JIMMA UNIVERSITY

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JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

EXPERIMENTAL INVESTIGATION OF THE PHYSICAL AND MECHANICAL PROPERTIES OF HYBRID WASTE TIRE STEEL AND BANANA FIBER-REINFORCED CONCRETE.

A Research Submitted to School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

By Wandimu Sirna

May ,2023

Jimma, Ethiopia

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By Wandimu Sirna

ADVISOR: ASSO. PROF. ELMER C. AGON (Ph. D)

CO-ADVISOR: ENG. GOSHUKENEA(M.Sc)

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BY

WANDIMU SIRNA

APPROVED BY BOARD OF EXAMINERS:

Engr. Elmer C Agon (Asso. Prof)	_____	_____
Main Advisor	Signature	Date
Engr. Goshu Kenea, (M.Sc.)	_____	_____
Co-Advisor	Signature	Date
Dr. Binaya Patnaik (Ph.D)	_____	5/6/23
External Examiner	Signature	Date
Engr. V.S. Ravi Kumar (M.Sc.)	_____	_____
Internal Examiner	Signature	Date
Engr.Ashagere Fetene (M.Sc)	_____	_____
Chair Person	Signature	Date

DECLARATION

I declare that this research titled "**Experimental Investigation of the physical and mechanical properties of hybrid waste tire steel and banana fiber-reinforced concrete** "is my original work and has not been presented by another person for a degree in any other university. The source of any materials mentioned all over this research is well acknowledged.

Wandimu Sirna _____ __/_____/ _____

Signature Date

This thesis has been submitted to my supervisors for approval.

1. Engr. Elmer C. Agon (Asso. Prof) _____ _/_____/_____

Main advisor Signature Date

2. Engr. GoshuKenea, MSc _____ _/_____/_____

Co-advisor Signature Date

ABSTRACT

Most of the civil engineering construction that has been constructed worldwide mainly use concrete as the primary construction material. But due to its weakness in tension resistance, concrete cannot be used alone. To overcome such problems, fibers may need to be considered as an additive. Workability, compressive strength, split tensile strength and flexural strength test were performed to determine the physical and mechanical properties of hybrid waste tire steel and banana fiber reinforced concrete. The average of three sample tests for each strength was used to determine the strength of hybrid concrete and tested at 7, 14, and 28 days of curing age. All cubes were made with $150mm \times 150mm \times 150mm$*, cylinders with 100mm diameter and 200 mm height and beams with cross-section* $100mm \times 100mm$ *and length of 500mm size. Control and three fibers reinforced concrete composites where casted using different proportions containing 1% of total volume of concrete. The hybrid mix contains 0%, 0.5%, 1% and 1.5% respectively. The study result revealed that the addition of hybrid fibers to the concrete reduces workability of wet concrete. The compressive strength shows increment by 28.11%, 16.70 and 10.90% from control at 7, 14 and 28 day respectively. The split tensile strength test result of hybrid waste tire steel and banana fiber reinforced concrete shows an increment from control by 38.47%, 35.64% and 30.63% respectively when 1% of hybrid fibers were added to the concrete. Flexural strength test result of hybrid waste tire steel and banana fiber reinforced concrete shows an enhancement by 44.61%,22.12% and 16.49% from control test result when 1%(0.75%SF + 0.25%BF) hybrid fiber were added to the concrete. It can therefore, be concluded that optimum result was obtained in each hybrid mix when 1% of hybrid waste tire steel and banana fiber was added to the concrete.*

Keywords: *Hybrid fibers, slump value, compaction factors, Compressive strength, Flexural strength and Split tensile strength*

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ACRONYMS

A	Area
ACI	American concrete Institute
AEC	Air entraining cement
ASTM	American society for testing and material
BF	Banana Fibers
BFS	Blast furnace slag cement
CC	Coloured cement
ETB	Ethiopian Birr
FRC	Fiber-reinforced concrete
HAC	High alumina cement
HPC	hydrophobic cement
JiT	Jimma Institute of Technology
LHC	Low heat cement
MSSD	Mass of Saturated surface dry
OPC	ordinary Portland cement
PBFS	Portland blast furnace slag cement
PPC	Portland pozolana cement
QSC	Quick setting cement
RHC	Rapid hardening cement
RTC	Recycled tire cord
S	Sample
SRC	Sulphate resisting cement
V	Volume
WC	White cement
WTSF	Waste tire steel fiber

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

Concrete is a composite construction material composed primarily of aggregate, cement and water. The aggregate is generally coarse gravel or crushed rocks such as limestone, or granite, along with a fine aggregate such as sand. The cement, commonly Portland cement, and other cementitious materials such as fly ash and slag cement, serve as a binder for the aggregate. Plain cement concrete has relatively high compressive strength but possesses a very low tensile strength, limited ductility, and little resistance to cracking. Internal micro-cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to the brittle fracture of the concrete. It has been recognized that the addition of small closely spaced and uniform dispersed fibers to concrete would act as a crack arrester and would substantially improve its properties. This type of concrete is known as Fiber Reinforced Concrete[1].Fiber-reinforced concrete (FRC) is concrete containing fibrous material, which increases its structural integrity. Cement concrete composite is the most important building material and its consumption is increasing in all countries. Fibers are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce the bleeding of water. Some types of fibers produce greater impact abrasion and shatter resistance in concrete[1]. Fibers include steel fibers, glass fibers, synthetic fibers, and natural fibers and are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage. Fibers can be divided into the following two groups based on the material used for manufacturing. Fibers are classified as metallic fibers (e.g. low carbon steel, stainless steel, galvanized iron, aluminum), mineral fibers(e.g. asbestos, glass, carbon),synthetic fibers (polyester, nylon, polypropylene, polyethylene) and natural fibers (bamboo, coir, jute or banana, sisal, wood, sugarcane bagasse)**.**The use of two or more types of fibers in a suitable combination may potentially improve the overall properties of concrete and also result in a good performance under different loading. The combination of two or more fibers is called hybridization[2]. Hybrid composite material has grown in popularity over the last few years due to its favorable proprieties. The fibers can prevent surface cracking through bridging action leading to increased impact resistance of the concrete. The combination of two or more different types of fibers (different fiber types and/or geometries) is becoming more common, to optimize overall system behavior. The intent is that the performance of these hybrid systems would exceed that induced by each

fiber type alone. That is, there would be a synergy. Banthia and Gupta [2004] classified these synergies into three groups, depending on the mechanisms involved:

1. Hybrids based on the fiber constitutive response, in which one fiber is stronger and stiffer and provides strength, while the other is more ductile and provides toughness at high strains [Banthia and Gupta2004].

2. Hybrids based on fiber dimensions, where one fiber is very small and provides micro-crack control at the early stages of loading; the other fiber is larger, to provide a bridging mechanism across macro cracks.

3. Hybrids based on fiber function, where one type of fiber provides strength or toughness in the hardened composite, while the second type provides fresh mix properties suitable for processing[3].

1.2 Statement of the Problem

Now a day, civil engineering constructions have their own structural and durability requirements. Every structure has its own intended purpose and hence to meet this purpose, modification in traditional cement concrete has become mandatory. It is well known that concrete is an extensively used construction material for its various advantages such as low cost, availability, fire resistance and can be molded to any shape based on the requirement. Additionally, the use of concrete is so widespread compared with alternative materials such as steel, one can cite the following: its components are economically competitive and available in many different areas of the globe; its application requires little energy, and it has good resistance against both structural and environmental actions[4].But it cannot be used alone everywhere because of its weakness in tension and facing problems of cracking, for that we have to add fibers in concrete to enhance its strength. Generally, the addition of fibers into the concrete is most commonly used in construction industries as the resistance of cracking and strengthening concrete. Although, various fibers are available across the world, in developing country like Ethiopia using those fibers with plain concrete is not well known because of lack of availability and awareness. So, preparing those fibers from locally available materials and testing their effects on concrete strength can optimize overall system. Inclusion of single type of fibers into concrete has been proven by different researchers at different time shows an enhancement in concrete strength to a limited extent. Recently it was found that the behavior of concrete can be improved more with addition of hybrid fibers such that combination of different types of fibers. The intent is that the performance of these hybrid systems would exceed that

induced by each fiber type alone. In addition to that the hybrid combination of metallic and natural fibers can offer potential advantages in improving concrete properties. It is also important in waste management by reducing waste tire from environment [4]. But most of the studies are mainly focuses on using hybrid fibers like steel and Polypropylene, steel and glass, steel and carbon, steel and palm fibers. However still there is limited knowledge on behavior of concrete using hybrid steel and banana fibers as a hybrid reinforcing fibers. This study was done to fill the gap on the experiences and knowledge on the effect of using hybrid steel and banana fibers on concrete properties.

1.3 Research Question

- What are the effects of hybrid waste tire steel and banana fibers on workability of concrete?
- What are the effects of hybrid waste tire steel and banana fibers on strength properties of concrete?
- For what maximum percentage of hybrid waste tire steel and banana fibers that the C20/25 concrete strength can be enhanced?

1.4 Objective of the Study

1.4.1 General Objective

The main objective of this experimental research was to investigate the physical and mechanical properties of hybrid waste tire steel and banana fiber-reinforced concrete.

1.4.1.1 Specific Objectives

- To study the workability of concrete with hybrid waste tire steel and banana fiber.
- To evaluate the strength properties of hardened concrete using different percentage of hybrid waste tire steel and banana fiber-reinforced concrete.
- To analyze the maximum percentage of hybrid waste tire steel and banana fiber that can enhance the strength of C20/25 concrete

1.5 Significance of the Study

A concrete that has been reinforced with those locally available and ecofriendly materials minimize the overall cost of Concrete. It was also improve resource sustainability in construction development and enhances knowledge and experiences for the community. For the third world country like Ethiopia, this study helps to raise awareness regarding recycling of waste material as well as to develop rules with respect to local reuse of waste tires. Encouraging

the local authorities to invest and support the recycling of waste tires for use within building materials would provide an ideal and environmentally friendly disposal method for a large percentage of waste tires.

1.6 Scope and Limitation of the Study

The scope of this research was investigating the effects of addition of different percentage value of combination of hybrid waste tire steel and banana fibers on the physical and mechanical properties of concrete, to get the optimum percentage value of combination of waste tire steel and banana fibers and to investigate stress strain of concrete. The research was done by adding different percentage value of combination of waste tire steel and banana fibers, such as 0%, 0.5%, 1% and 1.5% by weight of cement, on the concrete mix of C20/25 grade of concrete. The relevant laboratory tests that was conducted in this research includes, test on fresh concrete such as slump and compaction factor test and test on hardened concrete such as compressive, flexural and split tensile strength test. Three specimens were casted for each tests conducted at the age of 7, 14 and 28 days. Then different samples for different tests was taken, for compressive strength test 36 samples of cube 150x150x150 mm, for tensile strength test 36 samples of cylinder 100 x 200 mm and for flexural strength test 36 sample of beam 100 x 100 x 500 mm. This experimental investigation was not study analysis and design of hybrid waste tire steel and banana fiber reinforced concrete by software.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Historical Background of Fiber reinforced concrete

Plain concrete is a brittle material, with low tensile strength and strain capacities. To help overcome these disadvantages, there has been a steady increase since the late 1960s in the use of fiber reinforced concrete. Fiber reinforced concrete may be defined as a concrete incorporating relatively short, discrete discontinuous fibers. Instead the principal role of fiber is to control the cracking of the fiber reinforced concrete and then to modify the behavior of the material once the concrete matrix has cracked by bridging across the cracks as they begin to open fibers provide post cracking ductility to the fiber reinforced concrete. The use of fiber reinforced concrete has been increasing steadily in recent years. As of 2001, over 76 million m^3 of fiber reinforced concrete were produced annually, with the principal application begin slabs on grade (60%), Shotcrete (25%), and precast members (5%) and the remainder of the production distributed among a number of other specialty structural forms[5].The enhanced properties include tensile strength, compressive strength, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to impact and abrasion, shrinkage, expansion, thermal characteristics, and fire resistance[6].

2.2 Hybrid Fiber Reinforced Concrete

The combinations of fiber sizes, fiber materials, and or both have been increasingly introduced to the market. These combinations are known as hybrid fibers. In well- designed hybrid composites, there is positive interaction between the fibers, and the resulting hybrid FRC performance exceeds the sum of the individual fiber performances[7]. In a hybrid, two or more different types of fibers are rationally combined to produce a composite that derives benefits from each of the individual fibers and exhibits a synergistic response. The hybrid combination of metallic and non-metallic fibers can offer potential advantages in improving concrete properties as well as reducing the overall cost of concrete production[8].

2.3 Types of Hybrid Fiber

The usefulness of hybrid fiber reinforced concrete in various Civil Engineering applications is thus in disputable. Hence this study explores the feasibility of hybrid fiber reinforcement with a given grade of concrete. Hybrid Fiber Reinforced Concrete(HFRC) is formed from a combination of different types of fibers, which differ in material properties, remain bonded

together when added in concrete and retain their identities and properties[8].The combination of two or more different types of fibers (different fiber types and/or geometries) is becoming more common, with the aim of optimizing overall system behavior. The intent is that the performance of these hybrid systems would exceed that induced by each fiber type alone. That is, there would be a synergy Banthia and Gupta [2004] classified these synergies into three groups, depending on the mechanisms involved:

1. Hybrids based on the fiber constitutive response, in which one fiber is stronger and stiffer and provides strength, while the other is more ductile and provides toughness at high strains [Banthia andGupta2004].

2. Hybrids based on fiber dimensions, where one fiber is very small and provides micro crack control at early stages of loading; the other fiber is larger, to provide abridging mechanism across macro-cracks.

3. Hybrids based on fiber function, where one type of fiber provides strength or toughness in the hardened composite, while the second type provides fresh mix properties suitable for processing. The introduction of the paper explains the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper[7]

There are three types of reinforcing fibers that are commonly used: glass, aramid, and carbon. Recently, basalt fibers have become commercially available. Although applications are still in infancy, basalt fibers have shown great potential to replace carbon fibers due to their much lower cost. Regard less of the type of fiber used, each is available with different grades and varying properties. All fiber types exhibit linear elastic behavior when tested. Glass fiber became commercially available in 1939 with the start-up of an Owens Corning production facility. Glass FRP (GFRP) composites have relatively low stiffness, high elongation, and moderate strength and weight. Glass is by far the most widely used fiber, because of the combination of low cost and reasonable performance. Glass fibers are classified into three types: E-glass, S-glass, and alkali. Generally, fiber offers the resistance to suddenly applied loads, limits the shrinkage cracking’s, decreases the permeability and hence ultimately decreases the bleeding of water. The hybrid waste tire steel and banana fiber reinforced concrete was made from the combination of aggregate, banana fiber, waste tire steel, sand, Cement and water[9].

2.4 Aggregate

The intensive use of aggregates in constructions is a very important environmental concern[10].Aggregates are the inert particles that are bound together by the cementing agent (such as port land cement) to form a mortar or a concrete. Mortar is a mixture of fine aggregate, a cementing material, and water. A mixture of only cement and water is referred to as "neat cement." Concrete is composed of the ingredients of mortar plus coarse aggregates.[11]

2.4.1 Coarse Aggregate

The strength of concrete mix is dependent on many parameters like cement type, coarse aggregate and the interface between aggregate and mortar. However, generally the coarse aggregate is treated as an inert material and only its physical properties like shape, size, water absorption and specific gravity are studied. Whereas, we increase the quality of mortar mix, the strength of coarse aggregate also comes into picture. In case of high performance concrete, the type of coarse aggregate used has a great influence on the strength and elasticity modulus of concrete[12]. Coarse aggregate typically occupies over one-third of the volume of concrete, and research indicates that changes in coarse aggregate can change the strength and fracture properties of concrete. To predict the behavior of concrete under general loading requires an understanding of the effects of aggregate type, aggregate size, and aggregate content[13].Course aggregate particle sizes are those that are retained on a 5 mm (#4) sieve opening. There is no real maximum size aggregate, but in most concretes for pavements and structures the upper limit is usually 5 cm (2 in.), but may be larger. Coarse aggregates are obtained from gravel or crushed stone, blast furnace slag, or recycled concrete. Trap rocks, granite, limestone, and sandstones are satisfactory for crushed stone

2.4.2 Fine Aggregate

Natural sand has continually been excavated from river bed for use as a major source of fine aggregate in concrete construction. The boundary size definition of fine aggregates is one that passes a 5 mm (#4) sieve. Fine aggregates are derived from the same sources except that in the place of gravel, naturally occurring sand is used. All aggregates should be composed of hard particles and free of injurious amounts of clay, loam, and vegetable matter. The principal characteristics of aggregates that affect the strength, durability, and workability of a concrete are cleanness, grading, hardness, and shape. Usually the aggregates are stronger than the concrete from which they are made. A coating of dirt or dust on the aggregate will reduce the strength of concrete because it prevents the particles from properly bonding to the mortar. The process of selecting suitable ingredients of concrete and determining their relative amount with the

objective of producing a concrete of required strength, durability and workability as economically as possible is termed as mix design[14].A well-graded aggregate mix is essential to obtain an economical concrete of good quality. If poorly graded, even clean, sound aggregates will require excessive water for workability, resulting in lower strength, or the mix will require an excessive amount of cement to develop a given strength.

In fact, aggregates play a major role in concrete and they furnish bulk to the concrete, diminish shrinkage and effect financial system. Generally, 60 - 75% of the total volume of concrete is occupied by aggregates, which has two distinct categories- fine aggregate and coarse aggregate. Fine aggregate is the naturally occurring granular material consists of mineral particles and finely divided rock particles. Nowadays, because of the growth of building constructions and depletion of resources there is a huge demand for natural available sand material. Now need of the hour is partial or full replacement of fine aggregate with well processed manufactured sand as long term solution in current construction industry[15].

2.5 Banana Fiber

The natural fibers are renewable, non-abrasive, bio-degradable, possess a good calorific value, exhibit excellent mechanical properties and can be incinerated for energy recovery have low density and are inexpensive. This good environmental friendly feature makes the materials very popular in engineering markets such as the automotive and construction industry[16]. Natural fiber is used as an alternative resource to synthetic fibers as well as reinforcement for polymer composite materials and the manufacturing is inexpensive, renewable and environment friendly. Natural fibers have low cost, low density and low durability as compare to synthetic fibers[17]. This proposal mainly focuses the banana fiber based composites which have wide applications in construction. The banana fiber (BF) used for the research work is collected from the local village. Banana fiber reinforced concrete is high-performance fiber reinforced concrete with significant behavior under tension. In this proposal, examines the strength behavior of concrete reinforced with banana fibers. Banana plant (Scientific name: Musa acuminate) not only produces the delicious fruit but it also provides the textile fiber. Banana fiber is a waste product of banana cultivation and either not properly utilized or partially done so. Useful applications of such fibers would regularize the demand which would be reflected in a fall of the prices. The addition of Banana fibers to concrete makes it additional homogenized and isotropic and transforms it from a brittle to additional ductile materials. Conventional concrete includes varied micro cracks that are quickly exaggerated below the applied stresses. These cracks are liable for the low tensile, flexural strength, and impact resistance of concrete. Concrete

strengthened with Banana fibers impedes the crack growth and so enhances its strength and impact characteristics however it'll conjointly reduce the workability, the addition of super plasticizer (Sp) is useful to resolve the potential drawback of Tangling or balling of fibers[18].Banana fibers have highly strength, light weight, smaller elongation, fire resistance quality, strong moisture absorption quality, great potentialities and biodegradability. Banana fiber has recognized for apparels and home furnishings. Banana fiber has great potentialities for paper making special demand of handmade paper. Banana fiber is making products like filter paper, paper bags, greeting cards, lamp stands, pen stands, decorative papers, rope, mats and composite material etc. Banana fiber used as a raw material in industry for production of papers, tea bags, currency and reinforced as a polymer composite. These banana fibers have good physical and mechanical properties and can be employed more productively. Banana fiber is extracted from the plant Musa sapientum. Each of the stalks is 2.7−6.7 m tall with a trunk 10−20 cm wide at the base. The sheaths before expanding are 2–4m long, 13−20cm wide, and about 10mm thick at the center. The fibers run length wise in the sheaths. The sheaths vary in length, width, and color. The mature stalks are cut off at the roots and at a point just below where they begin to expand. In some countries the stripping method is used while modern plantations have replaced this hand-pulling operation with power-driven pulling machines[19].Banana fibers are economical, ecological and perishable. Emphasis is placed on the influence of fiber content on the key micromechanics properties relevant to composite ductility.

Figure 2-1 Banana Plant and Banana fibers

Table 2-1 Mechanical properties of several types of fiber[20]

Type of fiber	Average diameter, in.	Average length, in.	Absorption after 24 hr, percent	Average fiber density (SG)	Average tensile strength, psi	Average bonding strength, psi	Average elongation,percent
Bagasse	0.02	1.38	122.5	0.639	3,570	36	N/A
Coconut	0.027	11.02	58.5	0.58	8,825	40	2.6
Jute	0.004	15.75	62	1.28	53,500	20	N/A
Maguey	0.014	15.75	63	1.24	54,400	N/A	N/A
Lechuguilla	0.014	15.75	102	1.36	54,100	N/A	N/A
Banana	0.011	3.7	276	0.298	10,960	35	3
Guaney (palm)	0.017	17.44	129.9	1.195	50,000	40	2.88
Bamboo	Variable	Variable	51	0.72	54,680	45	1.8

Table 2-2 Physical Properties of Banana Fiber and some other natural fiber[21]

Fiber	Diameter(µm)	Density (g/cm3)	Cellulose Content(%)	Hemi cellulose content(%)	Legnin Content(%)
Bagasse	20-40	1.25	40	30	20
Banana	80-250	1.35	65	8	5
Coir	100-460	1.15	43	10-20	45
Flax	8-31	1.54	71.2	18.6	2.2
Hemp	13-40	1.48	70.2	23	5.7
Jute	-	1.45	71.5	13.6	13.1
Kenaf	4-9	-	36	21.5	17.8
Oil palm	150-500	0.7-1.55	65	19	13.2
Pineaple	20-80	1.45	81	-	12
Ramie	17-64	1.5	76.2	14.6	0.7
Sisal	50-200	1.45	73.1	14.2	11

2.6 Waste tire steel fiber

Steel fibers was produced either by cutting wire, by shearing sheets or from a hot melt extract. It is possible to make classification of steel fibers either based upon the product or shape of cross-section as provided under ASTM and JSCE respectively. ASTM A820 provides a classification for four general types of steel fibers based upon the product used in their manufacture:

Type I - Cold-drawn wire.

Type II - Cut sheet.

Type III - Melt-extracted.

Type IV - Other fibers.

The Japanese Society of Civil Engineers (JSCE) has classified steel fibers based on the shape of their cross-section:

Type 1 - Square section.

Type 2 - Circular section.

Type 3 - Crescent section

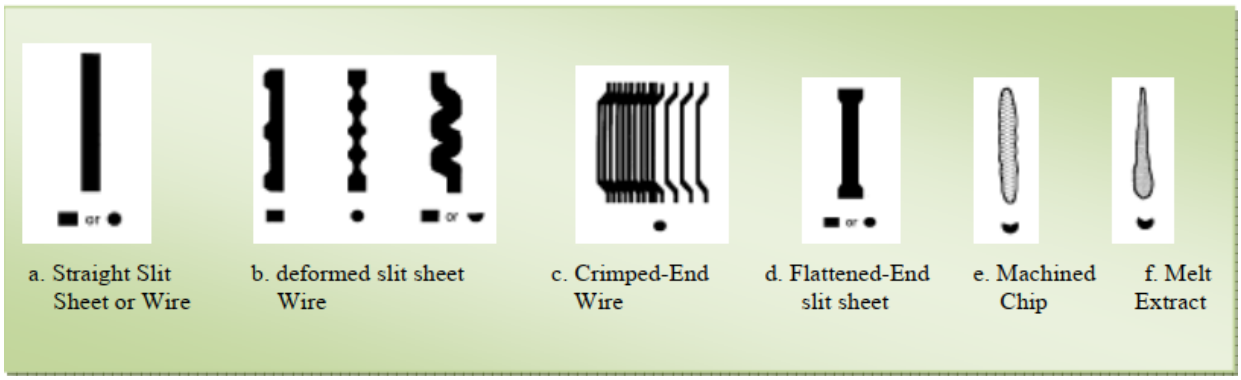

Figure 2-2 various steel fiber geometries [22]

The first generation of steel fiber were smooth, but it was soon found that, as a result, they did not develop sufficient bond with the cementitious matrix; modern steel fibers are generally either deformed along their lengths or at their ends to enhance the cement-fiber bond. Though they will rust visibly when exposed at the concrete surface, they appear to be highly durable within the concrete mass[5].The emergence of waste tire steel fiber (WTSF) which is an undervalued resource was borne out of the need to extract the useful materials in waste tires considering the sheer volume of this resource that is disposed of in landfills globally. These fibers find applications in tunnel linings, hydraulic structures, bridge decks, pavements and slope stabilization. Steel fibers recovered from waste tires were considered for use as reinforcement in concrete to improve the tensile properties of concrete as well as being an economically viable and environmentally friendly alternative[21].The fiber length has positive influence on compressive strength (increased by more than 10%), flexural strength (increased by more than 50%) and split-tensile strength(increased by more than 30%) while slump and flow (increased by more than 80%) were reduced but can be avoided through careful mixing,

reduction of coarse aggregates and utilization of short fibers. Utilization of WTSF contributes to the sustainability of the construction industry[10].Waste tire recycling is an example of generic material recycling that stands out as a dramatic case of environmental benefits from the reduction of waste stream for products unwelcome at disposal sites. Tires consume a large volume of limited landfill space, trap methane gas and 'bubble' to the surface because they become buoyant[22]. In order to prevent waste rubber and in particular discarded automobile tires from damaging the environment, it is highly desirable to recycle this material. However, the total mass quantity of tires currently recycled in a given year (not including reuse, retreading, or combustion) is less than 7% of the annual tire generation rate. A majority of the markets for recycled tire products can be expanded; but even if these markets reached their full potential, the number of tires generated each year would continue to far exceed the demand for scrap and used tires[23].Waste tires is one of the cheap, economical, easy and abundantly available source for producing a high tensile strength steel fibers known as RTC(Recycled tire cord), which can be used successfully in the concrete mix. Recently few researcher have carried research on used tire steel fibers concrete and the results seems to be satisfactory[10]

Table 2-3 Physical properties of steel fiber and some other fibers[5].

Fiber	Diameter(µm)	Specific Gravity	Modulus of Elasticity(Gpa)	Tensile Strength(Gpa)	Elongation at break(%)
Steel	5-500	7.84	200	0.5-2	0.5-3.5
Glass	9-15	2.6	70-80	2-3.5	-
Crocidolit	0.02-0.4	3.4	196	3.5	2-3
Chrysotile	0.02-0.4	2.6	164	3.1	2-3
Polypropylene	6-200	0.91	5-77	0.15-0.75	15
Aramid	10	1.45	65-133	3.6	2.1-4
PAN	7-9	1.6-1.7	230-380	2.5-4	0.5-1.5
Pitch	9-18	1.6-2.15	28-480	0.5-3	0.5-2.4
Nylon	20-200	1.1	4	0.9	13-15
Cellulose	-	1.2	10	0.3-0.5	-
Sisal	10-50	1.5	13-26	0.3-0.6	3-5
Wood Fiber	25-75	1.5	71	0.7-0.9	-

Figure 2-3 Waste Tire steel Fiber

2.7 Cement

There are over ten different types of cements that are used in construction purposes, and they differ by their composition and are manufactured for different uses. These are rapid- hardening cement (RHC), quick-setting cement (QSC), low- heat cement (LHC), sulphate-resisting cement (SRC), blast furnace slag cement (BFSC), high-alumina cement (HAC), white cement (WC), coloured cement (CC), pozzolanic cement (PzC), air-entraining cement (AEC), and hydro-phobic cement (HpC). RHC has increased the lime content compared to the Portland cement (PC).Purpose of having high lime content is to attain high strength in early days[24].The cements commonly available in the construction industry are Portland-Pozzolona Cement (PPC), Ordinary Portland Cement (OPC) and Portland Blast Furnace Slag Cement (PBFS)[10].Any material which can be made plastic and which gradually hardens to form an artificial stone-like material is referred to as a cementitious material. Hydraulic cements, namely Portland and natural, along with limes are the principal cementing materials used in structures. They become plastic by the addition of water and then the mix hardens.[11]

2.8 Water

The water used for concrete should be clean and free from dirt or organic matter.. Construction industries consume huge amounts of potable water during activities such as washing of aggregates, stone crushing, manufacturing, and curing of concrete, mortars, grouts, and wetting of masonry bricks. It is also responsible for wastewater generated during the finishing and cleaning of buildings and construction equipment. Therefore, the water-footprint of construction industry cannot be ignored to reach the state-of-the art sustainability[6].

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Study area

This research was conducted at Jimma University institute of technology , Jimma, Ethiopia. Jimma is the largest city in South-western Ethiopia. It was found Longitude of 35^0 0' 0'' to 38^0 0' 0'' E and Latitude of 7^0 0' 0'' to 9^0 0' 0''N and has an elevation of 1,780m.

