CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Optimization of Locally Available Jute Fibers as Discrete Reinforcement for Concrete

by

Hassan Abbas

A thesis submitted in partial fulfillment for the degree of Master of Science

in the

Faculty of Engineering
Department of Civil Engineering

2023

I want to dedicate this achievement my parents, teachers and friends who always encourage and support me in every crucial time

CERTIFICATE OF APPROVAL

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Acknowledgement

In the Name of Allah, The Most Gracious, The Most Merciful. Praise be to God, the Cherisher and Sustainer of the worlds. All thanks to Almighty Allah, The Lord of all that exist, who bestowed me with His greatest blessing i.e. knowledge and Wisdom to accomplish my task successfully.

Thousands of salutations and benedictions to the Holy prophet **Hazrat Muhammad (PBUH)** the chosen-through by whom grace the sacred Quran was descended from the Most High.

I am very thankful to **Engr. Prof. Dr. Majid Ali**, a great teacher, mentor and supervisor who made a difference in all aspect of my life. I am indebted to my co-supervisor **Engr. Talha Bin Tahir** for his valuable guidance, during thesis.

I want to express my heartiest regards to my parents who always supported me morally, spiritually & prayed for my success.

Hassan Abbas

Abstract

The construction industry is looking for ways to improve the strength and sustainability of construction materials, particularly concrete. One solution is to use natural fibers, such as jute fiber, which has high mechanical strength and low density, and is readily available in some regions. The addition of jute fiber to concrete can improve its properties while also being an eco-friendly solution. The properties of jute fiber-reinforced concrete will depend on various factors such as fiber length, content, treatment, mixing, and casting. The overall aim of this research is to replace traditional steel rebar with FRP rebar in concrete structures and to improve toughness and performance by incorporating jute fibers. The specific objective is to develop a mix design for jute fiber-reinforced concrete for commercial use.

This research aimed to optimize the properties of Jute fiber reinforced composite by using JF of varying lengths and percentages. Nine combinations of length and content were experimented to study their impact on plain concrete. Three lengths of jute fiber (30mm, 40mm and 50mm) were utilized with three content percentages (1%, 3% and 5%) of cement. A mix design of 1:2:3 (cement: sand : crush) with water to cement ratio 0.6 was used for plain concrete and a mix of 1:2:3 with water to cement ratio 0.7 was used for Jute fiber reinforced concrete. The mechanical properties were assessed to examine the effect of different length and content mixtures.

The results indicated that as the fiber content increased, the compressive strength (CS) decreased while keeping the fiber length constant. The highest strength was observed with 1% fiber content, as opposed to 5% fiber content. An increase in fiber length led to an improvement in compressive energy absorption capacities. The maximum split tensile strength was obtained with the longest fiber length, compared to 30mm and 40mm. When keeping the fiber length constant, the highest split tensile energy was found with 40mm fiber length. The highest flexural energy absorption capacities were obtained with 30mm fiber length. The highest flexural strength was found with 1% fiber content and 40mm fiber length. The high absorption capacities and lower strength as compared to plain concrete (PC)

make it suitable for non-spanning civil engineering products such as on-grade slabs, pavers, curbs, parking lots, and jogging tracks, among others.

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Abbreviations and Symbols

CE1	Compressive Pre-Crack Energy Absorption
CE2	Compressive Post-Crack Energy Absorption
CFRP	Coconut Fiber Reinforced Concrete
C-S	Compressive Strength
CTI	Compressive Toughness Index
Ed	Dynamic modulus of elasticity
ζ	Damping Ratio
E1	Initial energy absorption
E2	Post-cracking energy absorption
FAS	Fly Ash Silica
FE1	Flexural Pre-Crack Energy Absorption
FE2	Flexural Post-Crack Energy Absorption
fl	Longitudinal Frequency
f_r	Transverse Frequency
FRC	Fiber Reinforced Concrete
FRP	Fiber Reinforced Polymer
F-S	Flexural Strength
f_t	Torsional Frequency
FTI	Flexural Toughness Index
JFRC	Jute Fiber Reinforced Concrete
JF	Jute Fiber
JFRCC	Jute Fiber Reinforced Concrete Composite
JWS-FRC	Jute and Wheat Straw Fiber Reinforced Concrete
JYRCC	Jute Yarn Reinforced Concrete Composite

NFRC	Natural fiber reinforced concrete
PC	Plain Concrete
PCC	Precast Concrete
SE1	Splitting-Tensile Pre-Crack Energy Absorption
SE2	Splitting-Tensile Post-Crack Energy Absorption
SEM	Scanning Electron Microscopy
SP	Steel Reinforced Concrete
S-S	Splitting-Tensile Strength
STI	Splitting-Tensile Toughness Index
STM	Servo-Hydraulic Testing Machine
TE	Total energy absorption
TI	Toughness index
W/C	Water-Cement Ratio
WA	Water Absorption

Chapter 1

Introduction

1.1 Background

Concrete is a widely utilized building material, but it faces several inherent problems like low resistance to crack opening, insufficient tensile strength, and low fracture strain capacity [1]. The fragility of concrete members makes them vulnerable to severe strain rate loads, causing them to fail easily [2]. Impact loading has a crucial impact on the quality of concrete in terms of the sequence of cracking, extent of fragmentation, rate of strain, and deformation [3]. This results in a low strain capacity and poor toughness, leading to less absorption capacity. In light of these limitations, it's imperative to introduce innovative materials to address these issues and enhance the properties of concrete. Fiber reinforcement has proven to be an eco-friendly and effective solution in improving concrete properties and strength against strain rate loads [4] . The use of natural fibers like jute has been shown to improve the behavior of concrete by up to 7.5 percent and reduce crack initiation, as well as contributing to the control of concrete cracks, improved energy absorption, and increased tensile strength [5,6]. Studies have demonstrated that the addition of jute fiber to plain concrete results in a significant increase in tensile strength and a reduction in the need for tensile steel reinforcement by up to 28% in slab [7].

To the author's understanding, there has been no prior research conducted to optimize the use of locally available jute fibers as discrete reinforcement for concrete.

As a result, an experimental study is being designed to explore the optimization of jute fiber content under various loading conditions.

1.2 Research Motivation and Problem Statement

The application of concrete in various non-structural uses has led to variations in its properties. To address these limitations, the addition of steel fibers has been shown to be an effective solution, though it increases the cost. An alternative is to incorporate natural fibers, such as jute, to enhance the properties of concrete. It is essential to understand the properties of concrete having locally available jute fibers. The problem statement is as follows:

The mechanical performance characteristics of Jute Fiber Reinforced Concrete (JFRC) are contingent upon a range of variables, with fiber length and concentration exhibiting the most pronounced effect. To attain desired results for specific applications, as non-structural members like on-grade slabs the mix design needs to be optimized by properly selecting the fiber length and content.

Optimizing the performance of fiber content will help to achieve economy in term of cost and natural resources

1.2.1 Research Questions

Which fiber length and content optimized JFRC strength with respect to PC?

How much toughness of PC can be enhanced by using jute fiber (content and length)?

1.3 Overall Objective of the Research Program and Specific Aim of MS Thesis

The ultimate purpose of the research program is to replace longitudinal steel rebar with FRP rebar in concrete structures with additional use of natural fibers for improved toughness and performance.

The specific aim of this MS research work to categorize jute fiber properties and provide catalogue of different mix design for different non- structural applications.

1.4 Scope of Work and Study Limitations

In order to achieve the desired results for non-structural members, it is necessary to find the ideal mix designs of Jute fiber reinforced concrete by varying the length and content of fibers in the concrete. The objective is to maximize the improvement in selected properties while minimizing any loss at the same time, resulting in an optimal performance. To achieve this goal, cylindrical and beam specimens of Jute fiber-reinforced concrete will be fabricated and evaluated based on variations in fiber length and volumetric content. For comparative and control purposes, 6 cylindrical specimens and 3 beam specimens of plain concrete will also be prepared. For each unique combination of fiber length and content, 6 cylindrical and 3 beam specimens will be manufactured. As per the predetermined formulations, a total of 54 cylindrical and 27 beam specimens of Jute fiber-reinforced concrete are expected to be produced and tested. The objective of this investigation is to optimize the mix design and identify the optimal combination of fiber length and content to obtain the desired results for non-structural members.

- Only locally accessible jute fibers will be utilized in this study to determine their impact on concrete properties.
- The objective of this study is to focus solely on the effect of two parameters, fiber length and content variation, on concrete properties while ignoring other factors that may have an impact.
- The mix design of concrete that will be used in this study is of the ratio (C: S: A 1:2:3.5) with a water-cement ratio of 0.6. This specific mix design was selected to ensure consistency and control in the study.

1.4.1 Rationale Behind Variable Selection

The justification behind specification selection are:

- The current research uses the mix ratio of 1(C) : 2(S) : 3(A) and fiber contents of 1%, 3%, and 5% by mass of cement and fiber lengths of 30mm, 40mm, and 50mm, based on positive results found in previous studies [10].
- The objective of this study is to examine the effect of varying fiber content and length on the effectiveness of fiber reinforcement in concrete. The structural applications (i.e for spanning member) are outside the scope of this study.
- Durability is not a focus of this study.

1.5 Novelty of Work, Research Significance and Practical Implementations

The goal of optimizing a concrete mix is to achieve a mix design that balances various properties in such a way as to produce the most favorable results. It is not always possible to attain the maximum values for all properties simultaneously. When optimizing the mix design, there will inevitably be trade-offs between different properties. The aim is to maximize the gains and minimize the losses in some properties, which can be considered as the optimal result.

The utilization of concrete as a building material is highly valued due to its strength, toughness, and affordability in comparison to other construction materials. Despite its benefits, concrete also possesses several shortcomings such as low crack resistance, low tensile strength, and low fracture strain capacity, which limit its applications. To address these limitations, the addition of fibers in concrete has been proposed as an alternative reinforcement material instead of steel fibers.

One of the solutions to enhance the properties of concrete is to incorporate natural fibers, which not only improve its strength but also offer an eco-friendly alternative.

Furthermore, it allows for the utilization of readily available natural resources and reduces construction costs. The utilization of natural fibers, such as jute, as reinforcement in concrete is a cost-effective and sustainable approach to enhance its properties.

