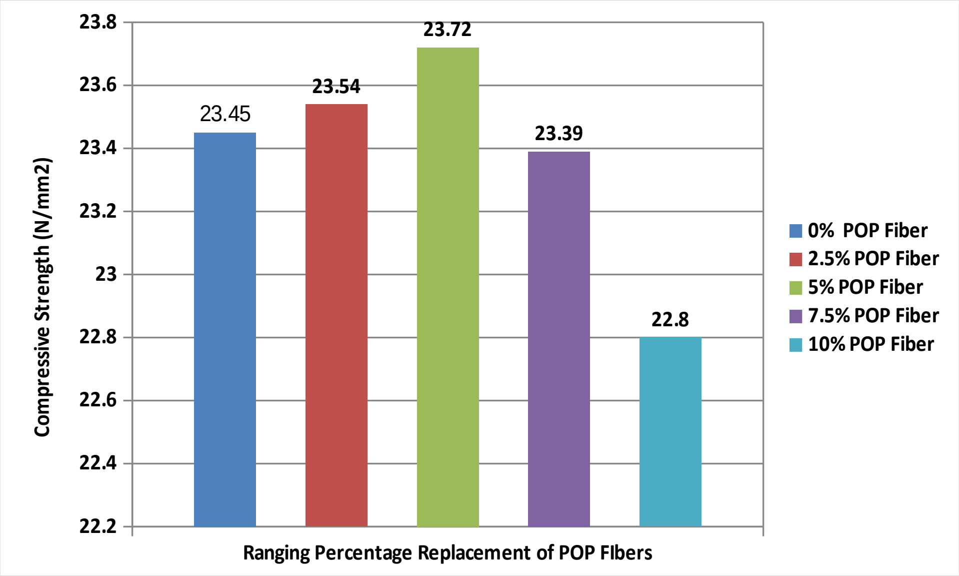

Figure 4.5: Graph of Compressive Strength against Percentage Replacement of Pop Fibers.

4.2.5 Flexural Strength

The results of flexural strength test are shown in Table 4.5 and Figure 4.6 and 4.7 respectively. Results obtained from the flexural strength test were similar to that obtained for compressive strength. It was observed that the flexural strength of the hardened concrete increased with curing days. This result is in agreement with that obtained by Lam and Yatim, (2015) which shows that the flexural strength increased with curing days. On addition of pop fiber to the concrete, it was observed that the flexural strength increased from 2.5% addition of pop fibers to 5% addition of pop fiber beyond 5% addition of pop fiber, the flexural strength decreased. The initial improvement in flexural strength of the hardened concrete could be attributed to the bending strength of pop fiber reinforced concrete which decreased with increasing content of the fibers.

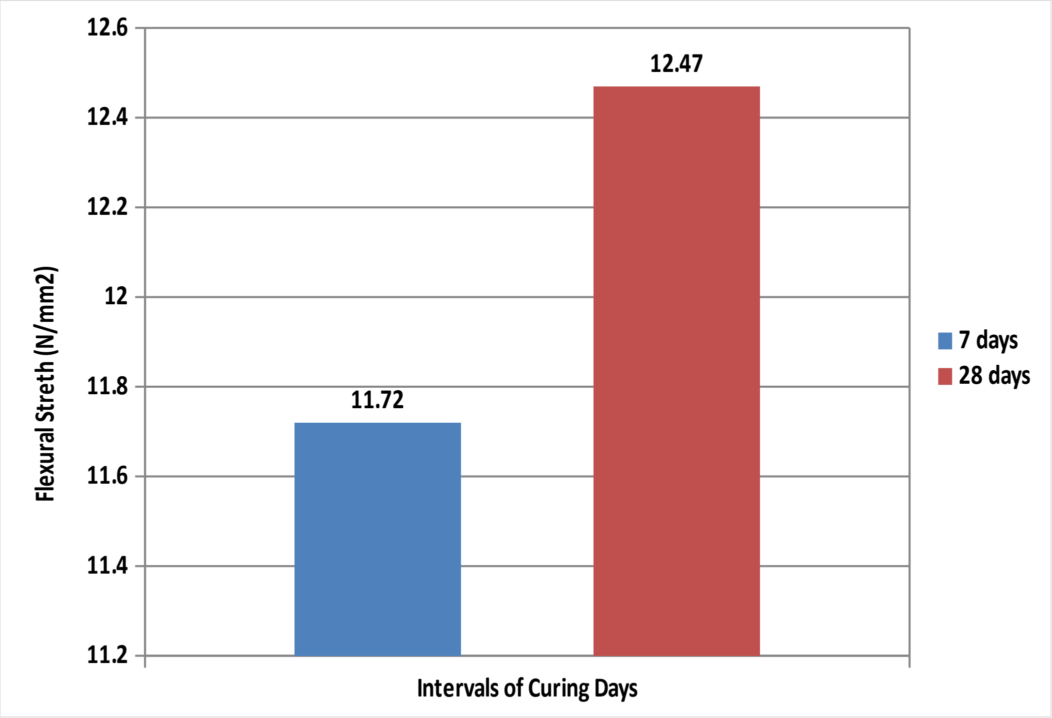

Figure 4.6: Graph of Flexural Strength against Curing Days

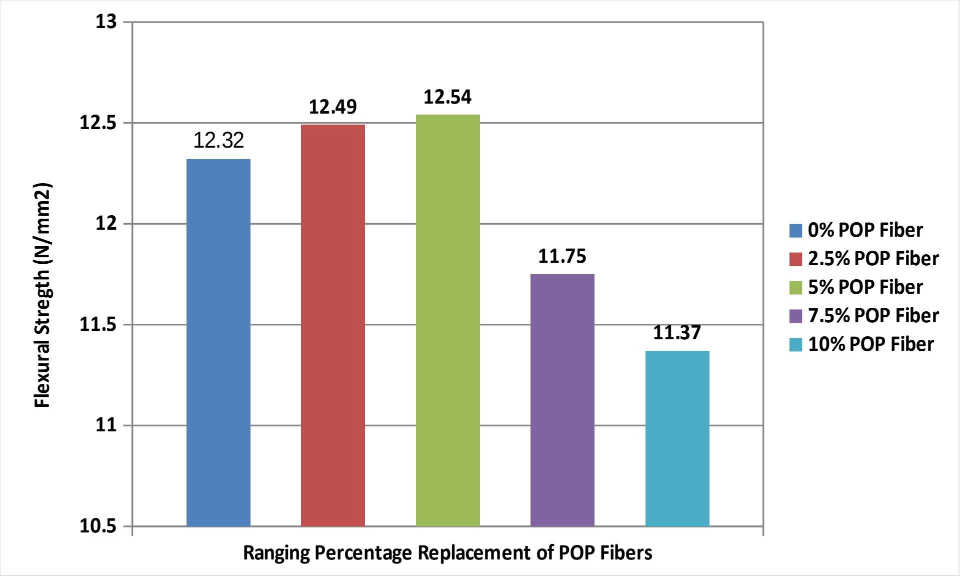

Figure 4.8: Graph of Flexural Strength against Percentage Replacement of Pop Fibers

4.2.6 Split Tensile Strength

Results obtained from split tensile strength test revealed that the tensile strength of pop fiber reinforced concrete was slightly higher than that of the plain concrete (non pop fiber reinforced concrete). It was observed that the split tensile strength of the concrete increased from 0% pop fiber content to 2.5% pop fiber content, beyond 2.5% pop fiber content, the split tensile strength decreased. The increase in tensile strength could be attributable to the ductile nature of pop fibers. Pop fiber reinforced concrete carries tension efficiently compared to plain concrete and absorb considerably substantial amount of energy than plain concrete. Works indicative of these findings are the works of Lam and Yatin, (2015) and Azzim and Yatim, (2018).

