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CONCRETE PROJECTS COMPETITION 2022

EFFECT OF COCONUT FIBER ON THE MECHANICAL PROPERTIES OF CONCRETE

A project conducted on the modification of concrete using only natural fibers as reinforcement in the form of coir or coconut fibers, considering the economic aspects to reduce the cost of development and promote environment safety by utilizing coconut wastes. This project opens the path on concrete for extensive research purpose.

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PROBLEM STATEMENT

Infusion of fiber to produce Fiber Reinforced Concrete (FRC) has been a new trend these days. As FRC has more tensile strength, more durability and more fatigue strength when compared to traditional concrete or non-reinforced concrete, the phenomena of conducting research & projects on including different synthetic fibers and plastics for developing FRC have been very common. But still, there is a lack in choosing the better ones in the selection of fibers, along with the negligence of using natural fibers, that can both be far too economical & significantly environment friendly. Introducing coconut fiber to concrete is such an inclusion that solves most of the problems that were evolved during the development of other FRC’s, and this can be the latest attempt to revolutionize concrete with the features that were not obtained using other fibers or plastics. In addition, the problems of managing the coconut fiber wastes and spending a portion of the budget for it will also be solved keeping the environment as good as it is.

RESEARCH SIGNIFICANCE

The ideation for the solution of the problem as stated in the 'problem statement' requires extensive research & thus the significance of this research for the development of concrete and the preservation of environment is way too high. Coconut fibers do not need to be prepared artificially, and its collection process is pretty simple. In contrast, coconut fiber waste management takes a fair share of budget, considering the fact that the total world production of coconut was 250-300 million tons in the year 2018. Therefore, this research also involves the procedure of developing concrete with greater strength but with lower budget.

Moreover, the past research engaged with developing FRC using artificial & synthetic fibers do not come to a conclusion on their stability at elevated temperature, their use in saline soils as well as saline water, their durability during their exposure in rain, since these factors do not provide much assist to the concept of re-building FRC. Moreover, random orientation of fibers without uniformity is a factor for the concrete being poor in quality. And last but not the least, other fiber reinforced concrete costs at an average of 10-15% more than that of non-reinforced concrete.

All these factors can be evaluated, and the problems have been solved with the use of coconut fibers in concrete. Coconut fibers have several advantages, like- these fibers are locally available; their collection process is cheap & heavy; they have low thermal conductivity which allows for natural cooling; they are not as dense as concrete; they have the capability to mitigate crack development in concrete; and most importantly, they are the toughest of all the natural fibers available for FRC. Besides, coconut fibers can provide strength at the same level, even at elevated temperatures and also checks all the problems as mentioned above. For this reason, this research will create a new path for the inclusion of natural fibers in concrete to increase its strength & enhance other properties as well keeping the expenditures for the whole process low.

ABSTRACT

Concrete, as a construction material, is used extensively in structural development and construction industry. Because of its high compressive strength but a poor tensile strength, concrete is reinforced with steel. As a result, the durability of the structures as well as the overall expenditure for the entire construction gets increased. Nowadays, the cost of construction has risen dramatically on one side creating an economic impact, and on the other hand, the environment pollution has reached its peak as waste management becomes more challenging. For this reason, a more balanced approach for the development of concrete has been adopted, with the sole priority given to the environment alongside the economic impact. In this study, an attempt has been made where a natural fiber such as coconut fiber has been used to improve the strength of concrete. Coconut fiber comes from the hard shell of coconut and even after processing & softening in water, develops a stronger, tougher & more durable fibrous structure, which is better in properties than other natural fibers. The mechanical characteristics of concrete after the application of coconut fiber were observed in this investigation.

In this study, various percentages of coconut fiber (0.25 %, 0.50% and 0.75% of fiber as per volume percentage of concrete) were used to find out "Compressive strength", "Split tensile strength", "Flexure strength" and "Compressive strength of concrete cylinders previously exposed to elevated temperature". Control specimens that were developed without fiber were also investigated as a part of the research. Then mechanical properties of coconut fiber reinforced concrete were compared to plain concrete specimens (without fiber). The failure pattern of coconut fiber reinforced concrete was observed. All the test procedures were done according to the standard ASTM methods.

From the compressive strength test, it is noticeable that at lower and higher fiber quantity (measured here in percentage of weight of concrete), coconut fiber leads to an increase of compressive strength up to 0.5% indicating the peak and then decreases with the increase in fiber content. For 0.5% fiber, it shows maximum compressive strength equal to 37.72 MPa which is **more than 43 %** than that of concrete with 0% of coconut fiber. For split tensile strength, it almost follows the same trend as compressive strength test. Initially, strength increases from **2.49 MPa to 2.7 MPa for 0% to 0.25% fiber addition**, whereas tensile strength increases 4% w.r.t the concrete with 0% of fiber. At approximately 0.6% fiber content, maximum split tensile strength (2.81 MPa) can be found. Similarly, the Flexure test results indicate that the modulus of rupture of concrete increases as much as 48% higher for approximately 0.4% coconut fiber content than in comparison to non-fiber reinforced concrete that possess 0% of fiber. After exposing the specimen at 200°C, the compressive strength was measured. At lower fiber content, compressive strength reduction was more than high fiber content. **The strength is reduced to only 15% when fiber amount is increased up to 0.75% of fiber.**

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ABBREVIATIONS

CFRC = Coconut Fiber Reinforced Concrete

JFRC = Jute Fiber Reinforced Concrete

FRC = Fiber Reinforced Concrete

W.r.t = With respect to

CHAPTER-1
INTRODUCTION

1.1 General

In the context of Bangladesh, concrete is the most common and frequently utilized construction material. It is made up of cement as the primary binder, as well as additional components such fly ash and slag, aggregate, water, and chemical admixtures as needed. Cement and water combine to produce a paste that hardens and binds the particles. Concrete is frequently referred to as "man-made rock." Concrete is a flexible building material that may be used in a wide range of projects. Having high strength, fire resistance, durability, and workability are some of the reasons for its appeal. Another key factor is that concrete can be made from locally accessible resources, making it less expensive than other construction materials.

Fiber reinforced concrete (FRC) is a composite material that is made up of Portland cement, aggregate, and discrete discontinuous fibers. Plain, unreinforced concrete has a poor strain capacity and is fragile.

1.2 Historical development of Fiber Reinforced Concrete

Fibers have been used to reinforce matrices that are weak in tension for over 4500 years. Ancient civilizations used straw fibers in sun-dried mud bricks to make a composite with increased toughness, i.e., a matrix with improved crack resistance and post-cracking response. Since the widespread use of Portland cement concrete as a construction material, attempts have been made to use fibers to stop cracks. Engineers had to overcome concrete's major flaws, which included its low tensile strength and brittleness. In 1847, a French engineer (Domski and Głodkowska n.d.) proposed the addition of continuous fibers to concrete in the form of wires or wire meshes.

Before the 1960s (Zollo 1997), the development of fiber reinforcement for concrete was extremely slow. Until then, some papers had described the basic concept of using fibers for reinforcement in concrete mixes, but no application had been found. Nonetheless, in the early 1950s, research on glass fibers was carried out in the United States, the United Kingdom, and Russia. Glass fibers were not only being researched in Russia, but they were also being used in the construction industry. This type of fiber, however, had been found to be vulnerable to alkaline attacks. The Portland Cement Association (PCA) began researching fiber reinforcement in the late 1950s.

The goal of incorporating fibers into the concrete matrix was to create a composite with increased compressive and tensile strength. When the results of the earliest developments in this field are examined, it can be seen that neither the compressive nor tensile strengths have increased in any significant way. At the time, researchers found it difficult to emphasize the actual benefits of fiber reinforcement.

The concept of energy absorption (or fracture toughness) was introduced later, during the modern development of FRC in the late 1970s and early 1980s, when testing equipment and analysis procedures became more quantitative and qualitatively better. The toughness of materials could be measured using this concept. The major advantage of FRC was discovered at that time, and it was none other than its exceptional ability to absorb large amounts of energy when compared to Ordinary Portland Cement Concrete. Even after more than three decades of research in this field, the primary advantage of FRC remains its high fracture toughness. Further research with various types of fibers and admixtures, on the other hand, is aimed at developing a composite with increased tensile and compressive strengths, as well as fracture toughness. High-performance fiber reinforced concrete is the name given to these FRC composites (HPFRC).

The historical development of fiber reinforced concrete is shown in below:

1. BC Horsehair
2. Uses of straw to reinforce mud bricks (By Egyptians)
3. 1900 -asbestos fiber to reinforce clay posts
4. 1920 -Griffith, theoretical vs. apparent strength
5. 1950 -Composite materials
6. 1960 -FRC
7. 1970 New initiative for asbestos cement replacement
8. 1970 SFRC, GFRC, PPFRC, Shotcrete
9. 1990 micromechanics, hybrid systems, wood-based fiber systems manufacturing techniques, secondary reinforcement, HSC ductility issues
10. 2000+ Structural applications, Code integration, new products.

1.3 Basic information of fiber reinforced concrete

The FRC can carry significant stresses over a relatively large strain capacity in the post-cracking stage if the fibers are sufficiently strong and bonded to the material (Johnston 1974). Short discrete fibers act as rigid inclusions in the concrete matrix when the fiber reinforcement is in the form of short discrete fibers. The fibers' main contribution is to increase the concrete's toughness. The area under a load-deflection (or stress-strain) curve is referred to as toughness.

When the ultimate flexural strength of plain concrete is exceeded, it fails suddenly. Fiber reinforced concrete, on the other hand, can withstand significant loads even at deflections far greater than the fracture deflection of plain concrete. Fiber-reinforced concrete can withstand loads at much higher deflections or strains than those at which matrix cracking first appears.

The presence of fibers in the concrete body or the provision of a tensile skin of fiber concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection, and other serviceability conditions due to the inherent material properties of fiber concrete.

Fig 1.1: Fiber reinforced Concrete

1.4 Areas of Application of FRC materials

Fiber reinforced concrete is ideally suited for concrete applications that require protection from plastic and drying shrinkage, improved durability, increased service life and reduced construction costs. Fiber reinforced concrete can be used for a variety of applications shown below.

- Thin Sheets (Dixit P S 2016)
- Shingles
- Roof Tiles
- Pipes
- Prefabricated Shapes
- Panels
- Shotcrete
- Curtain wall
- Slabs on Grade
- Precast Elements
- Composite Decks
- Aircraft Parking and pavement
- Impact Resisting Structures
- Dams
- Runway
- Vaults, Safes
- Hydraulic Structures
- Roller compacted concrete with steel fibers
- Sleepers
- Tunnel linings

It has been a technological challenge in both developing and developed countries to design low-cost, long-lasting fiber reinforced cement concrete. Steel, carbon, polymers, glass, and natural fibers are among the fibers currently in use. Carbon fibers in cement composites have been limited to a marketable level due to their non-ecological performance due to cost considerations. Natural fibers have the potential to be used as reinforcement in cementitious materials to combat innate scarcities, deflection, and other serviceability issues.

Jute, akwara, sisal, bamboo, sugarcane bagasse, and coconut husk are all used as reinforcing fibers in cement composites, which are typically used in building materials. This study is focused on fiber-reinforced concrete, specifically coconut as a fiber reinforcing material in concrete. The use of natural fibers in a relatively brittle cement matrix resulted in a composite with significant toughness and strength. For such fibers to achieve durability in a highly alkaline cement matrix, effective modifications must be made. It is preferable to use a chemical composition that can both transform the fiber surface and reinforce the cement composite.

Many projects are currently underway to investigate FRC technologies. The experimental assessment of flexural and compressive strengths of Coconut Fiber-Reinforced Concrete is the subject of this thesis (CFRC). The goal of the study was to look into the rheological and mechanical properties of CFRC with various jute fiber contents. Compression tests were used to determine the CFRC's compressive strength, and bending tests were used to determine its flexural strength. Finally, based on the test results and analysis, conclusions and recommendations have been drawn.

1.5 Objectives of the study

- To find out the “Compressive strength”, “Split Tensile Strength”,” Flexure strength” and “Compressive strength at elevated temperature” of Coconut Fiber Reinforced Concrete (CFRC).
- To compare the different types of strengths between plain concrete and fiber reinforced concrete with or without the addition of coconut fiber.
- To analysis the cracking pattern of Coconut Fiber Reinforced Concrete (CFRC).
- To understand the effectiveness of coconut fiber on the mechanical properties of reinforced concrete.
- To determine the optimum percentage of coconut fiber.

1.6 Research methodology

The experiment's framework has been established with detailed checklists corresponding to the milestone activities in order to achieve the objectives. In order to assess previous works in the area of the research works and to gather information about test specimen preparation, testing methods, and results analysis, a literature survey was conducted.

Then, on a simply supported beam specimen made from concrete mix with various coconut fiber contents, center-point bending tests were performed. On cylindrical specimens corresponding to the mixes used for each compressive strength at room temperature, compressive strength at elevated temperature and splitting tensile tests were also performed.