The properties of fiber-reinforced concrete depend on several factors such as fiber length, content, treatment, mixing, and casting techniques. The length of the fiber plays a crucial role in controlling crack formation in the structure, while the fiber content affects the fresh properties and overall strength of the concrete.

Based on the findings of this research, recommendations for the practical implementation of jute fiber-reinforced concrete are provided for various non-structural civil engineering applications, including parking lots, curbs, pavers, pre-fabricated pipes, on-grade slabs, and architectural and ornamental elements of buildings. These recommendations take into consideration the different lengths of the fibers and the percentage of fibers used, with the best option being the combination that exhibits superior suitable qualities.

1.6 Brief Methodology

In this experimental program, determination of mechanical as well as dynamic properties of plain concrete (PC) and jute fiber reinforced concrete (JFRC) having different jute fiber contents are done. For plain concrete (PC), the mix design ratio is 1(cement): 2(sand): 3(aggregate): 0.6 (w/c). Length of 30mm, 40mm and 50mm for jute fiber. 1%, 3% and 5% by cement mass are used for preparation of JFRC samples. For each individual combination, a total of 6 cylinders and 3 beamlets will be prepared at a particular fiber length and content. The specimens are tested for mechanical and dynamic properties.

1.7 Thesis Outline

There are six chapters in this thesis, which are as follows:

Chapter 1 of the thesis provides an overview of the research, including the introduction, research motivation, problem statement, overall goal, specific aim, scope of work, study limitations, and methodology.

Chapter 2 presents a literature review, including background information, the use of small linear natural fibers in concrete, experiments strategies, and the novel aspects of the current research project.

Chapter 3 details the experimental program, including information on the raw ingredients, casting method, mechanical properties of the materials, specimen details, and testing methodology.

Chapter 4 focuses on the experimental results, including dynamic properties at various levels of damage.

Chapter 5 provides a discussion of the results, including optimum combinations of fiber lengths and percentages, and guidelines for large-scale production.

Chapter 6 includes the conclusion and recommendations, followed by a bibliography.

Chapter 2

Literature Review

2.1 Background

The strength of hardened concrete is a crucial aspect of its overall performance. While it possesses enough strength for many structural purposes, it can be more brittle than other forms of concrete. To overcome this drawback, the addition of fibers to concrete has been explored as a means of enhancing its properties. Natural fibers have proven to be an effective means of improving the qualities of concrete and increasing its performance, toughness, and longevity. Many factors influence the properties of fiber-reinforced concrete, including the type of fiber used. Jute is one such naturally occurring fiber with outstanding characteristics and widespread availability. This plant-based fiber is characterized by its smooth, long, and shiny appearance and can be spun into strong, coarse threads. The addition of jute fibers to concrete has been shown to improve its hardness, toughness, and resistance to cracking, making it a valuable addition to concrete mix designs.

2.2 Behavior of Plain Concrete

In recent years, risks surrounding buildings and infrastructure have increased. As the danger of earthquakes and explosions rise, understanding how concrete responds at high strain rates is critical in civil engineering building design. It is investigated in experimental process over 60 cubic concrete specimens are tested using servo-hydraulic equipment designed particularly for them [11]. At a continuous confining stress, each specimen was subjected to an axial load in compression at a uniform strain rate of 105, 104, 103, 102 and 101 with two opposing side faces. This was done while compressing the specimens axially. Each specimen was compressed to 0, 35%, 61%, or 91 percent of its uniaxial compressive strength. When confining pressure is raised, concrete's biaxial strength grows at a lower slope with strain rate. Strain rate showed minimal to no effect on the concrete failure mechanism. Considering confinement and strain rate may assist create an empirical connection that may estimate concrete's ultimate strength under biaxial stress.

When concrete is stressed in both the axial and lateral directions, an increase in the strain rate leads to an increase in the material's ultimate strength. On the other hand, it was discovered that when the lateral confining pressure increased, the increase in the strength of biaxial concrete became less significant. There was no effect of strain rate on any of the failure modes that were observed in any of the specimens that were examined since the confining pressure was the primary factor that determined the failure modes. There are numerous possible fracture patterns that could signify them. Concreting of the stress-strain curves remains rather consistent over a range of strain rates. The tangent modulus of their material at modest stresses grows larger as the strain increases. rate increases. The non-linear region of the stress-strain curves is when the rise in tangent modulus becomes more substantial than it was before. The suggested unified formula for strength, which is determined as an equation, is able to account for the influence of both the strain rate and the confining pressure over the test range of parameters. This is because the strain rate and the confining pressure are treated as independent variables in the equation. Using the dynamic failure criterion, which is represented by the shear and main stresses in the octahedral space determine equation, it is possible to determine an accurate mechanics-based failure surface for concrete that is subjected to a biaxial stress condition. This can be done for concrete that is stressed in both directions.

The ability of concrete to resist cracking and maintain its toughness are crucial factors that determine the normal functioning and safety of the structure. For example, in a building structure, if a load-bearing column has a low tensile toughness, it may fail suddenly under a relatively small amount of stress, leading to a collapse of the entire structure. On the other hand, if the column has a high tensile toughness, it can deform and absorb energy without failing, helping to prevent or delay a collapse. One of the major issues of plain concrete is thermal and expansion cracking, which can be reduced by incorporating suitable materials into plain concrete. This material helps in reducing the formation and progression of cracks in the concrete structure.

Researchers are continuously working towards developing a concrete that does not break and is stronger, more flexible. The results from various studies suggest that the use of fiber reinforcement is an effective method for reducing brittle failure and improving the fracture performance of concrete.

2.3 Natural Fibers and their Use in Concrete

Fibers are a type of material that may be utilized in a wide number of applications and are quite similar to threads in appearance. Natural fibers are those that are derived from non-synthetic sources, such as plants (including vegetables, leaves, and wood), animals, or geological processes. Synthetic fibers are derived via chemical reactions in a laboratory. The acquisition of natural fibers at a reasonable cost and in close proximity to one's house may be accomplished in many regions of the world. Because of this, utilizing them as a construction material contributes to an increase in the characteristics of composites at a relatively cheap cost (almost nothing when compared to the total cost of the composites). They have the potential to be utilized in a way that will result in the attainment of sustainable development. [13].

In the past, concrete fibers were used to enhance both the material's behavior and its mechanical capabilities. This was done by adding the fibers to the concrete. This was done with the intention of improving the functionality of the concrete. Fibers may be used to improve a material's toughness, capacity to absorb energy and resistance to the propagation of fractures. This can all be achieved by improving the material's resistance. The improved features of natural fibers, such as cheap cost, local availability, and high strength, piqued the interest of researchers, and they focused their attention on natural fibers as a result. These are the reasons that natural fibers are used instead of synthetic ones. There are several naturally occurring fibers that may be found in plenty, including hemp, sisal, jute, and flax. Some of them can be found in greater quantities than others. The inability of natural fibers to withstand high temperatures, among other drawbacks, makes their usage inappropriate in some settings [14].

Khan and Ali [16] carried out a study to investigate the impacts that fly ash, coconut fibers, and silica fume has on the properties of concrete. The behavior of FA-SPC as well as the behavior of FASCFRC were both researched. The dosage of silica fume is determined to be 15% based on the mass of cement, in connection with the inclusion of 0 percent, 5 percent, 10 percent, and 15 percent fly ash content by weight of cement respectively. To make the FA-SCFRC, the length of the coconut fibers was determined to be 50 millimeters, and the dose of cement was 2% by mass. Both of these factors were taken into consideration during the preparation process. Because of this comparison, we were able to determine that FA-SCFRC displayed a higher quality than FA-SPC did, which led us to the conclusion that FA-SCFRC was the superior product. When compared to other doses, the total FA-SCFRC showed an improvement in mechanical qualities when a dose of 10% fly ash was used. Other dosages were also examined.

The study's purpose was to assess the properties of the concrete. It was established how effective various quantities of fiber dose were at 1%, 2%, 3%, and 5% content with fiber lengths of 2.5, 5, and 7.5 cm. When compared to PC, the damping ratio of coconut fiber reinforced concrete specimens had an enhanced value, as shown by the data, and this was supported by the conclusions that were reached as a result. Although there was a decline in both the structure's static and dynamic moduli, this indicated that the structure had sustained less damage overall. It was discovered that a dosage of 5% with a fiber length of 5 cm generated the best results all around.

[15] Wang and Chouw conducted a series of experiments to explore the efficacy of coconut fiber reinforced concrete when subjected to impact load circumstances.

The purpose of these experiments was to determine how well the concrete performed. In addition to determining the impact energy, a number of different tests involving drop heights were also conducted. When exposed to repeated impact loads, the findings indicated that the fracture resistance of coconut fiber reinforced concrete with a thickness of 25 and 50 millimeters was superior to that of coconut fiber reinforced concrete with a thickness of 75 millimeters.

[17] Experiments on straw fiber reinforced concrete were conducted in both China and Nepal in order to research the qualities of concrete. In comparison to regular concrete, it was shown that the compressive and flexural strengths of wheat straw fibers were enhanced at a volume percentage of 0.25%. Wheat straw was used in an inquiry on the relevance of plant fibers, employing procedures such as flexure and shear tests to determine the significance of plant fibers. It was decided that 25 millimeters of wheat straw would be the appropriate amount to add to the concrete, and the mix design ratio for Portland cement was determined to be 1:2:4. Increases of up to 30.4%, and 11.1% were seen in some of the material's attributes modulus of rupture and toughness index, respectively. In structural engineering, modulus of rupture is used to determine the maximum bending stress a material can withstand before it fails. When designing a structure, engineers need to ensure that the chosen materials have a modulus of rupture that is sufficient to support the expected loads, including dead loads, live loads, and wind and seismic loads. If the modulus of rupture is too low, the structure may bend or break under stress, leading to failure. The utilization of wheat straw was responsible for the development of cracks being slowed down to some extent. Wheat straw fibers have demonstrated improved performance on stiff flooring, and the usage of these fibers may lead to designs that are similar [18].

The results of studies that were carried out on the dynamic and mechanical properties of concrete that were reinforced with coconut fiber revealed that the material had exceptional qualities. In the concrete that was produced, different fiber lengths of 25, 50, and 75 millimeters were utilized, as well as different fiber concentrations of 1, 2, and 3 percent. The compressive behavior of plain concrete (PC) is more vulnerable to failure under applied load compared to fiber reinforced concrete [19].