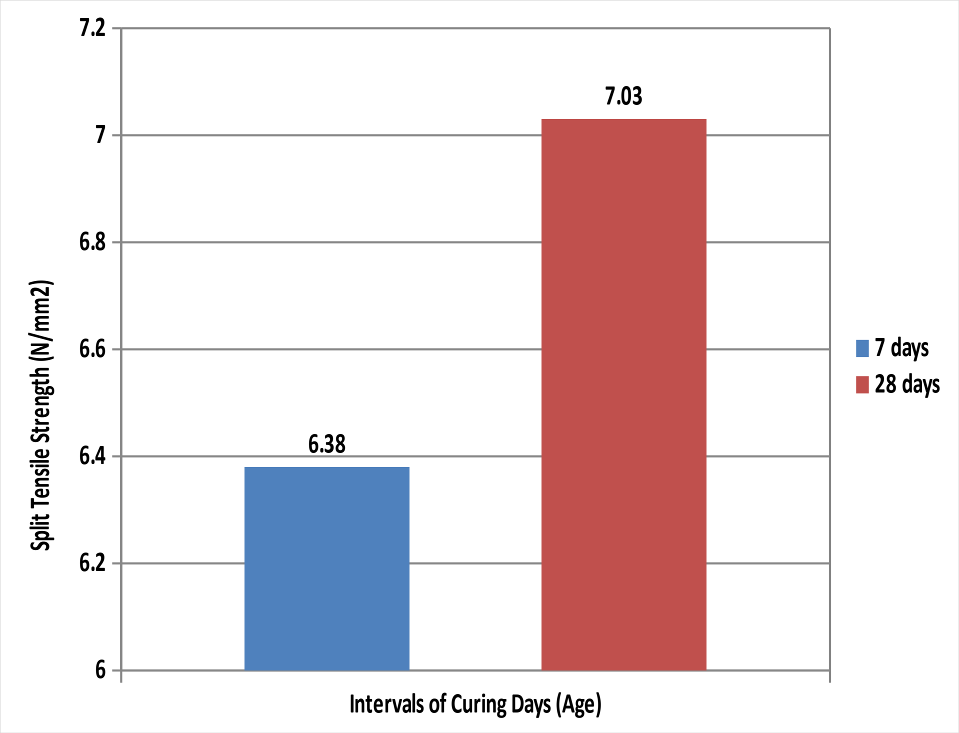

Figure 4.9: Graph of Split Tensile Strength against Curing Days

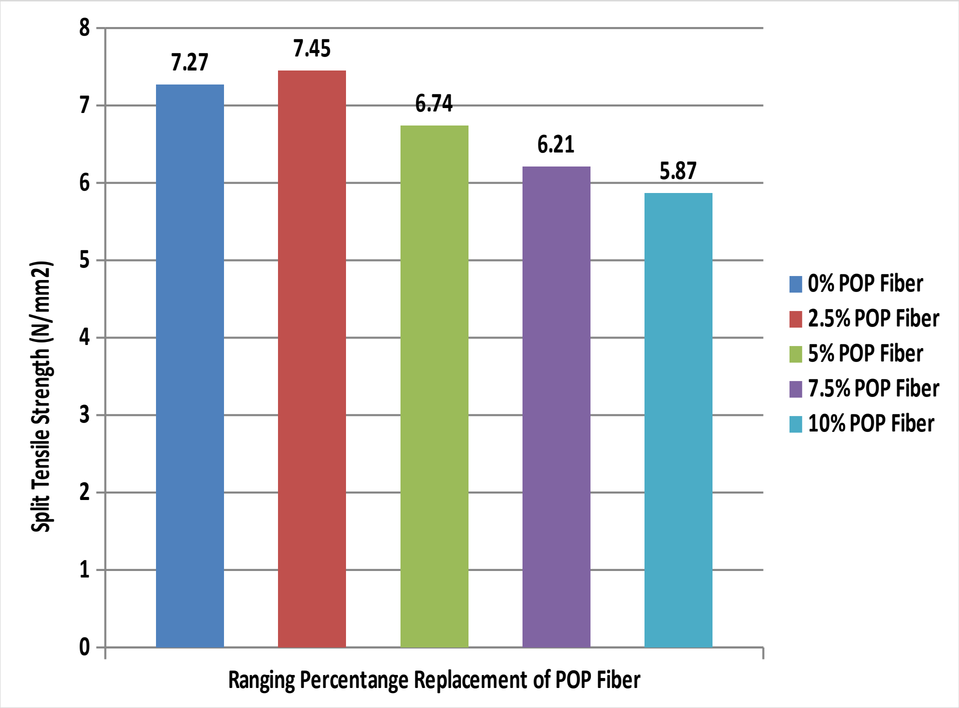

Figure 4.10: Graph of Split Tensile Strength against Percentage Replacement of Pop Fibers

4.2.7 Hardened Concrete Density

The increase in pop fiber content increased the density of the hardened concrete up to 5% pop fiber content. The decline in density could be ascribed to the reduction in cement paste in the concrete due to addition of high percentages of pop fibers in the sense that, the presence of pop fibers reduced the reaction between cement and water. The reduction in hydration process prevents the production of calcium silicate and calcium hydroxide which is a major contributor to concrete density. It was also observed that the concrete type formed by pop fiber reinforced concrete were normal weight concrete since the density of the concrete after 10% addition of pop fibers were greater than 1800kg/m^3 (Braja, 2006).

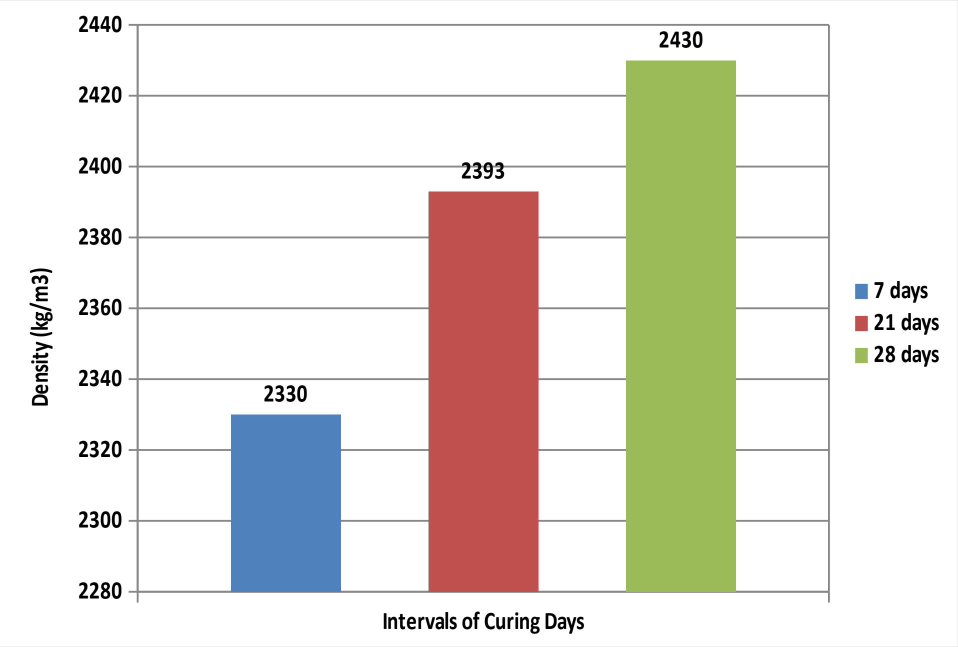

Figure 4.11: Graph of Density against Curing Days

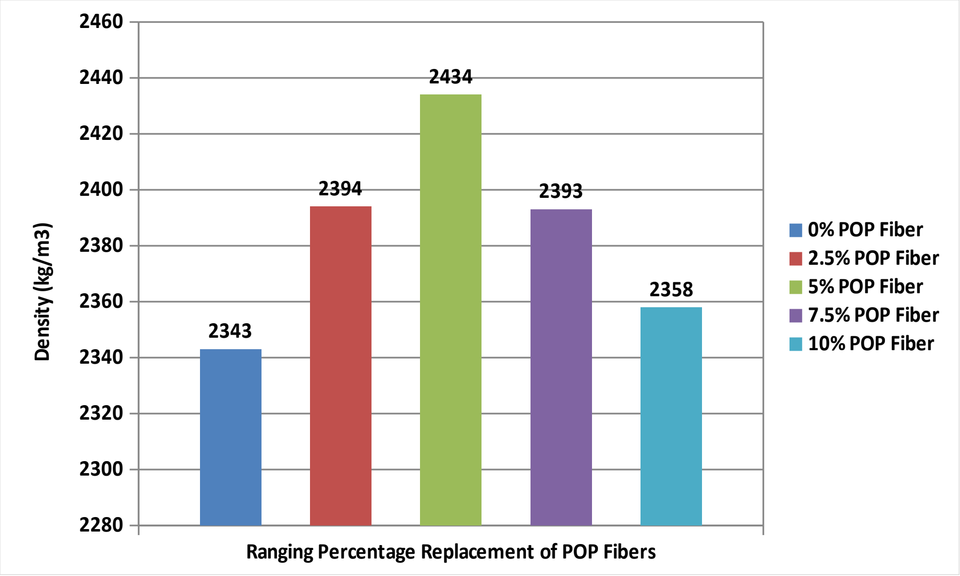

Figure 4.12: Graph of Density against Percentage Replacement of Pop Fibers

4.3 Failure Mode Evaluation

The cracking pattern of plain and pop fiber reinforced concrete are shown in Figure 4.13 and 4.14 respectively. The cracking was done using universal testing machine. It was observed that pop fiber reinforced concrete expands time of cracking compared to plain concrete. The fiber reduced the micro cracks and held the concrete together when receiving ultimate load. The energy absorption of aggregate reduced the brittle nature of plain concrete. It was also observed that failure of the plain concrete (control) occurred due to the formation of single cracks. However, for pop fiber reinforced concrete, when similar crack occurred, the presence of the fiber helped to bridge the cracks and the crack is smaller as shown in Figure 4.14 which led to a more ductile failure mode with greater toughness and residual strength.