Following the completion of the tests, observations and analysis of the results were carried out in order to determine the flexural, splitting tensile, and compressive strengths, as well as the relationship between various parameters. Finally, based on the findings of the analysis, conclusions and recommendations have been drawn. The focus of this project study is on the impact of coconut fiber reinforcement on concrete compressive, splitting tensile, and flexural strengths. These compressive, splitting tensile, and flexural strengths are assessed and analyzed on cylinders and beam specimens.

Furthermore, the research is focused on a specific type of natural fiber, namely coconut fiber. As a result, the wide range of morphological and chemical properties among natural fibers may have an impact on the generality of the study's conclusions and recommendations. The project deals with general insights into Coconut Fiber Reinforced Concrete (CFRC) design considerations because the study only focuses on a few aspects of the design parameters.

CHAPTER-2
LITERATURE REVIEW

2.1 General

Plain concrete is strong in compression but not in tension, and it has the drawback of being brittle. Since the late 1960s (Dixit P S 2016), there has been an increase in the use of fiber reinforced concrete (FRC) to overcome these shortcomings. Steel reinforcing bars are commonly used to reinforce regular concrete. Reinforcing concrete with a small amount of randomly distributed fibers is becoming increasingly popular in many applications. Their main goal is to improve the materials' energy absorption capacity and toughness, as well as the tensile and flexural strengths of concrete. They also reduce the permeability of concrete, resulting in a reduction in water flow (Kamran et al, 2013). Concrete with certain types of fibers has higher impact, abrasion, and shatter resistance (Kamran et al, 2013). Typically, fibers do not increase the flexural strength of concrete.

Many structural parts are now reinforced with steel fibers as a partial or complete replacement for conventional reinforcement to minimize construction time and labor costs (Minelli and Plizzari 2009). Fiber reinforced concrete can withstand significant stresses during the post-cracking stage because the fibers are bonded to the material. However, in order to understand the mechanism of fiber reinforced concrete better and gain a better understanding of the mechanical behavior and constitutive properties of concrete, this study will include a detailed examination of the mechanical behavior of jute fiber reinforced concrete.

Based on the literature review, a summary of fiber reinforced concrete, cement, coarse aggregate, and fine aggregate is provided in this chapter. This review was conducted to gain a better understanding of current knowledge of fiber reinforced concrete (ACI 554 IR 82) in terms of coarse aggregate, sand, and cement properties, as well as their compositions, benefits, and drawbacks. (Daniel et al. n.d.)

2.2 Definition of Fiber Reinforced Concrete

Fiber-reinforced concrete, often known as FRC, is a kind of concrete that contains fibrous material to improve structural strength (Yuhazri et al. 2020). It is made up of short discrete fibers that are evenly dispersed and orientated randomly. Steel fibers, glass fibers, synthetic fibers, and natural fibers are all types of fibers that give concrete different qualities (Gugelot and White 1950). In addition, different concretes, fiber types, geometries, distribution, orientation, and densities modify the nature of fiber-reinforced concrete.

The post cracking behavior of concrete containing fibers has significantly improved (Kosior-Kazberuk et al. 2018). Although the ultimate tensile strengths of fiber-reinforced concrete do not improve significantly, the tensile stresses at rupture do. Fiber reinforced concrete is significantly harder and more impact resistant than normal concrete (Yoo and Banthia 2019). Fibers are often used to regulate concrete cracking and affect the behavior of components once the concrete matrix has fractured, rather than to increase concrete strength. This is accomplished by bridging over fractures as they open, and fibers give the FRC with post-cracking ductility.

2.3 Different investigations and experiments on Coconut Fiber Reinforced Concrete (CFRC)

- The utility of fiber reinforced concrete in various civil engineering applications was investigated by (Reddy n.d.). Steel fiber, natural fibers, and synthetic fibers are all types of fibers that give concrete different qualities. The fibrous substance boosts structural integrity, according to the study. This research compelled us to use natural fibers, which are abundant and inexpensive.
- A person (Reddy n.d.) investigated the feasibility of employing coconut-fiber ropes as vertical reinforcement in low-cost building without mortar in earthquake-prone areas. Rope anchoring is accomplished by inserting the rope in the foundation and top tie-beams. The link between the rope and the concrete is critical to the structure's stability, and the rope's tensile strength is also discovered to be rather strong. To avoid the building collapsing, the rope tension created by earthquake loading should be less than both the pull-out force and the rope tensile load. According to the findings, the pull-out energy increases as

the embedment length, rope diameter, cement, and fiber content in the matrix increase.

- Using non-woven coir mesh matting, (Reddy n.d.) investigated fiber volume fraction by surface treatment with a wetting agent for coir mesh reinforced mortar. They conducted a four-point bending test and found that cementitious composites reinforced by three layers of coir mesh with a low fiber content of 1.8 percent improved flexural strength by 40 percent when compared to standard concrete. Flexural toughness was found to be 25 times stronger and flexural ductility was found to be roughly 20 times greater in the composites. The sole study work on static CFRC characteristics that the authors are aware of is a test done on concrete reinforced with 4 cm long coir fibers. There hasn't been any research done on the dynamic properties of CFRC yet. Only concrete reinforced with other fibers, such as polyolefin fibers or rubber debris, had been subjected to dynamic tests. In order to arrive at accurate findings about the effect of fiber length on CFRC characteristics, more fiber lengths and other parameters must be investigated thoroughly. Understanding the static and dynamic properties of CFRC is critical to comprehending the potential of such concrete in low-cost housing in earthquake-prone areas. However, the scale of the problem necessitates thorough research. To eliminate shrinkage cracks, CFRC blocks are utilized as pavement materials in parking spaces. We chose coconut fiber reinforced concrete because of the great crack resistance it provides.
- A researcher (Tom 2015) investigated the flexural strength, fracture toughness, and fracture energy of concrete reinforced with coconut, sugarcane bagasse, and banana fibers using third-point loading tests. The study found that coconut fiber reinforced concrete had the highest fracture, toughness, and energy when compared to other natural fibers, with a 25 percent improvement in flexural strength. Because of the advantages of coconut fiber over other natural fibers, we decided to employ it as a reinforcement material in our project.
- After 28 days of hydration, (Tom 2015) the physical property was measured (density, moisture content, water absorption, and thickness swelling) and mechanical (modulus of elasticity, modulus of rupture, and internal bond) properties of coir-based light weight cement board. JIS A 5908-1994 was used to measure the physical and mechanical properties, while JIS R 2618 was used to measure the thermal properties. Fiber length, coir pre-treatment, and mixture

ratio were the variables investigated. Among the tested specimens, 5 cm long boiled and washed fibers with the optimum cement: fiber: water weight ratio of 2:1:2 had the highest modulus of rupture and internal bond. The board's thermal conductivity was also lower than that of other commercial flake board composites. These papers influenced us to choose a 5cm fiber length after cleaning the fiber to remove the coir dust.

- A researcher (Reddy n.d.) investigated the effects of 1%, 2%, 3%, and 5% at fiber lengths of 2.5, 5, and 7.5 cm on the properties of concrete. The properties of plain cement concrete were used as a reference for proper analysis. The damping of CFRC beams was found to increase as the fiber content increased. CFRC with a fiber length of 5 cm and a fiber content of 5% was found to produce the best results. The optimum percentage of coconut fiber added in this study was 5%, which led us to use 4 percent, 5 percent, and 6 percent coconut fiber by weight of cement in our research.

2.4 Characteristics of fiber reinforced concrete

The following characteristics are observed for fiber reinforced concrete-

- Distributed throughout a cross section (Wang et al. 2021)
- Relatively short and closely spaced
- Generally, not possible to achieve the same area of reinforcement with fibers as with steel bars.
- In FRC, crack density is increased, but the crack size is decreased.
- The failure mechanism is by pull-out.
- Fibers slow down the propagation of cracks.
- Concrete mixtures containing fibers possess very low consistencies; however, the peaceability and compatibility of concrete is much better than reflected by the low consistency.
- Toughness of material can be increased (15-30%).
- Creep results don’t show much difference.
- Drying shrinkage show some difference.

2.5 Several parameters related to fiber reinforced concrete

1. Aspect ratio (Vallittu 2015): Fiber length/equivalent fiber diameter, where the equivalent diameter is the diameter of a circle having the same cross-sectional area as the fiber. For workability reason, this ratio ranges from 50 to 150.

2. Critical length. (Luz et al. 2018)l_c**:** Length above which the fiber will fracture rather than pull out when a crack intersects the fiber at its midpoint. $l_c = (\sigma_{fu} * r)/\tau_{fu}$, where σ_{fu} is the ultimate fiber strength, r is the radius and τ_{fu} is the maximum frictional shear stress .The effects of fiber length o shear stress transfer and l_c are shown in figure.

3. Fiber efficiency factor: Efficiency with which randomly oriented fibers can carry a tensile force in any one direction. The range of this factor is usually 0.2 to 1

4. Spacing Factor: If the fibers are close to enough together, the first cracking strength of the composite is higher than that of the matrix alone because the fibers effectively the stress intensity factor at the crack tip which controls fracture. A typical expression for the average fiber-fiber spacing for cylindrical fiber is $S = (Kd)/V_f^{1/2}$, where S is the fiber spacing , d is the diameter of the fiber and V_f is the fiber volume content .

5. First crack strength: The stress corresponding to the load at which the load versus deflection curve of the FRC first exhibits a significant nonlinearity.

2.6 Fiber matrix bond

The mechanical behavior (Gray 1986) of a composite system like FRC is determined not only by the properties of the fibers and cementitious systems, but also by the bonding between them. Because there may be chemical reactions between the cement and some types of fibers, the nature of the fiber—cement interface is particularly complicated. Also, as the cement matures or undergoes time-dependent volume changes, the nature of the interface may change. Generally, the particulate nature of the fresh concrete mix leads to the formation of water-filled spaces around the fibers, due to 1. bleeding of water around the fibers and 2. inefficient packing of the about 10 μm (0.4×10^{-3} in.) cement grains in the zone out to about 50 μm (2.0×10^{-3} in.) from the fiber surface. Hence, close to the fiber surface, the matrix is more porous than it is in the "bulk" cement paste. This is shown schematically in Figure and is typical for monofilament fibers. For "bundled" fibers, where the reinforcing unit consists of a bundle of closely spaced filaments (as in glass fiber reinforced concretes), the cement grains may be unable to penetrate the spaces between the individual filaments. In such mate-rials, the outer filaments may be well bonded to the matrix, but the inner filaments will not be. For properly designed FRC mixtures, the primary mode of failure is by fiber pull-out, since this consumes much more energy than is involved in breaking the fibers and leads to much better utilization of the fibers.

For diverse types of fibers, the general form of the connection is well established. There is a mixture of adhesion, friction, and mechanical interlock in steel fibers. There is also a chemical reaction between the cement and the glass for glass fibers; in particular, alkali attack weakens the fiber reinforcement, though to a lesser extent with AR glasses. Mechanical interlock is principally responsible for the binding between organic fibers. De-forming fibers along their lengths or at their ends to boost fiber—matrix binding strength is now widespread practice.

Large gains in bond strength do not translate to equivalent increases in FRC strength, but they do enhance post-cracking behavior. Table 22.2 demonstrates typical pullout strengths in various matrices for a variety of fibers.

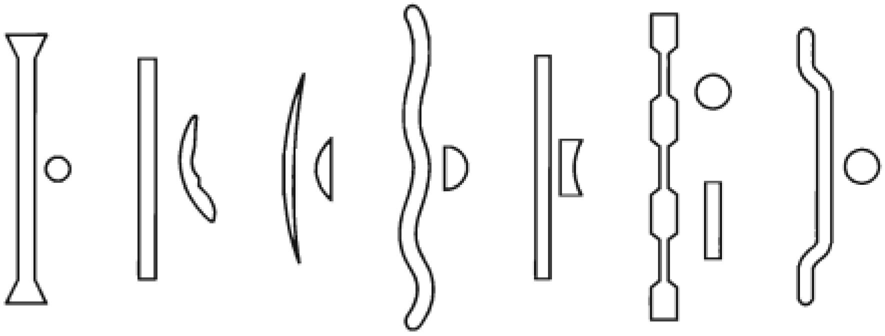

Fig 2.1: Typical cross sections of commonly available steel fiber

Table 2.1: Typical Fiber matrix pullout matrix strength (Naaman et al. 1991)

Matrix	Fiber	Pullout strength	
		MPa	lb /in^2
Cement paste	Asbestos	0.8-3.2	115-460
	Glass	6.4-10	930-1450
	Polycrystalline Alumina	5.6-13.6	810-1970
Mortar concrete	Steel	6.8-8.3	990-1200
	Steel	5.4	780
	Steel	3.6	520
	Nylon	4.2	610
	polypropylene	0.14	20
		1	150

2.7 Mechanics of fiber reinforced concrete

As previously stated, the primary function of fibers is to bridge cracks(Rao and Rao n.d.) that form in the matrix (Koker and Zijl 1310)when the composite's strain exceeds the brittle matrix's ultimate strain capacity. Fig 2.3 depicts a typical stress-strain curve for FRC with minimal fiber volume (less than 1%). The stress at which the matrix begins to crack (initial crack strength) is represented by 1 Point A. This is usually around the same stress that causes cracking in normal concrete, therefore the segment OA for both plain and fiber reinforced concrete is practically the same.