The integration of natural fibers into concrete has been found to be an economically viable and environmentally responsible method of upgrading its performance characteristics. The implementation of natural fibers in cement composites has demonstrated substantial enhancements in mechanical properties. The utilization of natural fibers as discrete reinforcement within conventional concrete has been shown to significantly augment its toughness and energy absorption capabilities. This methodology presents a more sustainable and cost-effective means of improving the performance of concrete.

2.3.1 Commercially Available Jute Fiber Properties

Table 2.1: Properties of commercially available jute fibers

References	Density (g/cm3)	Water absorption (%)	Tensile strength (MPa)	Elongation (%)	Youngs Modulus (GPa)
[28]	1.46	12-14	400-800	1.8	10-30
[25]	1.28	13	250-350	1.5-1.9	26-32
[17]	1.3	-	393-773	1.5-1.8	26.5
[27]	1.46	13%	400-500	1.6	30

Every fiber has different properties depending upon the origin and regions where they grow. It also depends upon weather conditions of that region. Most commonly research is done on Bangladesh region. Jute is one of the most affordable and durable natural fibers available, and is widely available in Bangladesh [20]. It is the second most produced textile fiber globally, following cotton, and Bangladesh is the second largest producer of jute in the world, contributing 33% of the total global production. The primary components of jute fibers are cellulose and lignin, derived from plant materials. Jute fibers boast several advantageous properties such as high tensile strength, moderate fire resistance, biodegradability, renewability, recyclability, and eco-friendliness, making it a superior choice compared to other types of fibers [21].

For the preparation of jute fiber reinforced concrete, untreated raw jute, known locally as "Tusha Pat", was used as the reinforcing fiber. Tusha Pat is a golden-colored fiber that measures between 1.0 to 2.0 meters in length. The physical properties of the jute fiber, such as its diameter, absorption, density, and tensile strength, were analyzed and found to be approximately 0.10 mm, 160%, 1.45 g/cm3, and 480 MPa, respectively. To further study its impact on the concrete, the jute fibers were cut into two different lengths of 10 mm and 20 mm [20].

The table above showcases the results of various studies conducted on the properties of jute fibers from different regions of the world. It is evident from the data that there is a significant amount of variation in the quality of fibers that are available. The tensile strength of jute fibers can range anywhere from 250 MPa to an impressive 800 MPa, with most regions having fibers that fall within the range of 400-800 MPa. The elongation of the fibers is also found to have a range of 1.6-1.9, and Young's modulus is typically between 25-30 GPa.

In conclusion, the studies show that there is a wide range of jute fibers available on the market. However, it is important to determine the properties of the locally available jute fibers in the Pakistani region in order to determine their suitability for various applications.

2.4 Dominating Factors Influencing for Optimized Properties of Composite

The material that is utilized for construction around the globe in the biggest amount is concrete. Since the Romans invented it, it's been used in more industries. Its greater strength, toughness, and economic feasibility explain this phenomenon. Its usage has been severely restricted because to its tensile weakness, poor crack resistance, and low fracture strain capacity. Fiber-reinforced concrete is an alternative to ordinary concrete. This compensates for plain concrete's brittleness. The fiber was used to reinforce brittle matrices in biblical times. Steel, glass, synthetic, and natural fibers are incorporated into concrete to make it more strain-resistant. Most concrete uses steel fiber Corrosion restricts steel fiber's usage. As an alternative, synthetic fibers are often offered. Synthetic fiber manufacture is expensive and energy-intensive. In circumstances such as these, natural fibers are frequently regarded as a potential choice for use in fiber-reinforced concrete. A cement-based concrete matrix that integrates natural fibers of varying lengths and diameters at random is known as natural fiber reinforced concrete (NFRC). The environment, the economy, and efforts to save energy and resources all benefit from the use of natural fiber. It also minimizes the demand for aggregate and cement, which contributes to expansion that is more sustainable. It is investigated the impact that jute fibers have on both freshly mixed and fully cured concrete. Concrete cylinders and beams were infused with jute fibers that were woven locally into two different lengths, 10 mm and 20 mm, and four different volumes, 0.00 percent, 0.25 percent, 0.50 percent, and 1.00 percent respectively [27]. The compressive and split tensile strengths of cylinder specimens were evaluated at 7, 28, and 90 days after initial testing. The flexural tensile strength of the beams was evaluated after a period of 28 days. In addition, a number of factorial experiments were carried out in order to investigate how the amount and size of jute fibers affected the quality of the concrete.

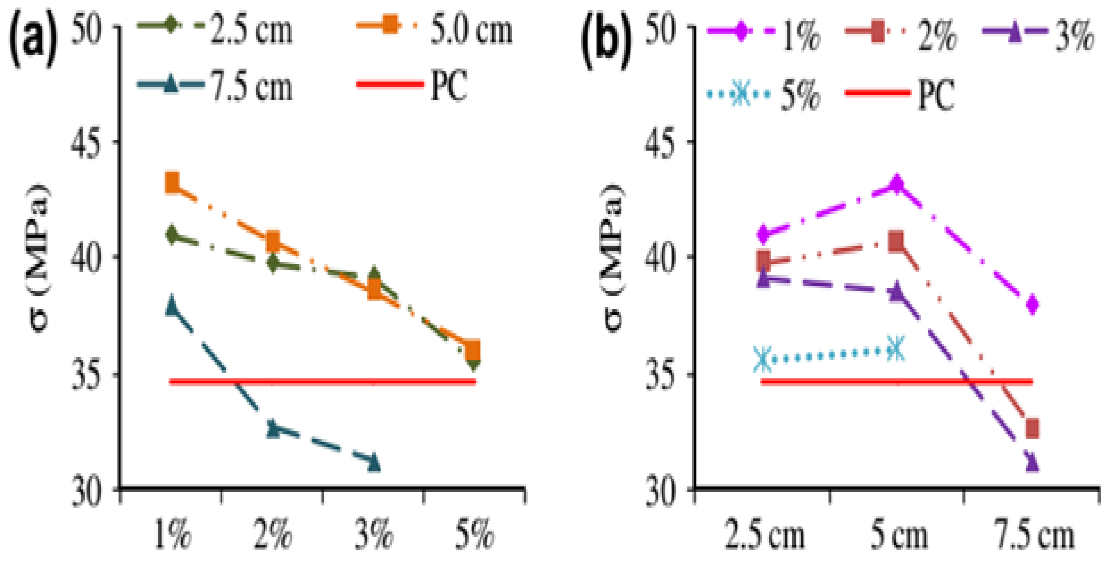


FIGURE 2.1: Influence of fiber (a) content and (b) length on compressive strength [14]

Ali et al. [14] performed an experimental examination on coconut fiber reinforced concrete to assess the dynamic and mechanical characteristics of the concrete as shown in figure 2.1. The propensity of the slump to collapse was reduced when there was a larger percentage of jute fibers in the concrete. When compared to the smaller jute fibers of 10 millimeters, the concrete mixes created with lengthy jute fibers of 20 millimeters (aspect ratio of 200) resulted in a greater reduction in a slump than those that were prepared with shorter jute fibers. This was the case because longer jute fibers have a greater surface area to volume ratio than shorter jute fibers (aspect ratio of 100). The accumulation of compressive strength increased in direct proportion to the amount of time the material was allowed to cure, which came as no surprise to everyone. The inclusion of as little as 0.25 percent jute fiber enhanced the compressive strength of concrete, and this effect was found independent of the length of the jute fiber that was employed. In contrast, the addition of jute fiber to the material at a concentration of 0.10 percent resulted in a decrease in the material's compressive strength. The influence that 0.50% jute fiber had on the compressive strength of concrete was, however, very variable depending on the size of the jute fiber. It was discovered that fibers with a length of 10 millimeters had a beneficial effect on compressive strength, but fibers with a length of 20 millimeters were shown to have a detrimental effect on compressive strength. The addition of jute fiber to concrete did not significantly affect the split tensile strength of the material either 28 or 90 days after it was placed. The tensile strength of concrete specimens that were prepared with lower amounts of jute fiber (0.25 and 0.50%, respectively) was found to be slightly superior to the tensile strength of concrete specimens that were planned with either no jute fiber or a higher proportion of jute fiber (1.00%) with a few notable exceptions. It was discovered that the addition of jute fibers to concrete with an aspect ratio of two hundred had a negative effect on the flexural strength of the material. This was true independent of the total quantity of fiber in the diet. When jute fibers with a diameter of 10 millimeters were used in the experiment, it was discovered that the influence of jute fiber on flexural strength is mostly reliant on fiber volume. The greatest and the smallest gains in flexural strength were attained for jute fiber concentrations of 0.5 percent and 0.25 percent. however, a reduction in flexural strength was observed for the maximum achievable concentration of jute fiber (1.00%). According to the results of a factorial research, the individual impacts of the jute fiber volume and length provided an adequate share, which was close to forty percent, to the slump of newly mixed concrete. This information was gleaned through analyzing the relationships between the factors. The contribution that was made by the volume and the length of the jute fiber was accountable for the remainder percentage, which came to twenty percent. The influence of jute fiber length on the split tensile strength was determined as 38.25 percent after 28 days, however this value reduced to 8.3 percent after 90 days of ageing. The proportion of split tensile strength that is proportional to the length and volume of jute fiber rose from 22.70 percent after 28 days to 55.10 percent after 90 days. On the other hand, throughout the ages of curing of between 28 and 90 days, the percentage that fiber volume contributed to the split tensile strength of concrete remained very steady (about 3739%). This was the case even though the curing time increased. When it comes to flexural tensile strength, the combination of jute fiber length and volume contributed the greatest amount possible (46.90 percent), accompanied by fiber volume, which contributed a moderate amount (36.35 percent), and finally jute fiber length, which contributed the least amount possible (16.75 percent). The incorporation of jute fibers reduced the amount and width of cracks, preventing concrete specimens from completely failing and revealing that the fail designs of tested specimens for compressive strength, split tensile strength, and flexural strength revealed that the inclusion of jute fibers reduced the number of cracks. This was proved by the fact that the incorporation of jute fibers resulted in a reduction in both the number of cracks and their breadth. The use of jute fibers into the mix design has a number of potential benefits, one of the most important of which is the enhancement of the flexural toughness of the concrete.