Figure 4.13: Failure Mode of Plain Concrete (Control)

Figure 4.14: Failure Mode of Pop Fiber Reinforced Concrete

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the findings obtained on strength enhancement of concrete using pop fibers, the following conclusion can be drawn.

1. Preliminary investigation of the aggregate samples employed in the study showed that the specific gravity of sand and granite were 2.55 and 2.61, sand was classified as A-2-4 according to AASHTO Soil Classification System and SM (sand mixed with silt) according to Unified Soil Classification System, granite on the other hand were classified as A-1-b according to AASHTO Soil Classification System and GC (gravel mixed with clay) according to Unified Soil Classification System.
2. The slump of the fresh concrete decreased with increasing percentages of pop fibers with the slump type formed as true slump.
3. The compressive and flexural strength of the concrete increased from 2.5% pop fiber content to 5% pop fiber content, beyond 5% pop content, the compressive and flexural strength of the hardened concrete decreased.
4. The split tensile strength of pop fiber reinforced concrete were slightly higher than the plain concrete with the tensile strength decreasing beyond 2.5% pop fiber addition to the concrete.
5. The density of the concrete increased from 2.5% pop fiber content to 5% pop fiber content, beyond 5% pop content, the density of the hardened concrete decreased.
6. Failure mode analysis revealed that the plain concrete failed due to the occurrence of single cracks while the pop fiber reinforced concrete exhibited ductile failure mode with residual toughness and strength.
7. Pop fiber was adjudged as feasible and a reasonably effective modifier for strength enhancement in concrete since a reasonable improvement in compressive strength of the hardened concrete was observed.

5.2 Recommendation

The following recommendation based on the findings obtained from the study on strength properties of concrete reinforced with pop fibers is as follows:

1. Concrete reinforced with pop fibers should not be used for structural purposes.
2. The study discourage the use of pop fiber in concrete beyond 10% as exceeding this limit could undermine the density and invariably the strength of the concrete.

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APPENDICES

APPENDIX A

SIEVE ANALYSIS TEST

Table A1: Sieve Analysis Result for Granite.

Sieve Sizes (mm)	Mass Retained	Percentage Mass Retained	Cumulative Percentage Retained	Cumulative Percentage Finer
31.5	0.14	0.01	0.01	99.99
25	88.5	8.59	8.60	91.40
20	362.11	35.16	43.76	56.24
12.5	504	48.93	92.69	7.31
9.5	14.61	1.42	94.11	5.89
6.3	29.02	2.82	96.93	3.07
4.75	14.83	1.44	98.37	1.63
Tray	12.44	1.21	99.57	0.43
	1025.65			

Table A2 Sieve Analysis Result for Sand.

Sieves Sizes (mm)	Mass Retained	% Mass Retained	Cumulative Retained	Cumulative Finer (%)
2	16.42	5.4733333	5.4733333	94.526667

1.18	**13.07**	**4.3566667**	**9.83**	**90.17**
0.86	**20.89**	**6.9633333**	**16.793333**	**83.206667**
0.6	**22.74**	**7.58**	**24.373333**	**75.626667**
0.425	**38.75**	**12.916667**	**37.29**	**62.71**
0.3	**47.76**	**15.92**	**53.21**	**46.79**
0.15	**70.04**	**23.346667**	**76.556667**	**23.443333**
0.075	**3.27**	**1.09**	**77.646667**	**22.353333**
Tray	**1.03**	**0.3433333**	**77.99**	**0**

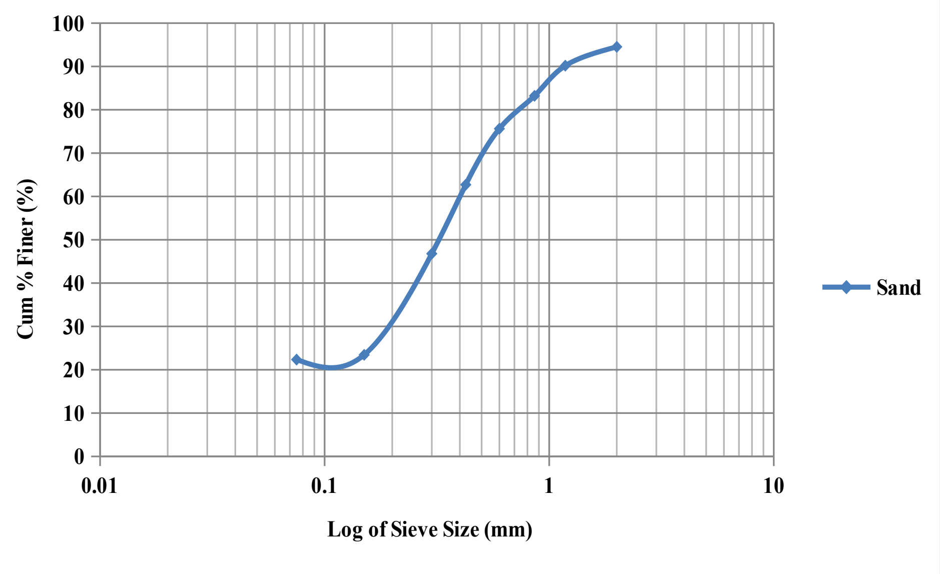

Figure A1: Particle Size Distribution Curve for Sand

APPENDIX B

SPECIFIC GRAVITY TEST

Table B1. Specific Gravity Result for Sand

Determinants	**Trial 1**	**Trial 2**	**Trial 3**
Wt of density bottle, W_1 (g).	**24.50**	**25.32**	**25.12**
Wt of bottle + dry soil, W_2 (g).	**34.48**	**35.31**	**35.10**
Wt of bottle + soil + water, W_3 (g).	**84.43**	**86.39**	**85.03**
Wt of bottle + water, W_4 (g).	**78.35**	**80.32**	**78.93**

The Specific gravity of the sample is calculated as follows:

Specific Gravity for Sand.

Trial 1 (G_{S1}) = $\frac{(W2-W1)}{(W2-W1)-(W3-W4)} = \frac{(34.48-24.50)}{(34.48-24.50)-(84.43-78.35)}$ **= 2.56**

Trial 2 (G_{S2}) = $\frac{(W2-W1)}{(W2-W1)-(W3-W4)} = \frac{(35.31-25.32)}{(35.31-25.32)-(86.39-80.32)}$ **= 2.55**

Trial 3 (G_{S3}) = $\frac{(W2-W1)}{(W2-W1)-(W3-W4)} = \frac{(35.10-25.12)}{(35.10-25.12)(85.03-78.93)}$ **=2.53**

Specific Gravity = $\frac{(GS1+GS2+GS3)}{3} = \frac{(2.56+2.55+2.53)}{3}$ **= 2.55**

Table B2: Specific Gravity Result for Crushed Granite.

Determinants	**Trial 1**	**Trial 2**	**Trial 3**
Wt of Saturated aggregate and basket in water W_1 (g).	**458.72**	**460.68**	**462.46**
Wt of basket in Water W_2 (g).	**190.48**	**192.84**	**192.88**
Wt of Saturated aggregate in air W_3 (g).	**438.62**	**442.24**	**440.82**
Wt of Oven-dried aggregate in air W_4 (g).	**432.80**	**434.28**	**434.86**

The Specific gravity of the sample is calculated as follows:

Apparent Specific Gravity for Crushed Granite.

Trial 1 (G_{S1}) = $\frac{W4}{¿¿} = \frac{432.80}{¿¿}$ **= 2.63**

Trial 2 (G_{S2}) = $¿¿ = \frac{434.28}{¿¿}$ **= 2.61**

Trial 3 (G_{S3}) = $\frac{W4}{¿¿} = \frac{434.86}{¿¿}$ **= 2.60**

Apparent Specific Gravity = $\frac{(GS1+GS2+GS3)}{3} = \frac{(7.84)}{3}$ **= 2.61**

Bulk Specific Gravity for Crushed Granite.