As a result, the fiber has minimal effect on the FRC's strength, but it considerably improves the post-peak toughness and load bearing capacity. The fibers may boost the strength of the FRC over the matrix in the post-cracking zone by transmitting loads across the cracks. They improve toughness by offering an energy absorption mechanism that involves the slow debonding and pulling out of the fibers that bridge the cracks. The stress field surrounding a developing crack in FRC is seen schematically in Figure 2.4. A traction free zone exists when the crack is large enough for all of the fibers to pull out; a fiber bridging zone exists when stress is transferred by frictional slip of the fibers; and a microcracked matrix process zone exists when enough aggregate interlock exists to transfer stress within the matrix itself.

The fiber stress is far lower than the yield stress in the first branch of the descending branch of the stress-strain curve, hence there is no yielding of the fibers. If the fibers are long enough to maintain their relationship, however, they may eventually collapse by yielding or breaking at high strains towards the curve's tail.

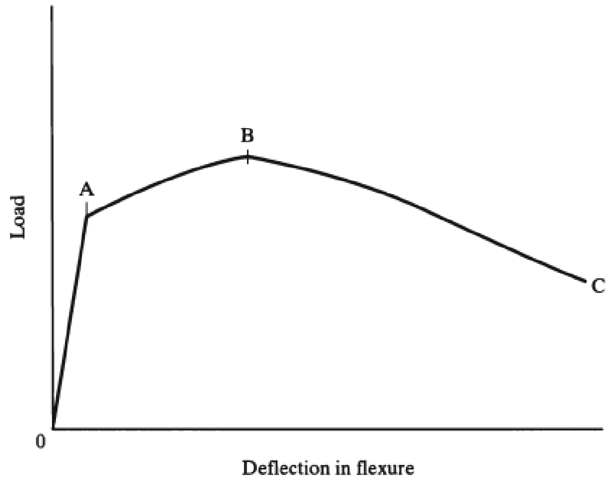

Fig 2.2: Typical load -deflection curve for FRC for flexure(Hossain et al. 2012)

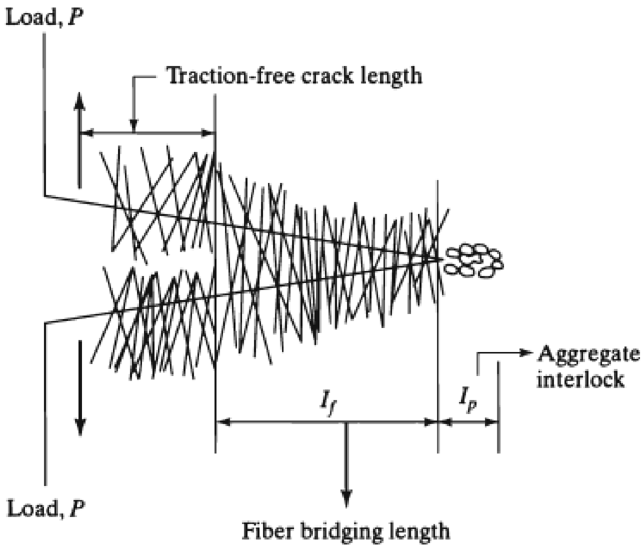

Fig 2.3: Schematic representation of fibers bridging across a crack(Kamat et al. 2004)

2.8 Mechanical properties of the fiber reinforced concrete

2.8.1 Compressive strength

Polymer fibers had a distinct impact on the characteristics of concrete, according to a study (Myers et al. 2008). Polymer fibers improved concrete behavior and boosted compression strength at a young age. Polymer fibers had a minor long-term influence since their strength and drying shrinkage were not significantly affected by their addition. However, it was discovered that the fibers come back into play after cracking, lowering crack widths and increasing ductility.

In another study (Balaguru and Khajuria 1996), polymeric fibers were used to test both standard and lightweight concrete. The inclusion of fibers did not have a significant long-term effect on compressive strengths. There was no significant difference in unit weight between the control mix and fiber reinforced concrete prepared with varying fiber contents.

The compressive strength of concretes containing fibers was found to be somewhat higher or lower than plain concretes (under 10%) after evaluating a variety of aggregates and mixes with polypropylene fibers (Aulia 2002). It suggests that the usage of 0.2 percent polypropylene fibers alone, rather than the affects raised by the other concrete elements, contributed to the low influences on such concrete qualities. Essentially, there was no difference between the compressive strength with and without fibers.

In a study, an unusual tendency was discovered (Soroushian et al. 1992). The compressive strength fell dramatically as more fibers were added. The plain concrete had a strength of around 6700 psi, while the average strength with fibers dropped to about 5200 psi at a 0.1 percent by volume dose with increased dosage rates. It's worth noting that when Soroushian and colleagues added fibers, they also included a little amount of superplasticizer.

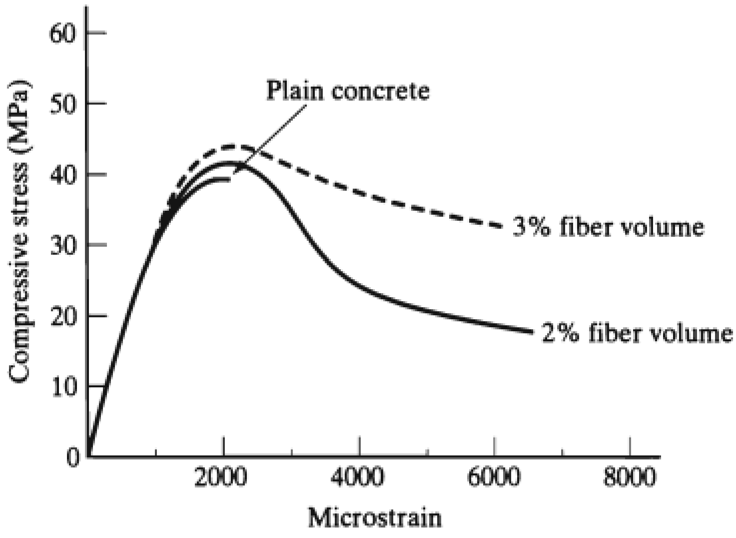

Fig 2.4: Stress-Strain deformation in compression of steel fiber(Bencardino et al. 2008)

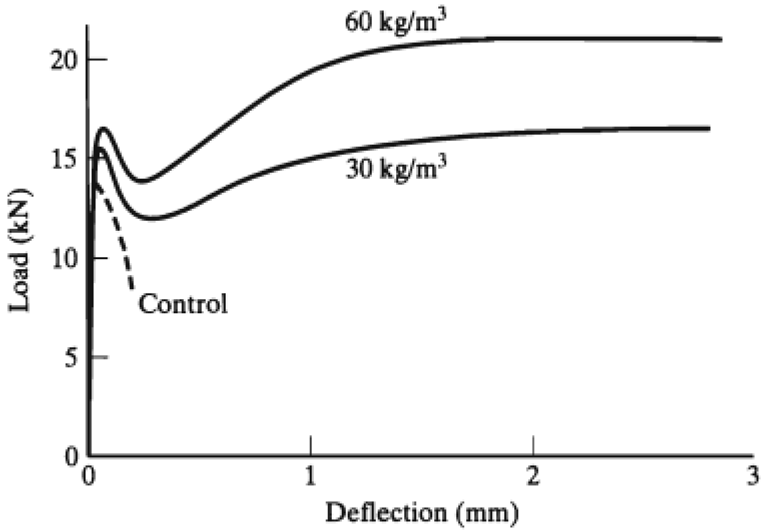

Fig 2.5: Influence of fiber content on load deflection curve(Dyer et al. 2004)

2.8.2 Toughness

The enhancement in flexural toughness (total energy absorbed in breaking a specimen in flexure) is the most significant benefit of fiber reinforcing in concrete. The region under a load-deflection (or stress-strain) curve is referred to as toughness. The addition of fibers to concrete considerably improves the material's durability (Minelli and Plizzari 2009). The fibers' primary function is to bridge cracks that form in concrete when it is loaded (or as it dries). In the post-cracking (or grain-softening) stage, if the fibers have sufficient strength and stiffness, and if they can obtain sufficient bond with the matrix, they will tend to keep the fracture width small and allow the FRC to bear significant stresses over a reasonably high strain capacity. As a result, the fibers can provide a significant amount of "ductility" after cracking.

While fiber additions have little influence on concrete strength, they have a huge impact on toughness (ix., on the area under the load-deflection curves under all types of loading). The post-cracking (descending) sections of the curves are virtually entirely where toughness increases. Toughness is increased by any increase in fiber volume, independent of fiber type. In this sense, however, some fibers are more successful than others. Deformed fibers, for example, which have a stronger bond with the matrix, will be more effective than smooth fibers of the same substance, which are more likely to pull out of the matrix. Fig 2.2 also shows that steel fibers (because to their increased rigidity) are more effective in this regard than polypropylene fibers.

It's important to remember that pulling a fiber out of the matrix takes a lot more energy than just breaking it: to get the most out of the fibers, they should be engineered to fail by pulling out of the matrix at loads as near as feasible to those required to break them. This is influenced by fiber type as well as fiber geometry (length, surface deformation, fiber profile). There is currently a lot of effort being put into optimizing fiber qualities so that FRC may be "tailor-made" for any application.

2.8.3 Tensile strength

When fibers bridging cracks have a tensile strength greater than that of the concrete, the ultimate tensile strength is obtained after cracking, when the fibers alone provide the strength. However, this has no effect on the mixture's cracking strength. Ductility has obviously risen significantly.

The splitting tensile strength of lightweight concrete with polymer fibers was also investigated in a prior study (Balaguru and Khajuria 1996). The splitting tensile strength of fiber reinforced specimens was generally higher. At 28 days, the strengths were not significantly different, though they were marginally greater at 7 days. The increases, however, were not large. The fiber reinforced specimens kept together even after the test, but the plain concrete specimens separated into two pieces.

Another study (Aydın 2013) discovered that fiber strength considerably enhanced the splitting tensile strength of steel fiber reinforced high strength concrete. The use of high strength fibers improved the mechanical characteristics and fracture behavior of high strength concrete by reducing the number of broken fibers and increasing the debonding process.

2.9 Different types of fiber

2.9.1 Glass fiber

Glass fibers (Kizilkanat et al. 2015) are made by drawing molten glass filaments through the bottom of a heated platinum tank or bushing in the shape of filaments. Typically, 204 strands are drawn at the same time. Chopped strands and continuous roving's of glass fibers are both available. Ordinary borosilicate glass fibers (E-glass) and soda-lime glass fibers (A-glass) are not suited for use in concrete since they will quickly lose strength due to the extremely alkaline environment. This has resulted in the development of alkali resistant (AR) glass fibers containing between 16 and 20% Zirconia (ZrO2). Glass fibers of this type are employed in thin sheet components like architectural panels. Elaborate work has been done in the past (Singh and Kumar 2014) on the effect of glass fiber on the strength of concrete.

Fig 2.6: Glass fiber **Fig 2.7:** steel fiber

2.9.2 Steel fiber

Steel fiber can be made by cutting wire, shearing sheets, or extracting it from a heated mold. Steel fibers were initially smooth, but it was quickly discovered that they lacked sufficient bonding with the cementitious matrix. To improve the cement-fiber bond, modern steel fibers(Song and Hwang 2004) are usually bent along their lengths or at their ends. When exposed to the concrete surface, they will corrode clearly.

Within the concrete mass, they appear to be extremely resilient. Stainless steel fibers may be required in specific circumstances, such as high-temperature refractory applications.

2.9.3 Synthetic fiber

These fibers are synthetic fibers that are the outcome of petrochemical and textile industry research and development (Hasan et al. n.d.). Currently, two types of fiber volumes are employed in applications: low volume percentage (0.1-0.3 percent by volume) and high-volume percentage (0.1-0.3 percent by volume) (0.8-0.8 percent by volume). Acrylic, Aramid, carbon, nylon, polyester, polyethylene, and polypropylene are some of the fiber types that have been attempted in cement concrete matrices.

Fig 2.8: Nylon fiber

Fig 2.9: Synthetic fiber

2.9.4 Nylon fiber

Nylon is a generic term that refers to a group of polymers. The basic polymer type, addition of various quantities of additive, production conditions, and fiber diameters all influence the qualities of nylon fiber. Only two varieties of nylon fiber are now available for use in concrete. Nylon is heat-resistant, hydrophilic, inert, and resistant to a wide range of materials. Nylon is particularly good at imparting impact resistance and flexural toughness to concrete, as well as sustaining and enhancing its load carrying capacity after a first crack.

2.9.5 Polyester fiber

Polyester monofilament fibers belong to the thermoplastic polyester group and are accessible in monofilament form. They are temperature sensitive, and their properties may be altered if they are exposed to temperatures over usual operating temperatures. Polyester fibers have a hydrophobic property. Polyester fibers(Rostami et al. 2020) have been utilized to reduce plastic-shrinkage cracking in concrete at low concentrations (0.1 percent by volume).