The hand lay-up approach was used to successfully fabricate a bidirectional jute fiber reinforced epoxy composite material. This was accomplished with great success. The pristine epoxy specimen has the lowest possible void content, whereas the 12-weight percent fiber loading specimen has the highest possible void content. In addition, the findings of the study indicate that the void content falls to a lower level as the fiber loading level rises. As the amount of fiber loading in the jute-epoxy composites is increased, the hardness, tensile characteristics, and impact strength of the composites all rise. The number of voids that are present in composites has a significant impact on the properties that are measured, such as flexural strength and inter-laminar shear strength. It has been discovered that these qualities improved when the fiber loading was decreased from 0 wt.% to 12 wt.%. Additionally, the void content was decreased from 12 wt.% to 48 wt.%, which also helped enhance the properties. Fiber reinforcement can be used in concrete, mortar, and cement paste to improve the material's fracture toughness, flexural strength, and resistance to fatigue, impact, thermal shock, and spalling. These are just some of the engineering properties of the basic materials that can be enhanced by using fiber reinforcement. Because fibers are readily available and require a modest amount of energy to produce, they have traditionally been seen as a potentially useful option for reinforcing cement-based matrices.

To determine whether or not they are suitable for integration in cement concrete, short discrete vegetable fibers such as sisal, coir, and jute have been tested. The concrete environment had no effect on the fiber's physical qualities, which showed no sign of degradation. The requisite levels of performance for concrete buildings are more difficult to achieve. According to [26], it is essential for concrete to possess qualities like as high strength and high resilience in order to ensure the long life of concrete buildings, increased serviceability, and improved operability. To determine whether or not they are suitable for integration in cement concrete, short discrete vegetable fibers such as sisal, coir, and jute have been tested. The concrete environment had no effect on the fiber's physical qualities, which showed no sign of degradation. Jute is a plant fiber that is harvested from a plant that has fruit that like large pineapples. When the plant is being harvested, the leaves are trimmed to be as near to the ground as possible.

The fibrous material is separated by hand or by machine from the fatty and connective tissues. After being dried, the fibers are next brushed in order to eliminate any leftover dirt, which results in a clean fiber. Finally, the design of the composite structure is also an important factor in optimizing its properties. The design must take into account the properties of the individual materials and the processing method used, as well as the intended use of the composite. The right design can help ensure that the composite has the desired strength, stiffness, and toughness.

In conclusion, the factors that influence the optimized properties of composites include the type of matrix material, the type of reinforcement fibers, the processing method and the mix design of the composite structure. By considering these factors, engineers and designers can produce composites with superior properties that are well-suited for a wide range of applications.

2.4.1 Jute Fibers Content and Length in Concrete

Natural jute fiber may strengthen concrete. This will examine ways to increase concrete's qualities, as well as the usage of jute and environmentally damaging polymer. Jute is abundant in Bangladesh, thus it's cheap.[27] Compressive, flexural, and tensile strengths of Jute Fiber Reinforced Concrete Composites have been examined (JFRCC). To introduce jute fiber, standard-sized cylinders, prisms, and cubes were created. The concrete mix ratio, water-cement ratio, fiber length, and fiber volume have all been altered to assess their effects. The samples were tested for flexural, compressive, and tensile strength using conventional testing equipment. JFRCC results were compared to ordinary concrete. Due to the broad cut length and increased number of reinforcing materials (jute fiber), composites tend to ball and have significant porosity, which degrades JFRCC's mechanical properties compared to ordinary concrete. In Table 2.1 effect of jute fibers content and length in concrete can be seen. There is brief comparison of mechanical properties of JFRC is done by different SMaRG researchers. Integrating short fibers with a low fiber content creates an intact structure that enhances the composite's mechanical properties. A high cement content was almost invariably connected with high increment values. So, adding jute fiber to high-cement-content concrete makes it more durable. Adding jute fiber to concrete is a promising step toward achieving sustainable development in Bangladesh, which has a large number of fields dedicated to jute cultivation.

In the course of experimental research, it was discovered that the incorporation of jute fiber into concrete composites leads to improved results for the mechanical characteristics of the material, provided that the fiber is of a specific length and

Table 2.2: Effect of Jute fibers content and length in concrete

Study No.	Fiber content	Mix design ratio	Fiber length (mm)	CS (MPa)	STS (MPa)	MoR (MPa)	CTI	STI	FTI	References
1	PC	1:2:3:0.7	-	13.2	2.1	2.68	2.5	1	1	Asad Zia (2017)
	5%	1:2:3:0.7	50 mm	8.4	1.7	2.9	5.6	1.02	1.86	
2	PC	1:2:3:0.6	-	30.29	4.1	6.2	5.35	1	1	Abdul Wahab (2018)
	5%	1:2:3:0.6	50 mm	23.01	4.2	6.35	9.12	1.55	1.67	
3	PC	1:2:3:0.6	-	24.18	2.56	6.14	1.92	1	1	Shah M Hassan Sabri (2018)
	5%	1:2:3:0.6	50mm	20.31	2.67	6.27	3.56	1.93	3.03	
4	PC	1:2:3:0.6	-	16.1	2.43	3.32	2.76	1	1	Hassan Raza (2020)
	5%	1:2:3:0.6	50mm	9.7	1.5	2.73	3.37	3.59	3.13	
5	PC	1:2:3:0.6	-	17.70	2.66	4.18	2.55	1	1	Fareed (2020)
	5%	1:2:3:0.6	50mm	8.63	1.49	3.62	4.16	4.07	3	
6	PC	1:2:3:0.6	-	14.24	9.5	3.95	2.89	1	1	Ubaid (2020)
	5%	1:2:3:0.6	50mm	11.8	6.1	2.25	3.85	3.22	2.66	
7	PC	1:2:3:0.7	-	22	2.15	5.2	1.6	1	1	M Bilal (2020)
	5%	1:2:3:0.6	50mm	19.21	2.5	5.8	2.23	1.77	2.64	
	PC	1:2:3:0.6	-	14.6	2.66	6	1.4	1	1	Hafiz Awais (2021)
8	1%	1:2:3:0.6	50mm	6	1.37	4.15	1.48	5.4	2.78	
	3%	1:2:3:0.6	50 mm	5.63	1.8	4.5	2.1	7.18	4.08	
	5%	1:2:3:0.6	50mm	7.14	1.59	4	4.98	8.2	4.68	
9	PC	1:2:3:0.6	-	26.2	2.56	6.14	1.92	1	1	Ghanzafar Rafi (2022)
	JFRC	1:2:3:0.6	50mm	21.5	2.67	6.27	3.42	1.93	3.03	

content. To be more exact, tensile, compressive, and flexural strengths are determined to Increase 0.1 and 0.25 % volume and 10- and 15-mm fiber cut length. Greater fiber length and content decreased mechanical characteristics. Finally, tensile strength increases by 35% over ordinary concrete. Bangladesh may make JFRCC from locally-made jute. JFRCC's socioeconomic feasibility is shown by its low cost, renewable resources, lightweight, and environmental friendliness.

Mechanical properties of concrete composites based on fiber length and yarn content. Compressive, flexural, and tensile strengths increased when fiber cut length was 10 or 15 mm and volume content was 0.1% or 0.25. Increasing fiber length and content decreased mechanical quality. Only JYRCC increased compressive, flexural, and tensile strengths more than ordinary concrete. In Table 2.2, the impact of jute fiber content and length on concrete can be observed through a comparison of the mechanical properties of JFRC conducted by various CUST researchers. The results show a reduction in compressive strength in all cases, but a significant increase in compressive toughness index. A mixed trend can be observed in terms of tensile and flexural strength compared to plain concrete, however, both have significantly higher toughness index when compared to plain concrete. Integrating short fibers with a low fiber content creates an intact structure that enhances the composite's mechanical properties. A high cement content was almost invariably connected with high increment values. So, adding jute fiber to high-cement-content concrete makes it more durable. Adding jute fiber to concrete is a promising step toward achieving sustainable development in Bangladesh, which has a large number of fields dedicated to jute cultivation. In the course of experimental research, it was discovered that the incorporation of jute fiber into concrete composites leads to improved results for the mechanical characteristics of the material, provided that the fiber is of a specific length and content. To be more exact, tensile, compressive, and flexural strengths are determined to Increase 0.1 and 0.25% volume and 10- and 15-mm fiber cut length. Greater fiber length and content decreased mechanical characteristics. Finally, tensile strength increases by 35% over ordinary concrete. Bangladesh may make JFRCC from locally-made jute. JFRCC's socioeconomic feasibility is shown by its low cost, renewable resources, lightweight, and environmental friendliness. Mechanical properties of concrete composites based on fiber length and yarn content. Compressive, flexural, and tensile strengths increased when fiber cut length was 10 or 15 mm and volume content was 0.1% or 0.25.

In conclusion, the study of the effect of jute fibers content and length in concrete showed that the addition of jute fibers can significantly improve the mechanical properties of concrete, including its tensile strength, compressive strength, and flexural strength. The optimal jute fiber content and length can vary depending on the specific requirements of a concrete mix. However, further research is needed optimized mix design to achieve maximum mechanical properties of JFRC.

2.5 Summary

From the preceding sections, it has been determined that plain concrete is insufficient in terms of its tensile strength and brittleness. To improve its dynamic and mechanical properties, natural fibers such as jute can be utilized in place of steel and synthetic fibers. Jute is an easily accessible and cost-effective alternative, with the ability to enhance the properties of concrete. The mechanical properties of jute fibers vary depending on their origin and surrounding conditions, with fiber content and length having a significant impact on the properties of jute fiber reinforced concrete. To achieve the desired outcomes from using JFRC, a mix design should be devised using locally sourced jute fibers. These combinations are suitable for non-structural applications such as non-spanning members.

Chapter 3

Experimental Program

3.1 Background

The investigation into the mechanical characteristics of jute fiber reinforced concrete is based on the varying lengths of the fibers and the percentages of fiber that are present in the concrete. The primary effects of using glass fiber reinforced concrete are an increase in mechanical characteristics, an increase in toughness, and an increase in energy absorption. Jute fibers are included in the experimental test set in order to improve fracture resistance. This is accomplished by the manipulation of the fiber's length as well as the proportion of fiber mixture that is contained inside the concrete. This chapter explains in detail how to determine the mix design, the raw ingredients, the casting technique, and the testing procedure for each and every specimen.