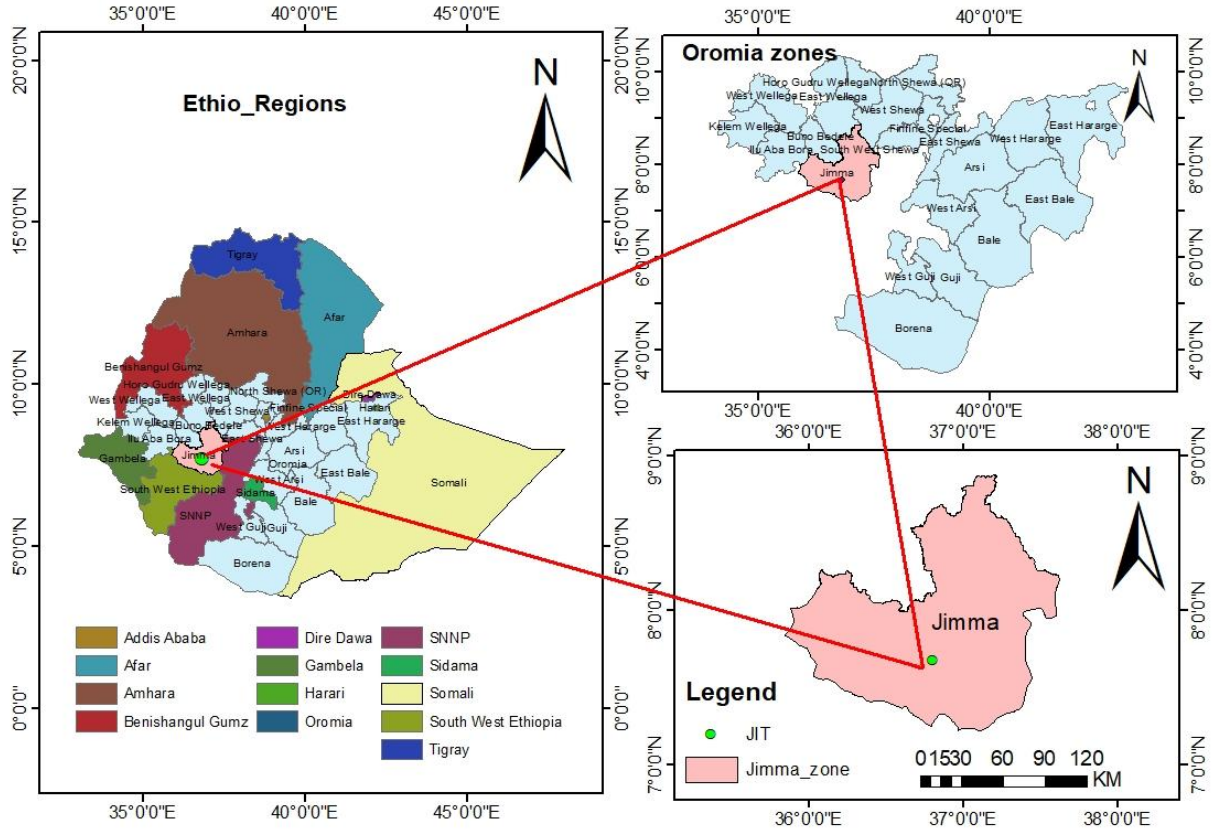

Figure 3-1 Study Area map

3.2 Materials

The experimental investigation used cement, aggregate, water, banana fiber, and waste tire steel fibers as its materials. In the context of this study, "conventional concrete" refers to regular concrete with a grade of C20/25 that includes cement, water, and aggregates as its primary ingredients. The hybrid fiber reinforced concrete test sample was casted using Portland cement, washed sand, washed coarse aggregate, banana fiber, steel fibers, mixing equipment, and placing tools. In order to test the flexural, compressive, and tensile strengths of the concrete for the experimental setup, a universal testing machine was also used.

3.2.1 Cement

All of the concrete specimens' mixtures were prepared using Portland Pozzolana Cement (PPC), Dangote product cement with a 32.5 grade. The cement used for production of concrete was Pozzolana Portland cement (PPC) which was manufactured by Dangote Cement Industries PLC. It was delivered from one of Jimma's stores that sold building supplies. The specific gravity of the Dangote PPC was known to have 3.15. The reason to select this cement is due its availability other than the type of cement on the market.

Prior to the determination of the amount of water required to prepare the cement paste, normal consistency test was performed. Three trials were carried out with different water – cement ratio until the proportional of water in mix achieved for a paste that the rod of Vicat apparatus settles $10 \pm 1mm$ below the original surface within 30 seconds. The consistence of PPC in this study is observed at water cement ratio of 33% which have penetration depth of 9mm. The usual range of water - cement ratio for normal consistency is between 26% and 33%.

3.2.2 Water

Washing aggregate, mixing, and curing of concrete were all done with potable water provided by Jimma Town Water Supply and Sewerage Authority.

3.2.3 Steel Fiber

The term "steel fiber" can refer to a variety of shapes with a range of lengths and diameters that are intentionally incorporated into concrete mixtures to increase tensile strength. The primary necessity for mixing stems from the characteristics of steel fiber, specifically its aspect ratio, which describes the ratio of its length to diameter. If the required workability and uniform distribution are met, the fiber performance will improve with increasing aspect ratio. This is due to the fact that pullout resistance is improved by increased aspect ratio[6].

3.2.3.1 Extraction of steel fiber

The steel fiber used for this experimental research was extracted from waste tire. The steel fiber separated from waste tire was used as fibers in concrete. As well known, the presence of steel fibers in concrete improves the performances of concrete, including post-cracking behavior and impact resistance[25].ASTM A820 dictate that the length of steel fiber ranges between 13 to 64mm.According to ACI 544.1R-96, the diameter of steel fiber ranges between 0.5 to 1 mm. Based on ASTM A820 and ACI 544.1R-96, the length of steel fiber used for this experimental research was 50mm long and its diameter was 1mm . It was chopped manually by using steel fiber cutter which is called Gutat.

3.2.3.2 Aspect Ratio of Steel fibers

The fiber strength, stiffness, and the ability of the fibers to bond with the concrete are important fiber reinforcement properties. Bond is dependent on the aspect ratio of the fiber. Steel fibers should be clean and free of rust, oil, and deleterious materials. The most common steel fiber diameters are in the range of 0.5 to 1.0 mm and a specific gravity of 7.85[3]. Steel fiber shapes include round, oval, polygonal, and crescent cross sections, depending on the manufacturing process and raw material used. Steel fibers in the common length range of 13 to 64 mm and should preferably have an aspect ratio in the range of 30 to 100[3].

Figure 3-2 Steel fiber and process of Chopping

3.2.4 Banana Fiber

Banana fiber is a waste product of banana cultivation. The addition of Banana fibers to concrete makes it additional homogenized and isotropic and transforms it from a brittle to additional ductile materials. Banana fibers have highly strength, light weight, smaller elongation, fire resistance quality, strong moisture absorption quality, great potentialities and biodegradability.

3.2.5 Extraction of Banana fiber and its usage

For this experimental study, banana fiber was extracted from locally available banana plant products from Oromia Region, Jima Zone Seto semero kebele.

The banana fiber extraction was carried out through the following process.

- The banana plant was cut at the bottom for extraction of fibers; it was long, had a circular cross-sectional area, and narrower from the bottom to the top.
- The banana trunk was covered with a white sheath; it was cut off from the bottom part of the plant.

- The trunk has more than four circular layers which aligned together up to the core center, the layers were separated using a blunted knife and prepared for fiber extraction.
- The separated trunk was aligned on the inclined wood plate. The white sheath was chopped frequently from the top to the bottom by using wotar (it was made from bamboo and has a little sharpness) and blunted knife.
- The fiber was extracted through this repeated action.

ACI 544.1R-96 dictates that the diameter of natural fiber ranges between 0.1 to 0.75mm[20].Since banana fiber is a type of natural fiber and its average diameter was taken according to ACI 544.1R-96. ACI 544.1R-96 also dictates that the length of natural fiber varies between 6 to 64 mm[20].Therefore depending on ACI 544.1R-96, the length of banana fiber was taken to 30mm.

Table 3-1 Aspect Ratio of Banana Fiber

Diameter(mm)	Length(mm)	Aspect Ratio(l/d)
0.2	30	150
0.4	30	75
0..6	30	50
Average		91.67

Figure 3-3 Banana fiber extraction process

Figure 3-4 Banana fiber and process of Chopping

3.2.6 Coarse Aggregate

3.2.6.1 Sieve Analysis of Coarse Aggregate

Sieve analysis is a procedure for determination of the particle size distribution of aggregates using series of square or round openings starting with the largest. It is used to determine the grading or aggregate the fineness modulus, an index to the fineness and coarseness and uniformity of aggregate[26].Grading or particle size distribution affects significantly some characteristics of concrete like packing density, voids content, and, consequently, workability, segregation, durability and some other characteristics of concrete[27]. Coarse aggregates are obtained from gravel or crushed stone, blast furnace slag, or recycled concrete. Trap rocks, granite, lime stones, and sandstones are satisfactory for crushed stone. For this reason, a coarse aggregate should be chosen that it insufficiently hard, free of cracks, clean, and free of surface coatings. The particle size of coarse aggregate is larger than 5mm or between 9.5mm and 37.5mm or a combination of crushed stone. According to ACI 2114R, 2002, gradation of coarse aggregate for high-strength concrete depends on the grade of concrete. Based on this the size of the coarse aggregate used for this experiment is 20mm.Fines in the coarse aggregate were removed by sieving through a 4.75mm sieve to confirm the requirement of ASTM C33.

3.2.6.2 Moisture content of coarse aggregate

Moisture content of coarse aggregate was carried out to know the required quantity of water for the desired strength and workability of concrete. Moisture content of course aggregates was determined by oven drying a sample of coarse aggregate (2000gm) in an oven at a temperature of 110^{o}c for 24hrs and dividing the weight difference by the oven-dry weight. The moisture content used for this experimental research was 0.81%.The detail result was discussed in APPENDIX C.

3.2.6.3 Specific Gravity and Absorption Capacity of coarse aggregate

The objective of determining specific gravity and absorption capacity of coarse aggregate is:-

- To determine bulk and apparent specific gravity
- To determine absorption of coarse aggregate

A sample of 2000gm aggregate is immersed in water for 24 hour to essentially fill the pores. It is then removed from the water, the water is dried from the surface of the particles, and the mass determined. Subsequently, the is placed in a graduated container and the volume of the sample is determined by the gravimetric or volumetric method. Finally, the sample is oven-dried and the mass was determined again. For the test done, bulk specific gravity (SSD) was 2.83 and absorption capacity was 0.92%.The test was done based on ASTM C-128. The detail result was discussed in APPENDIX A.

3.2.6.4 Unit weight of Coarse aggregate

Unit weight can be defined as the weight of a given volume of graded aggregate. It is the density measurement and is also known as bulk density. This test method is often used to determine bulk density values that are necessary for use for many methods of selecting proportions for concrete mixtures. The bulk density also used for determining mass/volume relationships. The unit weight of course aggregate used for this experimental research was 1748.4 Kg/m^3 and the tests was carried out according to ASTM C-29. The detail result was discussed in APPENDIX A.

Figure 3-5 Photo taken while Unit weight of coarse aggregate

$$\text{Apparent Specific gravity} = \frac{\text{MD}}{\text{MD} - \text{MW}}$$

$$\text{Bulk Specific gravity} = \frac{\text{MD}}{\text{MSSD} - \text{MW}} \text{Oven dry}$$

$$\text{Bulk Specific gravity} = \frac{\text{MSSD}}{\text{MSSD} - \text{MW}} \text{Saturated surface dry}$$

$$\text{Percentage of water absoption} = \frac{\text{MSSD} - \text{MD}}{\text{MD}} * 100$$

$$\text{Weight of aggregate in water} \quad \text{Ww} = \text{Wa} - \text{Wb}$$

Where

M_W =Weight in water of the saturated aggregate.

M_{SSD} =Weight in air of the saturated surface dry aggregate.

M_D= Weight in air of oven dried aggregate.

SSD =Saturated surface dry.

Table 3-2 Specific gravity, moisture content and absorption of coarse aggregate

Description	Trial-1	Trial-2	Trial-3	Avge
Ww=weight in water of saturated aggregate(Kg)	1.28	1.342	1.279	
M_{SSD} =weight in air of saturated surface dry(Kg)	2.004	2.005	2.002	
MD=weight in air of oven dried aggregate(Kg)	1.986	1.987	1.983	
Bulk Specific gravity=$M_D/(M_{SSD}-M_W)$	2.74309	2.99698	2.7427	2.83
Bulk Specific gravity(SSD)=$M_{SSD}/(M_{SSD}-M_W)$	2.76796	3.02413	2.769	2.85
Apparent Specific gravity=M_D/M_D-M_W	2.81303	3.08062	2.8168	2.90
Absorption Capacity(%)=(MSSD-MD)/MD*100	0.90634	0.90589	0.9581	0.92
Moisture content(%)=(MD-MSSD)/MSSD*100	0.8982	0.89776	0.94905	0.92

3.2.7 Sieve Analysis of Fine Aggregate

Sieve analysis is a procedure for the determination of the particle size distribution of fine aggregate using a series of square or round openings starting with the largest. It is used to determine the grading or aggregates and fineness modulus, an index to the fineness, coarseness and uniformity of aggregate. The fine aggregate used for this investigation was collected from Chewaka River. The natural river sand has maximum size of 4.75mm diameter and the analysis was done as per ASTM C 136

3.2.7.1 Moisture Content of Fine Aggregate

This test method was used for the determination of the percentage of moisture in a sample of aggregate by drying both surface moisture and moisture in the pores of the aggregate. This test method is sufficiently accurate for usual purposes, such as adjusting batch quantities of ingredients for concrete.

.Moisture content was calculated as:-

$$\text{Moisture Content} = \frac{(weight\ of\ original\ sample - Weight\ of\ oven\ dry\ sample)}{Weight\ of\ oven\ dry\ sample} * 100$$

The moisture content used for this experimental research was 0.6% and the test was conducted as per ASTM C 566-96(2004). The detail test result was discussed in APPENDIX A

3.2.7.2 Silt Content of fine aggregate

ASTM C33 states, the material in fine aggregates which is finer than 75μm is generally regarded as silt. Sand contain other materials such as dust, loam and clay that are finer than sand. The presence of such materials in sand used to make concrete or mortar decreases the bond between materials to be bound together and hence the strength of the mixture. The finer particles also decrease the quality of mixture produced resulting fast deterioration. According to the Ethiopian standard it is recommended to wash or reject if the silt content exceeds a value of 6%[28]. The detail test result was discussed in APPENDIX A.

Table 3-3 Silt Content of fine aggregate

S/N	Description	Sample 1	Sample 2	Sample 3
1	Volume of sample(silt + sand)=V_1(ml)	75	75	75
2	Volume of silt after 3hr = $V_{2(ml)}$	2.3	2	2
3	% Silt Content by volume $= \frac{\mathbf{V_2}}{\mathbf{V_1}} * 100$	3.1	2.67	2.67
Average		3		

3.2.7.3 Specific gravity and absorption capacity of fine aggregate

The objective of this test method was used to determine specific gravity and absorption capacity of fine aggregate. Specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in the mixtures. It is also used in the computation of voids and surface moisture on fine aggregate. Absorption capacity of fine aggregate is used to calculate change I the mass of fine aggregate due to water absorbed in the pore spaces within the constituent particles. According to the procedure discussed on ASTM C 128-93(Reapproved 2001), bulk specific gravity (SSD), apparent specific gravity and absorption capacity of fine aggregate were calculated the results were 2.52, 2.56 and 0.94% respectively.

According to ASTMC33/C33M (2011), the limitation for absorption capacity ranges from 0.2 to 2 % for fine aggregates. Accordingly, the moisture content obtained was within limits. The detail test result was discussed in APPENDIX A

Figure 3-6 Photo taken while specific gravity and absorption capacity was performed.

3.2.7.4 Unit Weight of fine aggregate

This test method was used to determine unit weight of fine aggregate in compacted or loose condition. It is also used to determine mass or volume relationship. The test method was carried out according to the procedure of ASTMC-29 and simply measured by filling a container of known volume and weighing it. Then dividing the aggregate weight by the volume of the container provides unit weight of the aggregate. The unit weight used for this experimental research was 1497.8 Kg/m^3. The detail test result was discussed in APPENDIX A

Figure 3-7 Photo taken while unit weight of fine was performed

Table 3-4 Summary of aggregate properties

Aggregate	Apparent specific gravity	Bulk specific gravity (SSD)	Bulk specific gravity (oven dry)	Absorption Capacity (%)	Unit weight (kg/m3)	Moisture Content (%)
Fine	2.56	2.52	2.50	0.94	1497.8	0.6
Coarse	2.90	2.85	2.83	0.92	1748.4	0.87

Figure 3-8 Washing course and Fine aggregate

3.3 Research Design

In order to attain the required specific objectives descriptive and experimental analysis type of study was applied on the research. The descriptive method was used to describe the way in which the fibers extracted, the composite made, sample fiber reinforced concrete can be casted and how the hybrid fiber reinforced concrete was made. An experimental study was implemented to manipulate the independent variables. After comprehensively organizing literature review of different previous published researches, designate the investigation of the physical and mechanical properties of hybrid waste tire steel and banana fiber-reinforced concrete. In this study, the investigation of the physical and mechanical properties of hybrid waste tire steel and banana fiber-reinforced concrete from literature review was analyzed.

3.4 Study Variables

3.4.1 Dependent Variables

The dependent variables used for this thesis was listed below.

- Workability of concrete
- Compressive strength
- Split tensile strength
- Flexural strength
- Modulus of elasticity
- Stress-Strain relationship

3.4.2 Independent Variables

The independent variables of this research thesis includes

- Hybrid percentage
- Curing period of concrete
- Water cement ratio

3.5 Population and Sampling method

The grade of concrete that used for this research is C20/25. By adding different percentage value of combination of hybrid waste tire steel and banana fiber reinforced concrete, sample taken for the different tests. The study used purposive sampling techniques and the procedure taken according to ASTM and ACI standards which means minimum of cube samples per each test day was 3 samples. The samples for compressive strength, split tensile strength and Flexural strength for all groups such as 0%, 0.5%, 1% and 1.5% tests taken on 7, 14 and 28 days. For compressive strength, split tensile strength and Flexural strength the cube size was 150mm*150mm*150mm, cylinders with 100mm diameter and 200 mm height and beams with cross-section $100mm \times 100mm$ and length of 500mm size casted respectively. Total number of

specimens casted for control, compressive strength, Split tensile strength and Flexural strength were 108 specimens.

Table 3-5 Summary of Total Population

Types of specimen	Compressive strength test			Tensile strength test			Flexural strength			Total specimen
	7 day	14 day	28 day	7 day	14 day	28 day	7 day	14 day	28 day	
Control (0%)	3	3	3	3	3	3	3	3	3	27
0.25%WTS +0.25%BF	3	3	3	3	3	3	3	3	3	27
0.75%WTS+0.25%BF	3	3	3	3	3	3	3	3	3	27
1%WTS+0.5%BF	3	3	3	3	3	3	3	3	3	27
Sum	12	12	12	12	12	12	12	12	12	108

3.6 Mix design of concrete

The process of choosing a concrete mixture's necessary and specified properties is known as mix design. By using these materials, the desired strength is achieved. On the other hand, mix proportioning is the process of figuring out how much of each ingredient to add to concrete in order to get the desired properties from the concrete using locally available materials. Concrete building becomes more cost-effective when concrete mix design is precise. Knowing the grade of concrete must come before calculating the precise amount of cement, sand, and aggregate needed in 1 m^3 of concrete. It is intended to prepare concrete grades C-25 which is the most commonly used grade of concrete throughout the country. The steps for the mix design were based on ACI 211.1 and listed as follow.

Step1: The desired strength is 25 MPa

The Collected data for mix design includes:-

- Fineness modulus of selected fine aggregate =3.28
- The specific gravity of the Dangote PPC = 3.15
- Fineness modulus of selected fine aggregate =2.88
- Unit weight of dry rodded coarse aggregate (Normal aggregate) =1748.4Kg/m3
- specific gravity of coarse and fine aggregate in saturated surface dry condition is 2.85 and 2.52
- Absorption characteristic of both coarse and fine aggregate is 0.94%and 0.92% respectively
- Free surface moisture in sand and coarse Aggregate 0.6% and 0.87% respectively.

Step 2: Determination of water to cement ratio

- From the strength point of view the estimated water to cement ratio is 0.62 and
- From the Exposure condition the estimated water to cement ratio is 0.5

Therefore, adopt water to cement ratio of 0.5

Step 3: Maximum size of aggregate and workability

The expected slump for workability selected as between 25 – 100mm and air content is 2%

Maximum size of coarse aggregate is 20mm.

Step 4: The concrete is non-air entrained since the structure is not exposed to severe weather as per ACI 211.1-91, for 20mm aggregate size the total density of water is **185 kg/m^3.**

Table 3-6 Mixing water and air content of aggregate as per ACI 211.1-91

Workability or Air content	*Water Content, Kg/m³ of concrete for indicated maximum aggregate size*							
	10 mm	*12.5 mm*	*20mm*	*25 mm*	40 mm	50 mm	70 mm	150 mm
	Non-air-entrained concrete							
Slump								
30–50 mm	205	200	185	180	160	155	145	125
80–100 mm	225	215	200	195	175	170	160	140
150–180 mm	240	230	210	205	185	180	170	–
Approximate entrapped air content per cent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained Concrete							
Slump								
30–50 mm	180	175	165	160	145	140	135	120
80–100 mm	200	190	180	175	160	155	150	135
150–180 mm	215	205	190	185	170	165	160	–
Recommended average total air content percent								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 5: weight of coarse aggregate

From ACI table 11.4 for maximum size of 20mm coarse aggregate and fineness modulus of sand 3.28 the dry rodded bulk volume of coarse aggregate is 0.6 per unit volume of concrete.

The weight of coarse aggregate = 0.6*1748.4Kg/m^3= 1049 kg/m^3

Table 3-7 Dry bulk volume of coarse aggregate given by ACI 211.1-91

Maximum Size of Aggregate	Bulk volume of dry rodded coarse aggregate per unit volume of concrete for fineness modulus of sand of			
F.M.	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
70	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Step 6: weight of fine Aggregate

From ACI table 11.9 as shown below, the first estimate of density(unit weight) of fresh concrete for 20mm maximum size of aggregate and non-air entrained concrete is 2355kg/m3

Table 3-8 Density (Unit weight of fresh concrete as given by ACI 211.1-91

Maximum size of	First estimate of density (unit weight) of fresh concrete	
aggregate mm	Non-air-entrained kg/m^3	Air-entrained kg/m^3
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

Weight of fine Aggregate = 2355 – (1049+ 370 + 185) =751kg/m^3

The absolute volume of mix ingredients per cubic meter of concrete based
Volume basis is:

$$\text{Cement} = \frac{\text{weight of cement}}{\text{sp.gravity}} = \frac{370}{3.15*1000} = 0.1175\text{m}^3$$

$$Water = \frac{185}{1 * 1000} = 0.185m3$$

$$\text{Coarse Aggregate} = \frac{1049}{2.85 * 1000} = 0.368\text{m3}$$

$$\text{Air}(2\%) = \frac{2}{100} = 0.02$$

Total volume without sand = 0.1175 + 0.185 + 0.368 + 0.02= 0.6905m^3

Volume of Sand=1-0.6905=0.3095m^3

Then the dry mass of sand = $0.3095 * 2.52 * 10^3$= 779.94Kg

Therefore, the mass of ingredients per cubic meter of concrete on dry weight basis is:

Cement = 370 kg

Water = 185 kg

Sand (fine aggregate) = 779.94Kg

Coarse aggregate = 1049 kg

Step 7: Proportion

Table 3-9 Concrete constituents before Adjustments

Ingredients	Cement	Sand	Coarse Aggregate	Water
Quantity(kg/m^3)	370	779.94	1049	185
Ratio	1	2.1	2.84	0.5
One bag Cement(kg)	50	105	142	25

Step 8: Adjustment for field condition

The proportions are required to be adjusted for the field conditions. Fine aggregate has surface moisture of 0.6%=0.006

Therefore, total free surface moisture in fine aggregate = $\frac{0.6}{100} * 751 = 4.506\text{kg/m3}$

Weight of fine aggregates = 751+ 4.506=755.506kg/m3

Coarse aggregate absorbs 0.92% of water. =0.009

Weight of coarse aggregate = $\frac{0.92}{100} * 1049 = 9.65\text{kg/m3}$

Therefore weight of coarse aggregate=1049+9.65=1058.65

Adjust the amount of water based on moisture content

The required mixing water = 185- 779.74(0.006-0.0092) – 1049*(0.0087 - 0.0094)

= 188.2303

Step 9: Adjusted mix design Proportion

Table 3-10 Adjustment of mix design

Ingredients (kg/m3)	Cement	Sand	Coarse Aggregate	Water
	370	755.506	1058.65	188.2303
Ratio	1	2.04	2.861	0.51
One bag cement(Kg)	50	102	143.05	25.5

Step 10: Hybrid fiber reinforced concrete mix design

The fiber reinforced concrete mix design was done for the unit cubic meter of concrete. The amount of fiber added for hybrid fibers were 1% of total volume of concrete. In order to change the volume of fiber in to mass, density of each fiber was taken. The dry density of steel fiber taken as 7850kg/m^3[7]. The dry density of banana fiber is 1000-7500kg/m^3 and the mean value of dry density is 1350kg/m^3 as per[29].The amount of hybrid fiber content 0.5 %(0.25%SF+0.25%BF), 1 %(0.75%SF+0.25%BF) and 1.5 %(1%SF+0.5%BF) by a total volume of concrete was added and calculated for 1m^3 of C-25 concrete strength.

For Steel Fiber

- For 1% steel fiber

In one-meter cube of concrete 0.01m3of steel fiber added

=7850kg/m3 *0.01m3 =78.5kg

- For 0.25% Steel fiber=7850kg/m3*0.0025m3=19.625kg
- For 0.75% Steel fiber=7850kg/m3*0.0075m3=58.88kg
- For 1% steel fiber=7850kg/m3*0.01m3=78.50kg

For banana fiber

- For 1% banana fiber

In one-meter cube of concrete 0.01m3 of banana fiber added

=1350kg/m3*0.01m3=13.5kg

- For 0.25% banana fiber=1350kg/m3*0.0025m3=3.375kg
- For 0.5% banana fiber =1350kg/m3*0.005m3=6.75kg

A total of four concrete mixes were prepared with plain concrete as control and each mix, 150x150x150mm cubes, cylinders with 100mm diameter and 200 mm height and beam with cross-section of $100mm \times 100mm$ and length of 500mm were prepared for compressive strength, splitting tensile strength and flexural strength respectively.

3.7 Mixing and Casting

The mix of hybrid concrete takes place the same as the normal concrete mix procedure. All ingredients of concrete are measured for required volume of concrete and casting of specimen was performed. The primary experiments performed in this study can be roughly classified into two categories. These are test on fresh concrete i.e. slump and compaction factor test, and test on hardened concrete which includes compressive strength tests, flexural strength tests, and split tensile tests.

3.8 Test conducted on concrete

3.8.1 Workability

The workability of a concrete mix is the relative ease with which concrete can be placed compacted and finished without separation or segregation of the individual materials. The workability of freshly mixed concrete is a measure of its ability to be mixed, handled, transported, and ,most importantly, placed and consolidated with a minimal loss of homogeneity and minimal entrapped air[30].

Workability is important because of two reasons.

- If the concrete mixture is too wet, coarse aggregates settle at the bottom of concrete mass and as a result concrete becomes non-uniform composition and
- If the concrete mixture is too dry it will be difficult to handle and place it in position.

There are various types of workability testing methods implemented both in the laboratory and at site. These are Slump cone test, Compaction factor test, Vee-bee Consistometer test and flow meter test. Among this slump cone test and compaction factor test was found in laboratory of Jimma Institute of Technology.

A. Slump Cone Test

The concrete or slump cone test determines the workability or consistency of the concrete mix prepared at the laboratory or the construction site during the progress of the work. A concrete slump test is carried out from batch to batch to check the uniform quality of concrete during

construction. According to ASTMC143/C143M standard, concrete pastes having a slump test value of lessthan15mm may not be adequately plastic and greater than 230mm may not be adequately cohesive. The slump test values between 15 mm and 230 mm are favorable in concrete production. On another hand, ACI 211.1-91 recommended a slump value in a range of 20mm to 100mm based on different types of construction like foundation, wall, column, beam, and others [22].In general, the slump value for fiber reinforced concrete determined from ASTM C143/C143M should be at least 25mm, but not greater than 175mm[31].Accordingly, the slump test value obtained from the experimental investigation was 26mm-40mm which is found in between the ranges specified in the standards

Equipment's required for Concrete Slump Test as per[32]

Mold:-The test specimen shall be formed in a mold made of metal not readily attacked by the cement paste. The metal shall not be thinner than 1.5 mm and if formed by the spinning process, there shall be no point on the mold at which the thickness is less than 1.15 mm .The cylinder mold shall be in the form of the lateral surface of the frustum of a cone with the base200 mm diameter, the top 100mm diameter, and the height 300mm.

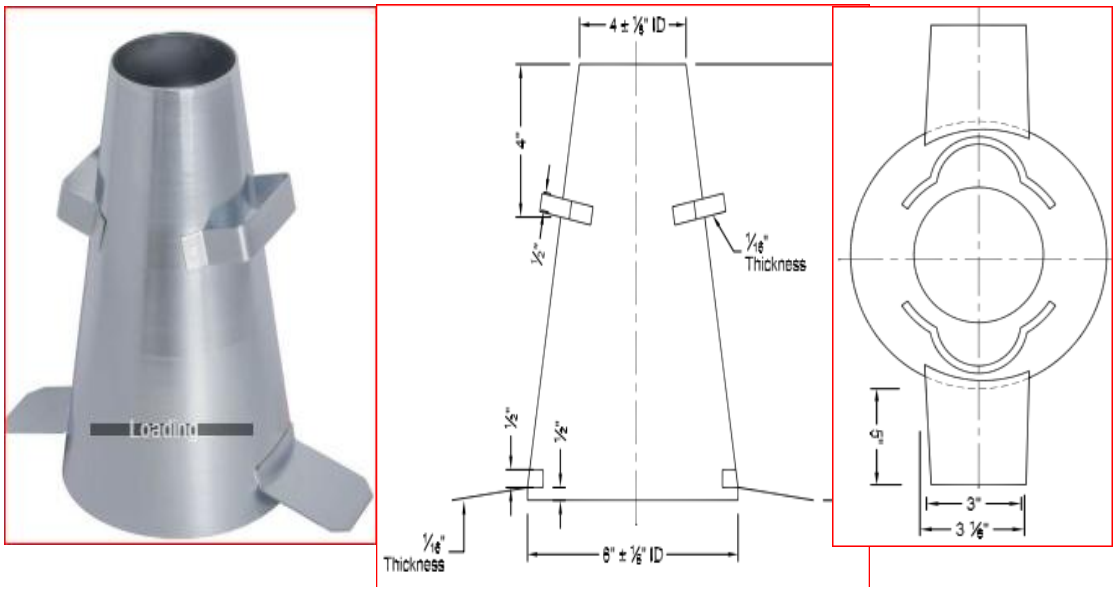

Figure 3-9 Cross-section of slump test mold[37]

Tamping Rod-The tamping rod shall be a round, straight steel rod 16 mm in diameter and approximately 600 mm length, having the tamping end or both ends rounded to a hemispherical tip the diameter of which is 16 mm

Measuring Device-A ruler, metal roll-up measuring tape, or similar rigid or semi-rigid length measuring instrument marked in increments of 5 mm or smaller. The instrument length shall be at least 300 mm.