2.9.6 Polyethylene fiber

Polyethylene monofilament with wart-like surface deformations has been created for concrete (Ahmed et al. 2007). Asbestos fibers could be replaced with polyethylene pulp. Up to the first crack, concrete reinforced with polyethylene fibers at contents of 2 to 4% by volume exhibits linear flexural load deflection, followed by an apparent transfer of load to the fibers, allowing an increase in load until the fibers break.

Natural fiber:

There are different types of natural fiber that are used in fiber reinforced concrete. These are given below-

- Coconut fiber
- Jute fiber
- Banana fiber
- Bamboo fiber
- Sisal fiber
- Kenaf fiber
- Elephant grass
- Sugar cane bagasse

2.9.7 Jute fiber

Jute fibers are removed from the stem's ribbon. Plants are gathered by cutting them close to the ground using a sickle-shaped knife. The little fibers, measuring 5 mm, are made by retting in water, stripping, beating, and drying the fiber from the core. A single jute fiber is a three-dimensional composite made up primarily of lignin, cellulose, and hemicelluloses, with tiny amounts of protein, extractives, and inorganic materials. After millions of years of evolution, these fibers were created to perform in a moist environment in nature.

2.9.8 Banana fiber

Banana fiber is a strong natural fiber that may easily be blended with cotton or other synthetic fibers to create blended fabrics and textiles (Elbehiry et al. 2020). Banana Fiber is also used in high-quality security/currency paper, agricultural produce packing material, ships towing ropes, and wet drilling cables, among other things.

2.9.9 Bamboo fiber

Bamboo fiber is a cellulosic fiber that has been regenerated from bamboo. It has a feel that is like a combination of cashmere and silk and is softer than cotton. It offers significantly greater moisture absorption and ventilation (Dewi et al. 2017) because the cross-section of the fiber is packed with numerous micro-gaps and micro-holes.

2.9.10 Sisal fiber

Agave sisalana is the agave from which sisal fiber is made. It is desired for cordage because of its strength, durability, stretchability, affinity for particular dyestuffs, and resistance to deterioration in saltwater, similar to coir (Okeola et al. 2018). For the carpet industry, the higher-grade fiber is processed into yarns.

Fig 2.10: Jute fiber

Fig 2.11: Banana fiber

Fig 2.12: Bamboo fiber

Fig 2.13: Sisal fiber

CHAPTER-3
MATERIALS

3.1 General

In this chapter, materials used, and their characteristics have been discussed. The materials used in this experiment are coarse aggregate, fine aggregate, cement, and coconut fiber.

3.2 Coarse aggregate

The size of coarse aggregate was mixing of 19 mm downgrade and 8 mm downgrade (well graded).

The coarse aggregate was collected from a local market .

Fig 3.1: Coarse aggregate

3.3 Fine aggregate

The fineness modulus of the fine aggregate used in this study was 2.7 and the gradation was well-graded.

The Sylhet sand was used in this experiment.

Fig 3.2: Fine aggregate

4.4 Cement:

Ordinary Portland cement (Bengal Cement) was used in this experiment.

Fig 3.3: Cement

Coarse aggregate and fine aggregate properties are given below:

Table 3.1: Aggregate property

Properties	CA	FA
Apparent Specific Gravity, Sa	2.68	2.69
Bulk Specific Gravity (O-D basis), Sd	2.64	2.55
Bulk Specific Gravity (SSD basis), Ss	2.67	2.65
Absorption Capacity (D) in %	-	1.12%
Unit weight (kg/m^3)	1500	1600
FM for Fine aggregate	-	2.7

3.5 Coconut fiber:

Coconut fiber is one of the natural fibers abundantly available in tropical regions and is extracted from the husk of coconut fruit. Coconut fibers reinforced composites have been used as cheap and durable nonstructural elements.

Coconut fiber is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fiber is Coir, Cocos nucifera and Arecaceae (Palm), respectively.

Brown coconut fiber is derived from mature coconuts, while white coconut fiber is extracted from immature coconuts. Brown fibers are thick, robust, and resistant to abrasion. White fibers are finer and smoother, but they are also weaker. Coconut fibers are a type of fiber found in coconuts. Bristle (long fibers), mattress, and commercial are the three types of commercially available (relatively short) and embellished (mixed fibers). Depending on the type of fiber, it can be used for a variety of purposes. Based on the demand, Brown fibers are commonly utilized in engineering.

Fig 3.4: Brown fiber- matured coconut

Fig 3.5: White fiber – immature coconut

Coconut fibers have several general benefits, including being moth-proof, resistant to fungi and rot, providing excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, springing back to shape even after constant use, being totally static free, and being easy to clean.

Fig 3.6: Coconut fiber sample

The following Table 3.2 and Table 3.3 shows physical property and composition of coconut fiber.

Table 3.2: Coconut fiber physical property (Ali 2011)

Density	800 kg / m^3
Modulus of Elasticity	4-6 GPa
Tensile Strength	175 MPa
Elongation to failure	30 %
Water Absorption	130-180 %

Table 3.3: Chemical composition of coconut fiber(Ali 2011)

Hemi-Cellulose (%)	Cellulose (%)	Lignin (%)	Reference
31.1[a]	33.2[a]	20.5[a]	Ramkrishna,et al.(2005)
15-28[b]	35-60[b]	20-48[b]	Agopyan,et al (2005)
16.8	68.9	32.1	Asasujarit.et al (2007)
-	43	45	Satyanarayana,et al (1990)
0.15-0.25	36-43	41-45	Corradini,et al (2006)

a =The compositions are % by weight of dry and powdered fiber sample

b = Chemical compositions are % by mass and author took other researcher's data

CHAPTER-4
METHODOLOGY

4.1 General

The major goal of this study was to see how the varying percentages of coconut fiber could affect the effect of variance in concrete mixes. A thorough methodology will aid in understanding the underlying principles and methods of the tests that must be carried out. This chapter explains the experimental setup and test procedures required to complete the current research's test regime. For low-rise buildings in many countries, including Bangladesh, no specific mix design is used. People rely on masons instead of consulting a civil engineer, and they utilize a standard ratio-based mix (nominal mix). As a result, such a design cannot provide precise strength. The proportions of materials in a concrete mix are commonly expressed in terms of parts or ratios of cement, fine and coarse aggregates. The proportions are measured in either volume or mass. In most cases, the water-cement ratio is stated in mass.

4.2 Mix design: The mix design of concrete has been carried out as per ACI Mix Design Method.

- Cement- OPC
- W / C ratio - 0.45
- Mix ratio - 1: 1.5: 3
- Fine aggregate – 2.7
- Coarse aggregate –Well graded (19 mm downgraded and 8 mm downgraded mixed)

4.3 Test specimen design

Total **36 cylinders** and **12 prismatic beams** were prepared for this experiment.

Table 4.1: Sample specimen distribution

Test type		Fiber content				Total
	Curing Days	0%	0.25%	0.50%	0.75 %	
			25mm	25 mm	25mm	
Compressive strength test	28 days	3	3	3	3	12 - Cylinder
Elevated Temperature test	28 days	3	3	3	3	12 - Cylinder
Flexure test	28 days	3	3	3	3	12- Prismatic beam
Split tensile test	28 days	3	3	3	3	12 - Cylinder

Table 4.2: Size of cylinder and beam mold

Flexure test	Beam	75 mm X 75 mm X 275 mm
Compressive strength test at room temperature	Cylinder	Dia-100mm X Height 200 mm
Split tensile strength test	Cylinder	Dia-100mm X Height 200 mm
Compressive strength test at elevated temperature	Cylinder	Dia-100mm X Height 200 mm

Test Type	cement (1440 kg/m3) Kg	Sand (1600 kg/m3) Kg	Coarse Aggregate (1500Kg/m3) Kg
Compressive at room temperature	10.364	17.273	32.387
Compressive at Elevated temperature	10.364	17.273	32.387
Flexure	10.200	17.000	31.876
Tensile	10.364	17.273	32.387
Total	41.292	68.819	129.037

The following Table 4.3 shows what amount of materials was needed during the performance of test.

Table 4.3: Total amount of materials

4.4 Sample preparation

The samples were prepared utilizing two distinct types of molds after the proper mixing of coconut fiber of different percentages (cylindrical & prismatic beam).

The samples were then prepared for four distinct types of tests after a proper 28-day cure in lime water (compressive strength at room temperature test, splitting tensile test, compressive strength at elevated temperature test & flexural strength test).

All of the procedures were carried out in the order specified in the test specification

4.4.1 Coconut fiber collection and preparation

Coconut fiber was collected from a local market.

This is the Coconut Fiber that are found from the brown colored matured Coconut Husk.

Fig 4.1: Brown coconut fiber

After collecting the coconut fiber, the fiber is extracted from husk by manually.

Then 1 inch or 25 mm length of these fibers were cut for this experiment.

Fig 4.2: 1” or 25 mm coconut fiber

4.4.2 Fiber amount calculation

The formula that is used to calculate the fiber amount is given below-

$$\% \text{ of fiber} = (M_f / \rho_f) / (M_c / \rho_c) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.1$$

Where,

M_f = Mass of the fiber

P_f = Density of the fiber (Assume = 800 kg /m3)

M_c = Mass of concrete

ρ_c = Density of concrete (2400 Kg/ m3)

For this experiment, the % of fiber is 0.25% , 0.50% and 0.75 % of the concrete.

When the % of fiber is known, the mass of the fiber will be found using above equation.

Table 4.4: Fiber amount for 0.25 % fiber

<table>
<tr><td>% Fiber</td><td>0.25%</td><td rowspan="7">Fiber (gm) = 50 gm</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Fiber unit weight (kg/m3)</td><td>800</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Concrete unit weight (kg/m3)</td><td>2400</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Concrete mass (kg)</td><td>60.024</td></tr>
</table>

Table 4.5: Fiber amount for 0.50 % fiber

% Fiber	0.50%	Fiber (gm) = 100 gm
Fiber unit weight (kg/m3)	800	
Concrete unit weight (kg/m3)	2400	
Concrete mass (kg)	60.024	

Table 4.6: Fiber amount for 0.75 % fiber

% Fiber	0.75%	Fiber (gm) = 150 gm
Fiber unit weight (kg/m3)	800	
Concrete unit weight (kg/m3)	2400	
Concrete mass (kg)	60.024	

Before using these fibers in mixer machine, these fibers were kept in saturated condition.

Fig 4.3: Coconut fiber in wet condition (Saturated)

4.4.3 Mold preparation

Before inserting fresh concrete into these specimens, the cylindrical and rectangular molds are carefully prepared. Before casting concrete specimens, the molds are greased on the inside.

Fig 4.4: Mold Tighting

Fig 4.5: Mold Lubricating

4.4.4 Concrete mixing

A concrete mixer (often colloquially called a cement mixer) homogeneously combines cement, aggregate such as sand or gravel, and water to form concrete. A typical concrete mixer uses a revolving drum to mix the components. After collecting all materials, casting procedures were started.

Fig 4.6: Concrete mixer machine

Fig 4.7: Fresh concrete

4.4.5 Slump measurement

After mixing all the ingredients, the value of slump was measured.

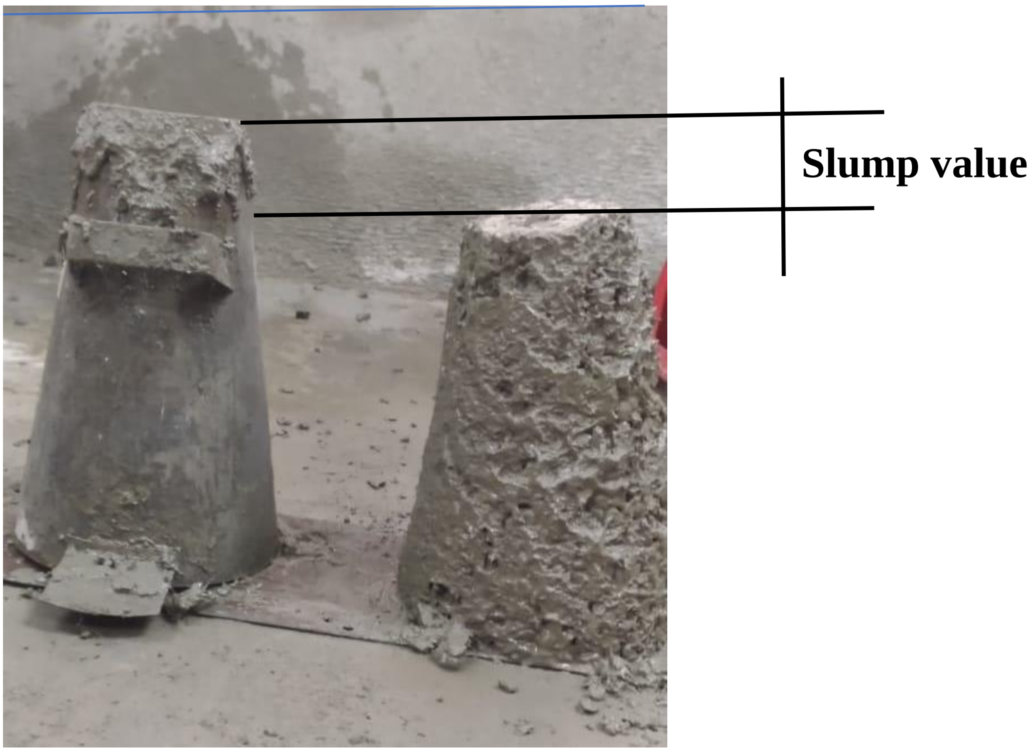

Fig 4.8: Slum test

% Fiber	Slump Value
0	4”
0.25	1”
0.50	1.5”
0.75	1.75”

Table 4.7: Slump value of different % of fiber

4.4.6 Concrete casting in mold

Casting in Cylinder for compressive strength, split tensile and elevated temperature.