Trial 1 (G_{S1}) = $\frac{W4}{¿¿} = \frac{432.80}{¿¿}$ **= 2.48**

Trial 2 (G_{S2}) = $\frac{W4}{¿¿}$ **=** $\frac{434.28}{¿¿}$ **= 2.49**

Trial 3 (G_{S3}) = $\frac{W4}{¿¿}$ **=** $\frac{434.86}{¿¿}$ **=2.54**

Bulk Specific Gravity = $\frac{(GS1+GS2+GS3)}{3}$ = $\frac{(2.48+2.49+2.54)}{3}$ **= 2.50**

APPENDIX C

SLUMP TEST

Table C1: Slump Test Result for Concrete at varying percentages of Pop Fibers

Percentage Replacement of Pop Fibers (%)	Height of Slump Cone (mm)	Height of Collapse (mm)	Slump Value at 0.55w/c ratio (mm)	Slump Type
0	300	265	35	True Slump
2.5	300	270	30	True Slump
5	300	275	25	True Slump
7.5	300	278	22	True Slump
10	300	285	15	True Slump

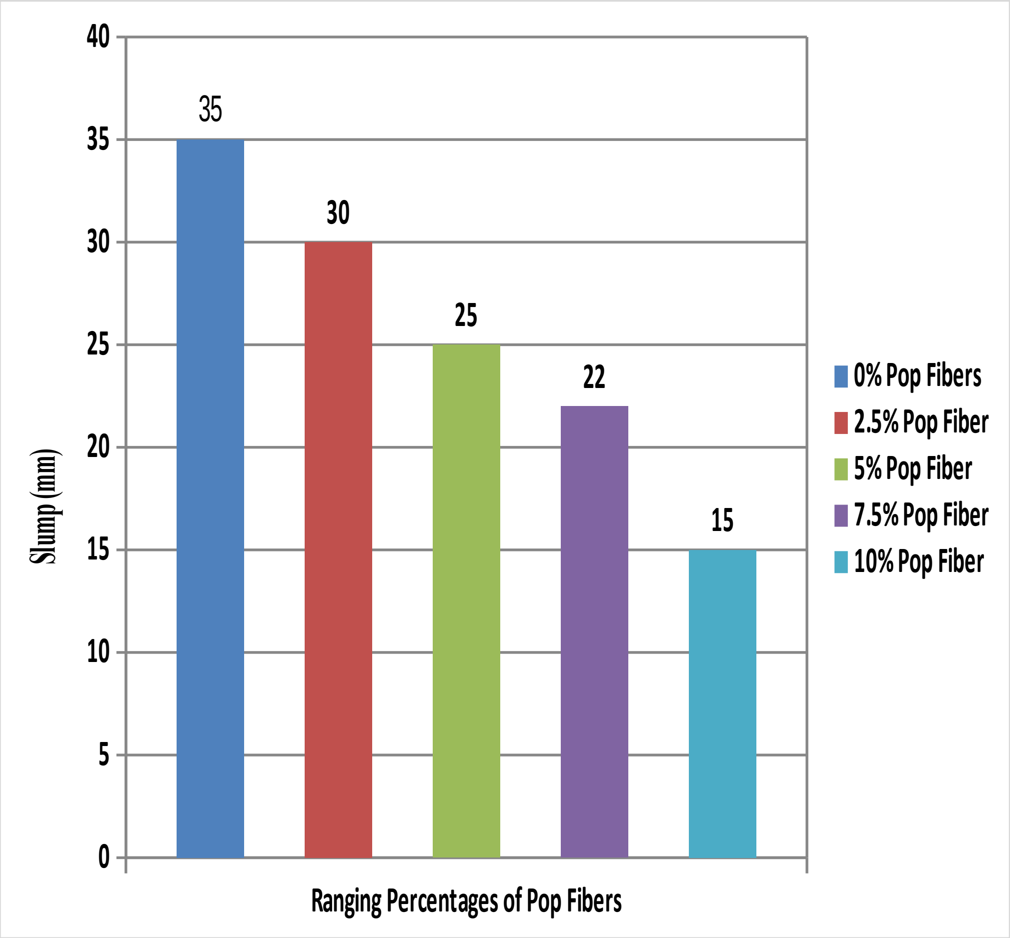

Figure C1: Graph Showing Slump of the Concrete at Varying Percentages of Pop Fiber

APPENDIX D
COMPRESSIVE STRENGTH TEST

Table D1: Compressive Strength Test Result for 0% POP Fiber

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
7 days	1: 2: 4	512.5	22.78	22.65
		504.8	22.44	
		511.2	22.72	
21 days	1: 2:4	525.5	23.36	23.53
		530.8	23.59	
		532.4	23.66	
28 days	1: 2: 4	541.2	24.05	24.05
		511.3	23.94	
		508.4	24.15	

Table D2: Compressive Strength Test Result for 2.5% POP Fiber

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
7 days	1: 2: 4	514.2	22.85	22.78
		511.7	22.83	
		509.8	22.66	
21 days	1: 2:4	528.4	23.48	23.62
		531.7	23.63	
		534.6	23.76	
28 days	1: 2: 4	540.4	24.02	24.22
		545.6	24.25	
		548.7	24.39	

Table D3: Compressive Strength Test Result for 5% POP Fiber

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
7 days	1: 2: 4	518.7	23.05	23.12
		521.2	23.16	
		520.8	23.15	
21 days	1: 2:4	530.4	23.57	23.71
		535.3	23.79	
		534.8	23.77	
28 days	1: 2: 4	544.1	24.18	24.32
		546.8	24.30	
		550.7	24.48	

Table D4: Compressive Strength Test Result for 7.5% POP Fiber

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
7 days	1: 2: 4	514.4	22.86	22.86
		515.6	22.92	
		512.8	22.78	
21 days	1: 2:4	522.4	23.22	23.24
		520.8	23.15	
		525.7	23.36	
28 days	1: 2: 4	538.8	23.95	24.06
		540.4	24.02	
		544.9	24.22	

Table D5: Compressive Strength Test Result for 10% POP Fiber

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
7 days	**1: 2: 4**	**504.2**	**22.41**	**22.27**
		500.5	**22.24**	
		498.7	**22.16**	
21 days	**1: 2:4**	**510.2**	**22.68**	**22.68**
		508.3	**22.59**	
		512.5	**22.78**	
28 days	**1: 2: 4**	**518.6**	**23.05**	**23.44**
		532.9	**23.68**	
		530.8	**23.59**	

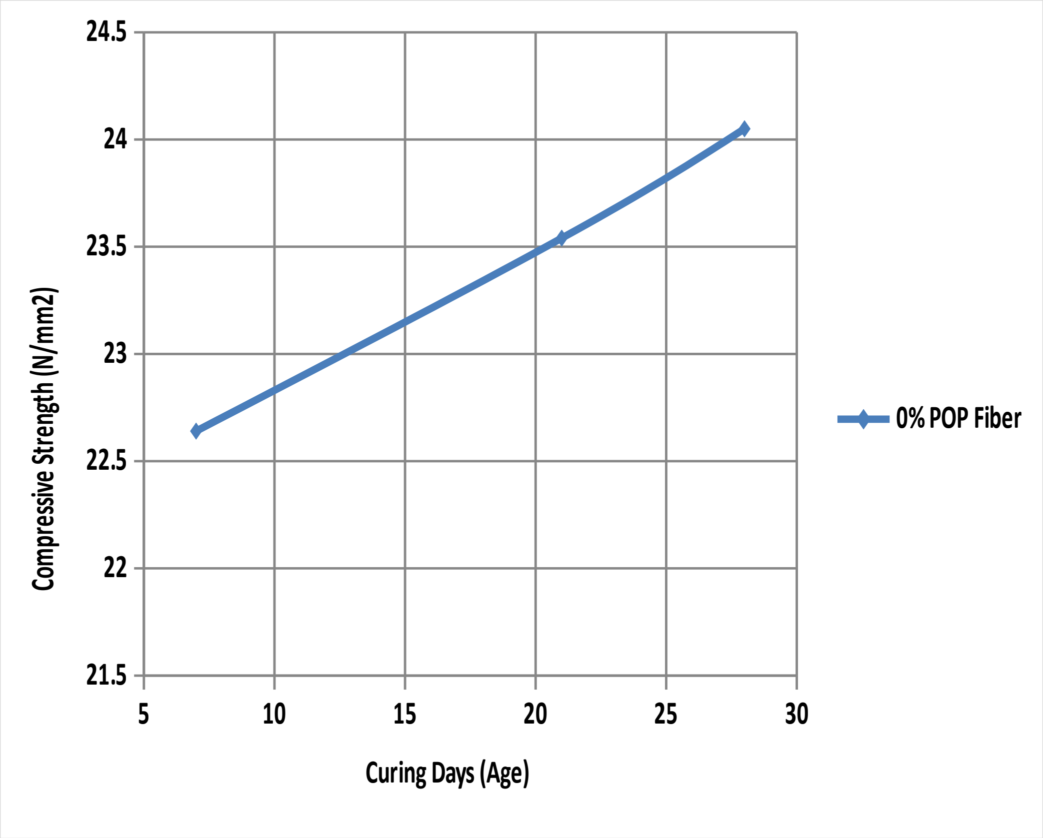

Figure E1: Graph Showing the Compressive Strength Values at 0% Pop Fiber Content

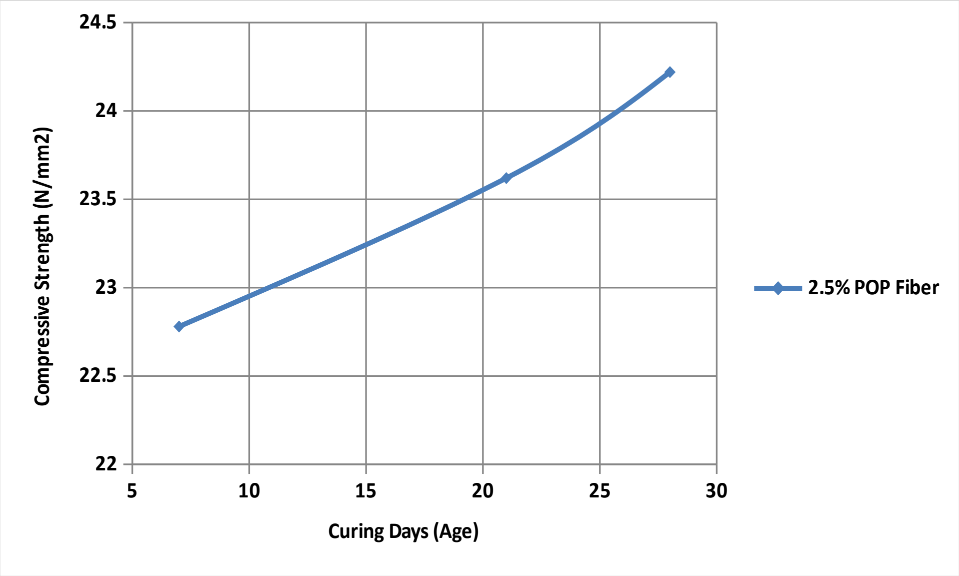

Figure E2: Graph Showing the Compressive Strength Values at 2.5% Pop Fiber Content