Procedure for Concrete Slump Cone Test[32]

1. The internal surface of the mould should be clean and apply oil.
2. Place the mould on a smooth horizontal non-porous base plate.
3. Fill the mould 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 mould. 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 that leaked out between the mould and the base plate.
7. Raise the mould from the concrete immediately and slowly in the vertical direction.
8. Measure the slump as the difference between the height of the mould and that of the height point of the specimen being tested.

When the slump test is carried out, the following are the shape of the concrete slump that can be observed.

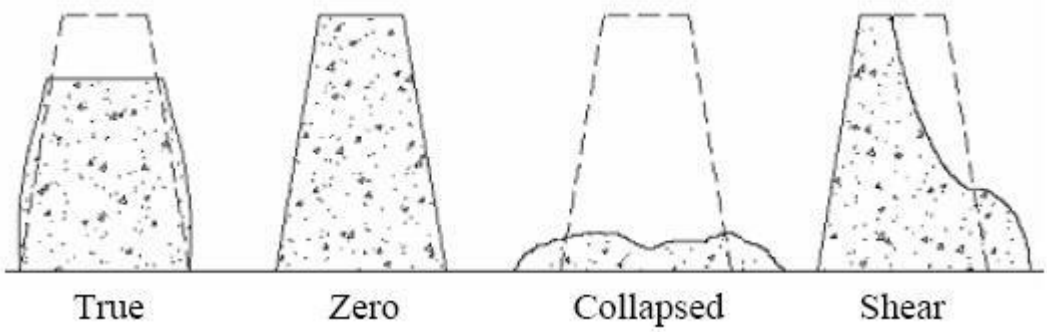

Figure 3-10 Types of Concrete Slump Test

Figure 3-11 Measuring slump of concrete

B. Compaction Factor Test

The compaction factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability and normally used when concrete is to be compacted by vibration. The method applies to plain and air-entrained concrete, made with lightweight, normal weight, or heavy aggregates having a nominal maximum size of 38 mm or less but not to aerated concrete or no-fines concrete. The compaction factor is defined as the ratio of the mass of compacted concrete in the compaction factor apparatus to the mass of fully compacted concrete. The compacting factor test is used to find out the low workability of concrete**.** The compaction factor is the ratio of weights of partially compacted to fully compacted concrete[33]

Equipment's required for compaction factor test as per[33]

Compaction factor apparatus consists of trowels, hand scoop (15.2 cm long), a rod of steel or other suitable material (1.6 cm diameter, 61 cm long rounded at one end) and a balance.

The procedure of the Compaction Factor Test on Concrete

1. Place the concrete sample gently in the upper hopper to its brim using the hand scoop and level it.
2. Cover the cylinder.
3. Open the trapdoor at the bottom of the upper hopper so that concrete falls into the lower hopper. Push the concrete sticking on its sides gently with the road.
4. Open the trapdoor of the lower hopper and allow the concrete to fall into the cylinder below.
5. Cut the excess concrete above the top level of the cylinder using trowels and level it.
6. Clean the outside of the cylinder.
7. Weight the cylinder with concrete to the nearest 10 g. This weight is known as the weight of partially compacted concrete (**W1**).
8. Empty the cylinder and then refill it with the same concrete mix in layers approximately 5 cm deep, each layer being heavily rammed to obtain full compaction.
9. Level the top surface.
10. Weigh the cylinder fully compacted. This weight is known as the weight of fully compacted concrete (**W2**).
11. Find the weight of empty cylinder (**W**).

$$\text{Compaction factor} = \frac{\text{weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}} = \text{CF} = \frac{\text{PC}}{\text{FC}} \dots\dots\dots eq\ 3.1$$

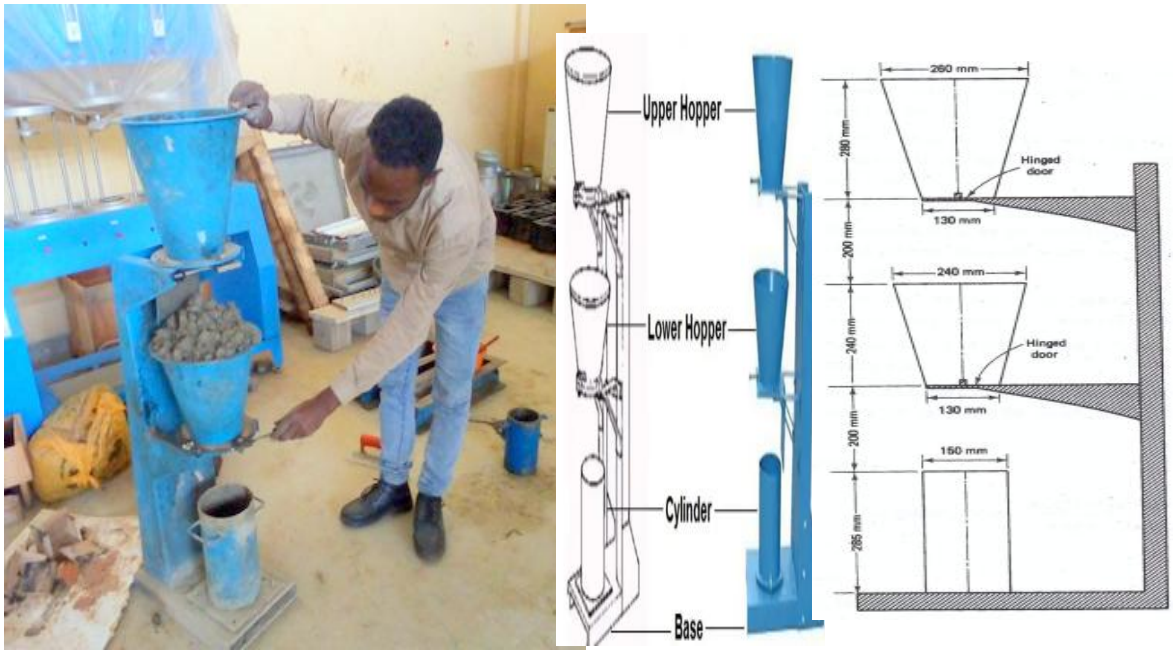

Figure 3-12 Compaction factor test apparatus

3.8.2 Compressive strength Test(as per ASTM C109)

The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water and fibers. The concrete strength depends on the size and shape of the test specimen and the manner of testing. Compression test is the most common test conducted on hardened concrete, partly because it is easy test to perform and partly because most of desirable characteristic properties of concrete are qualitatively related to its compressive strength. Compression test is carried out on specimens of cubical shape. The size of specimen is 150×150×150 mm was cast for C-25 grade of concrete added with hybrid fiber. This test was done by using universal testing machine that can apply maximum load of 2000KN and records the peak load and the corresponding compressive stress of concrete.

3.8.3 Concrete Cube test procedure[34].

1. Using mold release agent, spray cube mold.
2. Plastic consistency:
    a. Fill all cube molds halfway with mortar.
    b. Tamp mortar with tamper 25 times (per ASTM C109).
    c. Fill remainder of mold with mortar, tamp 25 times (per ASTM C109).
3. Screed off excess mortar so the surface of each specimen is flush with the top of the mold.
4. Clean off any excess material on the top of the mold.
5. Immediately upon completion of molding: Place laboratory specimens in the moist room and cure in accordance with the applicable portions of Test Method C109/C109M.

6. Identify cubes with product name, batch code, start time, age, test date, and water content.

7. Leave mold after 24 hours.

8. When testing cubes, it should not the apply the load to the original top or bottom cube surfaces (rotate cubes 90 degrees before loading in compression tester).

9. Record the compressive strength results

The compressive strength is given by:

$$\text{Compressive Stress } (\sigma) = \frac{Peak\ Load}{\text{Cross sectional area}} = \frac{P}{A} = \frac{P}{b*d} = \frac{P}{150*150}(Mpa) \dots\dots eq.3.2$$

Figure 3-13 Casting cube and cylinder specimen

3.8.4 Split Tensile Strength Test

No standard tests have been adopted to provide a direct measurement of the tensile strength of concrete. The problem of secondary stresses induced through gripping makes the test results difficult either to interpret or reproduce. The splitting tensile strength test is an indirect tension test for concrete. It is not practical to apply a true ‘’line ‘load along the top and bottom of the specimen, partly because the sides are not smooth enough and partly because this would induce extremely high compressive stresses nor the points of load application. Therefore, the load is usually applied through a narrow bearing strip of relatively soft material. As concrete is much weaker in tension than in compression, failure will be in splitting tension at a much lower load than would be required to crush the specimen in compression, thus permitting an estimate to be made of the tensile strength of the concrete. It is also possible to carry out splitting tension tests on cubes. This is done by loading through two hemispherical bars along the centerlines of two opposite faces[26].Concrete tensile strength is about 10 to 15% of its compressive strength. The strength of concrete in tension is an important property that greatly affects that extent and size of cracking in structures. A standard 100x200mm compression test cylinder is placed on its side and loaded in compression along a diameter[35].

Split Tensile Strength Testing Procedure (as per ASTM C39)

1. Plastic consistency:
    a. Fill all cylinders halfway with mortar.
    b. Rod mortar in cylinder 25 times with 3/8” rounded tamping rod.
    c. Tap sides of cylinder 10-15x with rubber mallet to release air.
    d. Fill cylinder with mortar.
    e. Rod 25 times.
    f. Tap sides of cylinder 10-15x to release air.
2. Screed off excess mortar so the surface of each specimen is flush with the top of the cylinder.
3. Place plastic cap or wet towels on the cylinder to prevent moisture loss.
4. Immediately upon completion of sample: Place laboratory specimens in moist room and cure in accordance with the applicable portion of Test Method C109/C109M
5. Identify cylinders with product name, batch code, start time, age, test date, and water content.
6. Leave cylinders undisturbed until appropriate break point, or 24 hrs.
7. De-mold cylinders at appropriate break point and record the results.

The stress was determined by using the following formula

$$\sigma t = \frac{2P}{\pi a^2} = \text{for cube specimen}$$

$$\sigma t = \frac{2P}{\pi l d} = \text{for cylinderical specimen}$$

Where,

$\sigma_{t=}$ horizontal tensile stress(KN/m2)

P=Applied compressive load (KN)

a =side length of cube (m)

d=diameter of cylinder which is =100mm

l=length of cylinder which is =200mm

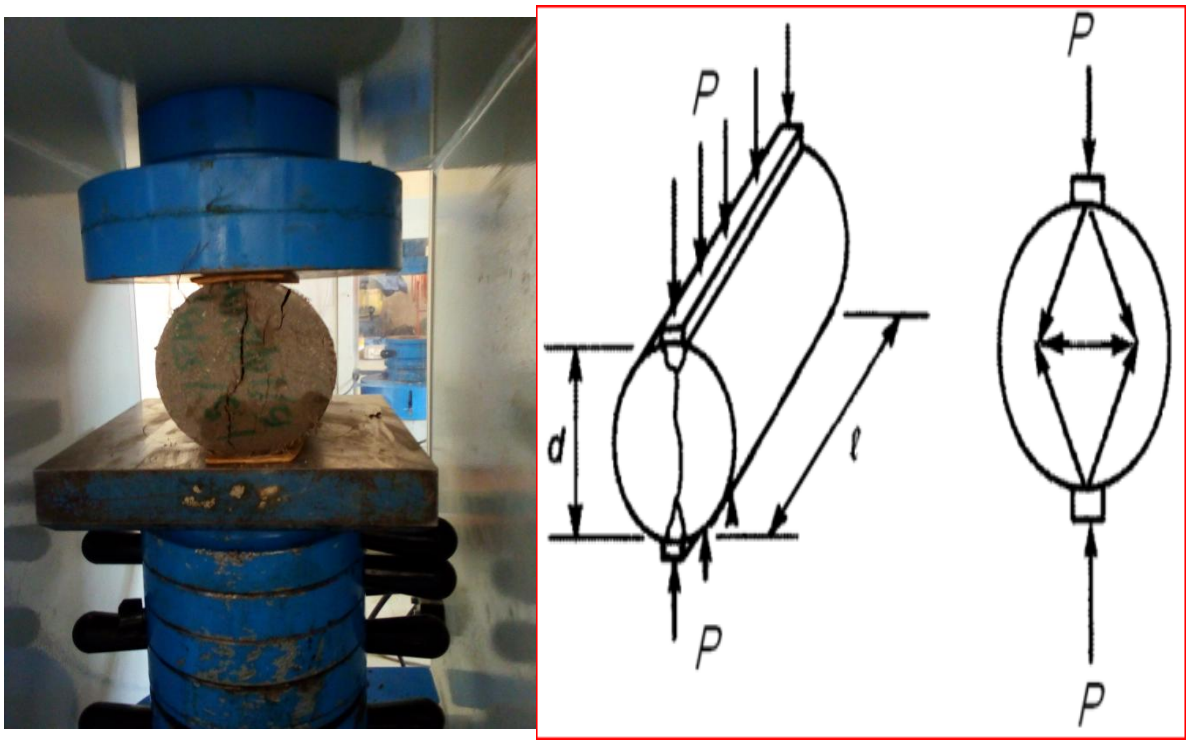

Figure 3-14 Split tensile strength test setup

3.8.5 Flexural Strength Test

This test gives another way of estimating tensile strength of concrete. During the pure bending, the member resisting the action is subjected to internal actions or stresses (shear, tensile and compressive). For a bending force applied downward on a member supported simply at its two ends, fibers above the neutral axis are generally subjected to compressive stresses and those below the neutral axis to tensile stresses. For this load and support system, portion of the member near the supports are subjected to relatively higher shear stresses than tensile stresses. In this test, the concrete member to be tested is supported at its ends and loaded at its interior

locations by gradually increasing load to failure. The failure load (loading value at which the concrete cracks heavily) is then recorded and used to determine the tensile stress at which the member failed, i.e. its tensile strength[26]. The significance of this test method is used to determine the modulus of rupture of specimens prepared and cured in accordance C31/C31M,C192/C192M or C293/C293M.It shall ensure that all forces are applied perpendicular to the face of the specimen without eccentricity[36].

The splitting tensile stress is obtained using the following formula

$$\sigma t = \frac{2P}{\pi l d} \quad \text{.....eq.3.3}$$

Where

σt = the spilt tensile strength of the concrete(MPa)

P= compressive load on the cylinder

L= length of the cylinder (200mm)

D= diameter of the cylinder (100mm)

3.8.6 Equipment and Materials

- A 100*100*500mm moulds made from steel and wood were used for the preparation of flexural beam.
- Point loading apparatus capable of maintaining the specified span length and distance between load applying blocks and support blocks to within ±0.13 cm
- Suitable loading machine capable of applying the loads at a uniform rate without interruption.

Flexural Strength Test Procedures (As per ASTM C78)

1. Make the specimens in accordance with the concrete batch procedure. Three samples for 7, 14 and 28day test from each mix was casted.

2. Curing: Allow the specimens to remain in the steel forms with the top properly covered for about 24 hours at normal room temperature.

3. Testing: Remove the specimens from the curing facility and mark the beam where it was in contact with the supports and at the opposite side where it was in contact with the third-point loading.

Figure 3-15 Casting flexural beam and casted beam specimen

Figure 3-16 Flexural Strength Setup

The flexure strength (modulus of rupture) is computed from the following equation:

a) If failure with in the middle third of the span, the equation is given by

$$M.R. = \frac{Pl}{bd^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. } 3.3$$

b) When the fracture occurs outside the middle third of the specimen but within 5% of the supported span length, compute the modulus of rupture from the following equation:

$$M.R. = \frac{3Pa}{bd^2} \ldots\ldots\ldots\

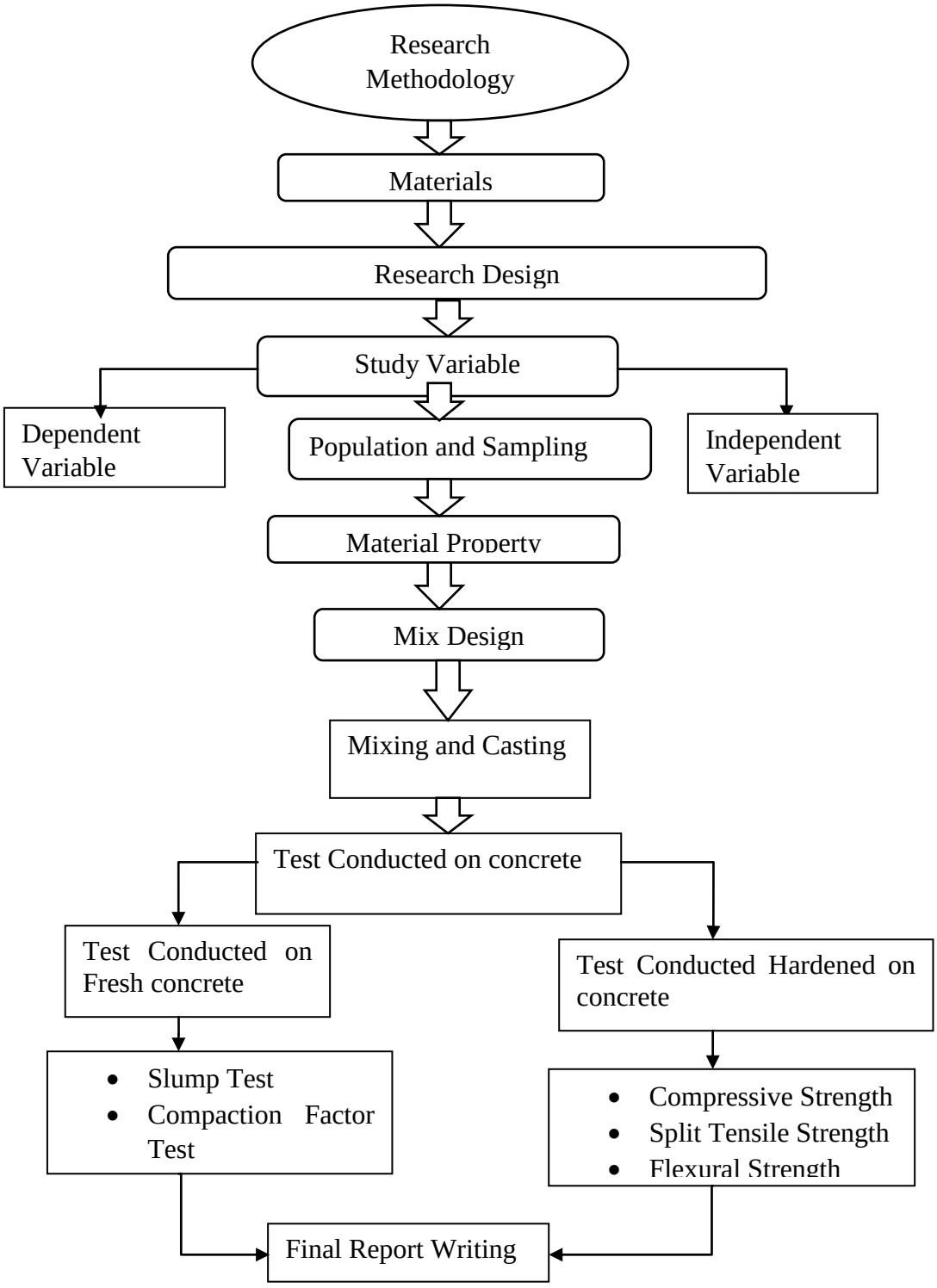

Figure 3-18 Structural Framework of research methodology

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Result and Discussion on Fresh and hardened hybrid concrete

In this part of thesis, fresh and hardened hybrid waste tire steel and banana fiber reinforced concrete properties such as workability, compressive strength, stress- strain relationship for compressive strength test, Modulus of elasticity, split tensile strength test and flexural strength test are discussed and analyzed with respect to control specimen and relevant standards.

4.2 Fresh Concrete Properties

4.2.1 Workability Test

As explained on ACI 544.1R-96, the workability of concrete decreases as fiber increases. The code also clarify that balling of fiber has detrimental effect on strength of concrete. Accordingly, the addition of fiber must be at the end of mixing processes after all ingredients have been mixed to reduce the balling effect of fibers. Slump cone test and compaction factor tests are done on fresh concrete to know the workability of hybrid waste tire steel and banana fiber reinforced concrete. The detail results of slump and compaction factor are illustrated under Appendix-B.

A. Slump Test

A concrete mix, either produced at a ready mix plant or on site, must be made of the right amount of cement, aggregate, and water to make the concrete workable enough for easy compaction and placing and strong enough for good performance in resisting stresses after hardening. Slump test is the simplest test for workability and is more widely used on construction site. The slump cone was filled in three equal layers and each layer was tamped 25 times with the tamping rod. The cone immediately lifted vertically and amount by which the concrete slumps were measured and recorded. The slump can vary from nill on dry mixes to complete collapse on very wet ones.ACI 211.1-91 recommends a slump value in a range of 20mm to 100mm based on different types of construction like foundation, wall, column, beam, and others [22].

Table 4-1 Slump of hybrid Concrete

S.NO	Slump Value (mm)	Percentage of Fiber Added
1	40mm	Control
2	30mm	0.5% [0.25 SF+0.25BF]
3	28mm	1% [0.75 SF+0.25BF]
4	26mm	1.5% [1 SF+0.5BF]

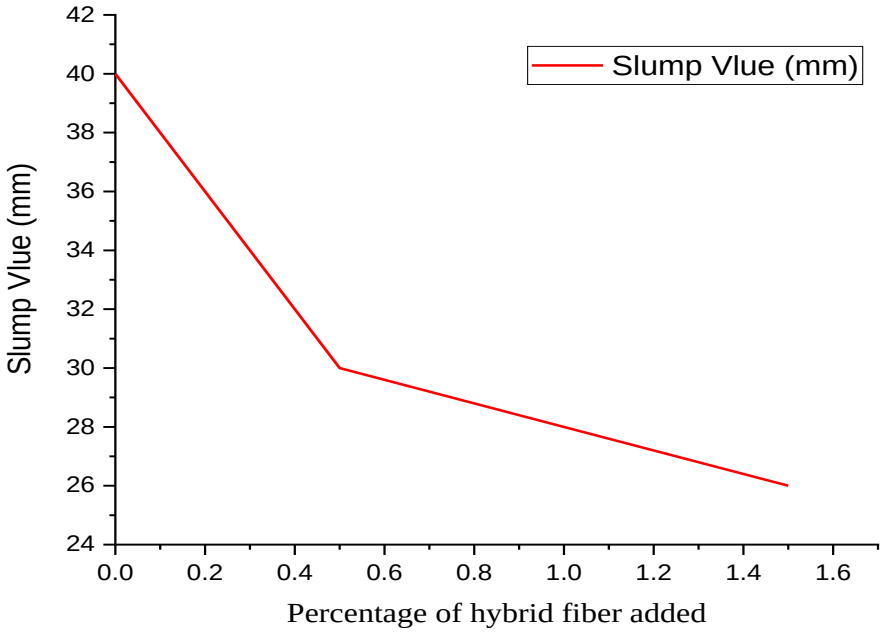

Figure 4-1 Slump test

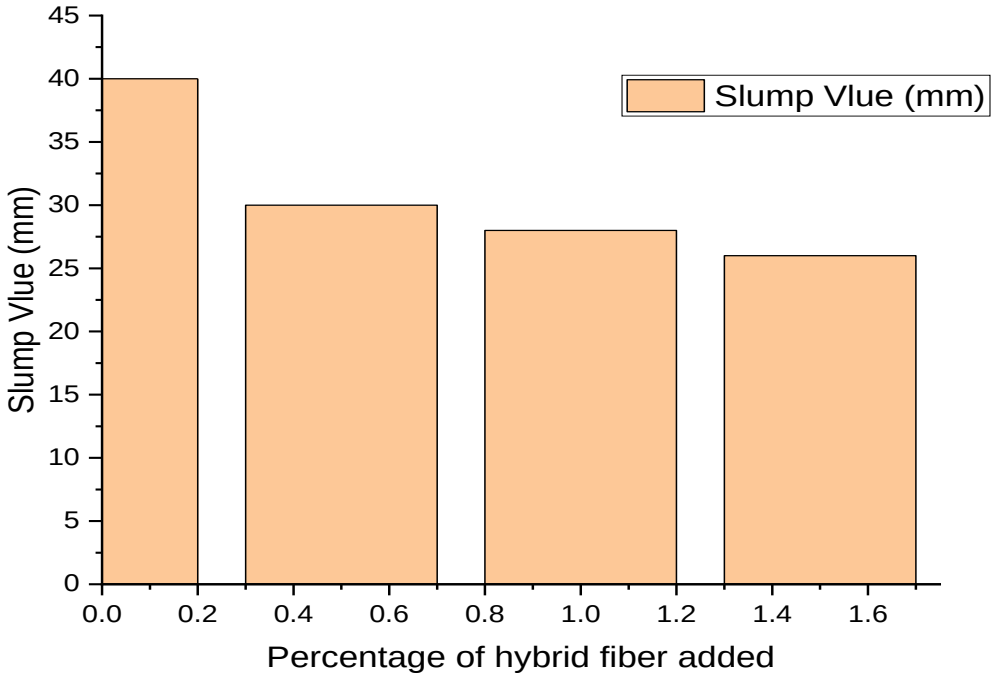

Figure 4-2 Slump Test by chart

From the experiment, it was clearly observed that the workability of hybrid concrete was decreased due to surface area of steel fiber requires water and Banana fiber absorbs more water.

Therefore, it was concluded that as the percentage of hybrid fiber increases, the workability of the concrete decreases.

B. Compaction Factor Test

The compaction factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability and normally used when concrete is to be compacted by vibration. It is the ratio of weights of partially compacted to fully compacted concrete.

$$\text{Compaction Factor Value} = \frac{W1 - W}{W2 - W}$$

Where

W1=Weight of partially compacted

W2=Weight of fully compacted

W=Weight of empty cylinder

Table 4-2 Compaction Factor for Hybrid concrete

S.No	Percentage of Hybrid Fiber Added	Weight of empty cylinder	Weight of Partially Compacted	Weight of Fully Compacted	Compaction Factor Value
	Control	3290	13419	14809	0.8793
2	0.5%(0.25%SF+0.25%BF)	3290	13207	14987	0.8478
3	1%(0.75%SF+0.25%BF)	3290	13118	15323	0.8167
4	1.5%(1%SF+0.5%BF)	3290	13019	15992	0.7659

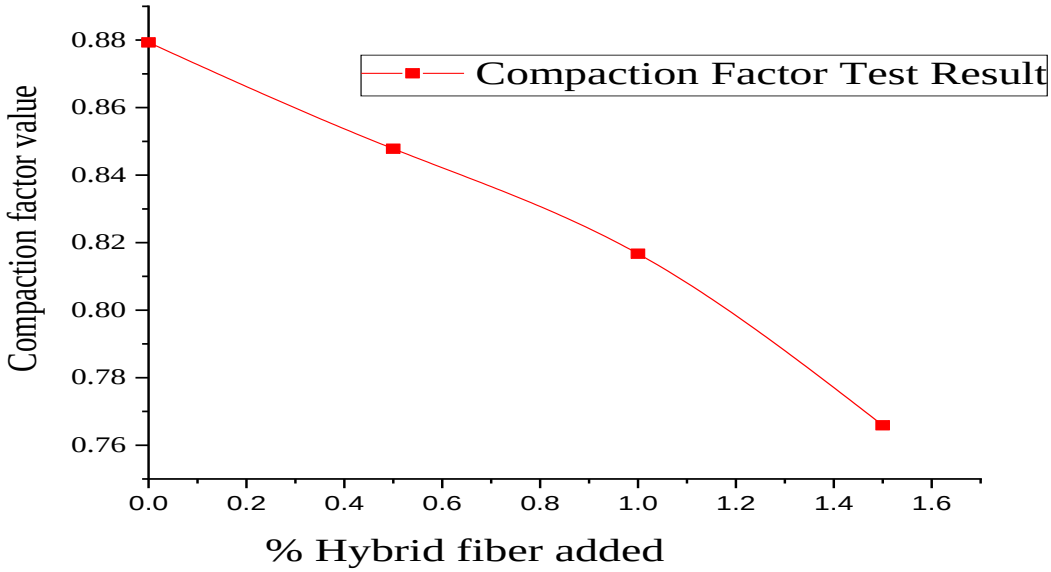

Figure 4-3 Compaction Factor Test Result

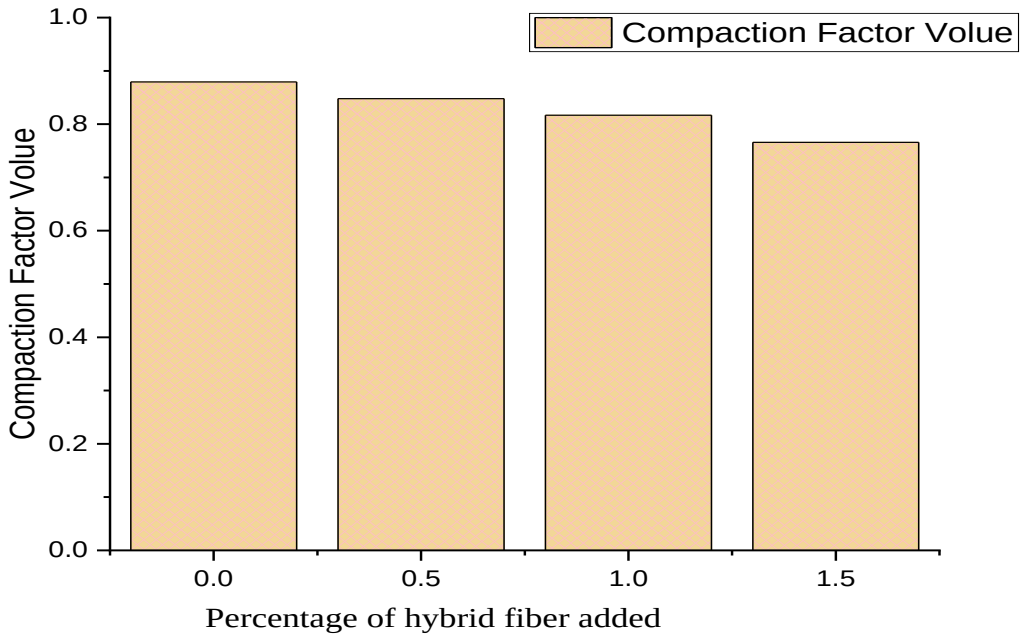

Figure 4-4 Compaction Factor Test Result by Chart

As it was clearly observed from figure 4.1, and 4.3**,** both compaction factor and slump test result was decreased for all hybrid waste tire steel and banana fiber reinforced concrete as compared to control mix. This is due to the increased surface area and water absorption of banana fibers.