Casting in beam mold for flexure test.

Fig 4.9: Concrete casting in mold

4.4.7 Concrete compaction: Compaction is the process of releasing trapped air from freshly laid concrete and compacting the aggregate particles to enhance the density of the concrete. It improves the bond between concrete and reinforcement and raises the ultimate strength of the concrete. When concrete is poured, it may contain hundreds or even thousands of air bubbles, weakening the concrete structure significantly. Concrete vibrators remove air bubbles from freshly poured concrete by vigorously shaking it.

Fig 4.10: Compaction of concrete using vibrator

4.4.8 Concrete curing: Concrete curing maintains enough moisture in concrete within a right temperature range to help cement hydration at early stages. Hydration indicates the chemical reaction between cement and water that results in the formation of various chemicals contributing to setting and hardening.

Fig 4.11: Concrete curing in lime water

4.5 Test procedure for hard concrete

Four types of tests are conducted for evaluating hardened concrete properties. The usual test for assessing concrete compressive strength was performed first. Following that, split tensile, elevated temperature and flexural strength tests were conducted. The following is a detailed description of each test type's testing procedure.

4.5.1 Compressive strength test at room temperature

For the compressive strength test, a cylindrical specimen with a diameter of 4 inches (100 mm) and a height of 8 inches (200 mm) was used. The test was carried out according to ASTM's standard test procedure (Designation: C 39/C 39M – 03). The test entailed applying a compressive axial force on molded cylinders or cores at a rate that stayed within a set range until failure.

The cured specimen was tested soon after it was taken from wet condition of damp storage to confirm that the compressive strength determined was for the specimen's moist condition. Prior to testing the specimen, it was verified that the load indicator was set to zero. Load was applied continuously and without shock once the specimen was placed in the testing equipment. The load was applied until the specimen failed, and the maximum load borne by the specimen was recorded during the test. The sort of failure and the concrete's appearance were also recorded.

The specimen's compressive strength was determined by dividing the greatest force borne by the specimen during the test by the specimen's average cross-sectional area. There was no need for a correction factor because the specimen length to diameter ratio (8/4=2) was greater than 1.75.

Fig 4.12: Sample specimen for compressive strength

To find the compressive strength, the below equation is used-

$$C = P/ (\pi * d^2/4) \quad \ldots\ldots 4.2$$

Where ,

C = compressive strength, psi [MPa],

P = maximum applied load indicated by the testing machine, lbf [N],

d = diameter, in. [mm].

Fig 4.13: Compression strength test machine **Fig 4.14:** Sample on testing machine

4.5.2 Split tensile test

The splitting tensile strength test used the same specimen as the compressive strength test (Diameter-100 mm and height-200 mm). The test was carried out according to the ASTM standard test procedure (Designation: C 496/C 496M – 04). This test technique entails applying a diametral compressive force along the length of a cylindrical concrete specimen at a pace that stays within a specified range until failure occurs.

This load application on the plane typically induces tensile stresses, with relatively large compressive stresses in the area immediately around the applied load, and tensile failure is more prevalent than compressive failure.

To begin the test, diametral lines were drawn on each end of the specimen to confirm that both ends were in the same axial plane. The specimen was then placed in the testing machine with its center aligned with the center of the testing machine's lower bearing block. The load was then applied at a steady rate indefinitely. At the point of failure, the maximum applied load given by the testing equipment was recorded. The sort of failure and the concrete's appearance were also recorded.

The splitting tensile strength of the specimen was calculated by following equation-

$$T = 2*p / (\pi*l*d) \quad \text{......} 4.3$$

Where,

T = splitting tensile strength, psi [MPa],

P = maximum applied load indicated by the testing machine, lbf [N],

l = length in [m]

d = diameter, in. [mm].

Fig 4.15: Sample specimen for split tensile

Fig 4.16: Split tensile strength testing machine **Fig 4.17:** Sample on testing machine

4.5.3 Flexure strength test

The flexural strength testing specimen was a basic beam with dimensions of 75mm*75mm*225mm. The test was carried out in accordance with ASTM's standard test method (Designation: ASTM C78). The modulus of rupture was calculated and provided as a result. Because surface drying of the specimen might result in a reduction in the observed flexural strength, the cured specimens were tested soon after being removed from moist storage. The load was then applied to the specimen in a continuous and shock-free manner. In flexure tests of concrete specimens, the third point loading method was utilized, which assured that forces applied to the beam were perpendicular to the specimen's face and applied without eccentricity. After testing, measurements across one of the shattered faces were taken to determine the dimensions of the specimen cross section for use in determining modulus of rupture. One measurement was taken at each edge and one at the cross-section’s center for each dimension. The average width and depth were calculated using the three measurements taken in each direction. All dimensions were rounded to the nearest 0.05 inch.

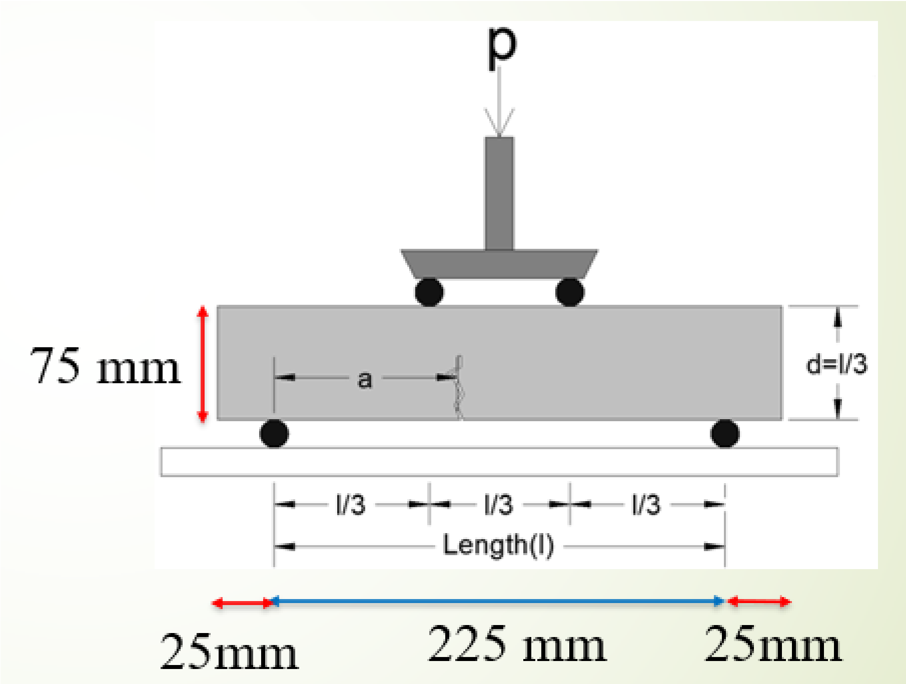

Fig 4.18: Sample specimen for flexure test.

Fig 4.19: Universal testing machine for flexure **Fig 4.20:** Sample on testing machine

The formula that is used to find out modulus of rupture is given below-

$$R = 3*p*a / (b*d^2) \quad \ldots\ldots 4.4$$

Where,

R = modulus of rupture, psi, or MPa,

P = maximum applied load indicated by

the testing machine, lbf, or N,

a = average distance between line of fracture

and the nearest support measured on the
tension surface of the beam, in., (or mm).

b = average width of specimen, in., or mm, at the fracture

d = average depth of specimen, in., or mm, at the fracture.

4.5.4 Compressive strength test at Elevated temperature

Fire outbreaks in our cities frequently. When concrete is exposed in high temperature, strength decreases and bonding between aggregate and cement also decreases. In this experiment, I have tried to show how amount of strength is reduced when sample specimens were heated to a particular temperature during a certain period. For this experiment, twelve samples were prepared whose size was dia-100 mm and height-200 mm.

This experiment is like the compressive strength test.

- Heating Temperature - 200°C
- Duration - 2 Hours
- After heating the specimen at that temperature,

The sample was tested in compressive strength machine for finding compressive strength. This strength will be compared to normal temperature compressive strength.

CHAPTER-5
RESULTS AND DISCUSSIONS

5.1 General

In this chapter, the outcomes that can be found from the experiment are discussed. Four kinds of tests were conducted, and all the findings are thoroughly presented in this chapter. The results include compressive strength test, split tensile test, flexure test and compressive strength at elevated temperature.

5.2 Fiber percentage effect

There is no specific change of pattern of strength for various % of fiber. Specific concrete strength criteria, on the other hand, show some tendencies. For example, varied fiber percentages can cause changes in compressive strength, and an effective fiber dose for higher compressive strength can be established, however this optimum fiber dose may not result in better split tensile or flexural strength.

5.3 Compressive strength at room temperature

Twelve Cylinders were tested for this experiment which size was Dia-100mm and Heigh- 200 mm. For each percentage of fiber, three specimens were tested, and average value is shown in Table 5.1. At a water cement ratio of 0.45, coconut fiber reinforced concrete was added to concrete in various proportions (0.25%, 0.50% and 0.75% of weight of concrete). The results of compressive strength are shown in Table 5.1 and graphically Fig 5.1.

Table 5.1: Compressive strength of CFRC at 28 days

% of fiber	Compressive strength (MPa)	Comparison w.r.t 0% fiber
0	26.38	0
0.25	36.24	37
0.5	37.72	43
0.75	35.35	34

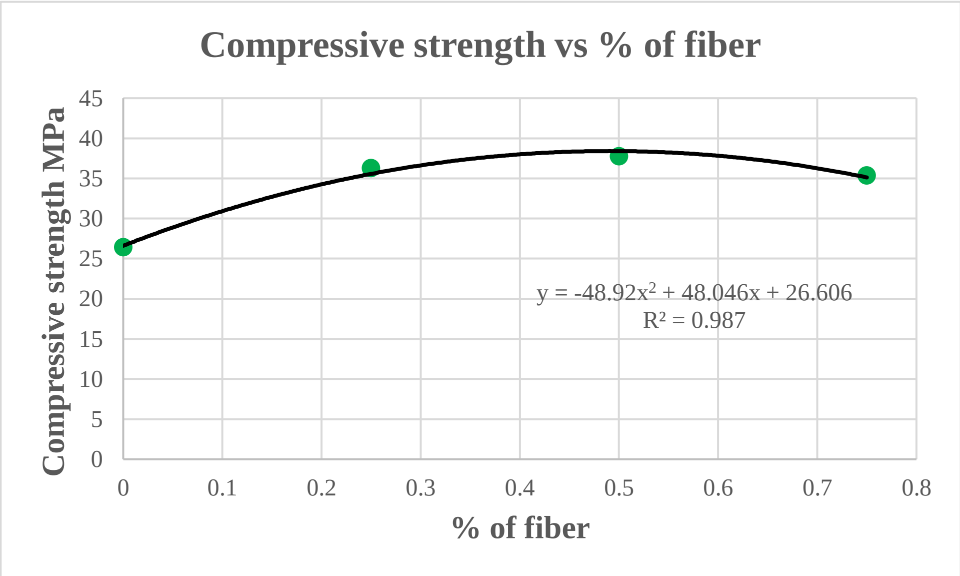

Fig 5.1: Compressive strength of CFRC vs % of fiber

When there is no fiber in concrete, the compressive strength is 26.38 MPa. After that addition of fiber, the strength increases. At 0.25% fiber, the strength increases 37% w.r.t 0% of fiber. For 0.5% fiber, it shows maximum compressive strength 37.72 MPa which is more than 43 % of 0% of fiber. Then, any additional percentage of fiber decreases the strength. The optimum percentage of fiber is 0.5 %.

5.3.1 Failure pattern of CFRC for compressive strength at room temperature

Without fiber, the lower part of sample was largely damaged.

 

Fig 5.2: Without fiber (Compressive strength test)

After addition of fiber in sample, the aggregate did to get separation due to bond between fiber and aggregate.

 

Fig 5.3: With fiber (Compressive strength test)

% of fiber	Compressive strength of CFRC (MPa)	Compressive strength of JFRC(Nishat 2018) (MPa)
0	26.38	15.07
0.25	36.24	20.68
0.5	37.72	9.7
0.75	35.35	6.06

The following Table 5.2 and Fig 5.4 shows comparison of compressive strength between CFRC and JFRC at 28 days.