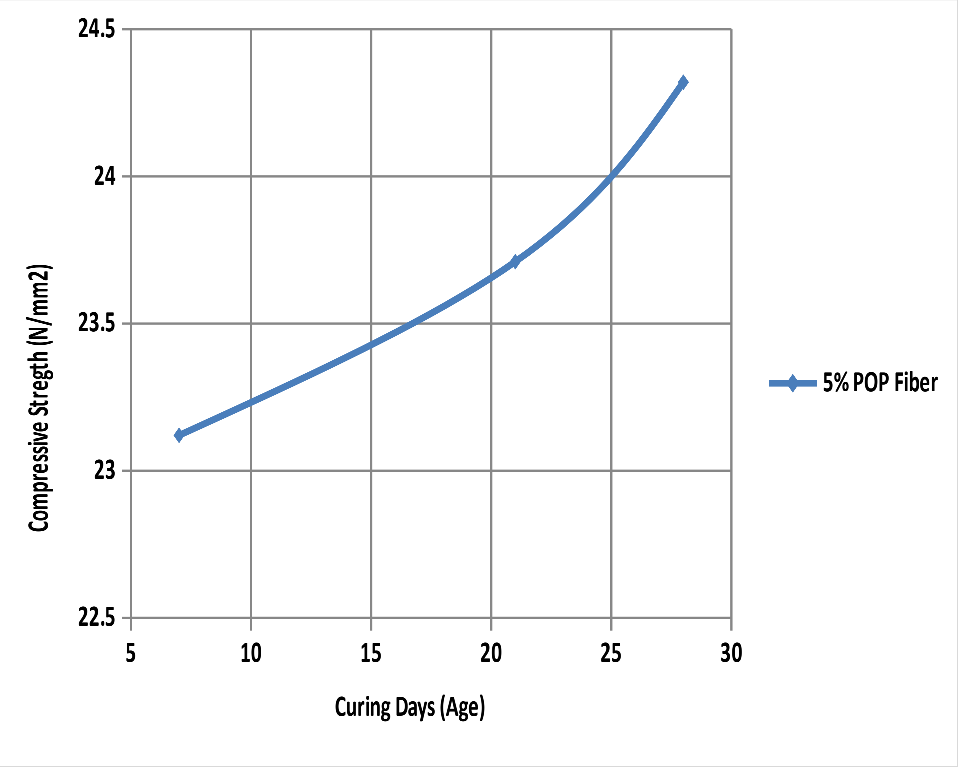

Figure E3: Graph Showing the Compressive Strength Values at 5% Pop Fiber Content

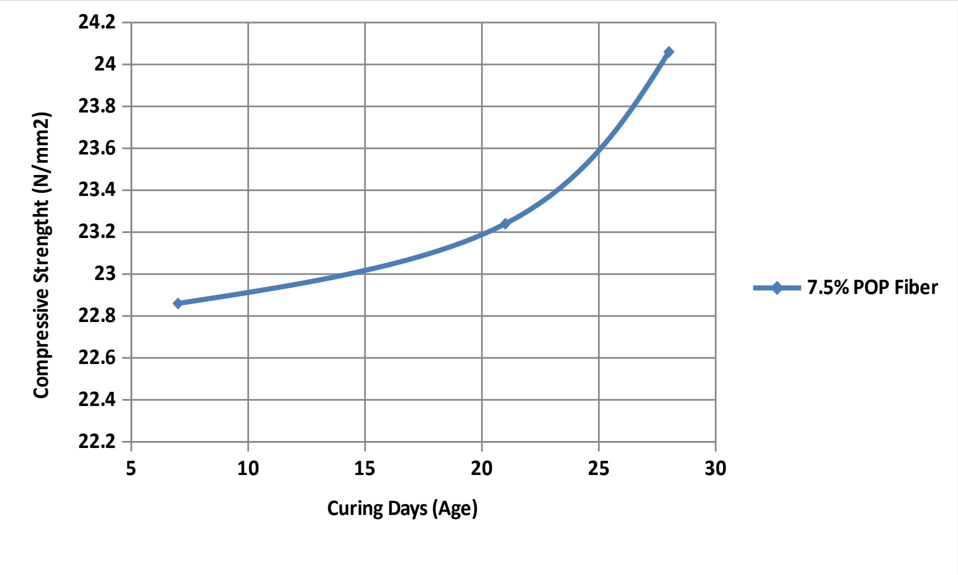

Figure E4: Graph Showing the Compressive Strength Values at 7.5% Pop Fiber Content

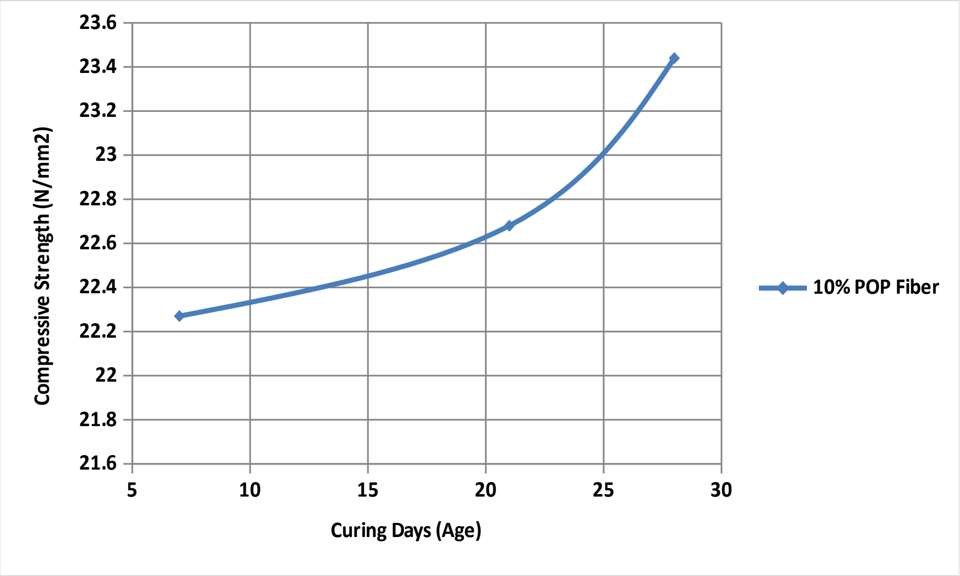

Figure E5: Graph Showing the Compressive Strength Values at 10% Pop Fiber Content

APPENDIX E

FLEXURAL STRENGTH TEST

Table E1: Flexural Strength Test Result for 0% POP Fiber

Curing Days (Age)	Weight (kg)	Area of Cube (mm^2)	Maximum Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	7.28	22,500	264.5	11.76	11.96
	8.02		270.4	12.02	
	8.18		272.2	12.10	
28 days	8.24	22,500	281.8	12.52	12.68
	8.28		285.7	12.70	
	8.31		288.3	12.81	

Table E2: Flexural Strength Test Result for 2.5% POP Fiber

Curing Days (Age)	Weight (kg)	Area of Cube (mm^2)	Maximum Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	8.09	22,500	268.4	11.93	12.10
	8.14		272.5	12.11	
	8.18		275.8	12.26	
28 days	8.34	22,500	289.8	12.88	12.88
	8.35		290.5	12.91	
	8.30		288.8	12.84	

Table E3: Flexural Strength Test Result for 5% POP Fiber

Curing Days (Age)	Weight (kg)	Area of Cube (mm^2)	Maximum Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	8.12	22,500	270.1	12.0	12.16
	8.18		274.5	12.2	
	8.20		276.2	12.28	
28 days	8.34	22,500	290.8	12.92	12.92
	8.35		291.4	12.95	
	8.30		290.2	12.90	