4.3 Test on Hardened Concrete

4.3.1 Mass versus Density of Hardened Concrete

The weights of each sample of concrete were measured just before testing them. The results for the weights and dimensions are given in Appendix C. Mass and density of cube crushed on 7, 14 and 28days are shown in **table 4.3** below.

Table 4-3 Mass and Density of hybrid fiber of cube specimen on 7 and 14 days

Mix No	% hybrid Fiber added	Mass of Cube on 7th Day (Kg)					Mass of Cube on 14 day(Kg)				
		S-1	S-2	S-3	Avg.	Density (Kg/M^3)	S-1	S-2	S-3	Avg	Density (Kg/m3)
1	Control	6.19	7.38	7.5	7.02	2080.99	8.41	7.31	7.62	7.78	2305.19
2	0.50%	7.11	7.28	7.17	7.19	2129.38	7.12	8.29	8.19	7.87	2330.86
3	1%	7.21	7.31	7.52	7.35	2176.79	8.32	8.24	7.38	7.98	2364.44
4	1.50%	7.11	7.09	7.31	7.17	2124.44	7.2	8.1	7.19	7.50	2221.23

Table 4-4 Mass and density of of cube specimen on 28 days

Mix No	% hybrid Fiber added	Mass of Cube on 28th days (Kg)				
		S-1	S-2	S-3	Avg	Density (Kg/M^3)
1	Control	7.52	6.48	8.81	7.60	2252.84
2	0.50%	8.19	7.32	8.16	7.89	2337.78
3	1%	8.61	8.45	7.58	8.21	2433.58
4	1.50%	7.26	8.12	8.22	7.87	2330.86

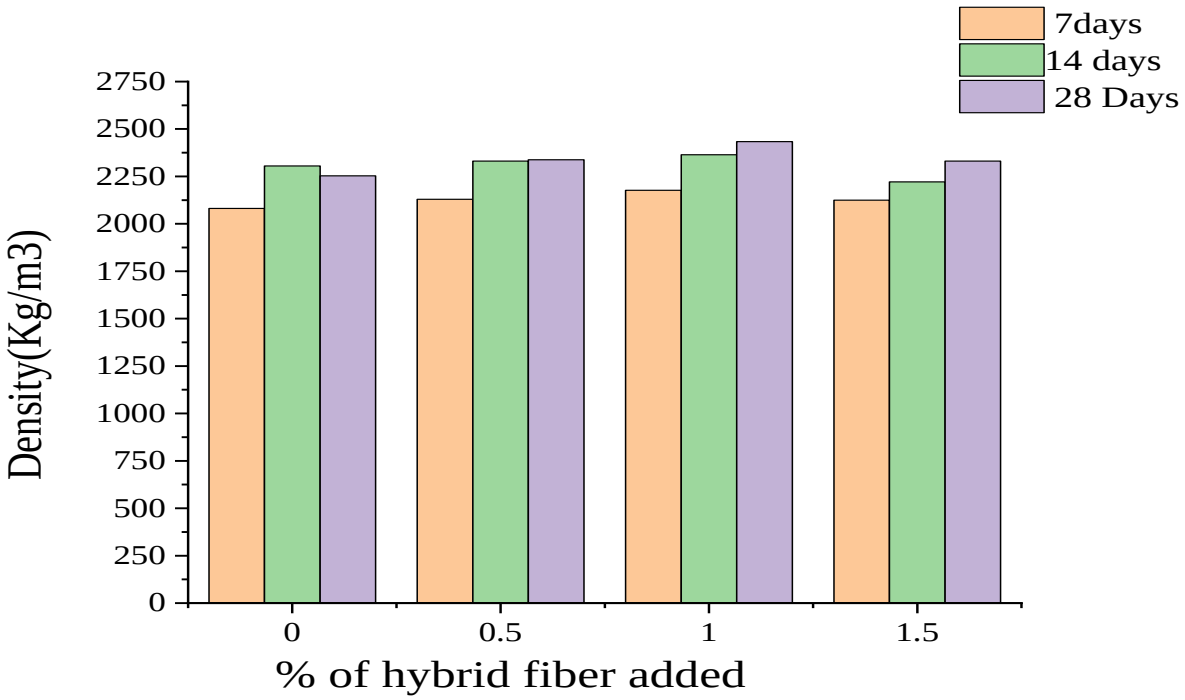

Figure 4-5 Mass and Density of hybrid concrete at 7, 14and 28 days

From the above graph, it was observed that as percentage of hybrid fiber increases, density of the fiber reinforced concrete increases. Density of control concrete was greater than density of hybrid fiber reinforced concrete.

4.3.2 Compressive Strength Test

The compressive strength test is one of the most common methods for determining the strength of hardened concrete. Compressive strength of concrete performs a critical role in controlling and conforming the quality of cement concrete work. The main factor that governs of the use of concrete in structures is its compressive strength. One of the main properties of the hardened concrete is its strength which the only represents its ability to resist compression loads. The compressive strength of the concrete is considered to be the main important and is often taken as core for the overall quality of concrete. The test was conducted on cubes that had been casted and cured and check its strength after 7, 14and 28 days.

Table 4-5 Compressive Strength Test Result on 7 days at peak load

Mix No	%Fiber Added	Avg.Peak Load(KN)	Area (m2)	Avg.Compressive Stress(Mpa)	Variation from Control(%)
1	Control	379.2	0.0225	16.85	-
2	0.5%	429.67	0.0225	19.09	13.34
3	1%	497.48	0.0225	22.11	31.19
4	1.5%	479.88	0.0225	21.33	26.55

Table 4-6 Compressive Strength Test Result on 14 days at peak load

Mix No	%Fiber Added	Avg.Peak Load(KN)	Area (m2)	Avg.Compressive Stress(Mpa)	Variation from Control(%)
1	Control	439.9	0.0225	19.5	-
2	0.5%	512.8	0.0225	22.7	16.6
3	1%	513.5	0.0225	22.8	16.7
4	1.5%	498.1	0.0225	22.13	11.7

Table 4-7 Compressive Strength Test Result on 28 days at peak load

Mix No	%Fiber Added	Avg.Peak Load(KN)	Area m2	Avg.Compressive Stress(Mpa)	Variation from Control(%)
1	Control	461	0.0225	20.5	-
2	0.5%	525.1	0.0225	23.3	13.9
3	1%	541.8	0.0225	24	17.5
4	1.5%	472.7	0.0225	21	2.5

Based on compressive strength test result shown in table 4.5, 4.6 and 4.7 above, it was clearly observed that

- As the date of curing increases, the compressive strength of hybrid fiber reinforced concrete also increases.
- Maximum compressive strength result of hybrid waste tire steel and banana fiber reinforced concrete was found at 1 %(0.75%SF +0.25%BF) and shows an enhancement by 28.11%, 16.7 %and 10.9% from the control at 7, 14 and 28 days respectively.
- In general, it can be concluded that addition of banana fiber and steel fibers gives an effective compressive strength if the amount of banana fiber is taken as 0.25% and steel fiber is 0.75% by volume of concrete.

4.3.3 Stress- Strain Relationship for compressive Strength Test Result

The average stress and strains are calculated for all mixes. The stress-strain curve is drawn for each mix and compare with control. The detailed cube stress-strain relationship for 7, 14 and 28 day tests are listed under appendix D and E

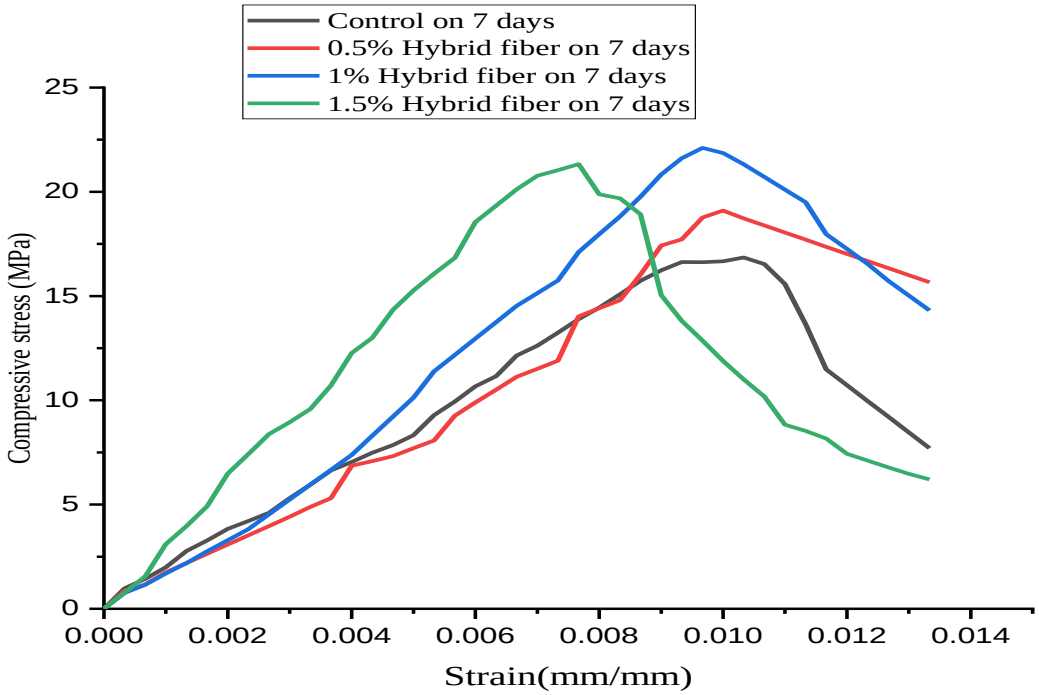

Figure 4-6 Stress- Strain Curve for 7th day compressive strength test

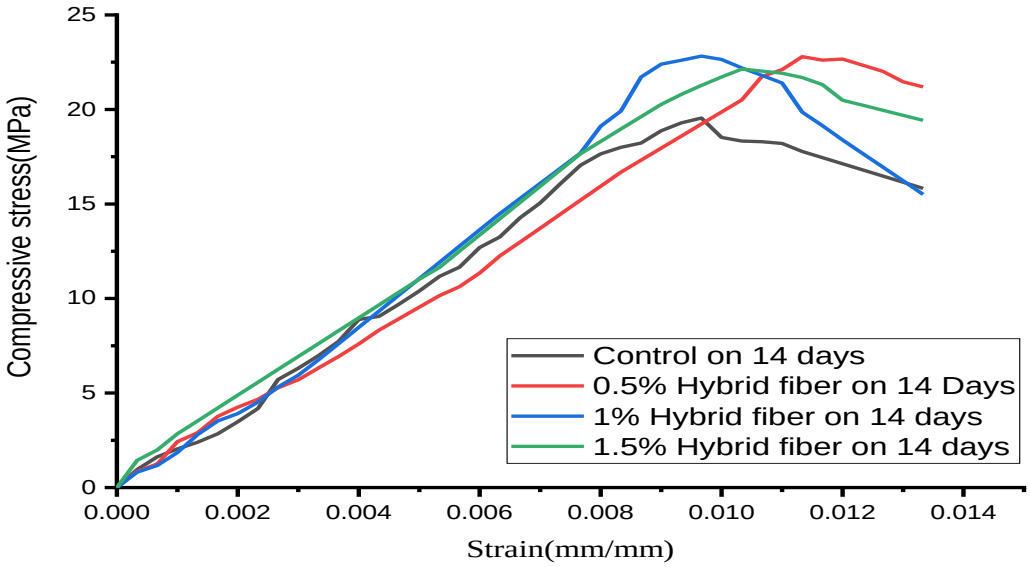

Figure 4-7 Stress- Strain Curve for 14 day compressive strength test

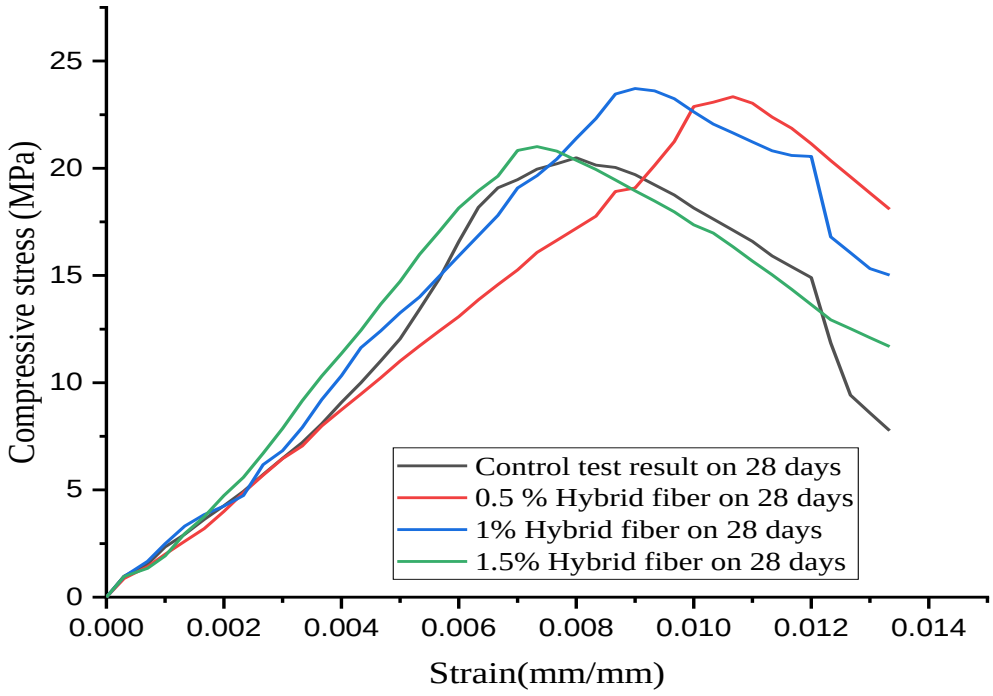

Figure 4-8 Stress- Strain Curve for 28th day compressive strength test

From the above stress- strain curve, the following observation was drawn.

- As the date of curing increases, the compressive strength and strains of concrete also increases.
- From the curve shown above, it was clearly observed that the compressive stress and the corresponding strain are directly proportional to some extent.
- The maximum compressive stress and average strain was observed when 1% of hybrid fiber (0.75%SF +0.25%BF) was added to the concrete.

4.3.4 Split Tensile Strength Test

Split tensile strength of concrete is indirect method of checking concrete tensile capacity. Tensile strength is property of concrete which describe tensile crack of concrete due to tensile applied loading. It is well-known that concrete is weak in tension as compared to its compressive strength capacity. Mostly the tensile capacity of concrete is 8% to 12% of its compressive strength. Therefore, in order to enhance this weakness of concrete, hybrid fibers are added to the concrete. Split tensile strength test result on 7, 14 and 28 days are shown in Table 4.8, 4.9 and 4.10 respectively. The detail split tensile strength test results are tabulated under appendix D.

Table 4-8 Split Tensile Strength on 7 day test Result at peak load

Mix No	Percentage of fiber Added	Sample	Peak Load(KN)	Split Tensile Stress(Mpa)	Average Peak Load(KN)	Average Stress(Mpa)	Variation From Control (%)
1	Control	1	86.07	2.74	86.02	2.74	
		2	89.6	2.85			
		3	82.4	2.62			
2	0.5%(0.25% SF +0.25% BF)	1	110.82	3.53	110.43	3.52	28.37
		2	117.94	3.76			
		3	102.52	3.26			
3	1%(0.75% SF +0.25% BF)	1	121.86	3.88	119.12	3.79	38.47
		2	119.15	3.79			
		3	116.34	3.71			
4	1.5%(1% SF +0.5% BF)	1	111.22	3.54	106.20	3.38	23.45
		2	101.67	3.24			
		3	105.71	3.37			

Table 4-9 Split Tensile Strength on 14 day test Result at peak load

Mix No	Percentage of fiber Added	Sample	Peak Load(KN)	Split Tensile Stress(Mpa)	Average Peak Load(KN)	Average Stress(Mpa)	Variation From Control(%)
1	Control	1	88.52	2.82	90.50	2.88	
		2	92.41	2.94			
		3	90.56	2.88			
2	0.5%(0.25% SF +0.25% BF)	1	112.46	3.58	114.34	3.64	26.35
		2	120.89	3.85			
		3	109.67	3.49			
3	1%(0.75% SF +0.25% BF)	1	123.49	3.93	122.75	3.91	35.64
		2	121.94	3.88			
		3	122.83	3.91			
4	1.5%(1% SF +0.5% BF)	1	110.94	3.53	107.88	3.34	19.21
		2	107.39	3.42			
		3	105.31	3.35			

Table 4-10 Split Tensile Strength on 28 day test Result at peak load

Mix No	Percentage of fiber Added	Sample	Peak Load(KN)	Split Tensile Stress(Mpa)	Average Peak Load(KN)	Average split Tensile Stress(Mpa)	Variation From Control(%)
1	Control	1	96.54	3.07	96.78	3.08	
		2	95.14	3.03			
		3	98.65	3.14			
2	0.5%(0.25% SF +0.25% BF)	1	116.64	3.71	119.13	3.79	23.09
		2	126.98	4.04			
		3	113.76	3.62			
3	1%(0.75% SF +0.25% BF)	1	125.62	4.00	126.42	4.03	30.63
		2	126.26	4.02			
		3	127.38	4.06			
4	1.5%(1% SF +0.5% BF)	1	112.49	3.58	112.96	3.60	16.72
		2	115.91	3.69			
		3	110.47	3.52			

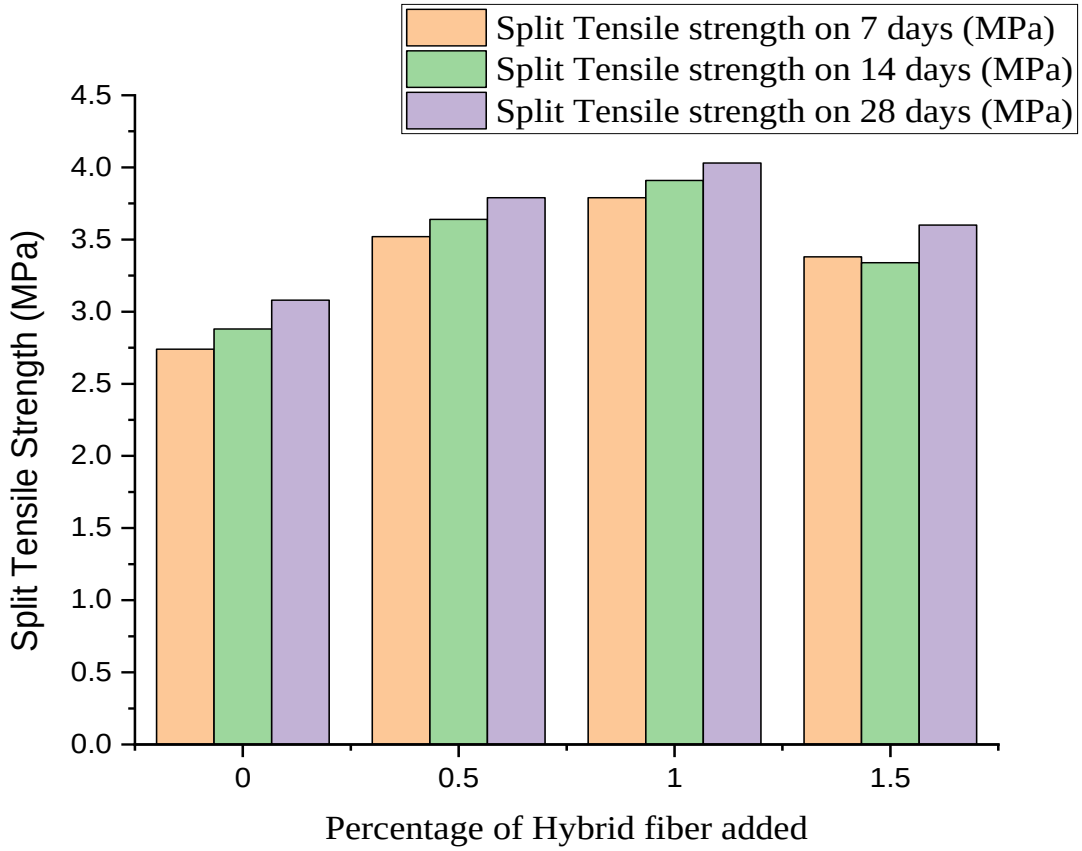

Figure 4-9 Split tensile strength versus percentage of hybrid fiber by chart

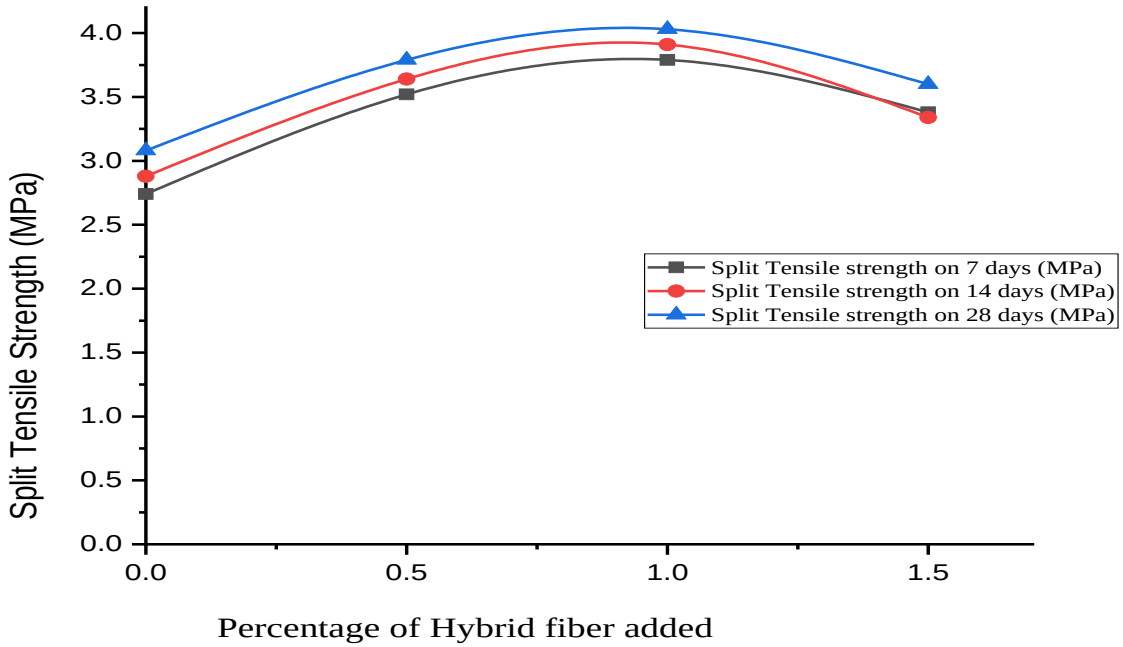

Figure 4-10 Split tensile strength versus percentage of hybrid fiber added graphically

- From the above Table 4.8, Table 4.9, Table 4.10**,** it was observed that split tensile strength increases as the period of curing age increases.
- From the hybrid mix, the optimum test result was obtained when hybrid fiber 0.75%SF +0.25%BF were mixed to the concrete.
- As the percentage hybrid fiber increases from control to hybrid mix of 1%, split tensile strength of hybrid concrete was increased by 3.79%,3.91%, and 4.03% respectively and shows decrement by 3.38%,3.34 and 3.6% respectively when 1.5%(1% SF +0.5% BF) of hybrid fiber was added to the concrete.
- It was concluded that, Optimum tensile strength test result of hybrid concrete was obtained when 1% of hybrid fiber was added to the concrete and show decrement when 1.5% of hybrid fiber was added to the concrete.

4.3.5 Flexural Strength Test Result

This gives another way of estimating tensile strength of concrete. During pure bending, the member resisting the action is subjected to internal action or stresses(shear, tensile and compressive).For a bending force applied downward on a member supported simply at its two ends, fibers above the neutral axis are generally, subjected to compressive stresses and those below the neutral axis to tensile stresses. For this load and support system, portion of the member near the supports are subjected to relatively higher shear stresses than tensile stresses. In this test, the concrete beam specimen with standard size of 100 mm x 100 mm x 500 mm was loaded at one third point from the support and at its interior location by a gradual increasing load at failure. According to ASTM C 42 the failure load (loading value at which the concrete cracks heavily) was then recorded and used to determine the tensile stress at which the member failed. The average flexural stresses were calculated from average rupture loads recorded from the testing machine and flexural stresses are determined for each sample.

$$\sigma = \frac{PL}{bd^2}\ \text{MPa} \ldots\ldots\ldots\

Table 4-11 Flexural strength test Result on 7th Day

Mix No	% fiber Added	Sample	Peak Load (KN)	Length (M)	Width (M)	Depth (M)	Corresponding Flexural Stress	Avg. Peak Load	Avg. Stress (Mpa)	Variation From control(%)
1	Control	1	7.32	0.5	0.1	0.1	3.66	8.50	4.25	
		2	8.65	0.5	0.1	0.1	4.33			
		3	9.52	0.5	0.1	0.1	4.76			
2	0.5% Hybrid Fiber	1	12.75	0.5	0.1	0.1	6.38	10.52	5.26	23.81
		2	10.39	0.5	0.1	0.1	5.20			
		3	8.42	0.5	0.1	0.1	4.21			
3	1% Hybrid Fiber	1	14.47	0.5	0.1	0.1	7.24	12.29	6.14	44.61
		2	11.65	0.5	0.1	0.1	5.83			
		3	10.74	0.5	0.1	0.1	5.37			
4	1.5% Hybrid Fiber	1	8.75	0.5	0.1	0.1	4.38	9.55	4.77	12.36
		2	9.31	0.5	0.1	0.1	4.66			
		3	10.58	0.5	0.1	0.1	5.29			

Table 4-12 Flexural strength test Result on 14 Day

Mix No	% fiber Added	Sample	Peak Load(KN)	Length (M)	Width (M)	Depth (M)	Corresponding Flexural Stress	Avg. Peak Load(KN)	Avg. Stress MMPa)	Variation From control(%)
1	Control	1	14.63	0.5	0.1	0.1	7.315	10.90	5.45	
		2	12.92	0.5	0.1	0.1	6.46			
		3	5.14	0.5	0.1	0.1	2.57			
2	0.5% Hybrid Fiber	1	14.13	0.5	0.1	0.1	7.065	12.52	6.26	14.93
		2	13.32	0.5	0.1	0.1	6.66			
		3	10.12	0.5	0.1	0.1	5.06			
3	1% Hybrid Fiber	1	18.34	0.5	0.1	0.1	9.17	13.31	6.65	22.12
		2	15.34	0.5	0.1	0.1	7.67			
		3	6.24	0.5	0.1	0.1	3.12			
4	1.5% Hybrid Fiber	1	19.42	0.5	0.1	0.1	9.71	11.36	5.68	4.25
		2	9.24	0.5	0.1	0.1	4.62			
		3	5.42	0.5	0.1	0.1	2.71			

Table 4-13 Flexural strength test Result on 28 Days

Mix No	% fiber Added	Sample	Peak Load (KN)	Length (M)	Width (M)	Depth (M)	Corresponding Flexural Stress	Avg. Peak Load (KN)	Avg. Stress (Mpa)	Variation From control(%)
1	Control	1	15.12	0.5	0.1	0.1	7.56	12.01	6.0	
		2	12.62	0.5	0.1	0.1	6.31			
		3	8.28	0.5	0.1	0.1	4.14			
2	0.5% Hybrid Fiber	1	14.34	0.5	0.1	0.1	7.17	12.38	6.2	3.11
		2	13.12	0.5	0.1	0.1	6.56			
		3	9.68	0.5	0.1	0.1	4.84			
3	1% Hybrid Fiber	1	16.18	0.5	0.1	0.1	8.09	13.99	7.0	16.49
		2	15.16	0.5	0.1	0.1	7.58			
		3	10.62	0.5	0.1	0.1	5.31			
4	1.5% Hybrid Fiber	1	16.16	0.5	0.1	0.1	8.08	12.6	6.3	5.22
		2	11.36	0.5	0.1	0.1	5.68			
		3	10.38	0.5	0.1	0.1	5.19			