Table 5.2: Compressive strength of CFRC and JFRC at 28 days

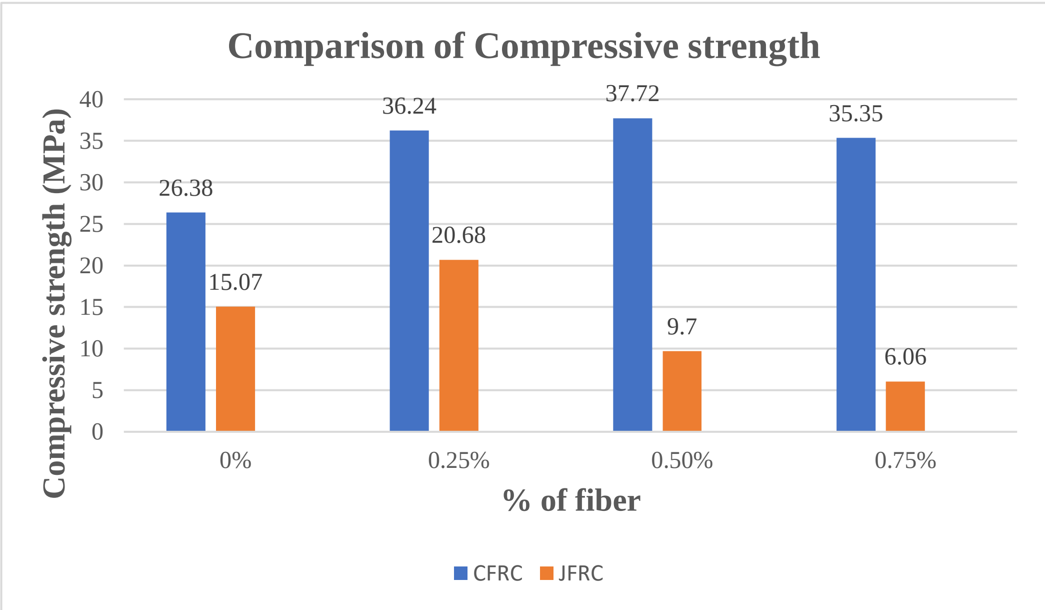

Fig 5.4: Comparison of compressive strength between CFRC and JFRC

5.4 Split tensile strength

Twelve Cylinders were tested for this experiment which size was Dia-100mm and Height- 200 mm. For each percentage of fiber, three specimens were tested, and average value is shown in Table 5.3. At a water cement ratio of 0.45, coconut fiber reinforced concrete was added to concrete in various proportions (0.25%, 0.50% and 0.75% of weight of concrete). The results of tensile strength are shown in Table 5.3 and graphically Fig 5.5.

Table 5.3: Split tensile strength of CFRC at 28 days

% of fiber	Split tensile strength (MPa)	Comparison w.r.t 0% of fiber
0	2.52	0
0.25	2.62	4
0.5	2.88	14
0.75	2.77	10

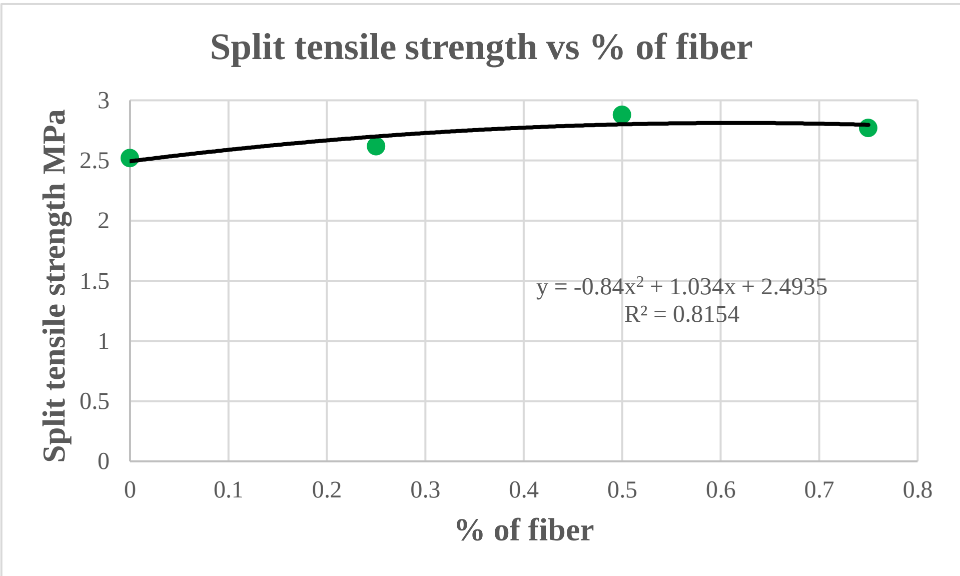

Fig 5.5: Split tensile strength of CFRC vs % of fiber

Like the compressive strength, split tensile strength followed the same trend. Initially, strength increases from 2.49 MPa to 2.7 MPa for 0% to 0.25% fiber where tensile strength increases 4% w.r.t 0% of fiber. At 0.6% fiber, maximum strength (2.81 MPa) can be found. Then strength decreases when extra fiber amount is added. The optimum % of fiber 0.6%

5.4.1 Failure pattern of CFRC for split tensile strength

The samples that were tested for tensile strength without fiber, they broke into two parts.

Fig 5.6: Without fiber (Split tensile strength)

With fiber, columnar vertical cracking was observed. Addition of the fiber holds together concrete.

Fig 5.7: With fiber (Split tensile strength)

ACI code suggests an empirical formula that may be used for determining split tensile strength. The formula is given below:

Split tensile strength, f_{ct} = 6 to 8 * $\sqrt{f'c}$ psi

Where f'_c = compressive strength

Table 5.4: Split tensile strength comparison between test result and empirical formula

% of fiber	From test strength (MPa)	From empirical formula (MPa)
0	2.52	2.99
0.25	2.62	3.50
0.5	2.88	3.57
0.75	2.77	3.46

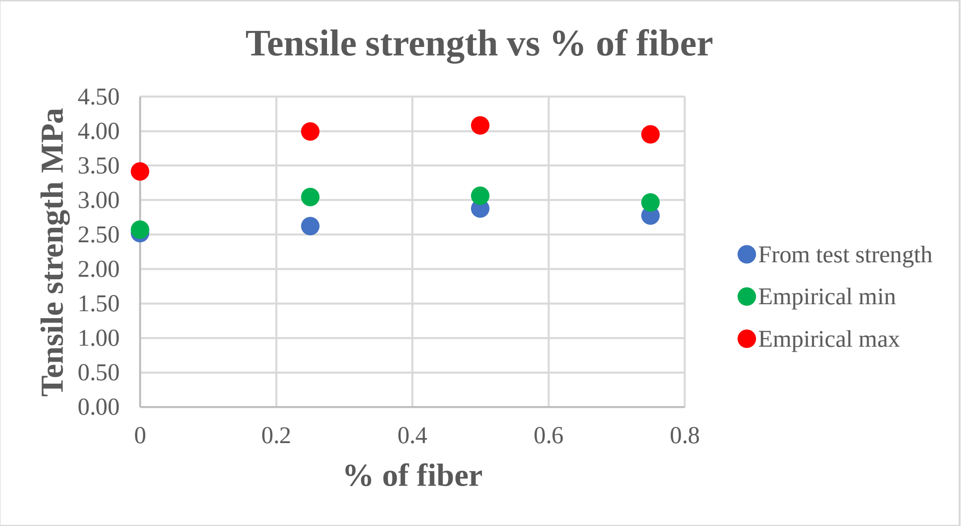

Fig 5.8: Split tensile strength comparison between test result and empirical formula

We get the value from the empirical formula gives higher value than from test experiment. The empirical formula that is suggested by ACI will not be used for split tensile strength.

% of fiber	Split tensile strength of CFRC (MPa)	Split tensile strength of JFRC(Nishat 2018) (MPa)
0	2.52	2.21
0.25	2.62	2.38
0.5	2.88	1.78
0.75	2.77	1.4

The following Table 5.5 and Fig 5.9 shows comparison of split tensile strength between CFRC and JFRC at 28 days.

Table 5.5: Split tensile strength of CFRC and JFRC at 28 days

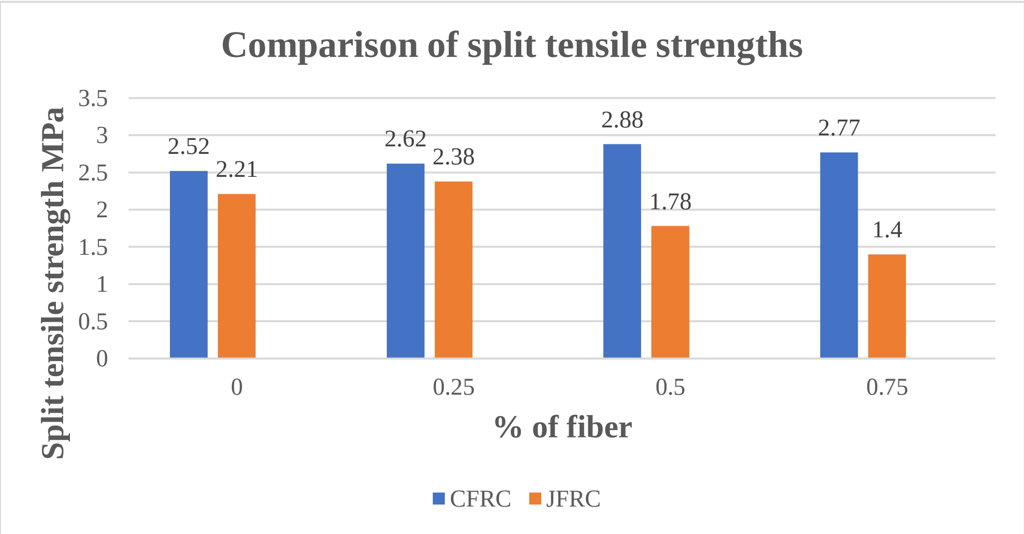

Fig 5.9: Comparison of tensile strengths between CFRC and JFRC

5.5 Flexure strength

Twelve beams were tested for this experiment which size was 75 mm X 75 mm X 225 mm. For each percentage of fiber, three specimens were tested, and average value is shown in Table 5.6. At a water cement ratio of 0.45, coconut fiber reinforced concrete was added to concrete in various proportions (0.25%, 0.50% and 0.75% of weight of concrete). The results of tensile strength are shown in Table 5.6 and graphically Fig 5.10.

Table 5.6: Flexure strength of CFRC at 28 days

% of fiber	Flexure strength (MPa)	Comparison w.r.t 0% fiber
0	5.31	0
0.25	8.3	56
0.5	6.89	30
0.75	6.28	18

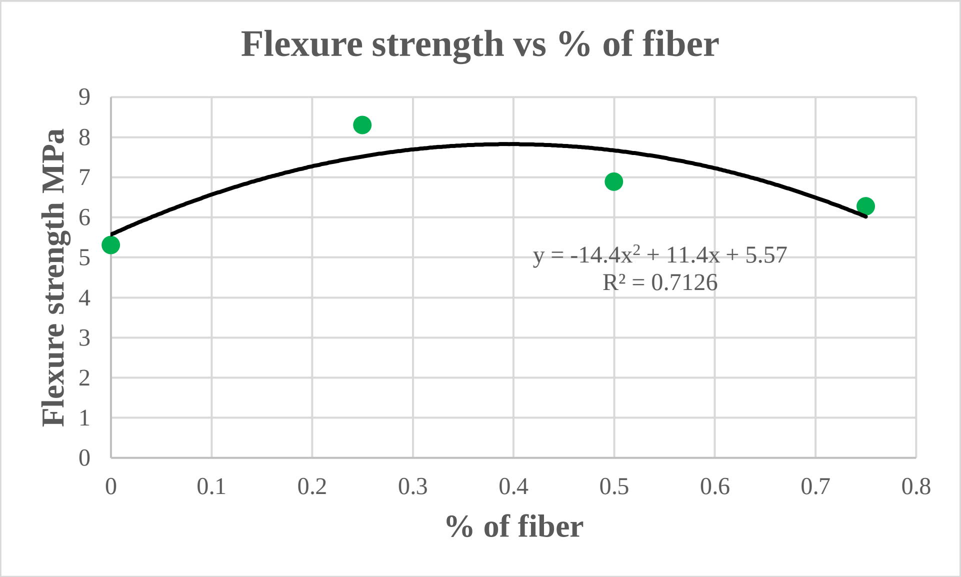

Fig 5.10: Flexure strength of CFRC vs % of fiber

From the Figure 5.10 it can be shown that initially strength increases when fiber is added. At 0.25% fiber, strength is gained 56% more of 0% of fiber. Maximum strength is found 7.83 MPa at 0.4% fiber. However, when the fiber content is increased beyond this value a downward slope of the graph is observed. So, the optimum fiber percentage is 0.4 %.