Table E4: Flexural Strength Test Result for 7.5% POP Fiber

Curing Days (Age)	Weight (kg)	Area of Cube (mm^2)	Maximum Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	7.93	22,500	260.5	11.58	11.45
	7.88		257.8	11.46	
	7.90		254.5	11.31	
28 days	8.12	22,500	271.8	12.08	12.05
	8.18		269.5	11.98	
	8.20		272.3	12.10	

Table E5: Flexural Strength Test Result for 10% POP Fiber

Curing Days (Age)	Weight (kg)	Area of Cube (mm^2)	Maximum Load (kN)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	7.82	22,500	252.7	11.23	10.94
	7.85		245.5	10.91	
	7.88		240.1	10.67	
28 days	7.98	22,500	262.5	11.67	11.80
	8.04		264.8	11.77	
	8.11		268.9	11.95	

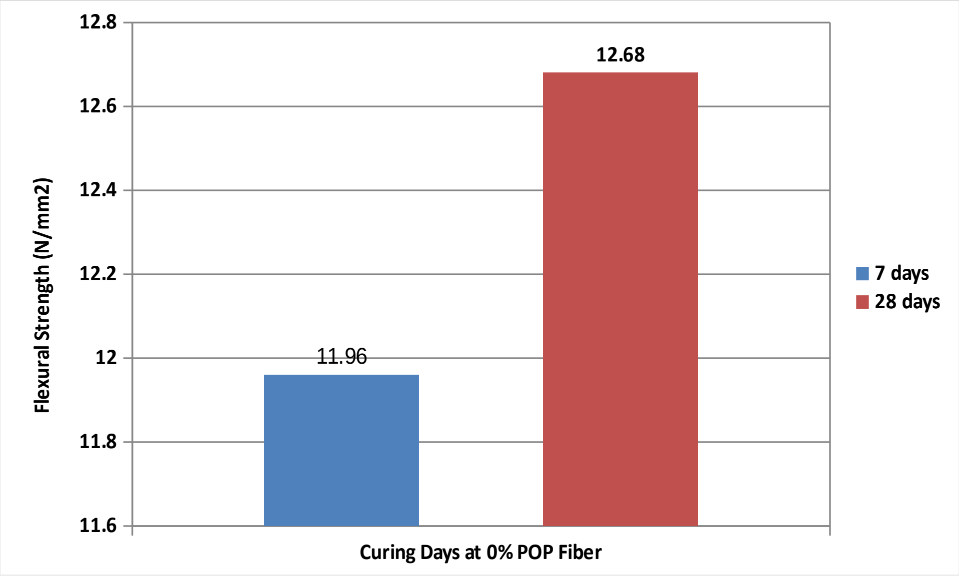

Figure F1: Graph Showing the Flexural Strength Values at 0% Pop Fiber Content

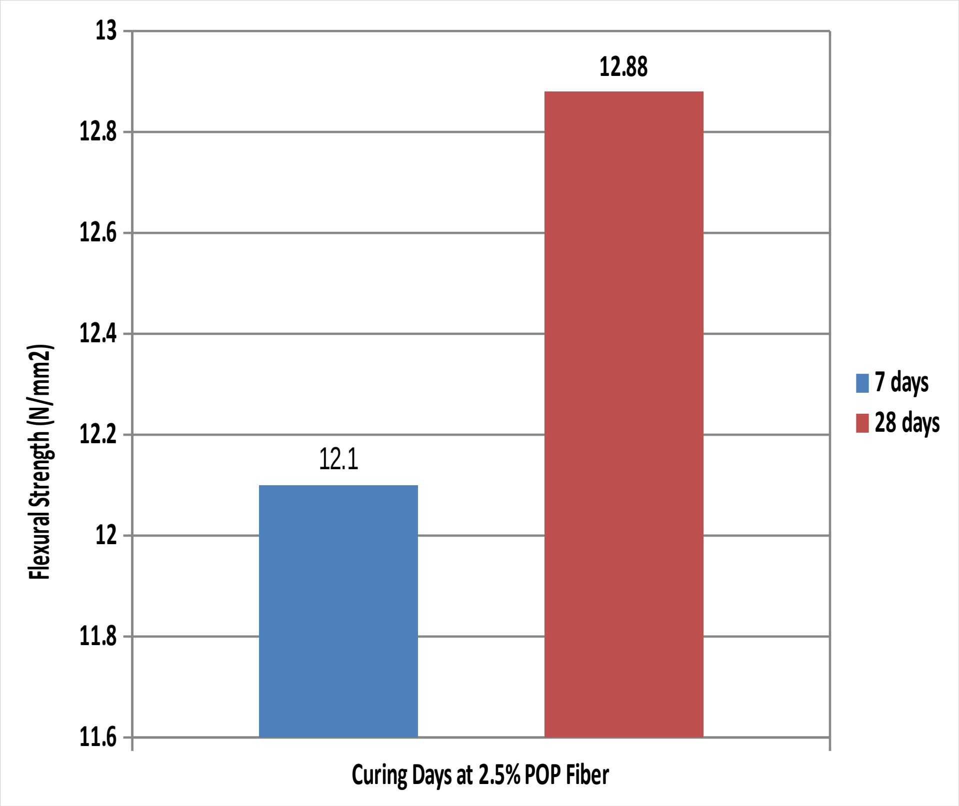

Figure F2: Graph Showing the Flexural Strength Values at 2.5% Pop Fiber Content

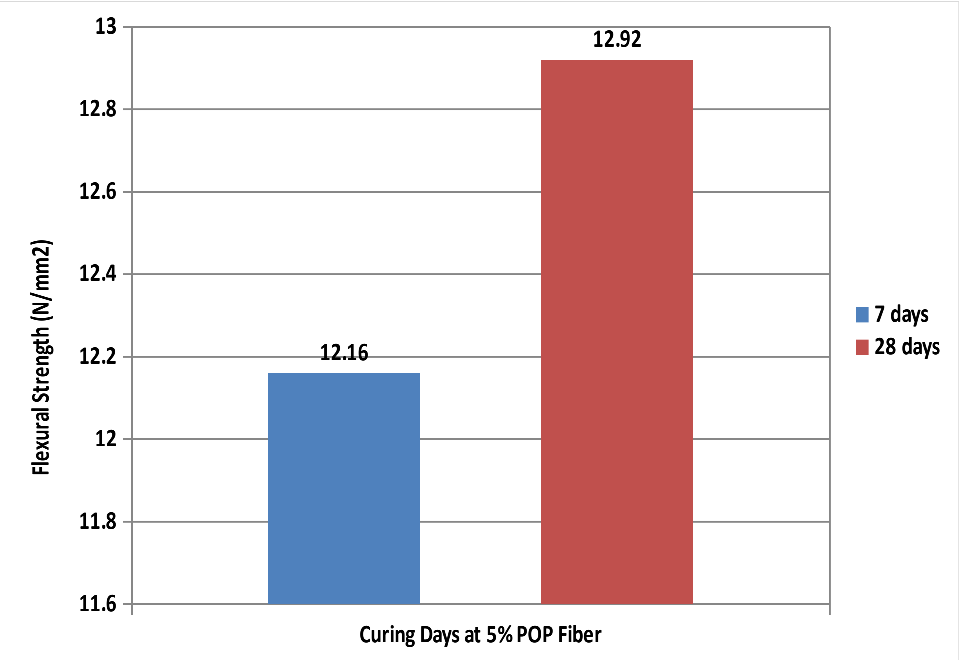

Figure F3: Graph Showing the Flexural Strength Values at 5% Pop Fiber Content

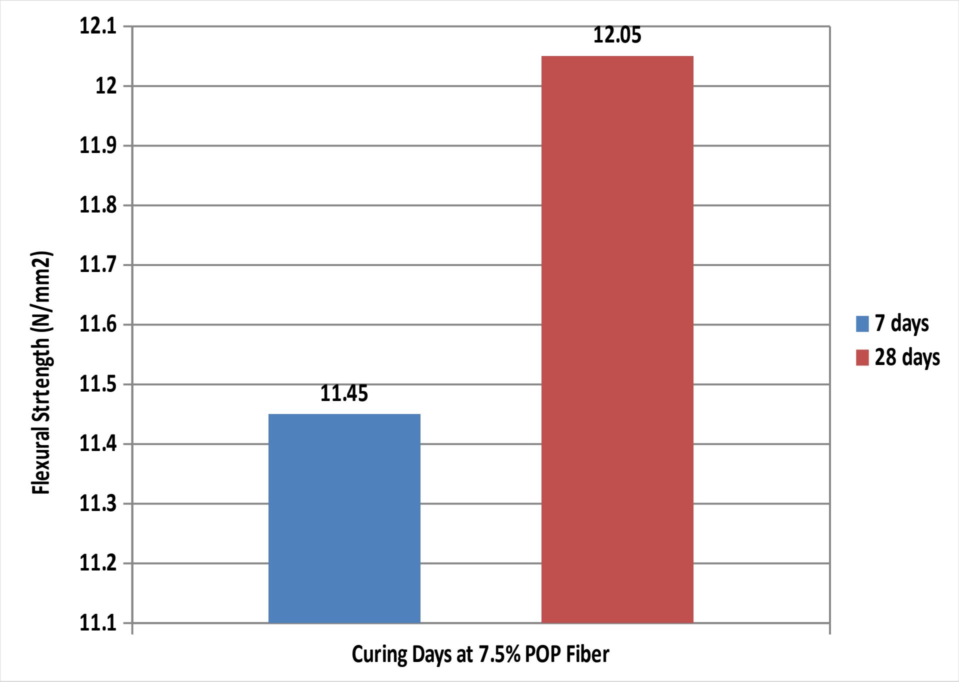

Figure F4: Graph Showing the Flexural Strength Values at 7.5% Pop Fiber Content

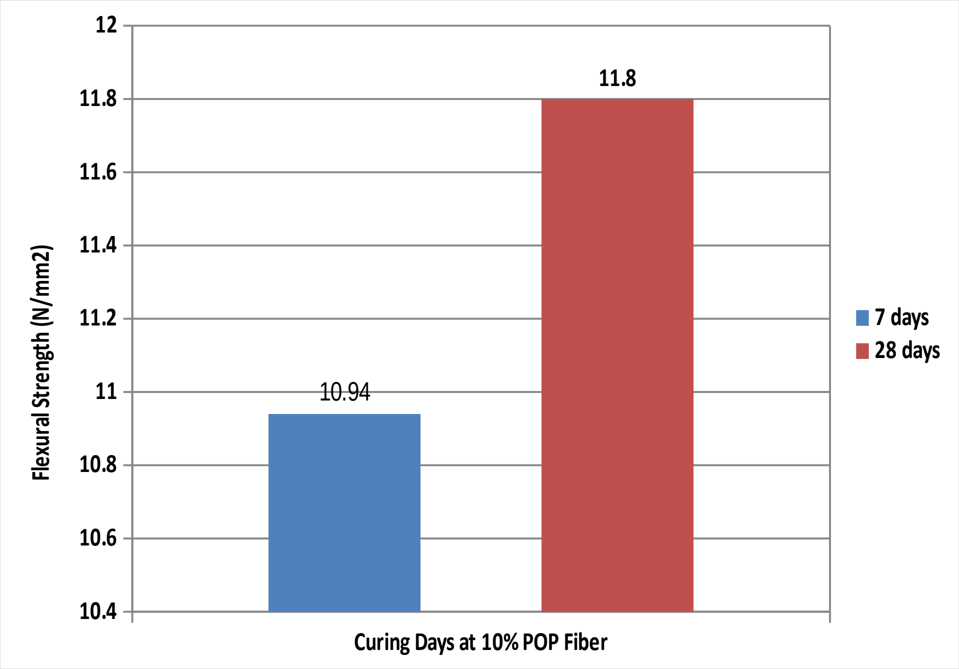

Figure F5: Graph Showing the Flexural Strength Values at 10% Pop Fiber Content

APPENDIX F

HARDENED DENSITY TEST

Table F1: Density Test for 0% POP Fiber

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m^3)	Average Density (kg/m^3)
7 days	7.72	7.68	2287	2277
	7.65		2267	
	7.68		2276	
21 days	7.84	7.91	2323	2344
	7.92		2347	
	7.97		2361	
28 days	8.12	8.13	2406	2408
	8.08		2394	
	8.18		2424	

Table F2: Density Test for 2.5% POP Fiber

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m^3)	Average Density (kg/m^3)
7 days	7.93	7.88	2350	2334
	7.88		2335	
	7.82		2317	
21 days	8.08	8.12	2394	2405
	8.15		2415	
	8.12		2406	
28 days	8.22	8.24	2436	2443
	8.21		2433	
	8.3		2460	

Table F3: Density Test for 5% POP Fiber

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m^3)	Average Density (kg/m^3)
7 days	8.14	8.05	2412	2386
	8.08		2394	
	7.94		2353	
21 days	8.23	8.25	2439	2444
	8.24		2441	
	8.28		2453	
28 days	8.31	8.34	2462	2471
	8.33		2468	
	8.38		2483	

Table F4: Density Test for 7.5% POP Fiber

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m^3)	Average Density (kg/m^3)
7 days	8.02	7.96	2376	2358
	7.99		2367	
	7.87		2332	