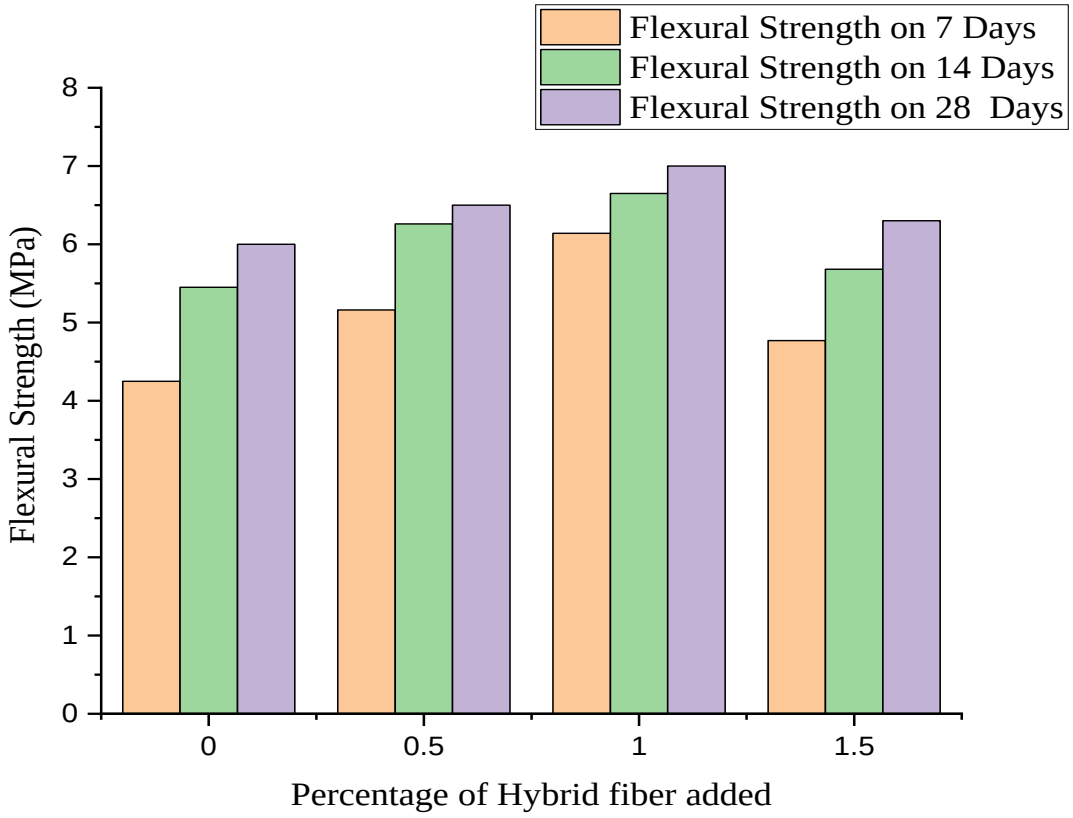

Figure 4-11 Flexural strength versus percentage of hybrid fiber added by chart

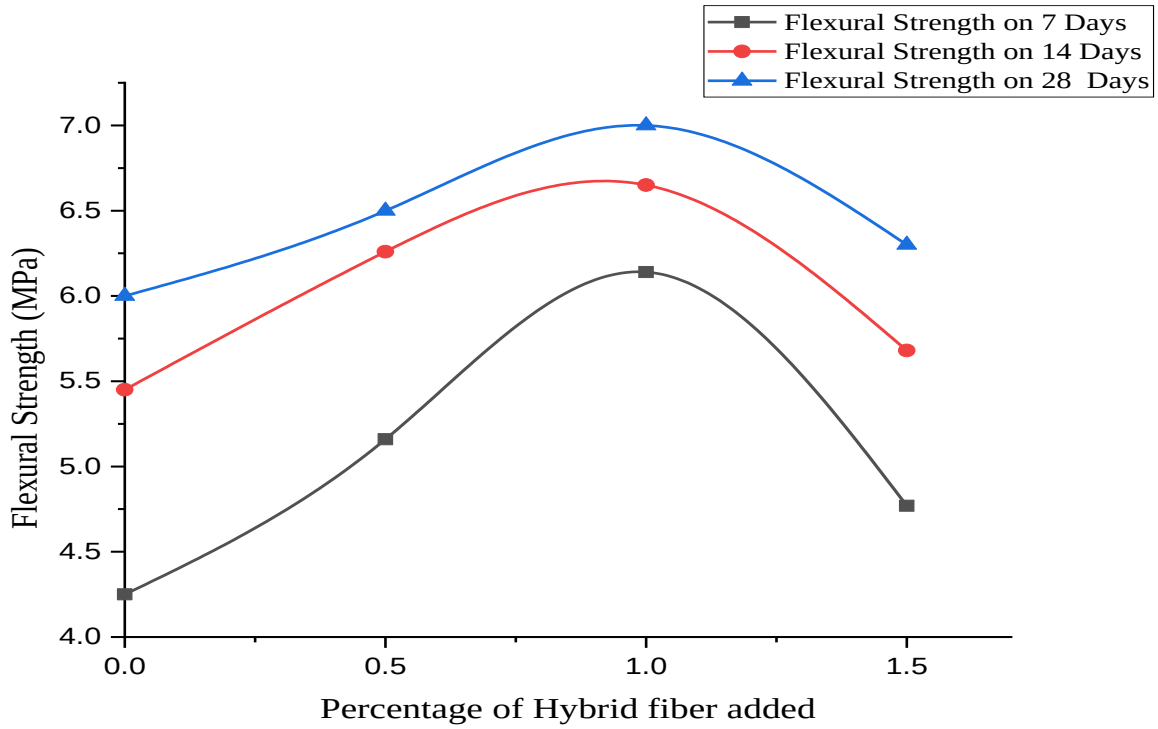

Figure 4-12 Flexural strength versus percentage of hybrid fiber added graphically

From Table 4.11 and 4.12 and 4.13, it was clearly observed that the flexural strength of hybrid waste tire steel and banana fiber reinforced concrete was increased for some hybridization ratio and the following conclusion was drawn.

- Flexural strength of hybrid concrete was increased as the age of curing increases.
- Variation in flexural strength from the control at 28 day was observed for 0.5%, 1% and 1.5% mix by 3.11%, 16.49% and 5.22% respectively.
- The optimum flexural strength 7MPa was obtained for hybrid fiber combination of 0.75%SF and 0.25%BF.
- The reason is that, when the beam was subjected to flexural loading, the shorter fiber bridge the micro cracks and prevent the expansion of the structure and when the shorter fiber fails the longer fiber will keep bridging the cracks until its fail which resulted in increase of flexural strength.
- The flexural strength of hybrid waste tire steel and banana fiber reinforced concrete shows decrement when 1%SF + 0.5% BF were added to the concrete.

4.4 Modulus of elasticity

Modulus of elasticity of concrete is the measure of stiffness of the concrete. It was good indicator of strength properties of concrete. At higher value of modulus of elasticity the concrete can with stand higher stress and become brittle. Modulus of elasticity of material is defined by the ratio of applied stress to corresponding strain with elastic limit. It was also defined as the slope of the line drawn from a stress of zero to a compressive stress of 0.45 f_c'[37]. Modulus of elasticity in tension or compression is a mechanical property that measures the tensile or compressive stiffness of a solid material when the force is applied lengthwise. It quantifies the relationship between tensile or compressive stress and strain. Modulus of elasticity is the slope of the linear part of stress-strain curve for material under tension or compression. ACI 318-05 on page 99 dictate that modulus of elasticity for concrete (E_c) was given by:-

$E_c = 0.043\ \rho^{1.5} \sqrt{f'c}$ Where

ρ – Density of concrete

f'_c – Concrete compressive strength

The tension and bending test are based on the principle of Hook's law and they are called static method. Static method is based on pulling or bending a sample of material in an instrument which measures force and measuring the changes of length. The change of length is usually very small and it is impossible to measure it by normal rules. It is measured by special device called extensometer. From Hook's law, modulus of elasticity is defined as ratio of stress to the strain.

$$E = \frac{\sigma}{\epsilon}$$

$\sigma = \text{Stress}$

$\epsilon = \text{strain}$

The method that have been used to measure modulus of elasticity are

- Tension or compression test
- Bending test

Table 4-14 Modulus of Elasticity o f cube specimen on 7 Days

Mix No	%Hybrid Fiber Added	Average Peak Load(KN)	Area (M^2)	Average Mass of Spacemen (Kg)	Strain	Volume of Cube Specimen (M^3)	Average Compressive Stress(MPa)	Density (Kg/M^3)	Mdulus of Elasticity (Mpa)
1	Control	379.2	0.0225	7.02	0.0103	0.003375	16.85	2080.0	16.744
2	0.25% SF + 0.25%BF	429.67	0.0225	7.19	0.010	0.003375	19.10	2130.37	18.48
3	0.75%SF +0.25% BF	497.48	0.0225	7.35	0.0096	0.003375	22.11	2177.78	20.55
4	1%SF+0.5% BF	479.88	0.0225	7.17	0.0077	0.003375	21.33	2124.44	19.45

Table 4-15 Modulus of Elasticity of cube specimen on 14 Days

Mix No	%Hybrid Fiber Added	Average Peak Load(KN)	Area (M^2)	Average Mass of Specemen (Kg)	Strain	Volume of Cube Specimen (M^3)	Average Compressive Stress (MPa)	Density (Kg/M^3)	Mdulus of Elasticity (Mpa)
1	Control	439.8	0.0225	7.78	0.0097	0.003375	19.55	2305.19	21.04
2	0.25% SF + 0.25%BF	512.77	0.0225	7.87	0.0113	0.003375	22.79	2331.85	23.11
3	0.75%SF +0.25% BF	513.53	0.0225	7.98	0.0093	0.003375	22.93	2364.44	23.62
4	1%SF+0.5 %BF	498.1	0.0225	7.5	0.0103	0.003375	22.14	2222.22	21.19

Table 4-16 Modulus of Elasticity of cube specimen on 28 Days

Mix No	%Hybrid Fiber Added	Average Peak Load(KN)	Area (M^2)	Average Mass of Spacemen (Kg)	Strain	Volume of Cube Specimen (M^3)	Average Compressive Stress(MPa)	Density (Kg/M3)	Mdulus of Elasticity (Mpa)
1	Control	461	0.0225	7.6	0.008	0.003375	20.49	2251.85	20.8
2	0.25% SF + 0.25%BF	525.11	0.0225	7.89	0.011	0.003375	23.34	2337.78	23.48
3	0.75%SF +0.25% BF	541.81	0.0225	8.21	0.009	0.003375	24.08	2432.59	25.32
4	1%SF+0.5%BF	472.69	0.0225	7.87	0.0073	0.003375	21.01	2331.85	22.19

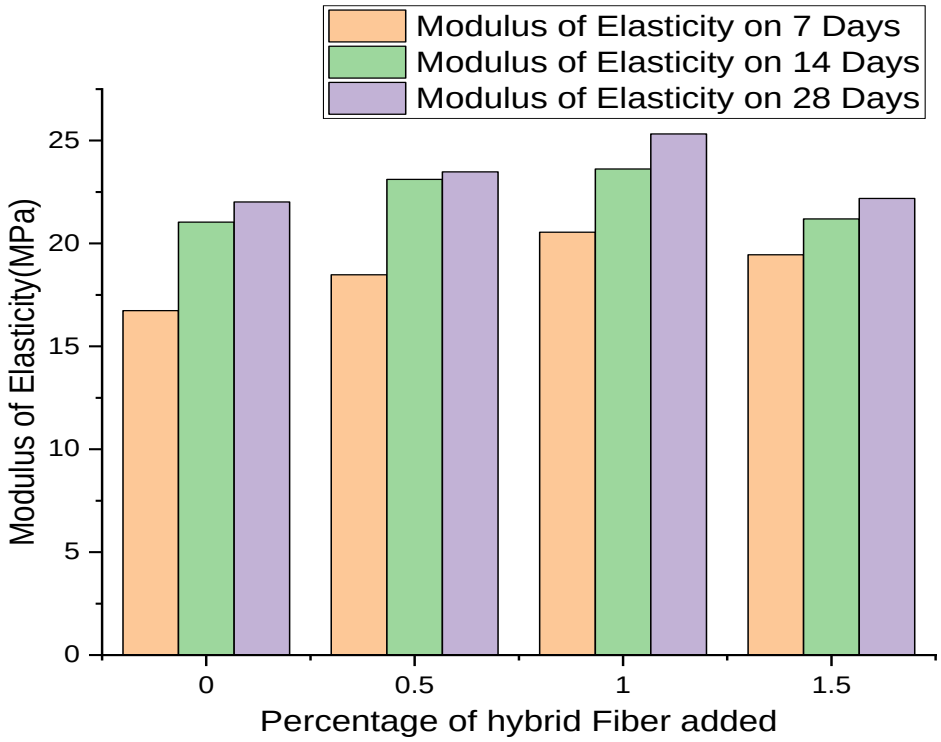

Figure 4-13 Modulus of elasticity versus percentage of hybrid fiber by chart

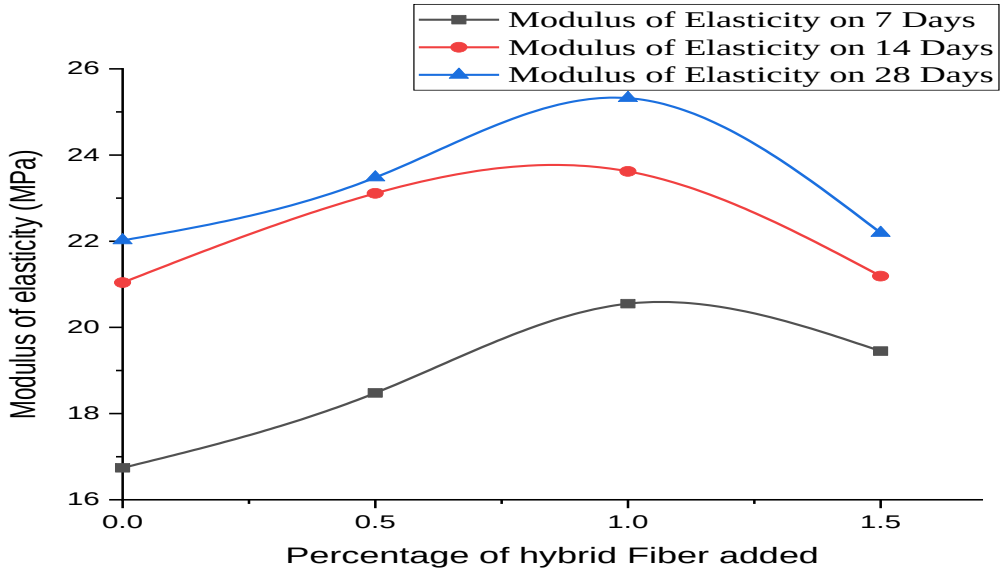

Figure 4-14 Modulus of elasticity versus percentage of hybrid fiber graphically

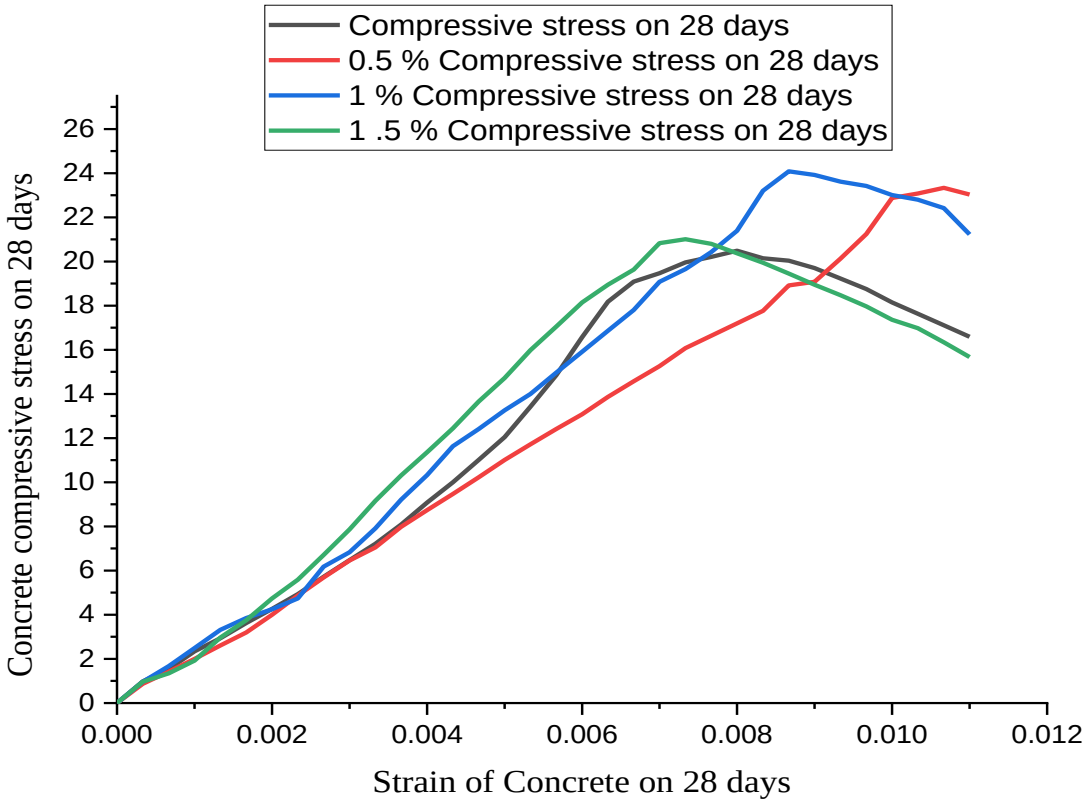

Figure 4-15 Stress-strain diagram on 28 days

From the above table 4.14, 4.15 and 4.16 it was clearly observed that:-

- Modulus of elasticity of each specimen increases as the age of curing date of concrete increases.
- Maximum modulus of elasticity of concrete cube specimen was obtained at 28 days when 1 %(0.75%SF +0.25% BF) was added to the concrete.
- Minimum modulus of elasticity of of concrete cube specimen was obtained for control mix at 7 days before hybrid fiber was added to the concrete.
- Modulus of elasticity of cube specimen was increased as percentage of hybrid fiber was increased from control to 1 %(0.75%SF+0.25%BF) and decreased when 1.5 %(1%SF +0.5%BF) was added to the concrete.
- Modulus of elasticity of concrete increases as concrete compressive strength increases.
- Modulus of elasticity increases as density of concrete increases.
- Modulus of elasticity of concrete increases as compressive strength of concrete increases.

4.5 Failures Observed on Specimen

The main objectives of adding fibers to plain concrete is to improve all the desired properties of fresh and hardened concrete. The basic purpose of using hybrid waste tire steel and banana fiber is to control cracks at different size levels in different zones of concrete, stress level and to enhance the properties of concrete by combining the benefits that each particular fiber type can impart. Therefore, it was observed that the addition of hybrid waste tire steel and banana fiber shows improvement in hardened concrete properties.

4.5.1 Failures Observed on Cube Specimen

The cube specimen tested under universal testing machine shows different failures when ultimate load was applied on it. As control cube specimen was compared with the fiber concrete cube specimen, the micro crack observed on control specimen was very large and that observed on hybrid waste tire steel and banana fiber reinforced concrete cube was very small. This improves that the benefit of hybrid fiber in crack control in concrete. It can be concluded that the failures observed on all hybrid waste tire steel and banana fiber reinforced concrete cube was satisfactory failure.

Figure 4-16 Control Cube Specimen and1% Hybrid fiber Cube Specimen

4.5.2 Failures Observed on cylinder Specimen

The addition of hybrid waste tire steel and banana fiber to plain concrete give a desired result in split tensile test as it was compared to control test. The higher tensile strength of Hybrid fiber makes the concrete more ductile and crack control at different levels of concrete. The failures observed on cylinder specimen for this experimental research was when the percentage of banana fiber is increased and make weak bond with steel fiber in concrete matrixes. On control specimen, the vertical crack split the specimen into two parts as tensile load increases. But the crack observed on the fiber reinforced concrete was bridged after hybrid fiber was added to the concrete.

Figure 4-17 Control cylinder specimen and 1%hybrid fiber cylinder specimen

4.5.3 Failures observed on beam specimen

The plain beam specimen tested under testing machine for flexural strength shows large vertical crack at mid span of the beam which shows failures of the specimen. But when hybrid fiber is added on plain concrete, the crack was somewhat bridged. It was observed that there is immediate collapse for plain concrete once the ultimate load is applied without showing any warning for failure. But when hybrid waste tire steel and banana fiber was added to plain concrete, there is variation on crack propagation and the crack formed is very small. This corporation of hybrid fiber improves the ductility of beam specimen to resist applied flexural load .

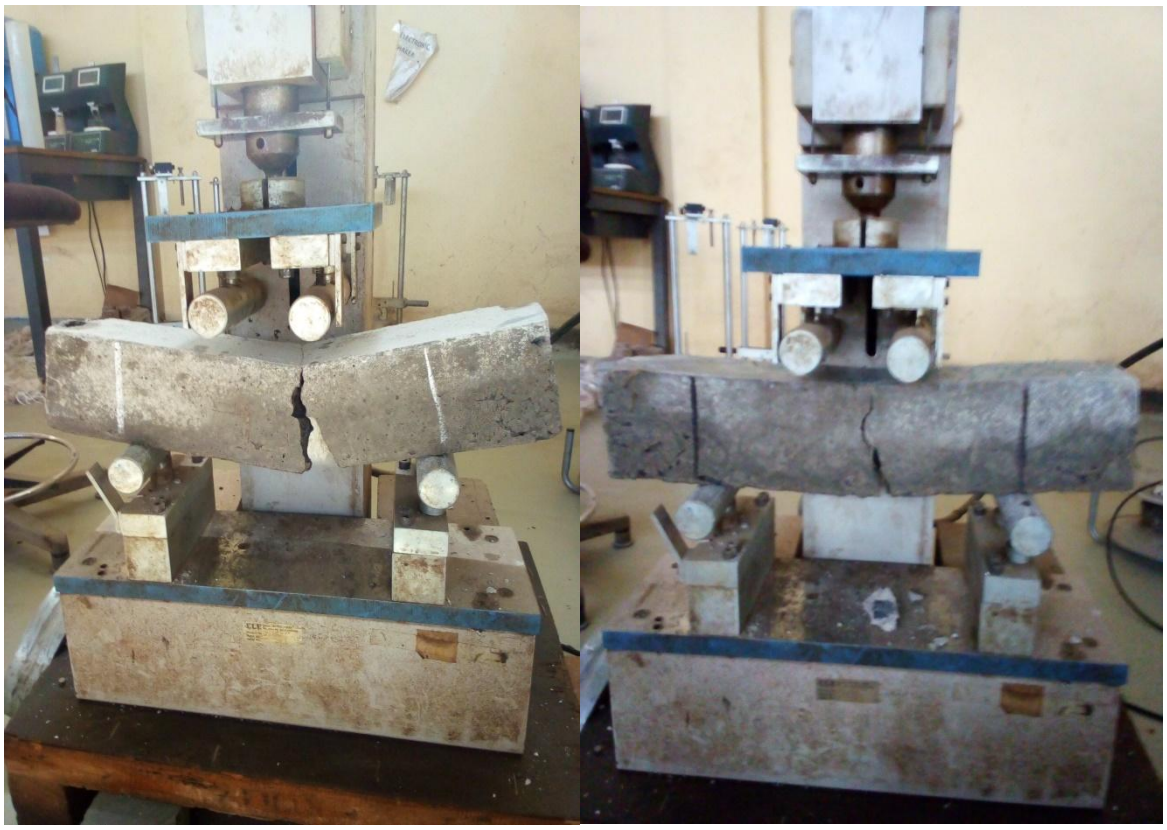

Figure 4-18 Control flexural Specimen and 1% Hybrid Fiber Flexural Specimen

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

Based on the experimental program conducted on the physical and mechanical properties of hybrid waste tire steel and banana fiber reinforced concrete, the following conclusions and recommendations are forwarded.

5.1. Conclusions

- Addition of hybrid waste tire steel and banana fiber to concrete shows low workability than plain concrete for all mixes.
- From the test result it can be seen that ,the addition of hybrid waste tire steel and banana fibers to plain concrete improves compressive, split tensile and flexural strength of the concrete
- 1% of hybrid waste tire steel and banana fibers were the maximum percentages that enhance the strength of C 20/25 concrete.

The experimental investigation on the mechanical properties of concrete mixed with banana stem fiber as well as hybrid steel fiber was studied and the result of finding shows that beyond 1% volume fraction of fiber content in concrete there is a gradual decrease in compressive, tensile and flexural strength[38].

Additionally**,** Effect on Compressive Strength of Fiber-Reinforced concrete By addition of Jute Fibers was studied and the result of finding shows that increase in fiber proportion beyond a certain limit leads to decrease in compressive strength as due to increase in fiber proportion the water absorption increases which leads to increase in porosity thereby decreasing the strength characteristics[39].

Therefore the current study found that the strength after proportion of 1% of hybrid fiber was decreased which is similar to previous researcher.

5.2 Recommendations

From the overall observation done in this experimental research, the following recommendations are forwarded.

1. Further studies on concrete plasticity variables for concrete containing hybrid waste tire steel and banana fibers to validate the experimental results by numerical method using finite element software.
2. Further studies on strength improvement of concrete properties by using fibers other than hybrid waste tire steel and banana fibers.

3. Further studies on the preparation of hybrid waste tire steel and banana fiber, especially waste tire steel fiber without disturbing the environment will be included in the future research.

4. Studying the effect of hybrid waste tire steel and banana fibers at the same lengths, same percentage combinations and for different concrete grade will be included in the future research.

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APPENDICES

APPENDIX-A. Physical Properties of Materials

A-1. Specific Gravity and Water Absorption Test for Aggregate

Specific gravity is the ratio between the weight of the substance and that of the same volume of water. It helps for design of concrete mix and calculating void content in aggregate. The water absorption value is the difference in weight between the saturated surface dry aggregate and oven dry sample expressed as percentage of dry weight of aggregate. Knowing the water absorption value of aggregate was helped to calculate the total water to be added to the concrete mix. The following procedures are the steps in which the physical properties of coarse aggregate and fine aggregates are determined in laboratory as per [28]

Step 1- rejecting materials passing 4.75mm sieve and using sample splitter 2 Kgs sample of aggregate measured and washed to remove fine particles

Step 2- using basket with sample immersed in distilled water for 24 hours at constant temperature

Step 3 – the basket placed at 50mm of water above the top of the basket and the entrapped air is removed by lifting the basket 25mm above the base of the tank by allowing to drop25 times at one drop per second

Step 4- after 24hour jolt and weight the basket with sample in water then remove sample from water allowed to drain then the empty basket placed in water jolted 25 times and weight in water

Step 5- the sample aggregate surface dried by cloth and weight then placed in an oven for 24 hours

Step 6 -after 24 hours the sample removed from oven and cooled for one hour and finally the dried sample weighted. Using the following formula, the specific gravity and absorption capacity calculated for coarse aggregate tabulated on table A-1

$$\text{Apparent Specific gravity} = \frac{\text{MD}}{\text{MD} - \text{MW}}$$

$$\text{Bulk Specific gravity} = \frac{\text{MD}}{\text{MSSD} - \text{MW}} \text{Oven dry}$$

$$\text{Bulk Specific gravity} = \frac{\text{MSSD}}{\text{MSSD} - \text{MW}} \text{Saturated surface dry}$$

$$\text{Percentage of water absoption } = \frac{\text{MSSD} - \text{MD}}{\text{MD}} * 100$$

$$\text{Weight of aggregate in water } \quad \text{Ww} = \text{Wa} - \text{Wb}$$

Where

M_W =Weight in water of the saturated aggregate

M_{SSD} =Weight in air of the saturated surface dry aggregate

M_D= Weight in air of oven dried aggregate

SSD =Saturated surface dry

Table A-1 Specific gravity, moisture content and absorption of coarse aggregate

Description	Trial-1	Trial-2	Trial-3	Avge
Ww=weight in water of saturated aggregate(Kg)	1.28	1.342	1.279	
M_{SSD} =weight in air of saturated surface dry(Kg)	2.004	2.005	2.002	
MD=weight in air of oven dried aggregate(Kg)	1.986	1.987	1.983	
Bulk Specific gravity=$M_D/(M_{SSD}-M_W)$	2.74309	2.99698	2.7427	2.83
Bulk Specific gravity(SSD)=$M_{SSD}/(M_{SSD}-M_W)$	2.76796	3.02413	2.769	2.85
Apparent Specific gravity=M_D/M_D-M_W	2.81303	3.08062	2.8168	2.90
Absorption Capacity(%)=(MSSD-MD)/MD*100	0.90634	0.90589	0.9581	0.92
Moisture content(%)=(MD-MSSD)/MSSD*100	0.8982	0.89776	0.94905	0.92

Fine Aggregate

Step 1- A sample of 500g fine aggregate which is at free-flowing condition without moisture measured and placed into the pycnometer then filled up with water 90 % capacity of the pycnometer.

Step 2 - Using rod the air bubbles are eliminated with adjusted temperature and the water level of pycnometer filled up to its calibrated capacity.

Step 3- The total weight of the pycnometer, sample and water recorded.