3.2 Raw Materials

The following are the components that go into manufacturing plain concrete: clean drinking water, conventional Portland cement, sand and aggregates that are available in the area, and aggregates that are standard. Sand and aggregates that are accessible in the area are also included. Although the JFRC is put together using the same components as before, this is the first time that jute fibers have been included as a separate component (JF). It is essential to keep in mind that jute fibers have a very high tensile strength, but their elongation is only between 1.5% and 1.8%. This disparity in properties is something that must be taken into consideration. In addition, instances of values with a high degree of rigidity can be found in table 3.1 Jute fiber that has been conditioned and measures 0.4 millimeters in diameter was purchased from a local market in Pakistan. The fiber was then hand-cut into lengths measuring 50, 40, and 30 millimeters, respectively. Images obtained from a scanning electron microscope are utilized in the process of dissecting the intricate microstructure of jute fiber.

Jute fibers are shown in their raw condition in Figure 3.1(a). These fibers have been cut into three distinct lengths: 30 mm, 40 mm, and 50 mm as shown in figure 3.1(b). The SEM view is displayed in the figure. As depicted in Fig. 3.1(c), the jute fiber is comprised of small tubes that run parallel to one another. The nano-threaded structure of the jute fiber is clearly visible, with the edges of the fibers revealing that they are hollow. This characteristic is thought to contribute to the jute fiber's ability to absorb water. On average, jute fibers have a diameter of around 0.4 millimeters, making them an attractive candidate for use in concrete mix designs.

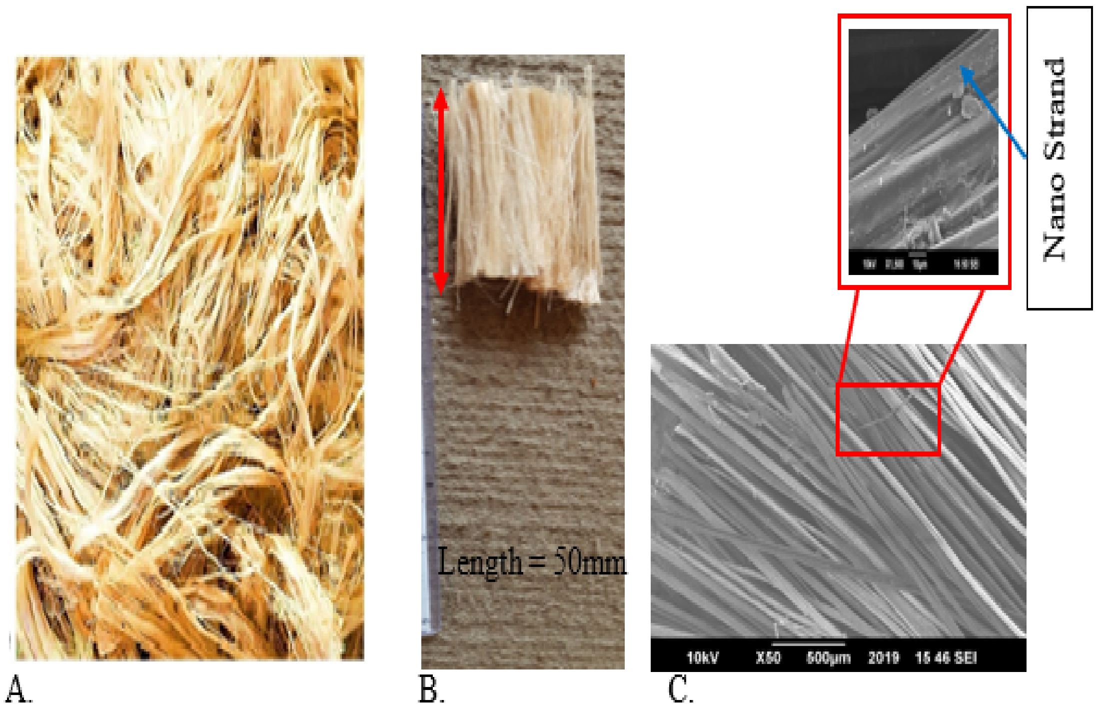


FIGURE 3.1: Jut fiber a) Raw fiber b) 50mm Fiber c) 0.5mm SEM view

Table 3.1: Mechanical properties of available jut fiber

Mechanical Properties of Jute Fiber				
Properties	**Values**			**Units**
Length	30	40	50	mm
Diameter	0.4	0.4	0.4	mm
Aspect Ratio	75	100	125	-
Density	1460	1460	1460	Kg/m^3
Tensile strength	583	583	583	MPa
Elongation	1.7	1.7	1.7	%

3.3 Selection and Mix Design of Casting Procedure

As can be seen in Table 3.2 The mix design ratio for the preparation of plain concrete (PC) is 1:2:3:0.60 (cement : sand : aggregate : water). The use of different fiber lengths of 30 mm, 40 mm, and 50 mm with 1%, 3%, and 5% fiber content, respectively, aims to optimize the mix design by maximizing the gain in properties while minimizing any loss. The optimization of concrete mix design involves finding a balance between different properties that are desirable for the specific application. All ingredients, except for water, should be weighed in kilograms and measured in liters. The water-cement (W/C) ratio for JFC specimens is kept the same as that for PC. A non-tilting rotary drum concrete blender was utilized for the production of both PC and JFC. For the production of PC, all ingredients including water were blended together for 3 minutes in the drum. In contrast, a layered approach was adopted for the preparation of JFC to prevent balling up of the mixture. All ingredients, including jute fibers, were placed in the blender drum and 33% of the water was evenly distributed over the ingredients. The remaining 67% of water was gradually added while the machine was still turning. To get a uniform consistency throughout the concrete, the blender must be turned

Table 3.2: Mechanical properties PC and JFC with Mix Design ratio of (1:2:3:0.6)

Property	**Fiber %**	**Cement kg/m^3**	**Fiber kg/m^3**	**Fine Aggregate kg/m^3**	**Coarse Aggregate kg/m^3**	**Water L/m^3**	**Water Cement Ratio**
PC	0	333.33	0	666.66	1000	200	0.6
JFC	1	332.84	6.68	664.13	996.21	199.24	0.6
JFC	3	331.53	10.02	662.87	994.31	198.86	0.6
JFC	5	330.81	16.67	661.61	992.42	198.48	0.6

on for a total of six minutes, with each layer receiving two minutes of devotion. In the case of molds, a total of 25 blows, which are performed with the aid of a temperature rod in accordance with the ASTM standard, are used to fill in each of the three layers in order to minimize the amount of space occupied by air gaps. Free felled molds are from 75 to 100 mm in size. Casting the specimens of PC and JFC is accomplished through the application of the following procedure. After forty-eight hours, the molds are extracted so that they can be labeled After that, the specimens are curated for twenty-eight days in a water-filled container before being examined again. It was observed that PC has maximum workability as compared to all other JFRC specimen. As the length and content of fibers in composite increases, workability decreases.

3.4 Specimens

In a current study for the determination of mechanical properties of PC and JFC, cylinders and beam-lets were cast. Cylinder molds had dimensions of 100 mm diameter and 200 mm height whereas beam-let molds had 100 mm width, 100 mm height, and 450 mm length. It can be seen in figure 3.2(a) sixty specimens (i.e. six for PC and fifty-four for JFRC) have to be cast for compressive strength and splitting tensile strength testing. Specimens (i.e. three for PC and nine for JFC) were cast for flexural strength testing as shown in figure 3.2 (b)

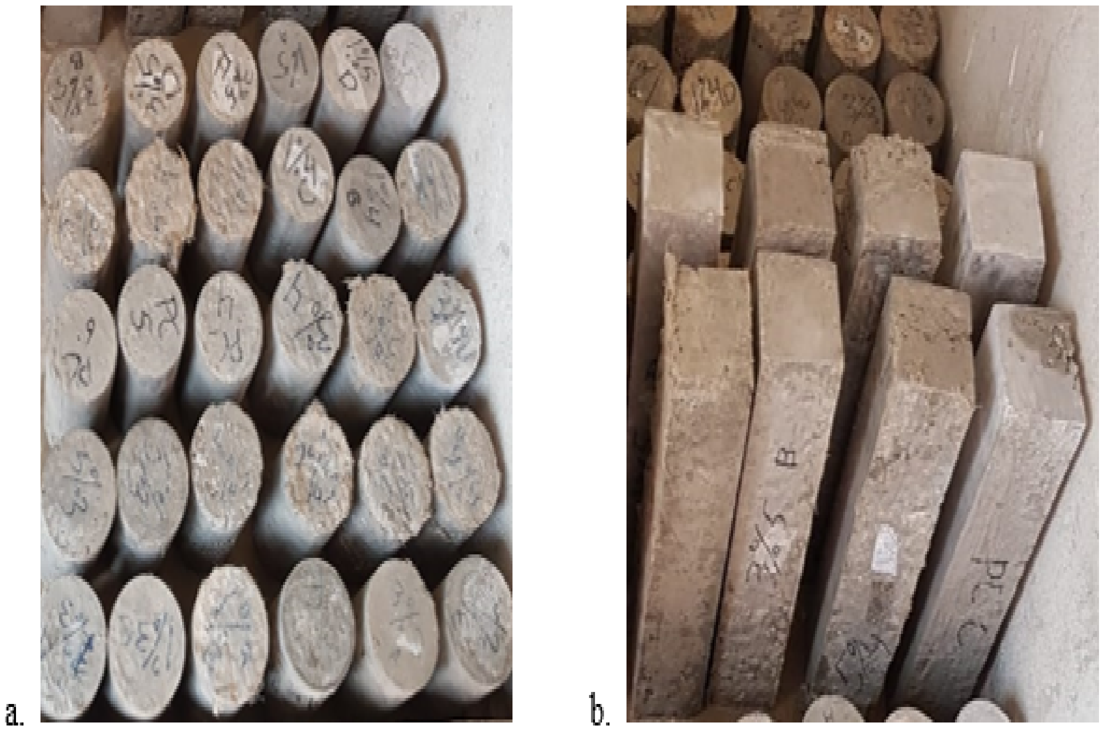


FIGURE 3.2: a) PC and JFRC cylinder b) PC and JFRC beamlet

Table 3.3 is showing specimens scheme with varying length and content of fiber. For the sake of Plain Concrete is represented by (O0). Three different fiber lengths and fiber-contents (%) have been selected based on previous researches. Inclusive of the control specimen, there are 10 combinations.