21 days	8.05	8.08	2385	2393
	8.11		2403	
	8.07		2391	
28 days	8.21	8.20	2433	2429
	8.18		2424	
	8.2		2430	

Table F5: Density Test for 10% POP Fiber

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m^3)	Average Density (kg/m^3)
7 days	7.84	7.75	2323	2295
	7.72		2287	
	7.68		2276	
21 days	7.99	8.03	2367	2379
	8.02		2376	
	8.08		2394	
28 days	8.09	8.10	2397	2401
	8.18		2424	
	8.04		2382	

APPENDIX G

Split Tensile Strength Test

Table G1: Split Tensile Strength Test Result for 0% POP Fiber

Curing Days (Age)	Weight (kg)	Mix by Volume	Failure Load (kN)	Tensile Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	8.04	1:2:4	148.5	6.6	6.88
	8.11		155.8	6.9	
	8.07		160.4	7.13	
28 days	8.14	1:2:4	165.8	7.37	7.65
	8.20		172.7	7.68	
	8.25		177.9	7.90	

Table G2: Split Tensile Strength Test Result for 2.5% POP Fiber

Curing Days (Age)	Weight (kg)	Mix by Volume	Failure Load (kN)	Tensile Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	8.08	1:2:4	150.4	6.68	6.99
	8.14		161.8	7.19	
	8.12		159.7	7.10	
28 days	8.18	1:2:4	174.8	7.77	7.91
	8.25		181.3	8.06	
	8.22		177.5	7.89	

Table G3: Split Tensile Strength Test Result for 2.5% POP Fiber

Curing Days (Age)	Weight (kg)	Mix by Volume	Failure Load (kN)	Tensile Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	8.08	1:2:4	150.4	6.68	6.99
	8.14		161.8	7.19	
	8.12		159.7	7.10	
28 days	8.18	1:2:4	174.8	7.77	7.91
	8.25		181.3	8.06	
	8.22		177.5	7.89	

Table G4: Split Tensile Strength Test Result for 5% POP Fiber

Curing Days (Age)	Weight (kg)	Mix by Volume	Failure Load (kN)	Tensile Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	7.92	1:2:4	140.2	6.23	6.38
	8.03		148.7	6.61	
	7.99		141.5	6.29	
28 days	8.12	1:2:4	156.8	6.97	7.09
	8.20		161.3	7.17	
	8.17		160.7	7.14	

Table G5: Split Tensile Strength Test Result for 7.5% POP Fiber

Curing Days (Age)	Weight (kg)	Mix by Volume	Failure Load (kN)	Tensile Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	7.82	1:2:4	133.5	5.93	6.04
	7.91		135.7	6.03	
	8.0		138.3	6.15	
28 days	8.08	1:2:4	144.3	6.41	6.38
	8.13		146.5	6.51	
	8.05		140.2	6.23	

Table G6: Split Tensile Strength Test Result for 10% POP Fiber

Curing Days (Age)	Weight (kg)	Mix by Volume	Failure Load (kN)	Tensile Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
7 days	7.71	1:2:4	124.5	5.53	5.61
	7.85		128.7	5.72	
	7.80		125.8	5.59	
28 days	7.94	1:2:4	133.8	5.95	6.12