C=0.9976Va+500+w

Where C –Weight of pycnometer filled with sample plus water

Va – Volume of water added to pycnometer

W - Weight of the pycnometer empty

Step 4 – Oven dried the aggregate removed from pycnometer at 105±5°Cfor an hour then cooled and measured B = 0.9976V +W where

B- Weight of flask filled with water

V- Volume of flask

W- Weight of flask

$$\text{Bulk specific gravity} = \frac{\text{A}}{\text{B} + 500 - \text{C}}$$

$$\text{Bulk specific gravity} = \frac{500}{\text{B} + 500 - \text{C}} \quad - \text{Saturated surface dry basis}$$

$$\text{Apparent specific gravity} = \frac{\text{A}}{\text{B} + \text{A} - \text{C}}$$

$$\text{Absorption Capacity} = \frac{(500 - \text{A})}{\text{A}} * 100$$

Where

A – Weight of oven dried sample

B – Weight of pycnometer filled with water

Table A-2 Specific Gravity and Water Absorption of Fine aggregate

Description	Trial -1	Trial -2	Trial -3	Avge
Weight of saturated & surface dry sand (gm)	500	500	500	
Weight of pycnometer + sample + water (C) (gm)	1856	1862	1842	
Weight of pycnometer +water (B) (gm)	1553	1552	1550	
Weight of oven dry sand (A) (gm)	497	495	494	
Bulk specific gravity=A/(B+500-C)	2.52	2.61	2.38	2.50
Bulk specific gravity(SSD)=500/(B+500-C)	2.54	2.63	2.40	2.52
Apparent specific gravity=A/(B+A-C)	2.56	2.68	2.45	2.56
Absorption capacity(%)=((500-A)/A)*100	0.60	1.01	1.21	0.94

Unit weight of aggregate

Table A-3 Unit weight for coarse Aggregate

Sample Type	Mass of Sample + cylinder(g)	Mass of empty Cylinder(g)	Mass of Sample(g)	Volume of cylinder(m3)	Unit Weight(Kg/M3)=mass of sample/volume of cylinder
Sample-1	19007	1676	17331	0.01	1733.1
Sample-2	19090	1676	17414	0.01	1741.4
Sample-3	19382	1676	17706	0.01	1770.6
Average					1748.40

Table A-4 Unit weight for Fine Aggregate (Chewaka)

Sample	Mass of Sample + cylinder(Kg)	Mass of cylinder (Kg)	Mass of Sample (Kg)	Volume of Cylinder (m3)	Unit Weight (Kg/M3)
1	8.672	1.051	7.621	0.005	1524.2
2	8.356	1.051	7.305	0.005	1461
3	8.592	1.051	7.541	0.005	1508.2
Average					1497.8

Table A-5 Total Moisture Content for Coarse Aggregate

S.NO	Description	Sample			Average
		1	2	3	
1	Weight of Original Sample ,A (Kg)	2	2	2	
2	Weight of oven dried Sample ,B (Kg)	1.986	1.983	1.979	
3	Moisture Content(%)=(A-B/B)*100	0.7	0.85	1.05	**0.87**

Table A-6 Total Moisture Content for Fine Aggregate

S.NO	Description	Sample			Average
		1	2	3	
1	Weight of Original Sample ,A (Kg)	0.5	0.5	0.5	
2	Weight of oven dried Sample ,B (Kg)	0.498	0.497	0.496	
3	Moisture Content(%)=(A-B/B)*100	0.40	0.60	0.81	0.60

Table 7. Silt Content of fine aggregate

S/N	Description	Sample 1	Sample 2	Sample 3
1	Volume of sample(silt + sand)=V_1(ml)	75	75	75
2	Volume of silt after 3hr = $V_{2(ml)}$	2.3	2	2
3	% Silt Content by volume $= \frac{\mathbf{V_2}}{\mathbf{V_1}} * 100$	3.1	2.67	2.67
Average		3		

Moisture Content of Banana Fiber

$$\text{Total Moisture Content} = \frac{\text{Original weight} - \text{Oven Dry Weight}}{\text{Oven Dry Weight}} * 100$$

Table A-7 Moisture Content for Banana Fiber

S.No	Original Weight(g)-A	Oven dry Weight(g)-B	Moisture Content (%)
Sample-1	100	90	11.11
Sample-2	100	88	13.64
Sample-3	100	91.5	9.29
Average			11.35

Particle Size Distribution test for Coarse and Fine Aggregate

Table A-8 Particle Size Distribution test for Coarse aggregate

Sieve size	Sample 1	Sample 2	Average mass	% Retained	Cumulative Percentage retained	Cumulative passing	ASTMC33 Requirement range	
							ASTM min	ASTM max
37.5	0	0	0	0	0	100	100	100
28	664	861	762.5	7.625	7.625	92.375	90	100
19	1202	1035	1119	11.19	18.82	81.18	20	85
12.5	1586	3671	5257	52.57	71.39	28.6	10	55
9.5	2262	1624	1943	19.43	90.82	9.185	0	15
4.75	1314	337	825.5	8.255	99.075	0.925	0	5
pan	80	12	92.5	0.925	100	0	0	0
Total					**287.73**			

(FM)= $(\Sigma CumulativePercentageRetained)/100$

$$FM = \sum \frac{7.625 + 18.82 + 71.39 + 90.82 + 99.075}{100} = 2.88$$

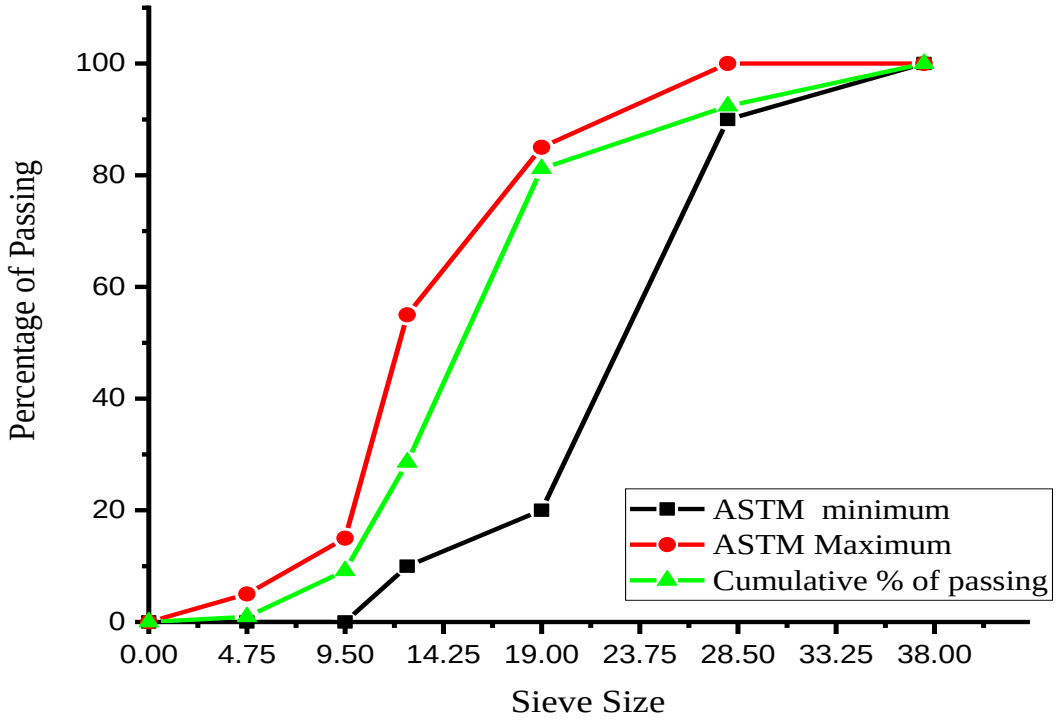

Figure A-1 Particle Size Distribution test for Coarse aggregate

Table A-9 Particle Size Distribution test for Fine aggregate

Sieve size	Sample -1	Sample-2	Sample -3	Average mass	% Retained	Cumulative % retained	Cumulative % passing	ASTMC33 Requirement range	
								ASTMC33 Min	ASTM C33 Max
9.5	0	0	0	0	0	0	100	100	100
4.75	52	56	24	44	2.2	2.2	97.8	95	100

2.36	214	220	514	316	15.8	18	82	80	100
1.18	308	299	303	303	24	44	56	50	85
0.6	584	589	627	600	30	74	26	25	60
0.3	598	340	142	360	18	92	8	10	30
0.15	140	126	94	120	6	98	2	2	10
Pan	52	24	44	0	2	100	0	0	0
Total						**328.2**			

(FM)= $(\Sigma CumulativePercentageRetained)/100$

$$\text{FM} = \Sigma\frac{2.2 + 18 + 44 + 74 + 92 + 98}{100} = 3.28$$

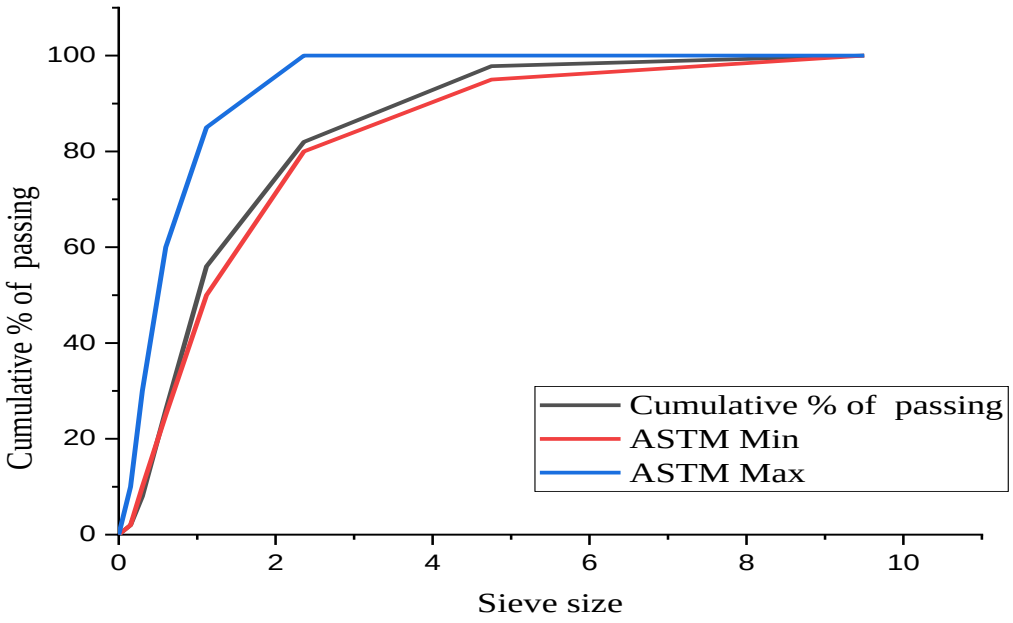

Figure A-2 Particle Size Distribution test for Fine aggregate

APPENDIX- B Compaction Factor Test and Slump Test Result On Fresh Concrete

Table B-1 Compaction Factor Test

S.No	Percentage of Hybrid Fiber Added	Weight of empty cylinder	Weight of Partially Compacted	Weight of Fully Compacted	Compaction Factor Value
	Control	3290	13419	14809	0.8793
2	0.5%(0.25%SF + 0.25% BF)	3290	13207	14987	0.8478
3	1%(0.75%SF +0.25%BF)	3290	13118	15323	0.8167
4	1.5%(1%SF+0.5%BF)	3290	13019	15992	0.7659

Table B-2 Slump Test Results

S/No	Slump Value (mm)	Percentage of Fiber Added
1	40mm	Control
2	30mm	0.5% [0.25 SF+0.25BF]
3	28mm	1% [0.75 SF+0.25BF]
4	26mm	1.5% [1 SF+0.5BF]

APPENDIX-C Mass and Density of Specimens

Table C-1 Mass and density of Cube

Mix No	% hybrid Fiber added	Mass of Cube on 7th Day(Kg)					Mass of Cube on 14 day(Kg)				
		S-1	S-2	S-3	Avg.	Density (Kg/M^3)	S-1	S-2	S-3	Avg	Density (Kg/m3)
1	Control	8.19	8.38	8.5	8.36	2476.1	8.41	8.31	8.62	8.45	2503
2	0.5%	8.11	8.28	8.17	8.19	2425.7	8.12	8.29	8.19	8.2	2430
3	1%	8.21	8.14	8.25	8.20	2429.6	8.32	8.24	8.38	8.31	2463
4	1.5%	8.11	8.09	8.31	8.17	2420.7	8.2	8.1	8.19	8.16	2419

Table C-2 Mass of Cube on 28th Day (Kg)

Mix No	% hybrid Fiber added	Mass of Cube on 28th Day(Kg)				
		S-1	S-2	S-3	Ave	Density (Kg/M^3)
1	Control	8.52	8.48	8.81	8.60	2549.1
2	0.5%	8.19	8.3	8.16	8.22	2434.5
3	1%	8.61	8.45	8.58	8.55	2532.3
4	1.5%	8.26	8.12	8.22	8.20	2429.6

Table C-2 Mass and density of Cylinder on 7 and 14 days

Mix No	% hybrid Fiber added	Mass of cylinder on 7 day (KG)					Mass of cylinder on 14 day (KG)				
		S-1	S-2	S-3	Avg	Density (Kg/M3)	S-1	S-2	S-3	Ave rage	Density (Kg/M3)
1	Control	3.81	3.88	3.75	3.82	2384.58	3.83	3.89	3.85	3.86	2410.4
2	0.50%	3.80	3.84	3.80	3.81	2381.67	3.85	3.81	3.74	3.8	2375
3	1%	3.92	3.89	3.90	3.90	2439.58	3.94	3.93	3.89	3.92	2450
4	1.50%	3.80	3.83	3.92	3.85	2406.04	3.82	3.84	3.91	3.86	2410.4

Table C-3 Mass and density of Cylinder on 28 days

Mix No	% hybrid Fiber added	Mass of cylinder on 28 day (KG)				
		S-1	S-2	S-3	Averag e	Density(Kg/M3)
1	Control	3.89	3.90	3.88	3.89	2431.04
2	0.50%	3.92	3.80	3.76	3.82	2390.42
3	1%	3.96	3.98	3.97	3.97	2481.25
4	1.50%	3.85	3.89	3.84	3.86	2410.21

Table C-3 Mass and density of Beam Specimen on 7 and 14 days

Mix No	% hybrid Fiber added	Mass of Beam on 7 day (KG)					Mass of Beam on 14 day (KG)				
		S-1	S-2	S-3	Avg	Desity (Kg/M3)	S-1	S-2	S-3	Avg	Density (Kg/M3)
1	Control	11.1	12.7	13.5	12.5	2489.3	12.5	12.9	12.6	12.7	2536.7
2	0.5%	12	12.2	12.1	12.1	2418.0	12.8	12.9	12.9	12.9	2573.3
3	1%	11.6	12.8	12.7	12.4	2476.0	12.6	12.9	12.9	12.8	2562.0
4	1.5%	12.2	11.7	12.1	12.0	2402.0	12.9	12.5	12.9	12.8	2551.3

Table C-4 Mass and density of beam specimen on 28 days

Mix No	% hybrid of hybrid fiber added	S-1	S-2	S-3	Avg	Density(Kg/M3)
1	Control	13.4	13.4	13.3	13.3	2674.7
2	0.5%	13.3	13.1	13.2	13.2	2645.3
3	1%	13.2	13.9	13.1	13.4	2684.7
4	1.5%	12.9	13.3	12.8	13.0	2603.3

APPENDIX-D Hardened Concrete test result

Table D-1 Split Tensile Strength on 7 day test Result at peak load

Mix No	Percentage of fiber Added	Sample	Peak Load	Split Tensile Stress(Mpa)	Average Peak Load(KN)	Average Stress(Mpa)	Variation From Control(%)
1	Control	1	86.07	2.74	86.02	2.74	0
		2	89.6	2.85			
		3	82.4	2.62			
2	0.5%(0.25 % SF +0.25% BF)	1	110.82	3.53	110.43	3.52	28.37
		2	117.94	3.76			
		3	102.52	3.26			
3	1%(0.75% SF +0.25% BF)	1	121.86	3.88	119.12	3.79	38.47
		2	119.15	3.79			
		3	116.34	3.71			
4	1.5%(1% SF +0.5% BF)	1	111.22	3.54	106.20	3.38	23.45
		2	101.67	3.24			
		3	105.71	3.37			

Table D-2 Split Tensile Strength on 14 day test Result at peak load

Mix No	Percentage of fiber Added	Sample	Peak Load	Split Tensile Stress(Mpa)	Average Peak Load(KN)	Average Stress(Mpa)	Variation From Control(%)
1	Control	1	88.52	2.82	90.50	2.88	0
		2	92.41	2.94			
		3	90.56	2.88			
2	0.5%(0.25% SF +0.25% BF)	1	112.46	3.58	114.34	3.64	26.35
		2	120.89	3.85			
		3	109.67	3.49			
3	1%(0.75% SF +0.25% BF)	1	123.49	3.93	122.75	3.91	35.64
		2	121.94	3.88			
		3	122.83	3.91			
4	1.5%(1% SF +0.5% BF)	1	110.94	3.53	107.88	3.44	19.21
		2	107.39	3.42			
		3	105.31	3.35			

Table D-3 Split Tensile Strength on 28 day test Result at peak load

Mix No	Percentage of fiber Added	Sample	Peak Load(KN)	Split Tensile Stress(Mpa)	Average Peak Load(KN)	Average Stress(Mpa)	Variation From Control(%)
1	Control	1	96.54	3.07	96.78	3.08	0
		2	95.14	3.03			
		3	98.65	3.14			
2	0.5%(0.25 % SF +0.25% BF)	1	116.64	3.71	119.13	3.79	23.09
		2	126.98	4.04			
		3	113.76	3.62			
3	1%(0.75% SF +0.25% BF)	1	125.62	4.00	126.42	4.03	30.63
		2	126.26	4.02			
		3	127.38	4.06			
4	1.5%(1% SF +0.5% BF)	1	112.49	3.58	112.96	3.60	16.72
		2	115.91	3.69			
		3	110.47	3.52			

Table D-4 Flexural Strength Test Result on 7th Day

Mix No	% fiber Added	Sample	Peak Load (KN)	Length (M)	Width (M)	Depth (M)	Corresponding Flexural Stress	Avg. Peak Load (KN)	Avg. Stress (Mpa)	Variation From control(%)
1	Control	1	7.32	0.5	0.1	0.1	3.66	8.50	4.25	
		2	8.65	0.5	0.1	0.1	4.33			
		3	9.52	0.5	0.1	0.1	4.76			
2	0.5% Hybrid Fiber	1	12.75	0.5	0.1	0.1	6.38	10.52	5.26	23.81
		2	10.39	0.5	0.1	0.1	5.20			
		3	8.42	0.5	0.1	0.1	4.21			
3	1% Hybrid Fiber	1	14.47	0.5	0.1	0.1	7.24	12.29	6.14	44.61
		2	11.65	0.5	0.1	0.1	5.83			
		3	10.74	0.5	0.1	0.1	5.37			
4	1.5% Hybrid Fiber	1	8.75	0.5	0.1	0.1	4.38	9.55	4.77	12.36
		2	9.31	0.5	0.1	0.1	4.66			
		3	10.58	0.5	0.1	0.1	5.29			

Table D-5 Flexural Strength Test Result on 14 Day

Mix No	% fiber Added	Sample	Peak Load (KN)	Length (m)	Width (m)	Depth (m)	Corresponding Flexural Stress	Avg. Peak Load (KN)	Avg. Stress (MPa)	Variation From control(%)
1	Control	1	14.63	0.5	0.1	0.1	7.315	10.90	5.45	
		2	12.92	0.5	0.1	0.1	6.46			
		3	5.14	0.5	0.1	0.1	2.57			
2	0.5% Hybrid Fiber	1	14.13	0.5	0.1	0.1	7.065	12.52	6.26	14.93
		2	13.32	0.5	0.1	0.1	6.66			
		3	10.12	0.5	0.1	0.1	5.06			
3	1%	1	18.3	0.5	0.1	0.1	9.17	13.31	6.65	22.12

	Hybrid Fiber		4							
		2	15.34	0.5	0.1	0.1	7.67			
		3	6.24	0.5	0.1	0.1	3.12			
4	1.5% Hybrid Fiber	1	19.42	0.5	0.1	0.1	9.71	11.36	5.68	4.25
		2	9.24	0.5	0.1	0.1	4.62			
		3	5.42	0.5	0.1	0.1	2.71			

Table D-6 Flexural Strength Test Result on 28 Day

Mix No	% fiber Added	Sample	Peak Load (KN)	Length (M)	Width (M)	Depth (M)	Corresponding Flexural Stress	Avg. Peak Load	Avg. Stress (Mpa)	Variation From control(%)
1	Control	1	15.12	0.5	0.1	0.1	7.56	12.01	6.0	
		2	12.62	0.5	0.1	0.1	6.31			
		3	8.28	0.5	0.1	0.1	4.14			
2	0.5% Hybrid Fiber	1	14.34	0.5	0.1	0.1	7.17	12.38	6.2	3.11
		2	13.12	0.5	0.1	0.1	6.56			
		3	9.68	0.5	0.1	0.1	4.84			
3	1% Hybrid Fiber	1	16.18	0.5	0.1	0.1	8.09	13.99	7.0	16.49
		2	15.16	0.5	0.1	0.1	7.58			
		3	10.62	0.5	0.1	0.1	5.31			
4	1.5% Hybrid Fiber	1	16.16	0.5	0.1	0.1	8.08	12.63	6.3	5.22
		2	11.36	0.5	0.1	0.1	5.68			
		3	10.38	0.5	0.1	0.1	5.19			

APPENDIX-E .Stress Versus Strain Relationship of Cube Test Results

Table E-1 Stress versus Strain Relationship of control Cube Test Result on 7 day

ΔH(mm)	H(mm)	Strain(ΔH/H)	Load(KN)			Avg.Load(KN)	Area(m2)	Stress(Mpa)			Avg.Stress(Mpa)
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0.00	0	0	0	0	0
0.05	150	0.0003	21	22	23	22.00	0.0225	0.93	0.98	1.02	0.98
0.1	150	0.0007	32	31	34	32.33	0.0225	1.42	1.38	1.51	1.44

0.15	150	0.0010	45	46	43	44.67	0.0225	2.00	2.04	1.91	1.99
0.2	150	0.0013	65	67	55	62.33	0.0225	2.89	2.98	2.44	2.77
0.25	150	0.0017	81	72	68	73.67	0.0225	3.60	3.20	3.02	3.27
0.3	150	0.0020	97	86	76	86.33	0.0225	4.31	3.82	3.38	3.84
0.35	150	0.0023	106	91	87	94.67	0.0225	4.71	4.04	3.87	4.21
0.4	150	0.0027	118	99	94	103.67	0.0225	5.24	4.40	4.18	4.61
0.45	150	0.0030	129	106	123	119.33	0.0225	5.73	4.71	5.47	5.30
0.5	150	0.0033	138	126	138	134.00	0.0225	6.13	5.60	6.13	5.96
0.55	150	0.0037	165	134	149	149.33	0.0225	7.33	5.96	6.62	6.64
0.6	150	0.0040	175	142	158	158.33	0.0225	7.78	6.31	7.02	7.04
0.65	150	0.0043	187	151	167	168.33	0.0225	8.31	6.71	7.42	7.48
0.7	150	0.0047	192	159	179	176.67	0.0225	8.53	7.07	7.96	7.85
0.75	150	0.0050	212	168	182	187.33	0.0225	9.42	7.47	8.09	8.33
0.8	150	0.0053	254	176	197	209.00	0.0225	11.29	7.82	8.76	9.29
0.85	150	0.0057	268	187	216	223.67	0.0225	11.91	8.31	9.60	9.94
0.9	150	0.0060	285	198	237	240.00	0.0225	12.67	8.80	10.53	10.67
0.95	150	0.0063	298	206	249	251.00	0.0225	13.24	9.16	11.07	11.16
1	150	0.0067	317	225	278	273.33	0.0225	14.09	10.00	12.36	12.15
1.05	150	0.0070	322	238	292	284.00	0.0225	14.31	10.58	12.98	12.62
1.1	150	0.0073	333	242	319	298.00	0.0225	14.80	10.76	14.18	13.24
1.15	150	0.0077	342	258	338	312.67	0.0225	15.20	11.47	15.02	13.90
1.2	150	0.0080	349	277	349	325.00	0.0225	15.51	12.31	15.51	14.44
1.25	150	0.0083	358	292	368	339.33	0.0225	15.91	12.98	16.36	15.08
1.3	150	0.0087	368	315	379	354.00	0.0225	16.36	14.00	16.84	15.73
1.35	150	0.0090	373	328	395	365.33	0.0225	16.58	14.58	17.56	16.24
1.4	150	0.0093	382	339	401.4	374.13	0.0225	16.98	15.07	17.84	16.63
1.45	150	0.0097	398	348	376	374.00	0.0225	17.69	15.47	16.71	16.62

1.5	150	0.0100	406	354	365	375.00	0.0225	18.04	15.73	16.22	16.67
1.55	150	0.0103	415.6	368	354	379.20	0.0225	18.47	16.36	15.73	16.85
1.6	150	0.0107	401	372	343	372.00	0.0225	17.82	16.53	15.24	16.53
1.65	150	0.0110	320	399.4	332	350.47	0.0225	14.22	17.75	14.76	15.58
1.7	150	0.0113	239	361	321	307.00	0.0225	10.62	16.04	14.27	13.64
1.75	150	0.0117	136	329	310	258.33	0.0225	6.04	14.62	13.78	11.48
1.8	150	0.0120	128	297	299	241.33	0.0225	5.69	13.20	13.29	10.73
1.85	150	0.0123	120	265	288	224.33	0.0225	5.33	11.78	12.80	9.97
1.9	150	0.0127	112	233	277	207.33	0.0225	4.98	10.36	12.31	9.21
1.95	150	0.0130	104	201	266	190.33	0.0225	4.62	8.93	11.82	8.46
2	150	0.0133	96	169	255	173.33	0.0225	4.27	7.51	11.33	7.70
2.05	150	0.0137	88	137	244	156.33	0.0225	3.91	6.09	10.84	6.95
2.1	150	0.0140	80	105	233	139.33	0.0225	3.56	4.67	10.36	6.19
2.15	150	0.0143	72	73	222	122.33	0.0225	3.20	3.24	9.87	5.44
2.2	150	0.0147	64	41	211	105.33	0.0225	2.84	1.82	9.38	4.68
2.25	150	0.0150	56	9	200	88.33	0.0225	2.49	0.40	8.89	3.93
2.3	150	0.0153	48	5	189	80.67	0.0225	2.13	0.22	8.40	3.59
2.35	150	0.0157	40	3	178	73.67	0.0225	1.78	0.13	7.91	3.27
2.4	150	0.0160	32	2	167	67.00	0.0225	1.42	0.09	7.42	2.98

Table E-2 Stress versus Strain Relationship of control Cube Test Result on 14 day

ΔH (mm)	H (mm)	Strain (ΔH/H)	Load (KN)			Avg. Load(KN)	Area(m2)	Stress(Mpa)			Avg.Stress(Mpa)
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.0003	23	20	21	21.33	0.0225	1.02	0.89	0.93	0.95
0.1	150	0.0007	36	37	37	36.67	0.0225	1.60	1.64	1.64	1.63

0.15	150	0.0010	43	46	49	46.00	0.0225	1.91	2.04	2.18	2.04
0.2	150	0.0013	52	52	58	54.00	0.0225	2.31	2.31	2.58	2.40
0.25	150	0.0017	64	63	65	64.00	0.0225	2.84	2.80	2.89	2.84
0.3	150	0.0020	78	78	79	78.33	0.0225	3.47	3.47	3.51	3.48
0.35	150	0.0023	98	92	92	94.00	0.0225	4.36	4.09	4.09	4.18
0.4	150	0.0027	135	116	135	128.67	0.0225	6.00	5.16	6.00	5.72
0.45	150	0.0030	146	132	148	142.00	0.0225	6.49	5.87	6.58	6.31
0.5	150	0.0033	155	149	167	157.00	0.0225	6.89	6.62	7.42	6.98
0.55	150	0.0037	168	157	197	174.00	0.0225	7.47	6.98	8.76	7.73
0.6	150	0.0040	198	186	216	200.00	0.0225	8.80	8.27	9.60	8.89
0.65	150	0.0043	187	195	229	203.67	0.0225	8.31	8.67	10.18	9.05
0.7	150	0.0047	196	214	245	218.33	0.0225	8.71	9.51	10.89	9.70
0.75	150	0.0050	216	228	258	234.00	0.0225	9.60	10.13	11.47	10.40
0.8	150	0.0053	229	246	279	251.33	0.0225	10.18	10.93	12.40	11.17
0.85	150	0.0057	238	257	292	262.33	0.0225	10.58	11.42	12.98	11.66
0.9	150	0.0060	254	289	314	285.67	0.0225	11.29	12.84	13.96	12.70
0.95	150	0.0063	268	299	328	298.33	0.0225	11.91	13.29	14.58	13.26
1	150	0.0067	279	338	346	321.00	0.0225	12.40	15.02	15.38	14.27
1.05	150	0.0070	294	354	368	338.67	0.0225	13.07	15.73	16.36	15.05
1.1	150	0.0073	312	375	398	361.67	0.0225	13.87	16.67	17.69	16.07
1.15	150	0.0077	336	396	419	383.67	0.0225	14.93	17.60	18.62	17.05
1.2	150	0.0080	349	412	430.46	397.15	0.0225	15.51	18.31	19.13	17.65
1.25	150	0.0083	368	428	419	405.00	0.0225	16.36	19.02	18.62	18.00
1.3	150	0.0087	378	443	409	410.00	0.0225	16.80	19.69	18.18	18.22
1.35	150	0.0090	399	476	399	424.67	0.0225	17.73	21.16	17.73	18.87
1.4	150	0.0093	416	497	389	434.00	0.0225	18.49	22.09	17.29	19.29
1.45	150	0.0097	428	512.32	379	439.77	0.0225	19.02	22.77	16.84	19.55