Table 3.3: Nomenclature of the proposed formulations

Fibers (%) of mass of cement	**Fiber length symbol**	**0mm (0)**	**30mm (1)**	**40mm (2)**	**50mm (3)**
0	O	O0	-	-	-
1	A	-	A1	A2	A3
3	B	-	B1	B2	B3
5	C	-	C1	C2	C3

3.5 Testing Procedure

Dynamic and Mechanical test are performed in this section to find different properties of concrete according to ASTM standards as per previous research. Average of two samples is taken to find out each result.

Hammer and accelerometer are used to find out Lateral, longitudinal and transverse frequencies of plain concrete and jute fiber reinforced concrete. Different type of test is performed to find out resonance frequencies. Compression, Flexural and split tensile testing are performed to get all mechanical properties of plain reinforced concrete and all specimen of jute fiber reinforced concrete.

3.5.1 Dynamic Properties of the Prototype

Testing of prototype columns of PRC and JFRC are put through dynamic simulations as part of the ongoing research activity. The ASTM standard C215-02 was followed in the process of determining various properties, such as torsional frequency, transverse frequency, longitudinal frequency, and damping ratios. The resonance testing device is depicted in figure 3.3.

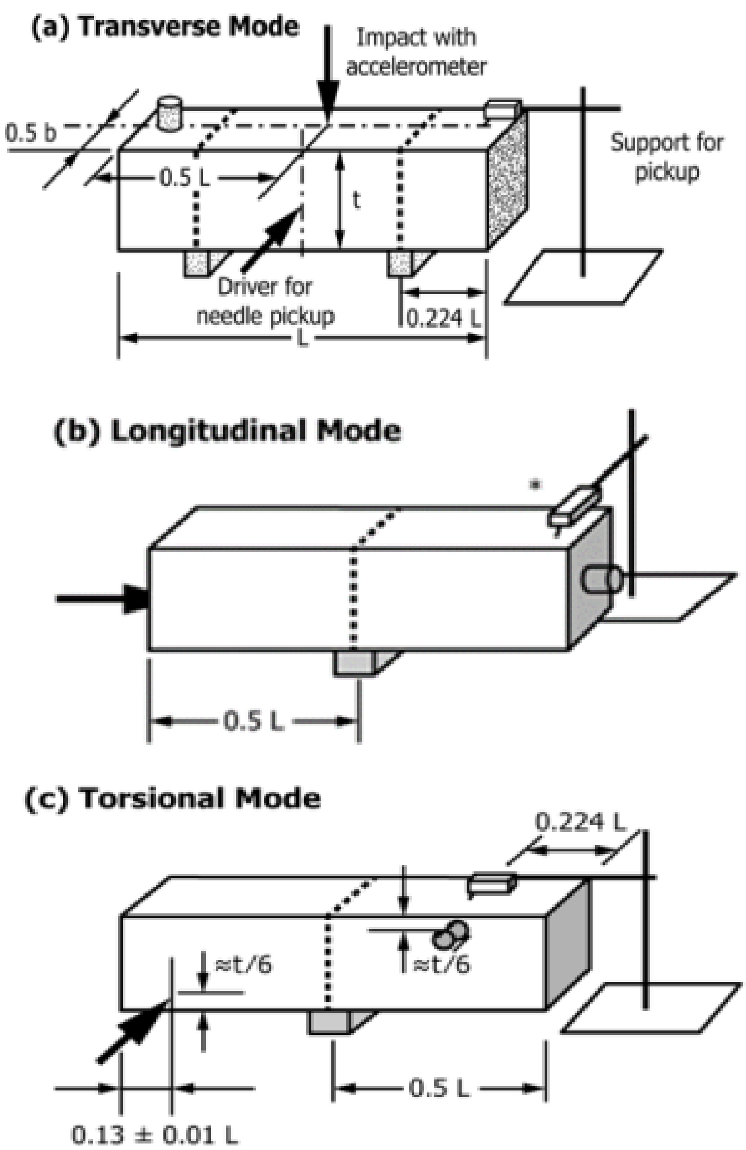


FIGURE 3.3: Resonance apparatus for dynamic testing as per ASTM C215 a) Transverse Frequency b) Longitudinal Frequency c) Torsional Frequency

3.5.2 Mechanical Properties of the Specimen

For all PC and JFRC specimens, mechanical tests have been done to determine the mechanical properties. The current study investigates how ordinary concrete stacks up against concrete composites incorporating jute fiber and yarn in terms of increases in flexural, compressive, and tensile strengths. The purpose of this research was to determine how much more powerful concrete composites are compared to traditional concrete. An Automatic Compression Testing Machine (MATEST s.r.l, Italy, capacity 3000 KN.), an Automatic Flexural Strength Testing Machine (MATEST s.r.l, Italy, capacity 150 KN.), and a Universal Testing Machine were used to conduct the compressive, flexural, and tensile tests, respectively.

A) Compressive Properties

Compressive strength is taken from the stress-strain graph. The area under the curve from zero to the peak load is considered the compressive initial energy absorption (CE1). The area under the curve from peak load to ultimate load is considered compressive post-cracking energy absorption (CE2). The total compressive energy absorption (CTE) is taken as the total area under the curve. The compressive toughness index (TI) is the ratio between total energy absorption to initial energy absorption.

B)Tensile Properties

An approach that provides an accurate picture of the material's mechanical characteristics is the evaluation of concrete's tensile strength, which may be done in a number of different ways. Because of its weakness and lack of tensile strength, concrete is unable to deal with direct stress in an effective manner. Toughness measures the energy required to crack a material. Testing the tensile strength of the concrete is required in order to determine the load at which the concrete components may fracture; as a result, failure due to tension is related to cracking. As a direct result of this, it is essential to test the tensile strength. Indirect tests for assessing the tensile strength of concrete are often known as breaking tests. These tests are also sometimes referred to as split tensile strength tests. The breaking of a concrete specimen is one of these tests that is performed. In the opposite direction, applying a compressive line load The test process consists of the generators of a concrete cylinder that has been put with its axis horizontal between the compressive planes. The splitting tensile strength test was carried out in accordance with the methodology outlined in the ASTM C 496/M496 standard. The area under the curve from zero to the peak load is considered the tensile initial energy absorption (TE1). The area under the curve from peak load to ultimate load is considered tensile post-cracking energy absorption (TE2). The total tensile energy absorption (TTE) is taken as the total area under the curve. The tensile toughness index (TI) is the ratio between total energy absorption to initial energy absorption.

C) Flexural Properties

Concrete's flexural strength is measured in terms of the material's ability to endure bending, and it is expressed in terms of the material's modulus of rupture. As a consequence of this, the two-point loading method was used in the testing of the flexural strength of concrete. Bearing blocks were used to ensure that the stresses that were given to the beam were perpendicular to the face of the specimen and that they were applied without eccentricity. Throughout the course of the test, the reaction maintained a consistent alignment with the direction in which the force was delivered. The procedure for the test was carried out in a manner that was in conformity with ASTM C 78-00. The area under the curve from zero to the peak load is considered the flexural initial energy absorption (FE1). The area under the curve from peak load to ultimate load is considered tensile post-cracking energy absorption (FE2). The total flexural energy absorption (FTE) is taken as the total area under the curve. The flexural toughness index (FTI) is the ratio between total energy absorption to initial energy absorption.

3.5.3 SEM Test

Scanning electron microscopic analysis is the best and versatile technique to find microstructural characteristic of concrete particles. This technique is used to study Cementious material at microscopic level. It is also used to see the behavior of cracks in concrete. The presence of cracks is predicted on basis of micro analysis. This technique also assists to see the behavior of fiber is concrete before and after cracking. Pull out and cavity in concrete due to stresses can be observed to study the attribute of fiber and its bonding with concrete.

3.6 Summary

For all PC and JFRC specimens, mechanical tests have been done to determine the mechanical properties. The current study investigates how ordinary concrete stacks up against concrete composites incorporating jute fiber and yarn in terms of increases in flexural, compressive, and tensile strengths. The purpose of this research was to determine how much more powerful concrete composites are compared to traditional concrete. An Automatic Compression Testing Machine (MATEST s.r.l, Italy, capacity 3000 KN.), an Automatic Flexural Strength Testing Machine (MATEST s.r.l, Italy, capacity 150 KN.), and a Universal Testing Machine were used to conduct the compressive, flexural, and tensile tests, respectively. ASTM standards are followed for finding mechanical and dynamic test for PC and JFRC. The results obtained are discussed in next chapter.

Chapter 4

Experimental Evaluation

4.1 Background

In the production of PC, a mix design ratio of 1: 2: 3: 0.6 is utilized, whereas in the production of JFC, a similar mix design is selected, along with the addition of 1%, 3%, and 5% jute fibers by mass of cement having a length of 30 mm, 40 mm, and 50 mm, respectively. These fibers' lengths are measured in millimeters. Utilizing this mix design ratio results in the production of PC. The investigation of the dynamic characteristics of concrete using a single fiber sample is what this is all about, and this is the method that is used to carry it out.

4.2 Dynamic Properties

Dynamic properties of Plain Concrete and Jute fiber reinforced concrete are examined to estimate the effect of jute fibers on the properties of concrete samples. Dynamic properties of PC specimen are obtained by the ASTM standard C215-14. Due to absence of a definite standard to find the dynamic properties of Jute fiber reinforced concrete, the same values are assumed to determine the dynamic properties of Jute fiber reinforced concrete.