5.5.1 Flexure test of CFRC Failure pattern

Without fiber, the beam sample broke into two parts. The sample did not show significant deflection without fiber and broke suddenly.

Fig 5.11: Without fiber

After the addition of the fiber, fiber bridging mechanism was observed. As a result, the sample did to get separation due to bonding of fiber. There was a significant amount of deflection before failure.

Fig 5.12: With fiber

ACI code suggests an empirical formula that may be used for determining flexure strength. The formula is given below:

Flexure strength, f_r = 8 to 12 * $\sqrt{f'c}$ psi

Where f'_c = compressive strength

Table 5.7: Flexure strength comparison between test result and empirical formula

% of fiber	From test strength (MPa)	From empirical formula (MPa)
0	5.31	4.27
0.25	8.3	5.00
0.5	6.89	5.10
0.75	6.28	4.94

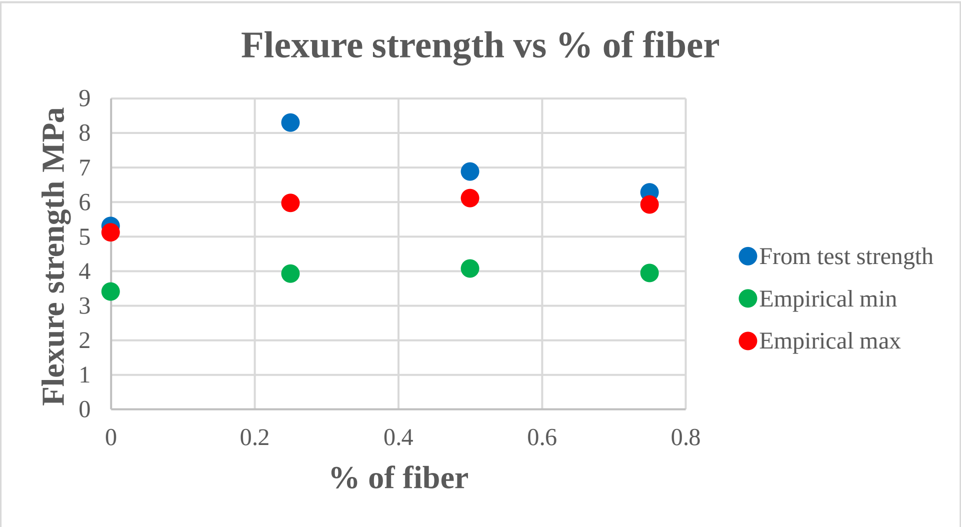

Fig 5.13: Flexure strength comparison between test result and empirical formula

Flexure strength from empirical formula gives lower value than the result of test experiment. From the empirical formula we get conservative value. The formula that is suggested by ACI may be used for flexure strength test.

The following Table 5.8 and Fig 5.14 shows comparison of flexure strength of CRFC and JFRC at 28 days.

Table 5.8: Flexure strength of CFRC and JFRC at 28 days

% of fiber	Flexure strength of CFRC (MPa)	Flexure strength of JFRC (Nishat 2018)(MPa)
0	5.31	3.72
0.25	8.3	3.36
0.5	6.89	1.71
0.75	6.28	1.47

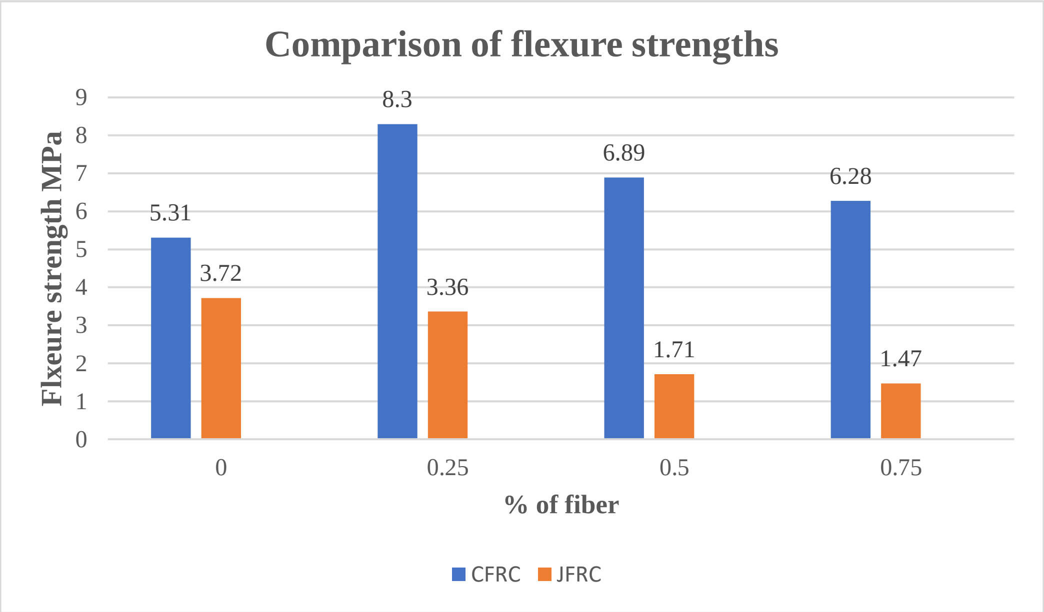

Fig 5.14: Comparison of flexure strengths between CFRC and JFRC

5.6 Compressive strength at elevated temperature

Twelve-cylinder samples were tested whose size was dia-100mm and height-200mm for determining the compressive strength at 200°C for 2 hours duration. At a water cement ratio of 0.45, coconut fiber was added to concrete in various proportions (0.25%, 0.50% and 0.75% of weight of concrete). The results of tensile strength are shown in Table 5.9 and graphically Fig 5.15.

Table 5 9: Compressive strength of CFRC at 28 days, 200°C (2 hours)

% Of fiber	Compressive strength (MPa)	Comparison w.r.t 0% fiber
0	41.96	0
0.25	33.15	-21
0.5	34.3	-18
0.75	35.8	-15

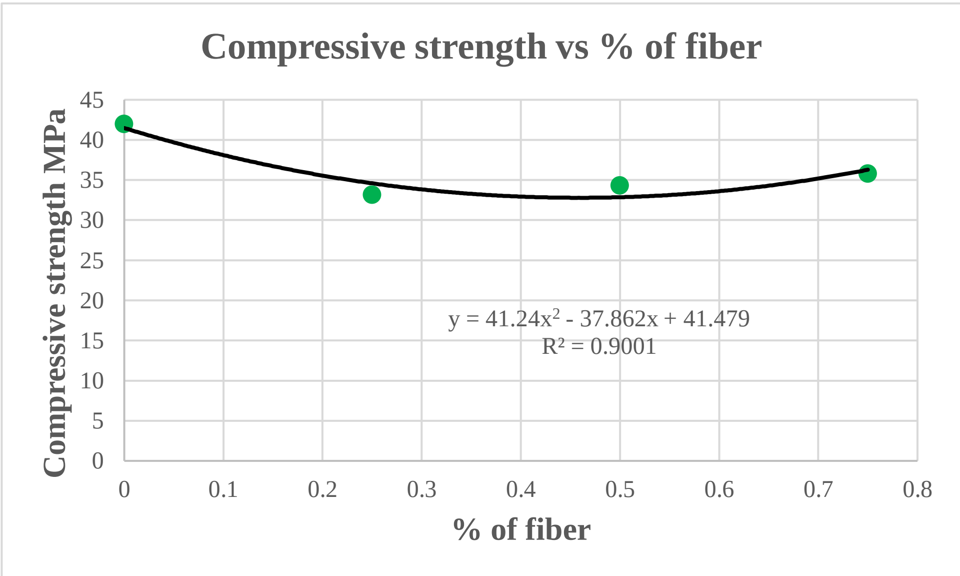

Fig 5.15: Compressive strength at 200°C (2 hours) vs % of fiber

At 0.25 % of fiber, compressive strength is reduced to 21 % w.r.t 0% of fiber. When fiber percentage is increased, less strength reduction is observed comparing to 0.25% of fiber. 15% strength reduction is found when fiber amount is increased up to 0.75% of fiber.

5.6.1 Failure pattern of CFRC for compressive strength at 200°C

Without fiber, there was a great damage at lower part of sample when test was done.

Fig 5.16: 0 % fiber (Compressive strength failure pattern) at 200°C

At 0.25% fiber, little portion of sample was broken as fiber holds together concrete

Fig 5. 17: 0.25 % fiber (Compressive strength failure pattern) at 200°C

When fiber is added up to 0.5%, there was a slight damage in the sample.

Fig 5.18: 0.5% fiber (Compressive strength failure pattern) at 200°C

After increasing fiber percentage to 0.75%, large damage occurred in the sample.

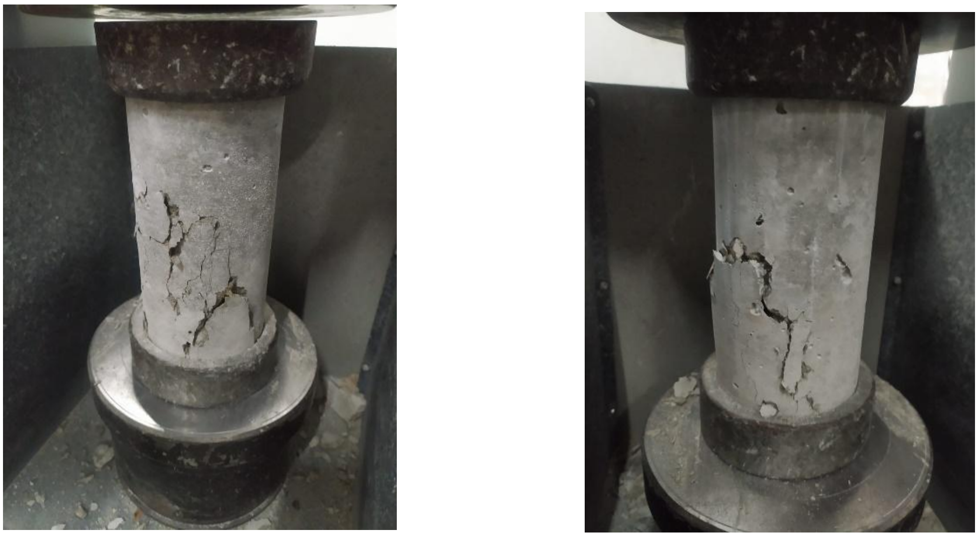

Fig 5.19: 0.75% fiber (Compressive strength failure pattern) at 200°C

The following Table 5.10 and Fig5.20 shows the comparison of Compressive strength at room temperature and 200°C (2 hours)

Table 5.10: Compressive strength at room temperature and 200°C (2 hours)

% of fiber	Compressive strength at room temperature (MPa)	Compressive strength at 200°C (MPa)
0.25	36.24	33.15
0.5	37.72	34.3
0.75	35.35	35.8

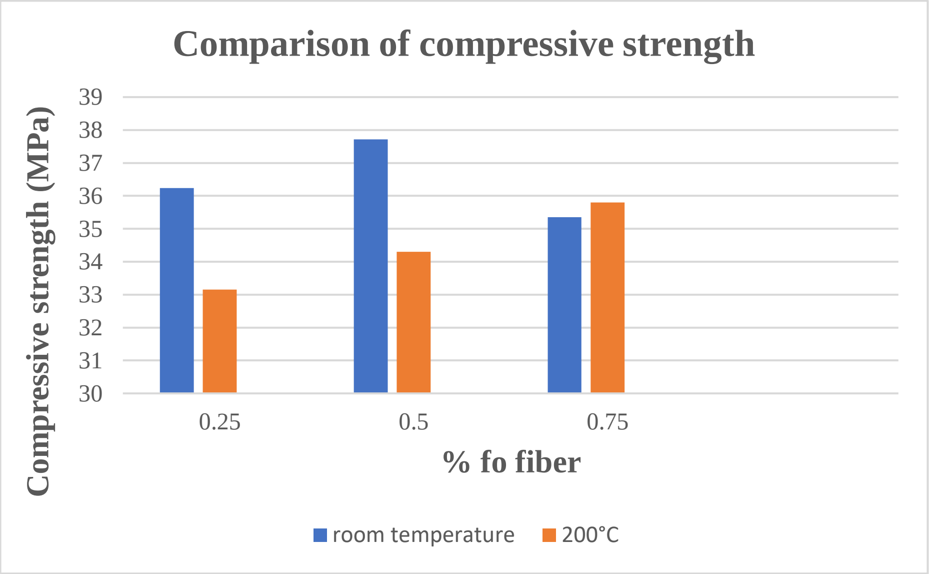

Fig 5.20: Comparison of Compressive strengths between room temperature and 200°C (2 hours)

CHAPTER-6
CONCLUSIONS & RECOMMENDATIONS

6.1 General

The conclusions that can be found from the test experiments are discussed below.