1.5	150	0.0100	439	422	389	416.67	0.0225	19.51	18.76	17.29	18.52
1.55	150	0.0103	448	411	378	412.33	0.0225	19.91	18.27	16.80	18.33
1.6	150	0.0107	479	407	349	411.67	0.0225	21.29	18.09	15.51	18.30
1.65	150	0.0110	486.41	403	339	409.47	0.0225	21.62	17.91	15.07	18.20
1.7	150	0.0113	472	399	329	400.00	0.0225	20.98	17.73	14.62	17.78
1.75	150	0.0117	464	395	319	392.67	0.0225	20.62	17.56	14.18	17.45
1.8	150	0.0120	456	391	309	385.33	0.0225	20.27	17.38	13.73	17.13
1.85	150	0.0123	448	387	299	378.00	0.0225	19.91	17.20	13.29	16.80
1.9	150	0.0127	440	383	289	370.67	0.0225	19.56	17.02	12.84	16.47
1.95	150	0.0130	432	379	279	363.33	0.0225	19.20	16.84	12.40	16.15
2	150	0.0133	424	375	269	356.00	0.0225	18.84	16.67	11.96	15.82
2.05	150	0.0137	416	371	259	348.67	0.0225	18.49	16.49	11.51	15.50
2.1	150	0.0140	408	367	249	341.33	0.0225	18.13	16.31	11.07	15.17
2.15	150	0.0143	400	363	239	334.00	0.0225	17.78	16.13	10.62	14.84
2.2	150	0.0147	392	359	229	326.67	0.0225	17.42	15.96	10.18	14.52
2.25	150	0.0150	384	355	219	319.33	0.0225	17.07	15.78	9.73	14.19
2.3	150	0.0153	376	351	209	312.00	0.0225	16.71	15.60	9.29	13.87
2.35	150	0.0157	368	347	199	304.67	0.0225	16.36	15.42	8.84	13.54
2.4	150	0.0160	360	343	189	297.33	0.0225	16.00	15.24	8.40	13.21

Table E-3 Stress versus Strain Relationship of control Cube Test Result on 28 day

ΔH(mm)	H(mm)	Strain(ΔH/H)	Load(KN)			Avg.Load(KN)	Area (m2)	Stress(Mpa)			Avg. Stress(Mpa)
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0.00	0	0.00	0.00	0	0
0.05	150	0.0003	24	23	19	22.00	0.0225	1.07	1.02	0.84	0.98

0.1	150	0.0007	38	35	31	34.67	0.0225	1.69	1.56	1.38	1.54
0.15	150	0.0010	62	53	43	52.67	0.0225	2.76	2.36	1.91	2.34
0.2	150	0.0013	75	68	55	66.00	0.0225	3.33	3.02	2.44	2.93
0.25	150	0.0017	88	84	73	81.67	0.0225	3.91	3.73	3.24	3.63
0.3	150	0.0020	101	102	85	96.00	0.0225	4.49	4.53	3.78	4.27
0.35	150	0.0023	114	121	98	111.00	0.0225	5.07	5.38	4.36	4.93
0.4	150	0.0027	127	144	115	128.67	0.0225	5.64	6.40	5.11	5.72
0.45	150	0.0030	140	165	132	145.67	0.0225	6.22	7.33	5.87	6.47
0.5	150	0.0033	153	187	147	162.33	0.0225	6.80	8.31	6.53	7.21
0.55	150	0.0037	166	212	168	182.00	0.0225	7.38	9.42	7.47	8.09
0.6	150	0.0040	179	242	192	204.33	0.0225	7.96	10.76	8.53	9.08
0.65	150	0.0043	192	268	215	225.00	0.0225	8.53	11.91	9.56	10.00
0.7	150	0.0047	205	295	243	247.67	0.0225	9.11	13.11	10.80	11.01
0.75	150	0.0050	218	324	271	271.00	0.0225	9.69	14.40	12.04	12.04
0.8	150	0.0053	250	352	304	302.00	0.0225	11.11	15.64	13.51	13.42
0.85	150	0.0057	282	379	341	334.00	0.0225	12.53	16.84	15.16	14.84
0.9	150	0.0060	314	432	373	373.00	0.0225	13.96	19.20	16.58	16.58
0.95	150	0.0063	346	467	414	409.00	0.0225	15.38	20.76	18.40	18.18
1	150	0.0067	378	489.3	421	429.42	0.0225	16.80	21.74	18.71	19.09
1.05	150	0.0070	410	476	428	438.00	0.0225	18.22	21.16	19.02	19.47

1.1	150	0.0073	442	469	436.4	449.14	0.0225	19.64	20.84	19.40	19.96
1.15	150	0.0077	474	462	428	454.67	0.0225	21.07	20.53	19.02	20.21
1.2	150	0.0080	506	455	422	461.00	0.0225	22.49	20.22	18.76	20.49
1.25	150	0.0083	496	448	416	453.33	0.0225	22.04	19.91	18.49	20.15
1.3	150	0.0087	501.4	441	410	450.81	0.0225	22.29	19.60	18.22	20.04
1.35	150	0.0090	492	434	404	443.33	0.0225	21.87	19.29	17.96	19.70
1.4	150	0.0093	470	427	401	432.67	0.0225	20.89	18.98	17.82	19.23
1.45	150	0.0097	448	420	398	422.00	0.0225	19.91	18.67	17.69	18.76
1.5	150	0.0100	426	413	386	408.33	0.0225	18.93	18.36	17.16	18.15
1.55	150	0.0103	404	406	380	396.67	0.0225	17.96	18.04	16.89	17.63
1.6	150	0.0107	382	399	374	385.00	0.0225	16.98	17.73	16.62	17.11
1.65	150	0.0110	360	392	368	373.33	0.0225	16.00	17.42	16.36	16.59
1.7	150	0.0113	338	385	351	358.00	0.0225	15.02	17.11	15.60	15.91
1.75	150	0.0117	316	378	346	346.67	0.0225	14.04	16.80	15.38	15.41
1.8	150	0.0120	294	371	341	335.33	0.0225	13.07	16.49	15.16	14.90
1.85	150	0.0123	272	192	336	266.67	0.0225	12.09	8.53	14.93	11.85
1.9	150	0.0127	250	176	210	212.00	0.0225	11.11	7.82	9.33	9.42
1.95	150	0.0130	228	160	192	193.33	0.0225	10.13	7.11	8.53	8.59
2	150	0.0133	206	144	174	174.67	0.0225	9.16	6.40	7.73	7.76
2.05	150	0.0137	184	128	156	156.00	0.0225	8.18	5.69	6.93	6.93
2.1	150	0.0140	162	112	138	137.33	0.0225	7.20	4.98	6.13	6.10

2.15	150	0.0143	140	96	120	118.67	0.0225	6.22	4.27	5.33	5.27
2.2	150	0.0147	118	80	102	100.00	0.0225	5.24	3.56	4.53	4.44
2.25	150	0.0150	96	64	84	81.33	0.0225	4.27	2.84	3.73	3.61
2.3	150	0.0153	74	48	66	62.67	0.0225	3.29	2.13	2.93	2.79
2.35	150	0.0157	52	32	48	44.00	0.0225	2.31	1.42	2.13	1.96
2.4	150	0.0160	30	16	30	25.33	0.0225	1.33	0.71	1.33	1.13

Table E-4. Stress versus Strain Relationship of 0.5% (0.25%SF +0.25%BF)

hybrid Cube Test Result on 7 day

ΔH	H	Strain(ΔH/H)	Load(KN)			Avg.Load(KN)	Area(m2)	Stress(Mpa)			Avg.Stress(Mpa)
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.00033	17	19	22	19.33	0.0225	0.76	0.84	0.98	0.86
0.1	150	0.00067	22	28	29	26.33	0.0225	0.98	1.24	1.29	1.17
0.15	150	0.00100	27	37	54	39.33	0.0225	1.20	1.64	2.40	1.75
0.2	150	0.00133	32	46	70	49.33	0.0225	1.42	2.04	3.11	2.19
0.25	150	0.00167	37	55	86	59.33	0.0225	1.64	2.44	3.82	2.64
0.3	150	0.00200	42	64	102	69.33	0.0225	1.87	2.84	4.53	3.08
0.35	150	0.00233	47	73	118	79.33	0.0225	2.09	3.24	5.24	3.53
0.4	150	0.00267	52	82	134	89.33	0.0225	2.31	3.64	5.96	3.97
0.45	150	0.00300	57	91	150	99.33	0.0225	2.53	4.04	6.67	4.41
0.5	150	0.00333	62	102	166	110.00	0.0225	2.76	4.53	7.38	4.89
0.55	150	0.00367	67	109	182	119.33	0.0225	2.98	4.84	8.09	5.30
0.6	150	0.00400	72	116	275	154.33	0.0225	3.20	5.16	12.22	6.86
0.65	150	0.00433	77	123	278	159.33	0.0225	3.42	5.47	12.36	7.08

0.7	150	0.00467	82	130	282	164.67	0.0225	3.64	5.78	12.53	7.32
0.75	150	0.00500	97	137	286	173.33	0.0225	4.31	6.09	12.71	7.70
0.8	150	0.00533	112	144	289	181.67	0.0225	4.98	6.40	12.84	8.07
0.85	150	0.00567	127	206	292	208.33	0.0225	5.64	9.16	12.98	9.26
0.9	150	0.00600	156	216	296	222.67	0.0225	6.93	9.60	13.16	9.90
0.95	150	0.00633	185	226	298	236.33	0.0225	8.22	10.04	13.24	10.50
1	150	0.00667	214	236	301	250.33	0.0225	9.51	10.49	13.38	11.13
1.05	150	0.00700	221	246	310	259.00	0.0225	9.82	10.93	13.78	11.51
1.1	150	0.00733	226	256	321	267.67	0.0225	10.04	11.38	14.27	11.90
1.15	150	0.00767	231	384	332	315.67	0.0225	10.27	17.07	14.76	14.03
1.2	150	0.00800	236	396	341	324.33	0.0225	10.49	17.60	15.16	14.41
1.25	150	0.00833	241	408	350	333.00	0.0225	10.71	18.13	15.56	14.80
1.3	150	0.00867	303	420	359	360.67	0.0225	13.47	18.67	15.96	16.03
1.35	150	0.00900	381	427	368	392.00	0.0225	16.93	18.98	16.36	17.42
1.4	150	0.00933	394	431	371	398.67	0.0225	17.51	19.16	16.49	17.72
1.45	150	0.00967	406.62	434	426	422.21	0.0225	18.07	19.29	18.93	18.76
1.5	150	0.01000	396	438.48	454.6	429.69	0.0225	17.60	19.49	20.20	19.10
1.55	150	0.01033	389	426	449	421.33	0.0225	17.29	18.93	19.96	18.73
1.6	150	0.01067	382	421	438	413.67	0.0225	16.98	18.71	19.47	18.39
1.65	150	0.01100	375	416	427	406.00	0.0225	16.67	18.49	18.98	18.04
1.7	150	0.01133	368	411	416	398.33	0.0225	16.36	18.27	18.49	17.70
1.75	150	0.01167	361	406	405	390.67	0.0225	16.04	18.04	18.00	17.36
1.8	150	0.01200	354	401	394	383.00	0.0225	15.73	17.82	17.51	17.02
1.85	150	0.01233	347	396	383	375.33	0.0225	15.42	17.60	17.02	16.68
1.9	150	0.01267	340	391	372	367.67	0.0225	15.11	17.38	16.53	16.34
1.95	150	0.01300	333	386	361	360.00	0.0225	14.80	17.16	16.04	16.00

2	150	0.01333	326	381	350	352.33	0.0225	14.49	16.93	15.56	15.66
2.05	150	0.01367	319	376	339	344.67	0.0225	14.18	16.71	15.07	15.32
2.1	150	0.01400	312	371	328	337.00	0.0225	13.87	16.49	14.58	14.98
2.15	150	0.01433	305	366	317	329.33	0.0225	13.56	16.27	14.09	14.64
2.2	150	0.01467	298	361	306	321.67	0.0225	13.24	16.04	13.60	14.30
2.25	150	0.01500	291	356	295	314.00	0.0225	12.93	15.82	13.11	13.96
2.3	150	0.01533	284	351	284	306.33	0.0225	12.62	15.60	12.62	13.61
2.35	150	0.01567	277	346	273	298.67	0.0225	12.31	15.38	12.13	13.27
2.4	150	0.01600	270	341	262	291.00	0.0225	12.00	15.16	11.64	12.93

Table E-5 Stress versus Strain Relationship of 0.5% (0.25%SF +0.25%BF) hybrid

Cube Test Result on 14 day

			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.00033	20	16	22	19.33	0.0225	0.89	0.71	0.98	0.86
0.1	150	0.00067	28	21	35	28.00	0.0225	1.24	0.93	1.56	1.24
0.15	150	0.00100	75	31	58	54.67	0.0225	3.33	1.38	2.58	2.43
0.2	150	0.00133	89	45	62	65.33	0.0225	3.96	2.00	2.76	2.90
0.25	150	0.00167	120	55	79	84.67	0.0225	5.33	2.44	3.51	3.76
0.3	150	0.00200	135	64	88	95.67	0.0225	6.00	2.84	3.91	4.25
0.35	150	0.00233	148	71	96	105.00	0.0225	6.58	3.16	4.27	4.67
0.4	150	0.00267	161	82	113	118.67	0.0225	7.16	3.64	5.02	5.27
0.45	150	0.00300	174	95	116	128.33	0.0225	7.73	4.22	5.16	5.70
0.5	150	0.00333	187	112	128	142.33	0.0225	8.31	4.98	5.69	6.33
0.55	150	0.00367	200	132	136	156.00	0.0225	8.89	5.87	6.04	6.93
0.6	150	0.00400	213	152	148	171.00	0.0225	9.47	6.76	6.58	7.60

0.65	150	0.00433	226	176	160	187.33	0.0225	10.04	7.82	7.11	8.33
0.7	150	0.00467	239	192	172	201.00	0.0225	10.62	8.53	7.64	8.93
0.75	150	0.00500	252	208	184	214.67	0.0225	11.20	9.24	8.18	9.54
0.8	150	0.00533	265	224	196	228.33	0.0225	11.78	9.96	8.71	10.15
0.85	150	0.00567	278	240	199	239.00	0.0225	12.36	10.67	8.84	10.62
0.9	150	0.00600	291	256	219	255.33	0.0225	12.93	11.38	9.73	11.35
0.95	150	0.00633	304	292	231	275.67	0.0225	13.51	12.98	10.27	12.25
1	150	0.00667	317	312	247	292.00	0.0225	14.09	13.87	10.98	12.98
1.05	150	0.00700	330	332	264	308.67	0.0225	14.67	14.76	11.73	13.72
1.1	150	0.00733	343	352	281	325.33	0.0225	15.24	15.64	12.49	14.46
1.15	150	0.00767	356	372	298	342.00	0.0225	15.82	16.53	13.24	15.20
1.2	150	0.00800	369	392	315	358.67	0.0225	16.40	17.42	14.00	15.94
1.25	150	0.00833	382	412	332	375.33	0.0225	16.98	18.31	14.76	16.68
1.3	150	0.00867	395	425	349	389.67	0.0225	17.56	18.89	15.51	17.32
1.35	150	0.00900	408	438	366	404.00	0.0225	18.13	19.47	16.27	17.96
1.4	150	0.00933	421	451	383	418.33	0.0225	18.71	20.04	17.02	18.59
1.45	150	0.00967	434	464	400	432.67	0.0225	19.29	20.62	17.78	19.23
1.5	150	0.01000	447	477	417	447.00	0.0225	19.87	21.20	18.53	19.87
1.55	150	0.01033	460	490	434	461.33	0.0225	20.44	21.78	19.29	20.50
1.6	150	0.01067	473	552	443	489.33	0.0225	21.02	24.53	19.69	21.75
1.65	150	0.01100	480	560	452	497.33	0.0225	21.33	24.89	20.09	22.10
1.7	150	0.01133	483	592.32	463	512.77	0.0225	21.47	26.33	20.58	22.79
1.75	150	0.01167	512	512	502	508.67	0.0225	22.76	22.76	22.31	22.61
1.8	150	0.01200	525	486	519	510.00	0.0225	23.33	21.60	23.07	22.67
1.85	150	0.01233	538	434	536	502.67	0.0225	23.91	19.29	23.82	22.34
1.9	150	0.01267	551	382	553	495.33	0.0225	24.49	16.98	24.58	22.01
1.95	150	0.01300	564	330	554.92	482.97	0.0225	25.07	14.67	24.66	21.47

2	150	0.01333	586.53	278	566	476.84	0.0225	26.07	12.36	25.16	21.19
2.05	150	0.01367	522	226	524	424.00	0.0225	23.20	10.04	23.29	18.84
2.1	150	0.01400	472	174	486	377.33	0.0225	20.98	7.73	21.60	16.77
2.15	150	0.01433	436	122	448	335.33	0.0225	19.38	5.42	19.91	14.90
2.2	150	0.01467	368	278	410	352.00	0.0225	16.36	12.36	18.22	15.64
2.25	150	0.01500	292	252	372	305.33	0.0225	12.98	11.20	16.53	13.57
2.3	150	0.01533	246	226	334	268.67	0.0225	10.93	10.04	14.84	11.94
2.35	150	0.01567	168	200	296	221.33	0.0225	7.47	8.89	13.16	9.84
2.4	150	0.01600	91	174	258	174.33	0.0225	4.04	7.73	11.47	7.75

Table E-6 Stress versus Strain Relationship of 0.5% (0.25%SF +0.25%BF)

hybrid Cube Test Result on 28 day

ΔH	H	Strain (ΔH/H)	Load(KN)			Avg. Load (KN)	Area (m2)	Stress(Mpa)			Avg. Stress (Mpa
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.00033	19	20	20	19.67	0.0225	0.84	0.89	0.89	0.87
0.1	150	0.00067	28	30	38	32.00	0.0225	1.24	1.33	1.69	1.42
0.15	150	0.00100	37	41	57	45.00	0.0225	1.64	1.82	2.53	2.00
0.2	150	0.00133	48	55	73	58.67	0.0225	2.13	2.44	3.24	2.61
0.25	150	0.00167	60	71	85	72.00	0.0225	2.67	3.16	3.78	3.20
0.3	150	0.00200	75	91	104	90.00	0.0225	3.33	4.04	4.62	4.00
0.35	150	0.00233	92	109	128	109.67	0.0225	4.09	4.84	5.69	4.87
0.4	150	0.00267	112	131	141	128.00	0.0225	4.98	5.82	6.27	5.69
0.45	150	0.00300	119	156	161	145.33	0.0225	5.29	6.93	7.16	6.46
0.5	150	0.00333	126	174	176	158.67	0.0225	5.60	7.73	7.82	7.05
0.55	150	0.00367	133	193	213	179.67	0.0225	5.91	8.58	9.47	7.99

0.6	150	0.00400	140	217	233	196.67	0.0225	6.22	9.64	10.36	8.74
0.65	150	0.00433	147	234	258	213.00	0.0225	6.53	10.40	11.47	9.47
0.7	150	0.00467	154	260	276	230.00	0.0225	6.84	11.56	12.27	10.22
0.75	150	0.00500	161	283	299	247.67	0.0225	7.16	12.58	13.29	11.01
0.8	150	0.00533	168	297	326	263.67	0.0225	7.47	13.20	14.49	11.72
0.85	150	0.00567	175	314	349	279.33	0.0225	7.78	13.96	15.51	12.41
0.9	150	0.00600	182	331	370	294.33	0.0225	8.09	14.71	16.44	13.08
0.95	150	0.00633	189	358	389	312.00	0.0225	8.40	15.91	17.29	13.87
1	150	0.00667	196	378	410	328.00	0.0225	8.71	16.80	18.22	14.58
1.05	150	0.00700	210	404	416	343.33	0.0225	9.33	17.96	18.49	15.26
1.1	150	0.00733	236	427	422	361.67	0.0225	10.49	18.98	18.76	16.07
1.15	150	0.00767	262	433	428	374.33	0.0225	11.64	19.24	19.02	16.64
1.2	150	0.00800	288	439	434	387.00	0.0225	12.80	19.51	19.29	17.20
1.25	150	0.00833	314	445	440	399.67	0.0225	13.96	19.78	19.56	17.76
1.3	150	0.00867	340	451	486	425.67	0.0225	15.11	20.04	21.60	18.92
1.35	150	0.00900	342	457	489	429.33	0.0225	15.20	20.31	21.73	19.08
1.4	150	0.00933	404	463	492	453.00	0.0225	17.96	20.58	21.87	20.13
1.45	150	0.00967	466	473	495	478.00	0.0225	20.71	21.02	22.00	21.24
1.5	150	0.01000	528	489	527.26	514.75	0.0225	23.47	21.73	23.43	22.88
1.55	150	0.01033	544	493	521	519.33	0.0225	24.18	21.91	23.16	23.08
1.6	150	0.01067	563.33	510	502	525.11	0.0225	25.04	22.67	22.31	23.34
1.65	150	0.01100	560	511.69	483	518.23	0.0225	24.89	22.74	21.47	23.03
1.7	150	0.01133	550	497	464	503.67	0.0225	24.44	22.09	20.62	22.39
1.75	150	0.01167	540	491	445	492.00	0.0225	24.00	21.82	19.78	21.87
1.8	150	0.01200	532	469	426	475.67	0.0225	23.64	20.84	18.93	21.14
1.85	150	0.01233	520	447	407	458.00	0.0225	23.11	19.87	18.09	20.36
1.9	150	0.01267	510	425	388	441.00	0.0225	22.67	18.89	17.24	19.60

1.95	150	0.01300	500	403	369	424.00	0.0225	22.22	17.91	16.40	18.84
2	150	0.01333	490	381	350	407.00	0.0225	21.78	16.93	15.56	18.09
2.05	150	0.01367	480	359	331	390.00	0.0225	21.33	15.96	14.71	17.33
2.1	150	0.01400	470	337	312	373.00	0.0225	20.89	14.98	13.87	16.58
2.15	150	0.01433	460	315	293	356.00	0.0225	20.44	14.00	13.02	15.82
2.2	150	0.01467	450	293	274	339.00	0.0225	20.00	13.02	12.18	15.07
2.25	150	0.01500	440	271	255	322.00	0.0225	19.56	12.04	11.33	14.31
2.3	150	0.01533	430	249	236	305.00	0.0225	19.11	11.07	10.49	13.56
2.35	150	0.01567	420	227	217	288.00	0.0225	18.67	10.09	9.64	12.80
2.4	150	0.01600	410	205	198	271.00	0.0225	18.22	9.11	8.80	12.04

Table E-7. Stress versus Strain Relationship of 1% (0.75%SF +0.25%BF) hybrid Cube Test Result on 7 day

			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.00033	13	15	23	17.00	0.0225	0.58	0.67	1.02	0.76
0.1	150	0.00067	19	24	35	26.00	0.0225	0.84	1.07	1.56	1.16
0.15	150	0.00100	27	39	48	38.00	0.0225	1.20	1.73	2.13	1.69
0.2	150	0.00133	35	54	59	49.33	0.0225	1.56	2.40	2.62	2.19
0.25	150	0.00167	43	69	74	62.00	0.0225	1.91	3.07	3.29	2.76
0.3	150	0.00200	51	84	87	74.00	0.0225	2.27	3.73	3.87	3.29
0.35	150	0.00233	59	99	100	86.00	0.0225	2.62	4.40	4.44	3.82
0.4	150	0.00267	75	118	113	102.00	0.0225	3.33	5.24	5.02	4.53
0.45	150	0.00300	91	137	126	118.00	0.0225	4.04	6.09	5.60	5.24
0.5	150	0.00333	107	156	139	134.00	0.0225	4.76	6.93	6.18	5.96
0.55	150	0.00367	123	175	152	150.00	0.0225	5.47	7.78	6.76	6.67
0.6	150	0.00400	139	194	165	166.00	0.0225	6.18	8.62	7.33	7.38

0.65	150	0.00433	155	213	192	186.67	0.0225	6.89	9.47	8.53	8.30
0.7	150	0.00467	171	232	219	207.33	0.0225	7.60	10.31	9.73	9.21
0.75	150	0.00500	187	251	246	228.00	0.0225	8.31	11.16	10.93	10.13
0.8	150	0.00533	192	304	273	256.33	0.0225	8.53	13.51	12.13	11.39
0.85	150	0.00567	197	325	300	274.00	0.0225	8.76	14.44	13.33	12.18
0.9	150	0.00600	202	346	327	291.67	0.0225	8.98	15.38	14.53	12.96
0.95	150	0.00633	207	367	354	309.33	0.0225	9.20	16.31	15.73	13.75
1	150	0.00667	212	388	381	327.00	0.0225	9.42	17.24	16.93	14.53
1.05	150	0.00700	217	409	396	340.67	0.0225	9.64	18.18	17.60	15.14
1.1	150	0.00733	222	430	411	354.33	0.0225	9.87	19.11	18.27	15.75
1.15	150	0.00767	278	451	426	385.00	0.0225	12.36	20.04	18.93	17.11
1.2	150	0.00800	310	462	441	404.33	0.0225	13.78	20.53	19.60	17.97
1.25	150	0.00833	342	472	456	423.33	0.0225	15.20	20.98	20.27	18.81
1.3	150	0.00867	374	489	471	444.67	0.0225	16.62	21.73	20.93	19.76
1.35	150	0.00900	406	514.24	486	468.75	0.0225	18.04	22.86	21.60	20.83
1.4	150	0.00933	438	502	519	486.33	0.0225	19.47	22.31	23.07	21.61
1.45	150	0.00967	470	496	526.43	497.48	0.0225	20.89	22.04	23.40	22.11
1.5	150	0.01000	475.52	490	510	491.84	0.0225	21.13	21.78	22.67	21.86
1.55	150	0.01033	469	484	486	479.67	0.0225	20.84	21.51	21.60	21.32
1.6	150	0.01067	458	478	462	466.00	0.0225	20.36	21.24	20.53	20.71
1.65	150	0.01100	447	472	438	452.33	0.0225	19.87	20.98	19.47	20.10
1.7	150	0.01133	436	466	414	438.67	0.0225	19.38	20.71	18.40	19.50
1.75	150	0.01167	425	398	390	404.33	0.0225	18.89	17.69	17.33	17.97
1.8	150	0.01200	414	385	366	388.33	0.0225	18.40	17.11	16.27	17.26
1.85	150	0.01233	403	372	342	372.33	0.0225	17.91	16.53	15.20	16.55
1.9	150	0.01267	385	359	318	354.00	0.0225	17.11	15.96	14.13	15.73
1.95	150	0.01300	374	346	294	338.00	0.0225	16.62	15.38	13.07	15.02

2	150	0.01333	363	333	270	322.00	0.0225	16.13	14.80	12.00	14.31
2.05	150	0.01367	352	320	246	306.00	0.0225	15.64	14.22	10.93	13.60
2.1	150	0.01400	341	307	222	290.00	0.0225	15.16	13.64	9.87	12.89
2.15	150	0.01433	330	294	198	274.00	0.0225	14.67	13.07	8.80	12.18
2.2	150	0.01467	319	73	174	188.67	0.0225	14.18	3.24	7.73	8.39
2.25	150	0.01500	308	52	150	170.00	0.0225	13.69	2.31	6.67	7.56
2.3	150	0.01533	40	31	274	115.00	0.0225	1.78	1.38	12.18	5.11
2.35	150	0.01567	35	24	265	108.00	0.0225	1.56	1.07	11.78	4.80
2.4	150	0.01600	30	16	256	100.67	0.0225	1.33	0.49	11.38	4.40

Table E-8. Stress versus Strain Relationship of 1%

(0.75%SF +0.25%BF) hybrid Cube Test Result on 14 day

ΔH	H	Strain(ΔH/H)	Load(KN)			Avg.Load(KN)	Area(m2)	Stress(Mpa)			Avg.Stress(Mpa)
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.00033	17	16	22	18.33	0.0225	0.76	0.71	0.98	0.81
0.1	150	0.00067	23	21	35	26.33	0.0225	1.02	0.93	1.56	1.17
0.15	150	0.00100	36	31	58	41.67	0.0225	1.60	1.38	2.58	1.85
0.2	150	0.00133	82	45	62	63.00	0.0225	3.64	2.00	2.76	2.80
0.25	150	0.00167	104	55	79	79.33	0.0225	4.62	2.44	3.51	3.53
0.3	150	0.00200	112	64	88	88.00	0.0225	4.98	2.84	3.91	3.91
0.35	150	0.00233	138	71	96	101.67	0.0225	6.13	3.16	4.27	4.52
0.4	150	0.00267	164	82	113	119.67	0.0225	7.29	3.64	5.02	5.32
0.45	150	0.00300	190	95	116	133.67	0.0225	8.44	4.22	5.16	5.94
0.5	150	0.00333	216	112	128	152.00	0.0225	9.60	4.98	5.69	6.76
0.55	150	0.00367	242	133	139	171.33	0.0225	10.76	5.91	6.18	7.61

0.6	150	0.00400	268	154	150	190.67	0.0225	11.91	6.84	6.67	8.47
0.65	150	0.00433	294	175	161	210.00	0.0225	13.07	7.78	7.16	9.33
0.7	150	0.00467	320	196	172	229.33	0.0225	14.22	8.71	7.64	10.19
0.75	150	0.00500	346	217	183	248.67	0.0225	15.38	9.64	8.13	11.05
0.8	150	0.00533	372	238	194	268.00	0.0225	16.53	10.58	8.62	11.91
0.85	150	0.00567	398	259	205	287.33	0.0225	17.69	11.51	9.11	12.77
0.9	150	0.00600	424	280	216	306.67	0.0225	18.84	12.44	9.60	13.63
0.95	150	0.00633	450	301	227	326.00	0.0225	20.00	13.38	10.09	14.49
1	150	0.00667	472	322	238	344.00	0.0225	20.98	14.31	10.58	15.29
1.05	150	0.00700	494	343	249	362.00	0.0225	21.96	15.24	11.07	16.09
1.1	150	0.00733	516	364	260	380.00	0.0225	22.93	16.18	11.56	16.89
1.15	150	0.00767	538	385	271	398.00	0.0225	23.91	17.11	12.04	17.69
1.2	150	0.00800	548	460	282	430.00	0.0225	24.36	20.44	12.53	19.11
1.25	150	0.00833	559	492	293	448.00	0.0225	24.84	21.87	13.02	19.91
1.3	150	0.00867	584	510	304	466.00	0.0225	25.96	22.67	13.51	20.71
1.35	150	0.00900	588.6	560	392	513.53	0.0225	26.16	24.89	17.42	22.82
1.4	150	0.00933	580	562	406	516.00	0.0225	25.78	24.98	18.04	22.93
1.45	150	0.00967	536	564	410	503.33	0.0225	23.82	25.07	18.22	22.37
1.5	150	0.01000	492	566	414	490.67	0.0225	21.87	25.16	18.40	21.81
1.55	150	0.01033	448	568	418	478.00	0.0225	19.91	25.24	18.58	21.24
1.6	150	0.01067	404	570	422	465.33	0.0225	17.96	25.33	18.76	20.68
1.65	150	0.01100	360	572	426	452.67	0.0225	16.00	25.42	18.93	20.12
1.7	150	0.01133	316	594.32	430	446.77	0.0225	14.04	26.41	19.11	19.86
1.75	150	0.01167	272	586	434	430.67	0.0225	12.09	26.04	19.29	19.14
1.8	150	0.01200	228	575	438	413.67	0.0225	10.13	25.56	19.47	18.39
1.85	150	0.01233	184	564	548	432.00	0.0225	8.18	25.07	24.36	19.20
1.9	150	0.01267	140	553	570	421.00	0.0225	6.22	24.58	25.33	18.71