It can be seen in Table 4.1 damping ratio in jute fiber reinforced concrete is double as compared to PC in case of cylindrical specimen and almost 75% more in case of

TABLE 4.1: Resonance frequency and damping ratio for beam and cylinder specimen

Specimen	Concrete	No. of specimen	Resonance Frequency			Damping Ratio
			f_l	f_t	f_r	
Beams	PC	3	1300 ± 156	1541 ± 49	1496 ± 105	2.68 ± 0.35
	JFRC	3	1220 ± 50	1202 ± 73	1324 ± 82	3.71 ± 1.15
Cylinder	PC	6	3314 ± 605	1735 ± 326	1448 ± 12	2.60 ± 0.44
	JFRC	6	1537 ± 417	999 ± 212	1407 ± 18	4.30 ± 0.97

beam-let as compared to plain concrete. Average values of both beam and cylinder specimens are same. The little difference may be attributed towards heterogeneity in composite. Although with the addition of jute fiber in concrete value of strength decreases but there is major increase in damping ratio is because of high energy absorption capacity of specimen. It is because of part of fiber in post cracking behavior of jute fiber reinforced concrete.

4.3 Compressive Properties

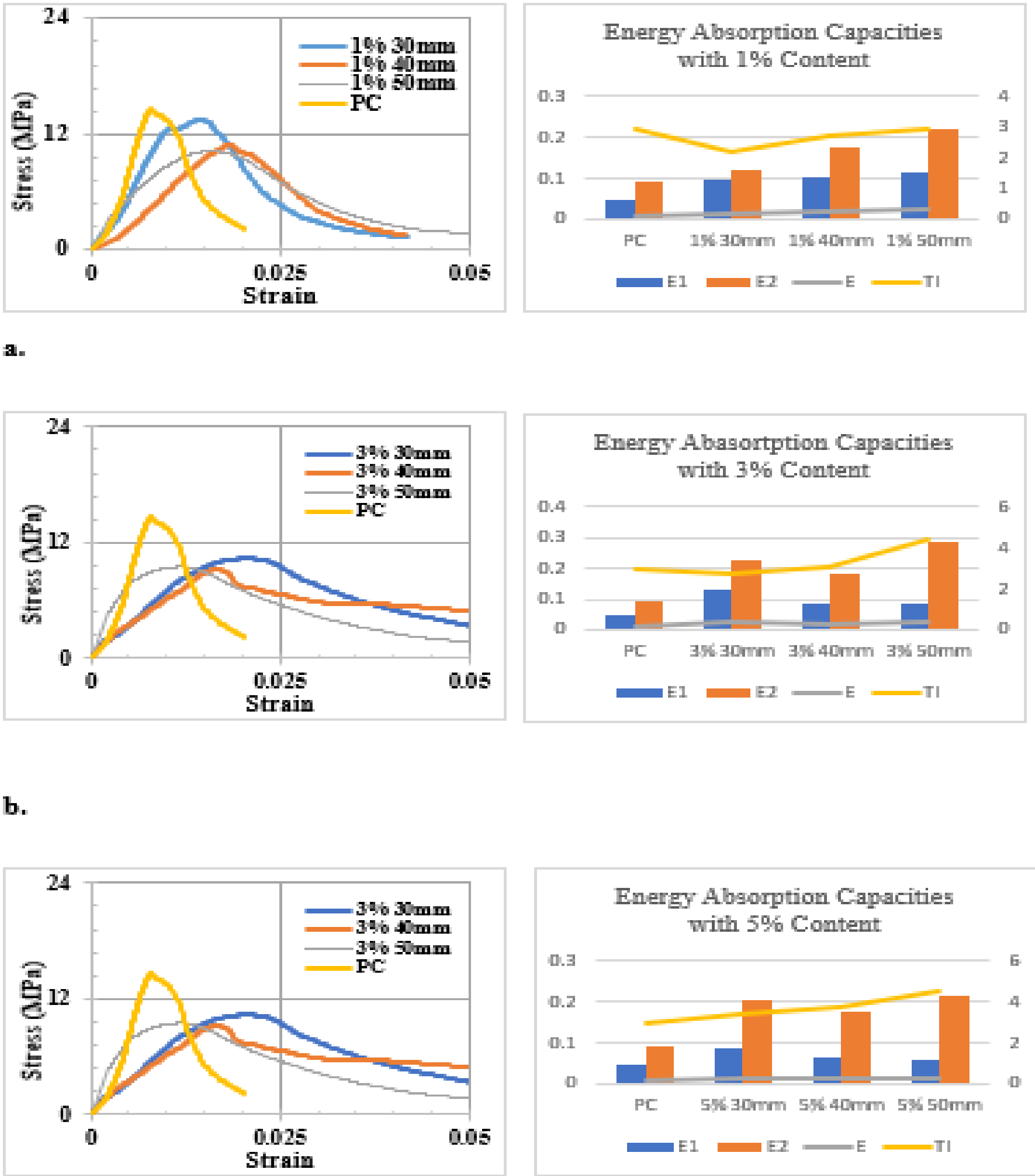
The compressive strength of concrete is used to determine its ability to resist the crushing impacts of a static load. The compressive force of static loads Because compressive strength testing is the most common, and many desirable properties of concrete are linked to its strength, it is critical that the compressive strength of concrete should be taken into account during structural design. Table 4.2 is showing compressive properties of plain concrete and all specimen of jute fiber reinforced concrete with different percentage of content and lengths. It can be clearly seen from the table that maximum strength value is 14.6 MPa of PC. In case of JFRC maximum strength value is A1 specimen which have highest value of 13.4 MPa. As the fiber length and percentage of fiber increases in jute fiber reinforced concrete strength is decreasing but value of toughness Index increasing. Maximum toughness index is 4,52 which is C3 specimen. C3 specimen has 50 mm length and 5% content of fiber and It is almost double of PC.

Table 4.2: Compressive properties of PC and JFRC

	Compressive Properties				
Specimen	**Strength (MPa)**	**CE1 (MJ/m^3)**	**CE2 (MJ/m^3)**	**CE (MJ/m^3)**	**TI**
O0	14.6 ± 1.4	0.08 ± 0.02	0.09 ± 0.02	0.17 ± 0.01	2.12 ± 0.70
A1	13.42±1.2	0.1± 0.02	0.2± 0.01	0.22± 0.02	2.22± 0.2
A2	10.86±1.1	0.1± 0.02	0.18± 0.01	0.28± 0.02	2.69± 0.1
A3	10.23±1.1	0.11± 0.02	0.22± 0.01	0.33± 0.02	2.97± 0.2
B1	10.33±1.2	0.13± 0.02	0.23± 0.02	0.36± 0.01	2.73± 0.1
B2	9.5±0.9	0.09± 0.02	0.18± 0.01	0.27± 0.01	3.13± 0.2
B3	9.±0.6	0.08± 0.02	0.29± 0.01	0.37± 0.01	4.39± 0.1
C1	7.42±0.4	0.09± 0.01	0.21± 0.02	0.29± 0.01	3.4± 0.1
C2	6.8±0.5	0.06± 0.02	0.18± 0.01	0.24± 0.02	3.72± 0.2
C3	7.52±0.2	0.06± 0.01	0.22± 0.02	0.28± 0.01	4.52± 0.1

4.3.1 Compressive Results on The Basis of a Fixed Percentage And Varying Length

The graph that is shown above in figure 4.1 (a) demonstrates the compressive behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 1% content and 30mm, 40mm and 50mm length of fiber. It can be seen in stress-strain curve compressive strength (C-S) of plain concrete is maximum 14.2 MPa. In case of JFRC maximum CS is with 1% content and 30mm length of fiber and reduces as length of fiber increase in mixture. Second graph is showing Energy absorption Capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.143 MJ/m^3. This value is increase in case of JFRC. As length of fiber increases in mixture C-E increases it is because of change is post cracking behavior of plain concrete due to



c.

FIGURE 4.1: Compressive properties of PC and JFRC with a)1% b)3% c)5% content

availability of fiber in it. Figure 4.2 (b) demonstrates the compressive behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 3% content and 30mm, 40mm and 50mm length of fiber. In case of JFRC maximum CS is with 3% content and 30mm length of fiber and reduces as length of fiber increase in mixture. Second graph shows the result of the compressive energy absorption capacity of Plain concrete and JFRC wtih different lengths of jut fibers of 3% content. The Plain Concrete PC energy absorption capacity before cracking CE1 = 0.048 MJ/m^3

and energy after cracking CE2 = 0.094 MJ/m^3 and the total energy is CE = CE1 + CE2 = 0.142 MJ/m3 and the compressive toughness index is CTI = CE/CE1 = 2.95. In case of JFRC as the length of fiber increases in mixture C-E increases and it is maximum at 50mm length. Figure 4.2 (c) demonstrates the compressive behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 5% content and 30mm, 40mm and 50mm length of fiber. In case of JFRC maximum CS is with 5% content and 30mm length of fiber and reduces as length of fiber increase in mixture. Second graph shows the result of the compressive energy absorption capacity of Plain concrete and JFRC wtih different lengths of jut fibers of 5% content. The Plain Concrete PC energy absorption capacity before cracking CE1 = 0.048 MJ/m^3 and energy after cracking CE2 = 0.094 MJ/m^3 and the total energy is CE = CE1 + CE2 = 0.142 MJ/m^3 and the compressive toughness index is CTI = CE/CE1 = 2.95. In case of JFRC as the length of fiber increases in mixture C-E increases and it is maximum at 50mm length. The JFRC energy absorption capacity before cracking CE1 = 0.06 MJ/m^3 and energy after cracking CE2 = 0.22 MJ/m^3 and the total energy is CE = CE1 + CE2 = 0.28 MJ/m^3 and the compressive toughness index is CTI = CE/CE1 = 4.66.

The values of toughness index and energy absorption have been considerably increased in all Jute fiber reinforced concrete specimens. It can be noted in Figure 4.2 that under compression loading the PC specimens should stiff behavior while JFC showed bridging effect due to jute fiber. In PC some of the fragments have fallen down. As length of the fiber increases in specimen bridging effect increase which is the reason of increase of post crack energy absorption capacities.