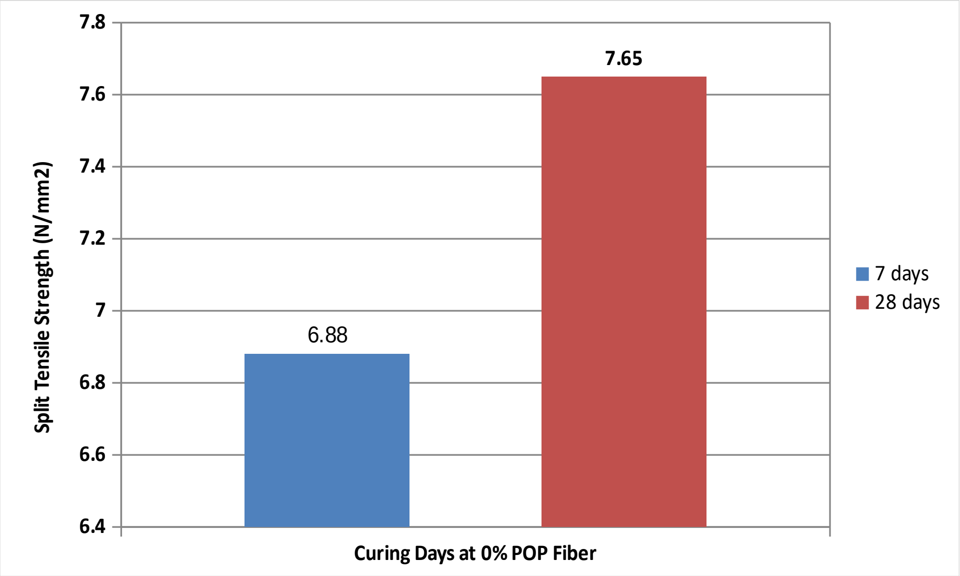

Figure G1: Graph Showing the Split Tensile Values at 0% Pop Fiber Content

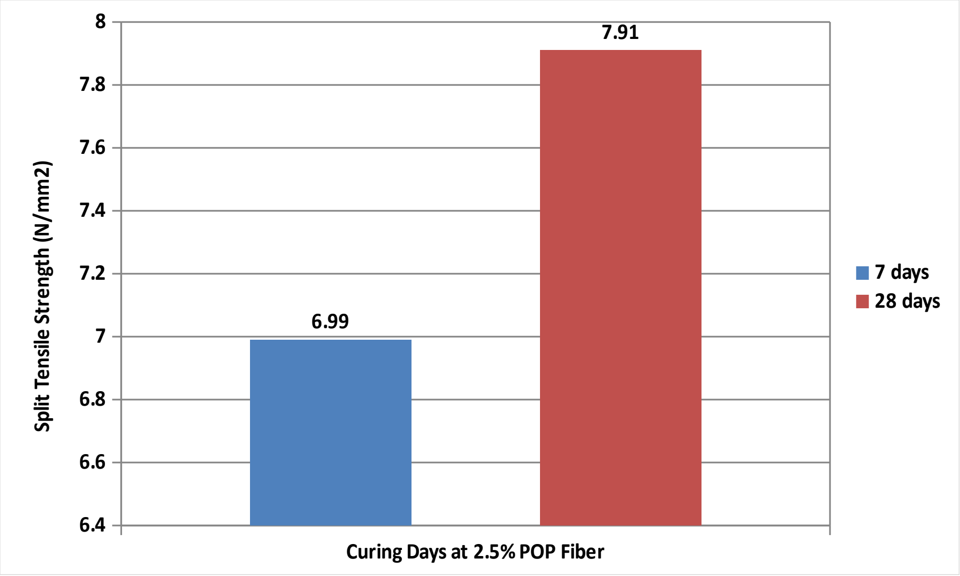

Figure G2: Graph Showing the Split Tensile Values at 2.5% Pop Fiber Content

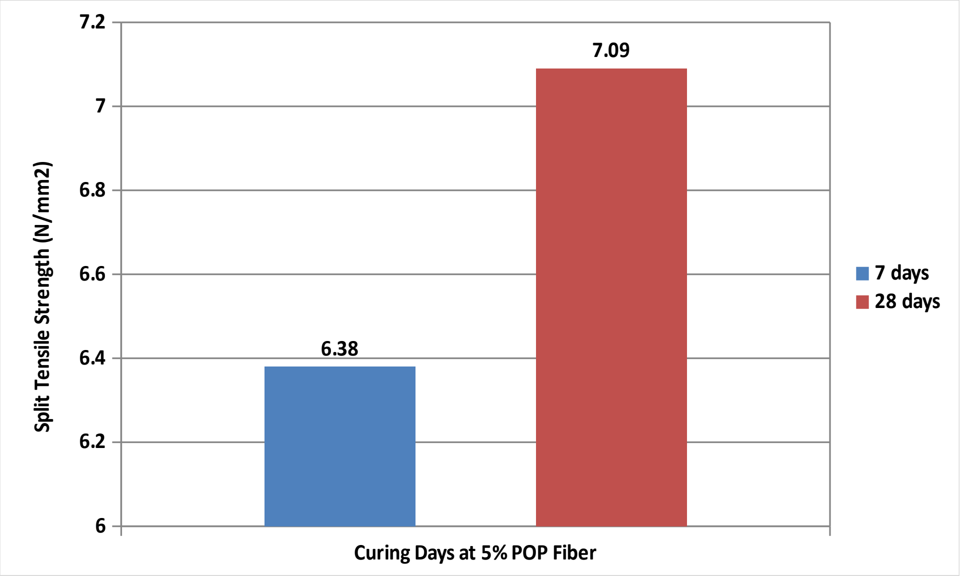

Figure G3: Graph Showing the Split Tensile Values at 5% Pop Fiber Content

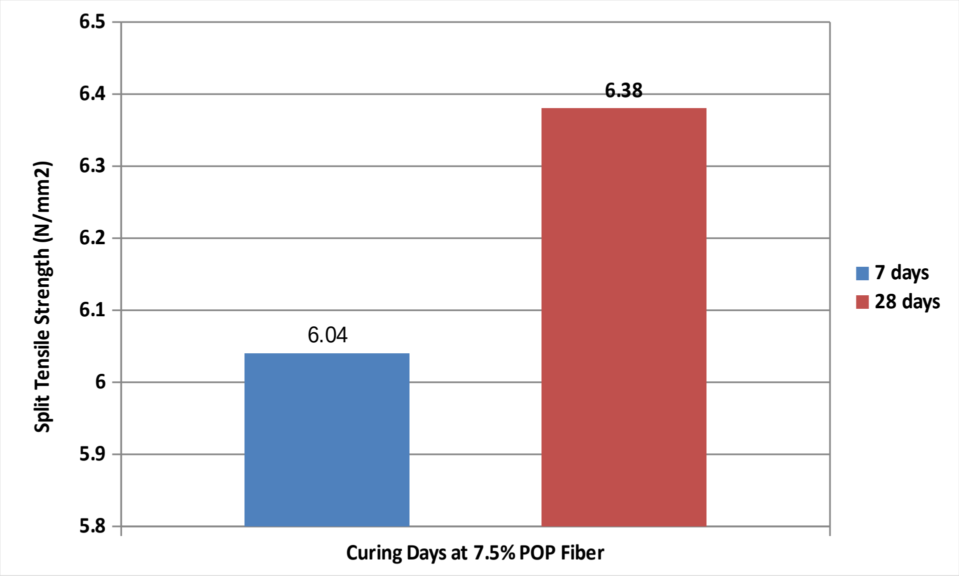

Figure G4: Graph Showing the Split Tensile Values at 7.5% Pop Fiber Content

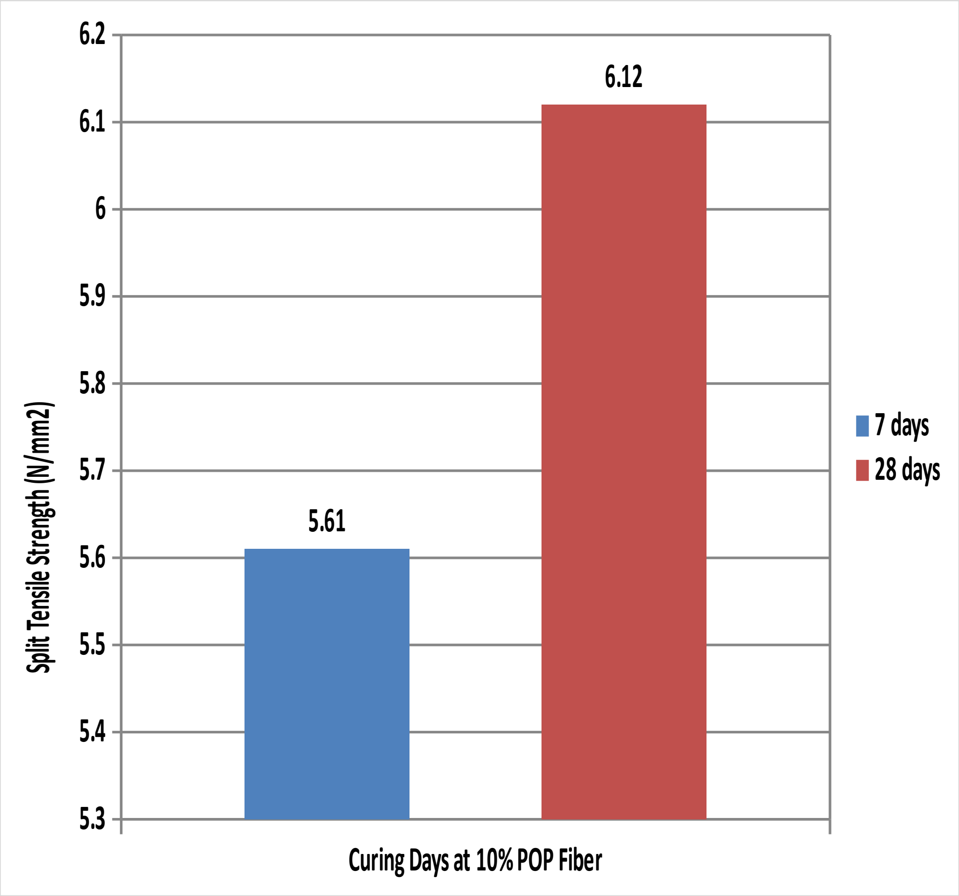

Figure G5: Graph Showing the Split Tensile Values at 10% Pop Fiber Content