1.95	150	0.01300	154	542	592	429.33	0.0225	6.84	24.09	26.31	19.08
2	150	0.01333	145	338	614	365.67	0.0225	6.44	15.02	27.29	16.25
2.05	150	0.01367	138	301	564.8	334.60	0.0225	6.13	13.38	25.10	14.87
2.1	150	0.01400	132	264	553	316.33	0.0225	5.87	11.73	24.58	14.06
2.15	150	0.01433	121	227	490	279.33	0.0225	5.38	10.09	21.78	12.41
2.2	150	0.01467	116	190	440	248.67	0.0225	5.16	8.44	19.56	11.05
2.25	150	0.01500	111	153	390	218.00	0.0225	4.93	6.80	17.33	9.69
2.3	150	0.01533	107	116	340	187.67	0.0225	4.76	5.16	15.11	8.34
2.35	150	0.01567	101	79	290	156.67	0.0225	4.49	3.51	12.89	6.96
2.4	150	0.01600	91	42	240	124.33	0.0225	4.04	1.87	10.67	5.53

Table E-9. Stress versus Strain Relationship of 1%

(0.75%SF +0.25%BF) hybrid Cube Test Result on 28 day

ΔH(mm)	H(mm)	Strain (ΔH/H)	Load(KN)			Av. Load (KN)	Area (M2)	Stress (Mpa)	Av.Stress(Mpa)		
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.0003	22	22	21	21.67	0.0225	0.98	0.98	0.93	0.96
0.1	150	0.0007	46	42	25	37.67	0.0225	2.04	1.87	1.11	1.67
0.15	150	0.0010	70	62	36	56.00	0.0225	3.11	2.76	1.60	2.49
0.2	150	0.0013	94	82	48	74.67	0.0225	4.18	3.64	2.13	3.32
0.25	150	0.0017	99	102	59	86.67	0.0225	4.40	4.53	2.62	3.85
0.3	150	0.0020	104	110	73	95.67	0.0225	4.62	4.89	3.24	4.25
0.35	150	0.0023	114	116	90	106.67	0.0225	5.07	5.16	4.00	4.74
0.4	150	0.0027	156	154	107	139.00	0.0225	6.93	6.84	4.76	6.18
0.45	150	0.0030	198	139	124	153.67	0.0225	8.80	6.18	5.51	6.83
0.5	150	0.0033	240	154	140	178.00	0.0225	10.67	6.84	6.22	7.91

0.55	150	0.0037	282	174	166	207.33	0.0225	12.53	7.73	7.38	9.21
0.6	150	0.0040	324	182	191	232.33	0.0225	14.40	8.09	8.49	10.33
0.65	150	0.0043	366	207	212	261.67	0.0225	16.27	9.20	9.42	11.63
0.7	150	0.0047	386	221	231	279.33	0.0225	17.16	9.82	10.27	12.41
0.75	150	0.0050	406	235	254	298.33	0.0225	18.04	10.44	11.29	13.26
0.8	150	0.0053	426	248	271	315.00	0.0225	18.93	11.02	12.04	14.00
0.85	150	0.0057	446	267	297	336.67	0.0225	19.82	11.87	13.20	14.96
0.9	150	0.0060	466	280	328	358.00	0.0225	20.71	12.44	14.58	15.91
0.95	150	0.0063	486	297	355	379.33	0.0225	21.60	13.20	15.78	16.86
1	150	0.0067	506	311	385	400.67	0.0225	22.49	13.82	17.11	17.81
1.05	150	0.0070	526	337	425	429.33	0.0225	23.38	14.98	18.89	19.08
1.1	150	0.0073	546	343	438	442.33	0.0225	24.27	15.24	19.47	19.66
1.15	150	0.0077	554	360	465	459.67	0.0225	24.62	16.00	20.67	20.43
1.2	150	0.0080	562	390	492	481.33	0.0225	24.98	17.33	21.87	21.39
1.25	150	0.0083	570	450	546.37	522.12	0.0225	25.33	20.00	24.28	23.21
1.3	150	0.0087	576.43	510	539	541.81	0.0225	25.62	22.67	23.96	24.08
1.35	150	0.0090	569	512	520	533.67	0.0225	25.29	22.76	23.11	23.72
1.4	150	0.0093	558	514	501	524.33	0.0225	24.80	22.84	22.27	23.30
1.45	150	0.0097	547	516	482	515.00	0.0225	24.31	22.93	21.42	22.89
1.5	150	0.0100	536	518	463	505.67	0.0225	23.82	23.02	20.58	22.47
1.55	150	0.0103	525	520	444	496.33	0.0225	23.33	23.11	19.73	22.06
1.6	150	0.0107	514	522	425	487.00	0.0225	22.84	23.20	18.89	21.64
1.65	150	0.0110	503	524	406	477.67	0.0225	22.36	23.29	18.04	21.23
1.7	150	0.0113	492	526	387	468.33	0.0225	21.87	23.38	17.20	20.81
1.75	150	0.0117	481	568.68	368	472.56	0.0225	21.38	25.27	16.36	21.00

1.8	150	0.0120	478	560	349	462.33	0.0225	21.24	24.89	15.51	20.55
1.85	150	0.0123	473	549	112	378.00	0.0225	21.02	24.40	4.98	16.80
1.9	150	0.0127	468	538	78	361.33	0.0225	20.80	23.91	3.47	16.06
1.95	150	0.0130	463	527	44	344.67	0.0225	20.58	23.42	1.96	15.32
2	150	0.0133	458	516	40	338.00	0.0225	20.36	22.93	1.78	15.02
2.05	150	0.0137	453	505	38	332.00	0.0225	20.13	22.44	1.69	14.76
2.1	150	0.0140	448	494	36	326.00	0.0225	19.91	21.96	1.60	14.49
2.15	150	0.0143	443	454	34	310.33	0.0225	19.69	20.18	1.51	13.79
2.2	150	0.0147	438	443	32	304.33	0.0225	19.47	19.69	1.42	13.53
2.25	150	0.0150	433	432	30	298.33	0.0225	19.24	19.20	1.33	13.26
2.3	150	0.0153	428	421	28	292.33	0.0225	19.02	18.71	1.24	12.99
2.35	150	0.0157	423	410	26	286.33	0.0225	18.80	18.22	1.16	12.73
2.4	150	0.0160	418	399	24	280.33	0.0225	18.58	17.73	1.07	12.46
2.45	150	0.0163	413	388	22	274.33	0.0225	18.36	17.24	0.98	12.19
2.5	150	0.0167	408	377	20	268.33	0.0225	18.13	16.76	0.89	11.93

Table E-10. Stress versus Strain Relationship of 1.5%

(1% SF + 0.5% BF) hybrids Cube Test Result on 7 day

ΔH (mm)	H (mm)	Strain (ΔH/H)	Load (KN)			Avg. Load (KN)	Area (m2)	Stress (Mpa)			Avg. Stress(Mpa)
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.0003	14	15	23	17.33	0.0225	0.62	0.67	1.02	0.77
0.1	150	0.0007	28	36	41	35.00	0.0225	1.24	1.60	1.82	1.56
0.15	150	0.0010	61	72	76	69.67	0.0225	2.71	3.20	3.38	3.10
0.2	150	0.0013	82	92	94	89.33	0.0225	3.64	4.09	4.18	3.97

0.25	150	0.0017	99	112	121	110.67	0.0225	4.40	4.98	5.38	4.92
0.3	150	0.0020	136	146	156	146.00	0.0225	6.04	6.49	6.93	6.49
0.35	150	0.0023	155	168	178	167.00	0.0225	6.89	7.47	7.91	7.42
0.4	150	0.0027	179	189	198	188.67	0.0225	7.96	8.40	8.80	8.39
0.45	150	0.0030	192	198	214	201.33	0.0225	8.53	8.80	9.51	8.95
0.5	150	0.0033	199	218	230	215.67	0.0225	8.84	9.69	10.22	9.59
0.55	150	0.0037	226	236	261	241.00	0.0225	10.04	10.49	11.60	10.71
0.6	150	0.0040	275	278	275	276.00	0.0225	12.22	12.36	12.22	12.27
0.65	150	0.0043	290	298	289	292.33	0.0225	12.89	13.24	12.84	12.99
0.7	150	0.0047	326	339	303	322.67	0.0225	14.49	15.07	13.47	14.34
0.75	150	0.0050	342	372	317	343.67	0.0225	15.20	16.53	14.09	15.27
0.8	150	0.0053	368	386	331	361.67	0.0225	16.36	17.16	14.71	16.07
0.85	150	0.0057	391	400	345	378.67	0.0225	17.38	17.78	15.33	16.83
0.9	150	0.0060	432	414	406	417.33	0.0225	19.20	18.40	18.04	18.55
0.95	150	0.0063	447	428	430	435.00	0.0225	19.87	19.02	19.11	19.33
1	150	0.0067	462	442	454	452.67	0.0225	20.53	19.64	20.18	20.12
1.05	150	0.0070	468	456	478	467.33	0.0225	20.80	20.27	21.24	20.77
1.1	150	0.0073	475	461	484	473.33	0.0225	21.11	20.49	21.51	21.04
1.15	150	0.0077	486	463	490.64	479.88	0.0225	21.60	20.58	21.81	21.33
1.2	150	0.0080	521.64	498	322	447.21	0.0225	23.18	22.13	14.31	19.88
1.25	150	0.0083	552	512	301	455.00	0.0225	24.53	22.76	13.38	20.22
1.3	150	0.0087	512	515.26	280	435.75	0.0225	22.76	22.90	12.44	19.37
1.35	150	0.0090	468	308	259	345.00	0.0225	20.80	13.69	11.51	15.33
1.4	150	0.0093	422	280	238	313.33	0.0225	18.76	12.44	10.58	13.93
1.45	150	0.0097	402	271	217	296.67	0.0225	17.87	12.04	9.64	13.19
1.5	150	0.0100	384	260	196	280.00	0.0225	17.07	11.56	8.71	12.44
1.55	150	0.0103	366	256	175	265.67	0.0225	16.27	11.38	7.78	11.81

1.6	150	0.0107	348	241	168	252.33	0.0225	15.47	10.71	7.47	11.21
1.65	150	0.0110	330	191	161	227.33	0.0225	14.67	8.49	7.16	10.10
1.7	150	0.0113	312	186	154	217.33	0.0225	13.87	8.27	6.84	9.66
1.75	150	0.0117	294	176	147	205.67	0.0225	13.07	7.82	6.53	9.14
1.8	150	0.0120	276	142	140	186.00	0.0225	12.27	6.31	6.22	8.27
1.85	150	0.0123	258	135	133	175.33	0.0225	11.47	6.00	5.91	7.79
1.9	150	0.0127	240	128	126	164.67	0.0225	10.67	5.69	5.60	7.32
1.95	150	0.0130	222	122	119	154.33	0.0225	9.87	5.42	5.29	6.86
2	150	0.0133	204	119	112	145.00	0.0225	9.07	5.29	4.98	6.44
2.05	150	0.0137	186	112	105	134.33	0.0225	8.27	4.98	4.67	5.97
2.1	150	0.0140	168	108	98	124.67	0.0225	7.47	4.80	4.36	5.54
2.15	150	0.0143	150	101	91	114.00	0.0225	6.67	4.49	4.04	5.07
2.2	150	0.0147	132	95	84	103.67	0.0225	5.87	4.22	3.73	4.61
2.25	150	0.0150	114	91	77	94.00	0.0225	5.07	4.04	3.42	4.18
2.3	150	0.0153	96	72	70	79.33	0.0225	4.27	3.20	3.11	3.53
2.35	150	0.0157	78	61	63	67.33	0.0225	3.47	2.71	2.80	2.99
2.4	150	0.0160	60	48	56	54.67	0.0225	2.67	2.13	2.49	2.43

Table E-10. Stress versus Strain Relationship of 1.5%

(1% SF + 0.5% BF) hybrids Cube Test Result on 14 day

ΔH(mm)	H(mm)	Strain(ΔH/H)	Load(KN)			Avg.Load(KN)	Area(m2)	Stress(Mpa)			Avg. Stress(Mpa)
			Sample 1	Sample 2	Sample 3			Sample 1	Sample 2	Sample 3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.0003	36	29	32	32.33	0.0225	1.60	1.29	1.42	1.44
0.1	150	0.0007	48	41	45	44.67	0.0225	2.13	1.82	2.00	1.99
0.15	150	0.0010	68	59	65	64.00	0.0225	3.02	2.62	2.89	2.84

0.2	150	0.0013	76	77	85	79.33	0.0225	3.38	3.42	3.78	3.53
0.25	150	0.0017	84	95	105	94.67	0.0225	3.73	4.22	4.67	4.21
0.3	150	0.0020	92	113	125	110.00	0.0225	4.09	5.02	5.56	4.89
0.35	150	0.0023	100	131	145	125.33	0.0225	4.44	5.82	6.44	5.57
0.4	150	0.0027	108	149	165	140.67	0.0225	4.80	6.62	7.33	6.25
0.45	150	0.0030	116	167	185	156.00	0.0225	5.16	7.42	8.22	6.93
0.5	150	0.0033	124	185	205	171.33	0.0225	5.51	8.22	9.11	7.61
0.55	150	0.0037	132	203	225	186.67	0.0225	5.87	9.02	10.00	8.30
0.6	150	0.0040	140	221	245	202.00	0.0225	6.22	9.82	10.89	8.98
0.65	150	0.0043	148	239	265	217.33	0.0225	6.58	10.62	11.78	9.66
0.7	150	0.0047	156	257	285	232.67	0.0225	6.93	11.42	12.67	10.34
0.75	150	0.0050	164	275	305	248.00	0.0225	7.29	12.22	13.56	11.02
0.8	150	0.0053	168	293	325	262.00	0.0225	7.47	13.02	14.44	11.64
0.85	150	0.0057	188	311	345	281.33	0.0225	8.36	13.82	15.33	12.50
0.9	150	0.0060	208	329	365	300.67	0.0225	9.24	14.62	16.22	13.36
0.95	150	0.0063	228	347	385	320.00	0.0225	10.13	15.42	17.11	14.22
1	150	0.0067	248	365	405	339.33	0.0225	11.02	16.22	18.00	15.08
1.05	150	0.0070	268	383	425	358.67	0.0225	11.91	17.02	18.89	15.94
1.1	150	0.0073	288	401	445	378.00	0.0225	12.80	17.82	19.78	16.80
1.15	150	0.0077	308	419	465	397.33	0.0225	13.69	18.62	20.67	17.66
1.2	150	0.0080	328	437	471	412.00	0.0225	14.58	19.42	20.93	18.31
1.25	150	0.0083	348	455	477	426.67	0.0225	15.47	20.22	21.20	18.96
1.3	150	0.0087	368	473	483	441.33	0.0225	16.36	21.02	21.47	19.61
1.35	150	0.0090	388	491	489	456.00	0.0225	17.24	21.82	21.73	20.27
1.4	150	0.0093	408	501	495	468.00	0.0225	18.13	22.27	22.00	20.80
1.45	150	0.0097	428	507	501	478.67	0.0225	19.02	22.53	22.27	21.27
1.5	150	0.0100	448	511	507	488.67	0.0225	19.91	22.71	22.53	21.72

1.55	150	0.0103	468	516.66	509.62	498.09	0.0225	20.80	22.96	22.65	22.14
1.6	150	0.0107	488	511	488	495.67	0.0225	21.69	22.71	21.69	22.03
1.65	150	0.0110	492.32	492	495	493.11	0.0225	21.88	21.87	22.00	21.92
1.7	150	0.0113	489	473	502	488.00	0.0225	21.73	21.02	22.31	21.69
1.75	150	0.0117	475	454	509.62	479.54	0.0225	21.11	20.18	22.65	21.31
1.8	150	0.0120	461	435	487	461.00	0.0225	20.49	19.33	21.64	20.49
1.85	150	0.0123	447	416	502	455.00	0.0225	19.87	18.49	22.31	20.22
1.9	150	0.0127	433	397	517	449.00	0.0225	19.24	17.64	22.98	19.96
1.95	150	0.0130	419	378	532	443.00	0.0225	18.62	16.80	23.64	19.69
2	150	0.0133	405	359	547	437.00	0.0225	18.00	15.96	24.31	19.42
2.05	150	0.0137	391	340	562.19	431.06	0.0225	17.38	15.11	24.99	19.16
2.1	150	0.0140	377	321	276	324.67	0.0225	16.76	14.27	12.27	14.43
2.15	150	0.0143	363	302	251	305.33	0.0225	16.13	13.42	11.16	13.57
2.2	150	0.0147	349	283	226	286.00	0.0225	15.51	12.58	10.04	12.71
2.25	150	0.0150	280	264	201	248.33	0.0225	12.44	11.73	8.93	11.04
2.3	150	0.0153	271	245	176	230.67	0.0225	12.04	10.89	7.82	10.25
2.35	150	0.0157	262	226	151	213.00	0.0225	11.64	10.04	6.71	9.47
2.4	150	0.0160	253	207	126	195.33	0.0225	11.24	9.20	5.60	8.68

Table E-11. Stress versus Strain Relationship of 1.5% (1% SF + 0.5% BF)

hybrids Cube Test Result on 28 day

ΔH(mm)	H (mm)	Strain(ΔH/H)	Load(KN)			Avg.Load(KN)	Area(M2)	Stress(Mpa)			Av.Stress(Mpa)
			Sample1	Sample2	Sample3			Sample1	Sample2	Sample3	
0	0	0	0	0	0	0	0	0	0	0	0
0.05	150	0.0003	24	19	22	21.667	0.0225	1.07	0.84	0.98	0.96

0.1	150	0.0007	28	27	36	30.333	0.0225	1.24	1.20	1.60	1.35
0.15	150	0.0010	35	38	57	43.333	0.0225	1.56	1.69	2.53	1.93
0.2	150	0.0013	75	49	76	66.667	0.0225	3.33	2.18	3.38	2.96
0.25	150	0.0017	97	56	100	84.333	0.0225	4.31	2.49	4.44	3.75
0.3	150	0.0020	123	75	122	106.667	0.0225	5.47	3.33	5.42	4.74
0.35	150	0.0023	147	89	141	125.667	0.0225	6.53	3.96	6.27	5.59
0.4	150	0.0027	176	114	163	151.000	0.0225	7.82	5.07	7.24	6.71
0.45	150	0.0030	206	139	186	177.000	0.0225	9.16	6.18	8.27	7.87
0.5	150	0.0033	236	170	212	206.000	0.0225	10.49	7.56	9.42	9.16
0.55	150	0.0037	268	197	231	232.000	0.0225	11.91	8.76	10.27	10.31
0.6	150	0.0040	295	218	254	255.667	0.0225	13.11	9.69	11.29	11.36
0.65	150	0.0043	327	236	277	280.000	0.0225	14.53	10.49	12.31	12.44
0.7	150	0.0047	363	261	298	307.333	0.0225	16.13	11.60	13.24	13.66
0.75	150	0.0050	384	288	322	331.333	0.0225	17.07	12.80	14.31	14.73
0.8	150	0.0053	419	317	343	359.667	0.0225	18.62	14.09	15.24	15.99
0.85	150	0.0057	439	341	371	383.667	0.0225	19.51	15.16	16.49	17.05
0.9	150	0.0060	465	366	394	408.333	0.0225	20.67	16.27	17.51	18.15
0.95	150	0.0063	471	385	423	426.333	0.0225	20.93	17.11	18.80	18.95
1	150	0.0067	477	403	445	441.667	0.0225	21.20	17.91	19.78	19.63
1.05	150	0.0070	522.22	421	463	468.740	0.0225	23.21	18.71	20.58	20.83
1.1	150	0.0073	491	435	492.06	472.687	0.0225	21.82	19.33	21.87	21.01
1.15	150	0.0077	468	447	489	468.000	0.0225	20.80	19.87	21.73	20.80
1.2	150	0.0080	441	459	475	458.333	0.0225	19.60	20.40	21.11	20.37
1.25	150	0.0083	414	471	461	448.667	0.0225	18.40	20.93	20.49	19.94
1.3	150	0.0087	387	479	447	437.667	0.0225	17.20	21.29	19.87	19.45
1.35	150	0.0090	360	486	433	426.333	0.0225	16.00	21.60	19.24	18.95
1.4	150	0.0093	333	495	419	415.667	0.0225	14.80	22.00	18.62	18.47

1.45	150	0.0097	306	502	405	404.333	0.0225	13.60	22.31	18.00	17.97
1.5	150	0.0100	279	501.68	391	390.560	0.0225	12.40	22.30	17.38	17.36
1.55	150	0.0103	252	517	377	382.000	0.0225	11.20	22.98	16.76	16.98
1.6	150	0.0107	225	515	363	367.667	0.0225	10.00	22.89	16.13	16.34
1.65	150	0.0110	198	511	349	352.667	0.0225	8.80	22.71	15.51	15.67
1.7	150	0.0113	171	509	335	338.333	0.0225	7.60	22.62	14.89	15.04
1.75	150	0.0117	144	504	321	323.000	0.0225	6.40	22.40	14.27	14.36
1.8	150	0.0120	117	497	307	307.000	0.0225	5.20	22.09	13.64	13.64
1.85	150	0.0123	90	490	293	291.000	0.0225	4.00	21.78	13.02	12.93
1.9	150	0.0127	85	481	279	281.667	0.0225	3.78	21.38	12.40	12.52
1.95	150	0.0130	80	472	265	272.333	0.0225	3.56	20.98	11.78	12.10
2	150	0.0133	75	463	251	263.000	0.0225	3.33	20.58	11.16	11.69
2.05	150	0.0137	70	454	237	253.667	0.0225	3.11	20.18	10.53	11.27
2.1	150	0.0140	65	445	223	244.333	0.0225	2.89	19.78	9.91	10.86
2.15	150	0.0143	60	436	209	235.000	0.0225	2.67	19.38	9.29	10.44
2.2	150	0.0147	55	427	195	225.667	0.0225	2.44	18.98	8.67	10.03
2.25	150	0.0150	50	418	181	216.333	0.0225	2.22	18.58	8.04	9.61
2.3	150	0.0153	45	409	167	207.000	0.0225	2.00	18.18	7.42	9.20
2.35	150	0.0157	40	400	153	197.667	0.0225	1.78	17.78	6.80	8.79
2.4	150	0.0160	35	391	139	188.333	0.0225	1.56	17.38	6.18	8.37
2.45	150	0.0163	30	382	129	180.333	0.0225	1.33	16.98	5.73	8.01
2.5	150	0.0167	25	373	125	174.333	0.0225	1.11	16.58	5.56	7.75
2.55	150	0.0170	20	364	121	168.333	0.0225	0.89	16.18	5.38	7.48
2.6	150	0.0173	18	355	117	163.333	0.0225	0.80	15.78	5.20	7.26
2.65	150	0.0177	16	346	113	158.333	0.0225	0.71	15.38	5.02	7.04
2.7	150	0.0180	14	337	109	153.333	0.0225	0.62	14.98	4.84	6.81
2.75	150	0.0183	12	328	105	148.333	0.0225	0.53	14.58	4.67	6.59

2.8	150	0.0187	10	319	101	143.333	0.0225	0.44	14.18	4.49	6.37
2.85	150	0.0190	8	310	97	138.333	0.0225	0.36	13.78	4.31	6.15
2.9	150	0.0193	6	301	93	133.333	0.0225	0.27	13.38	4.13	5.93

APPENDIX-F .Stress - Strain Curves for Control compressive strength

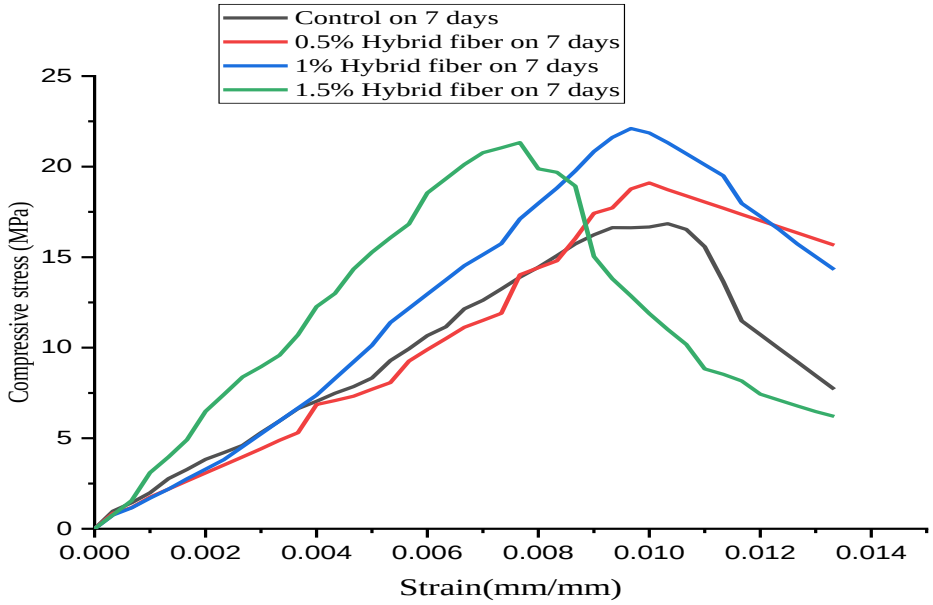

Figure 25. Stress- Strain Curve for 7th day compressive strength test

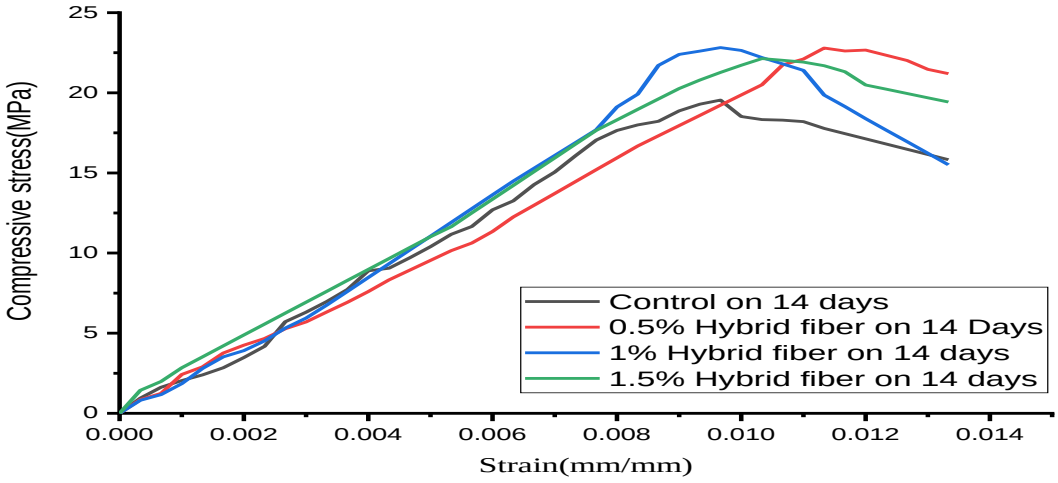

Figure 26. Stress- Strain Curve for 14 day compressive strength test

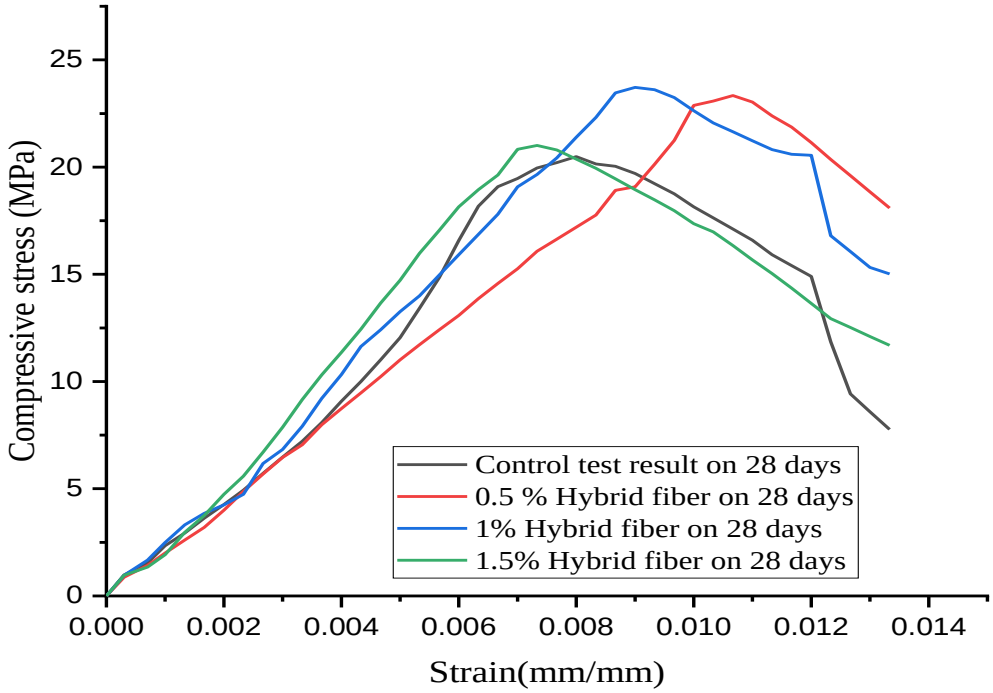

Figure 27. Stress- Strain Curve for 28th day compressive strength test