6.2 Findings of the experiments

In this section, the findings of this study have been summarized -

- Beyond 0.5% fiber, any further addition of the fiber reduces the compressive strength at room temperature. The maximum compressive strength 37.72 MPa at 0.5% fiber which is 43% higher w.r.t 0% of fiber. The optimum dose of fiber for compressive strength test is 0.5%.
- With the increase amount of fiber (up to 0.6%), tensile strength firstly increased and obtain the maximum value, after that tensile strength starts to fall slowly. The maximum value for 0.6% fiber is 2.81MPa which is 12% more than 0% of fiber. The optimum percentage of fiber for tensile strength is 0.6%.
- From 0% fiber to 0.25% fiber, there is an increment of flexure strength. After 0.25% of fiber, the increment of flexure strength continues. The maximum flexure strength is 7.83 MPa for 0.4% fiber which is 47% higher w.r.t 0% of fiber. The optimum percentage of fiber is 0.4%.
- Compressive strength test at 200°C is 41.96 MPa without fiber. When fiber is added to the concrete (up to 0.25 %) and as a result strength reduction is noticed from 41.96 MPa to 33.15 MPa (21% strength reduction w.r.t 0% of fiber). Then extra fiber is added (up to 0.50%) and strength is increased from 33.15 MPa to 34.30 MPa (18% strength reduction w.r.t 0% of fiber). For 0.75% fiber, the strength is 35.80 MPa which is more than 0.25% and 0.50% of fiber (15% strength reduction w.r.t 0% of fiber). Strength loss is less due to having more fiber % than previous fiber as more fiber absorbs more heat.

6.3 Limitations of the study

1) Available data and references were used to determine the mechanical properties of coconut fiber, which can vary depending on the type of coconut fiber.

2) Throughout the experiment, accurate length that was used in experiment might not be maintained properly.

3) The gradation of coarse aggregate and fine aggregate may differ from the expectation.

4) Due to the addition of the fiber, the samples were not so smooth like plain concrete. As a result, the measurement may differ.

5) Due to lack of proper instrument, the deflection for bending test measurement was taken manually.

5) The water that was used for curing process may be polluted by dust materials or any other due to the open exposure of curing process.

6.4 Recommendations

1) The impact of coconut fibers on high-strength concrete should be explored, allowing CFRC to be used in industrial and commercial projects.

2) Corrosion study for CFRC should be tested.

3) This study should be done by varying fiber length and water cement ratio and strengths should be compared.

4) Not only does it enhance strength, but it may also be cost effective when used adequately in construction.

5) Due to having good insulation property, CFRC can improve the thermal property of concrete. This may be effective for tropical country because it maintains the room temperature within comfort level.

6) The presence of coconut fiber gives concrete a great ductility, thereby preventing fragile collapse.

7) Admixtures may be used for better workability of concrete.

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APPENDIX

Sample calculation:

Fiber amount calculation:

The formula that is used to calculate the fiber amount is given below-

% of fiber = $(M_f / \rho_f) / (M_c / \rho_c)$

Where,

M_f = Mass of the fiber

P_f = Density of the fiber (Assume = 800 kg /m3)

M_c = Mass of concrete

ρ_c = Density of concrete (2400 Kg/ m3)

For this experiment, the % of fiber is 0.25% , 0.50% and 0.75 % of the concrete.

When the % of fiber is known , the mass of the fiber will be found using above equation.

For the first trial, let, fiber(%) = 0.25 %,

Fiber unit weight, ρ_f = 800 kg /m^3

Concrete unit weight , ρ_c = 2400 kg/m^3

Concrete mass, M_c = 60.024 kg

Mass of the fiber, $M_f = \frac{0.25}{100} * \frac{Mc}{\rho c} * \rho_f$

$= \frac{0.25*60.024*800}{100*2400}$

= 0.050 kg

= 50 gm

Compressive strength calculation:

Fiber	Compressive Strength				
	X	P	A	C	C
	KN	KN	mm^2	Psi	MPa
0%	219	215	7854	3973	27.40
	202	198	7854	3660	25.24
	212	208	7854	3845	26.51
			Avg	3826	26.38
0.25%	307	303	7854	5594	38.57
	256	252	7854	4655	32.09
	303	299	7854	5520	38.06
			Avg	5256	36.24
0.50%	307	303	7854	5594	38.57
	304	300	7854	5539	38.19
	290	286	7854	5281	36.41
			Avg	5471	37.72
0.75%	272	268	7854	4949	34.13
	305	301	7854	5557	38.31
	268	264	7854	4876	33.62
			Avg	5127	35.35

Dia = 100 mm

Height = 200 mm

Fiber = 0.25 %

Area, $\boldsymbol{A} = \pi r2$
= 3.1416*(2*25)^2 mm^2
= 7854 mm^2

Machine reading, x = 307 KN

Calibration equation : y = 0.9972 * x – 3.2205

Load , P = 0.9972 * 307 – 3.2205 = 302.92 = 303 KN

Compressive strength = $\frac{Load}{Area}$

$= \frac{303000}{7854}$

= 38.57 MPa

Split tensile strength calculation:

Fiber	Split Tensile Strength				
	X	P	A	T	T
	KN	KN	mm^2	Psi	MPa
0 %	62	63	62832	291	2.00
	72	73	62832	337	2.32
	100	101	62832	467	3.22
			Avg	365	2.52
0.25 %	75	76	31419	351	2.42
	90	91	31420	420	2.90
	68	80	31421	369	2.55
			Avg	380	2.62
0.50 %	102	103	62832	476	3.28
	88	89	62832	411	2.83
	78	79	62832	365	2.51
			Avg	417	2.88
0.75 %	90	91	62832	420	2.90
	88	89	62832	411	2.83
	80	81	62832	374	2.58
			Avg	402	2.77

Dia = 100 mm

Height = 200 mm

Fiber = 0.25 %

Area, **A** = πld = 3.1416 * 100 * 200 = 62832 mm^2

Machine reading, x= 108 KN

Calibration equation y = 1.0033 *x +0.7663

Load, P = 1.0033 * 108 + 0.7663 = 109 KN

Split tensile strength $= \frac{2*P}{\pi ld}$

$= \frac{2*109000}{62832}$

= 3.47 MPa

Flexure strength calculation:

Fiber	Flexure test						
	X	P	a	b	d	f	f
	KN	KN	mm	mm	mm	Psi	MPa
0%	9.1	9.9782	85	75	75	875	6.03
	8.67	9.49746	79	75	75	774	5.34
	7	7.6304	84	75	75	661	4.56
					Avg	770	5.31
0.25%	12	13.2204	84	75	75	1145	7.90
	12.37	13.63406	82	75	75	1153	7.95
	12.7	14.003	91	75	75	1314	9.06
					Avg	1204	8.30
0.50%	10	10.9844	79	75	75	895	6.17
	12.5	13.7794	75	75	75	1066	7.35
	11	12.1024	83	75	75	1036	7.14
					Avg	999	6.89
0.75%	9.4	10.3136	79	75	75	840	5.79
	10.1	11.0962	87	75	75	996	6.86
	9.3	10.2018	85	75	75	894	6.17
					Avg	910	6.28

Length = 225 mm

Width = 75 mm

Height = 75 mm

The formula that is used to find out modulus of rupture is given below-

$R = 3*p*a / (b*d^2)$

Fiber = 0.25 %

Machine reading, x = 12 KN

Calibration equation y =1.118 * x - 0.1956

Load, P = 1.118 * 12 – 0.1956 = 13.2204 KN

Flexure strength, R = $\frac{3*13.2204*1000*84}{75*75*75}$

= 7.90 MPa

Compressive strength at elevated temperature test:

This calculation is same as the compressive strength test at normal temperature.

Deflection of beam sample in flexure test:

This table shows the beam deflection for 0.0% fiber.

Gage (mm)	0.01	
0% fiber		
Load	deflection reading	Deflection
KN		mm
0.5	2	0.02
1	6	0.06
1.5	10	0.1
2	14	0.14
2.5	16	0.16
3	17	0.17
3.5	21	0.21
4	23	0.23
4.5	25	0.25
5	27	0.27
5.5	28	0.28
6	30	0.3
6.5	33	0.33
7	34	0.34

This table shows the beam deflection for 0.25% fiber.

0.25 % fiber								
Sample-1			Sample-2			Sample-3		
Load	deflection reading	Deflection	Load	deflection reading	Deflection	Load	deflection reading	Deflection
KN		mm	KN		mm	KN		mm
0.5	4	0.04	0.5	4	0.04	0.5	3	0.03
1	7	0.07	1	8	0.08	1	5	0.05
1.5	11	0.11	1.5	11	0.11	1.5	7	0.07
2	15	0.15	2	13	0.13	2	13	0.13
2.5	19	0.19	2.5	21	0.21	2.5	15	0.15
3	21	0.21	3	25	0.25	3	20	0.2
3.5	25	0.25	3.5	28	0.28	3.5	24	0.24
4	28	0.28	4	31	0.31	4	27	0.27
4.5	30	0.3	4.5	34	0.34	4.5	30	0.3
5	32	0.32	5	36	0.36	5	32	0.32
5.5	35	0.35	5.5	40	0.4	5.5	36	0.36
6	38	0.38	6	42	0.42	6	40	0.4
6.5	40	0.4	6.5	45	0.45	6.5	43	0.43
7	44	0.44	7	47	0.47	7	46	0.46
7.5	47	0.47	7.5	50	0.5	7.5	49	0.49
8	49	0.49	8	52	0.52	8	52	0.52
8.5	51	0.51	8.5	55	0.55	8.5	53	0.53
9	54	0.54	9	56	0.56	9	55	0.55
9.5	56	0.56	9.5	57	0.57	9.5	57	0.57
10	57	0.57	10	60	0.6	10	60	0.6
10.5	60	0.6	10.5	61	0.61	10.5	61	0.61
11	62	0.62	11	62	0.62	11	61	0.61
11.5	65	0.65	11.5	63	0.63	11.5	63	0.63
12	150	1.5	12	64	0.64	12	65	0.65
			12.37	66	0.66	12.7	70	0.7

This table shows the beam deflection for 0.50% fiber.

0.50 % fiber								
Sample-1			Sample-2			Sample-3		
Load	deflection reading	Deflection	Load	deflection reading	Deflection	Load	deflection reading	Deflection
KN		mm	KN		mm	KN		mm
0.5	5	0.05	0.5	5	0.05	0.5	5	0.05
1	9	0.09	1	7	0.07	1	11	0.11
1.5	11	0.11	1.5	11	0.11	1.5	15	0.15
2	15	0.15	2	15	0.15	2	17	0.17
2.5	17	0.17	2.5	17	0.17	2.5	22	0.22
3	21	0.21	3	22	0.22	3	25	0.25
3.5	24	0.24	3.5	25	0.25	3.5	30	0.3
4	29	0.29	4	27	0.27	4	33	0.33
4.5	35	0.35	4.5	31	0.31	4.5	38	0.38
5	36	0.36	5	33	0.33	5	40	0.4
5.5	38	0.38	5.5	36	0.36	5.5	45	0.45
6	42	0.42	6	41	0.41	6	47	0.47
6.5	45	0.45	6.5	45	0.45	6.5	52	0.52
7	47	0.47	7	48	0.48	7	55	0.55
7.5	51	0.51	7.5	50	0.5	7.5	57	0.57
8	53	0.53	8	52	0.52	8	60	0.6
8.5	56	0.56	8.5	55	0.55	8.5	63	0.63
9	58	0.58	9	57	0.57	9	66	0.66
9.5	62	0.62	9.5	60	0.6	9.37	70	0.7
10	64	0.64	10	63	0.63			

This table shows the beam deflection for 0.75% fiber.

0.75 % fiber								
Sample-1			Sample-2			Sample-3		
Load	deflection reading	Deflection	Load	deflection reading	Deflection	Load	deflection reading	Deflection
KN		mm	KN		mm	KN		mm
0.5	1	0.01	0.5	9	0.09	0.5	7	0.07
1	4	0.04	1	16	0.16	1	15	0.15
1.5	9	0.09	1.5	25	0.25	1.5	19	0.19
2	15	0.15	2	28	0.28	2	25	0.25
2.5	20	0.2	2.5	32	0.32	2.5	31	0.31
3	22	0.22	3	36	0.36	3	35	0.35
3.5	27	0.27	3.5	39	0.39	3.5	38	0.38
4	31	0.31	4	41	0.41	4	42	0.42
4.5	35	0.35	4.5	43	0.43	4.5	44	0.44
5	37	0.37	5	46	0.46	5	47	0.47
5.5	41	0.41	5.5	47	0.47	5.5	51	0.51
6	44	0.44	6	52	0.52	6	56	0.56
6.5	47	0.47	6.5	54	0.54	6.5	59	0.59
7	48	0.48	7	56	0.56	7	62	0.62
7.5	50	0.5	7.5	57	0.57	7.5	64	0.64
8	52	0.52	8	61	0.61	8	68	0.68
8.5	55	0.55	8.5	63	0.63	8.5	70	0.7
9	57	0.57	9	66	0.66	9	72	0.72
9.5	59	0.59	9.5	68	0.68	9.5	74	0.74
10	60	0.6	10	70	0.7	10	77	0.77
10.5	64	0.64	10.43	75	0.75	10.48	82	0.82
10.78	68	0.68						