4.3.2 Results on The Basis of Fixed Length and Varying Percentages

The graph that is shown above in figure 4.3 (a) demonstrates the compressive behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 30mm length and 1%, 3% and 5% content of fiber. It can be seen in stress-strain curve compressive strength (C-S) of plain concrete is maximum 14.2 MPa. In

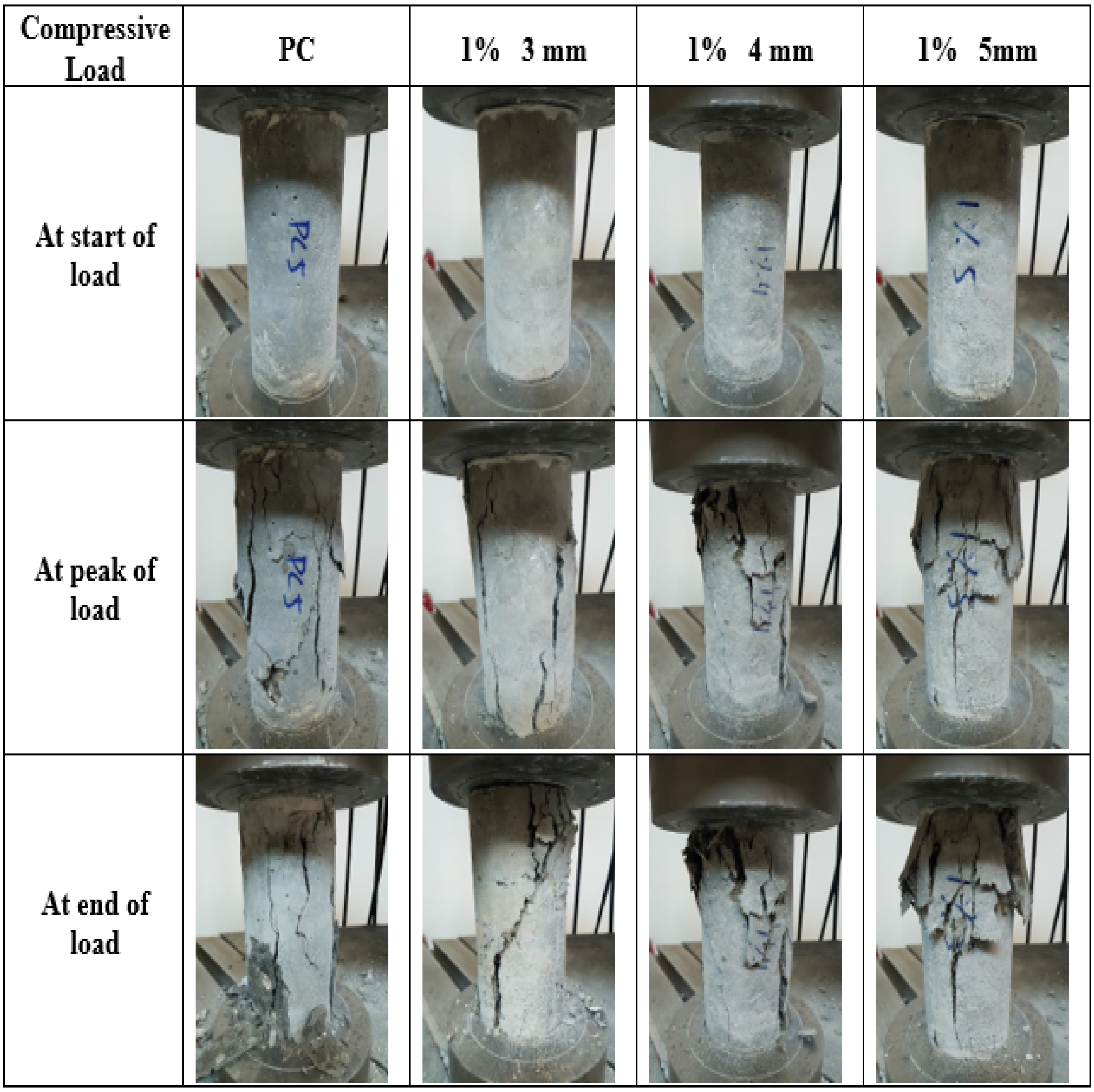


FIGURE 4.2: Cracking Behavior with different length and 1% content of Jute fiber

case of JFRC maximum CS is with 30mm length and 1% content of fiber and reduces as content of fiber increase in mixture. Second graph is showing Energy absorption Capacities of PC and JFRC with 30mm length. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.143 MJ/m^3. This value is increase in case of JFRC. As content of fiber increases in mixture C-E increases it is because of change is post cracking behavior of plain concrete due to bridging effect of fiber in it. figure 4.3 (b) demonstrates the compressive behavior of plain concrete (PC) and Jute fiber

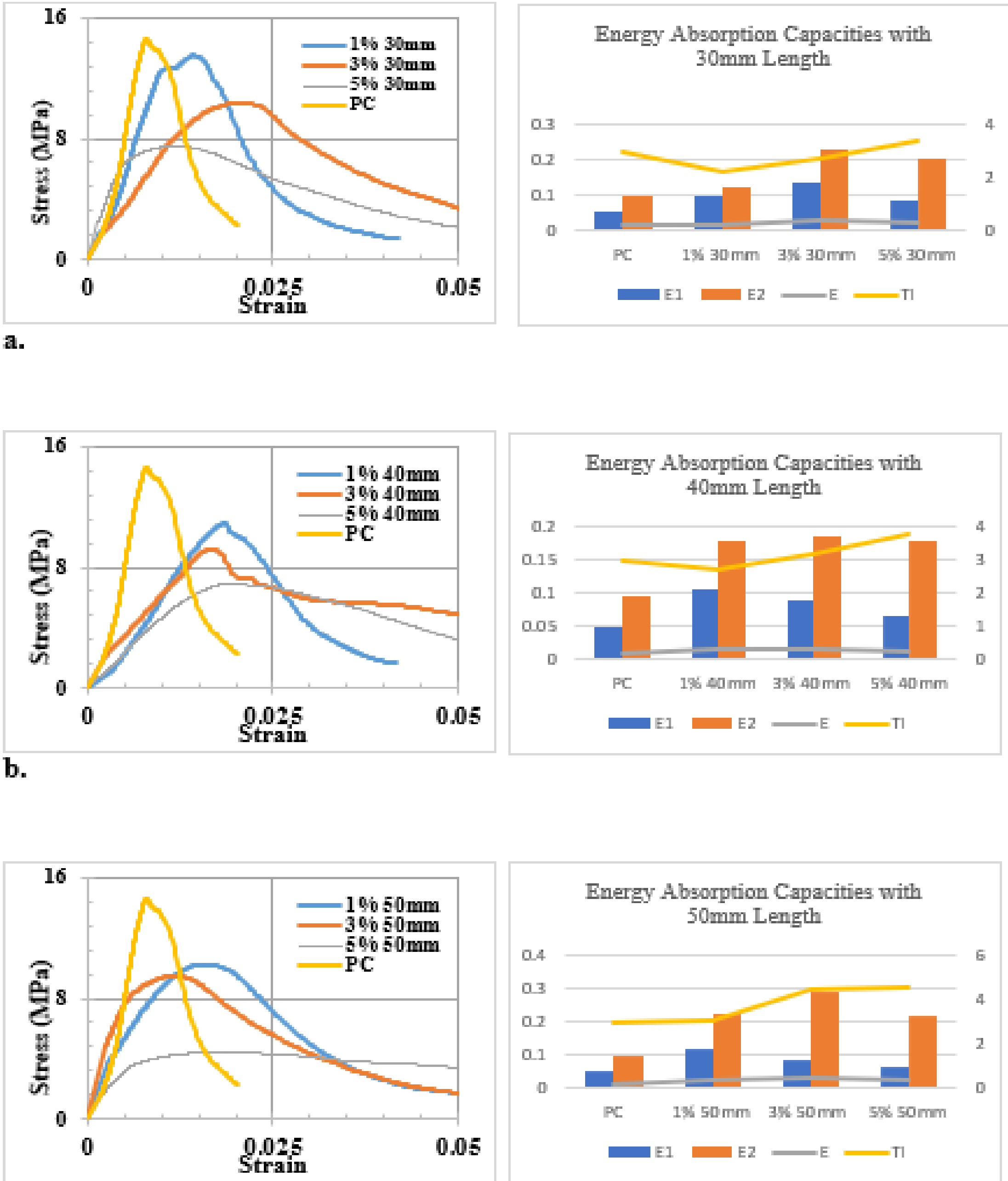


FIGURE 4.3: Compressive properties of PC and JFRC with a) 30mm b)40mm c)50mm length

reinforced concrete (JFRC) with 40mm length and 1%, 3% and 5% content of fiber. It can be seen in stress-strain curve compressive strength (C-S) of plain concrete is maximum 14.2 MPa. In case of JFRC maximum CS is with 30mm length and 1% content of fiber and reduces as content of fiber increase in mixture. Second graph is showing Energy absorption Capacities of PC and JFRC with 40mm length. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.143 MJ/m^3. This value is increase in case of JFRC. As content of fiber increases in mixture C-E increases and it is maximum with 40mm and 5% content fiber which is 0.28 MJ/m^3. figure 4.3 (c) demonstrates the compressive behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 50mm length and 1%, 3% and 5% content of fiber. It can be seen in stress-strain curve compressive strength (C-S) of plain concrete is maximum 14.2 MPa. In case of JFRC maximum CS is with 30mm length and 1% content of fiber and reduces as content of fiber increase in mixture. Second graph is showing Energy absorption Capacities of PC and JFRC with 40mm length. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.143 MJ/m^3. This value is increase in case of JFRC. As content of fiber increases in mixture C-E increases and it is maximum with 50mm and 3% content fiber which is 0.28 MJ/m3The JFRC energy absorption capacity before cracking CE1 = 0.088 MJ/m^3 and energy after cracking CE2 = 4.44 MJ/m^3 and the total energy is CE = CE1 + CE2 = 0.37 MJ/m3 and the compressive toughness index is CTI = CE/CE1 = 4.4. But specimen with 5% content and 50mm show less value of energy absorption capacities it can be due to poor mixing of fresh concrete with too much fiber content and length so it is advisable to use 3% content with 50 mm length to gain maximum post cracking energy. There is increase in the values of toughness index and energy absorption in all Jute fiber reinforced concrete specimens. It can be noted in Figure 4.4 that under compression loading the PC specimens showed stiff behavior while JFRC showed bridging effect due to jute fiber. This bridging effect is maximum in 3% content fiber as compared to 1% and 5%.

4.4 Split Tensile strength

Split tensile strength is measured from strain-deformation curves. Area under the curve is measured as energy absorption capacity of specimen. Splitting tensile

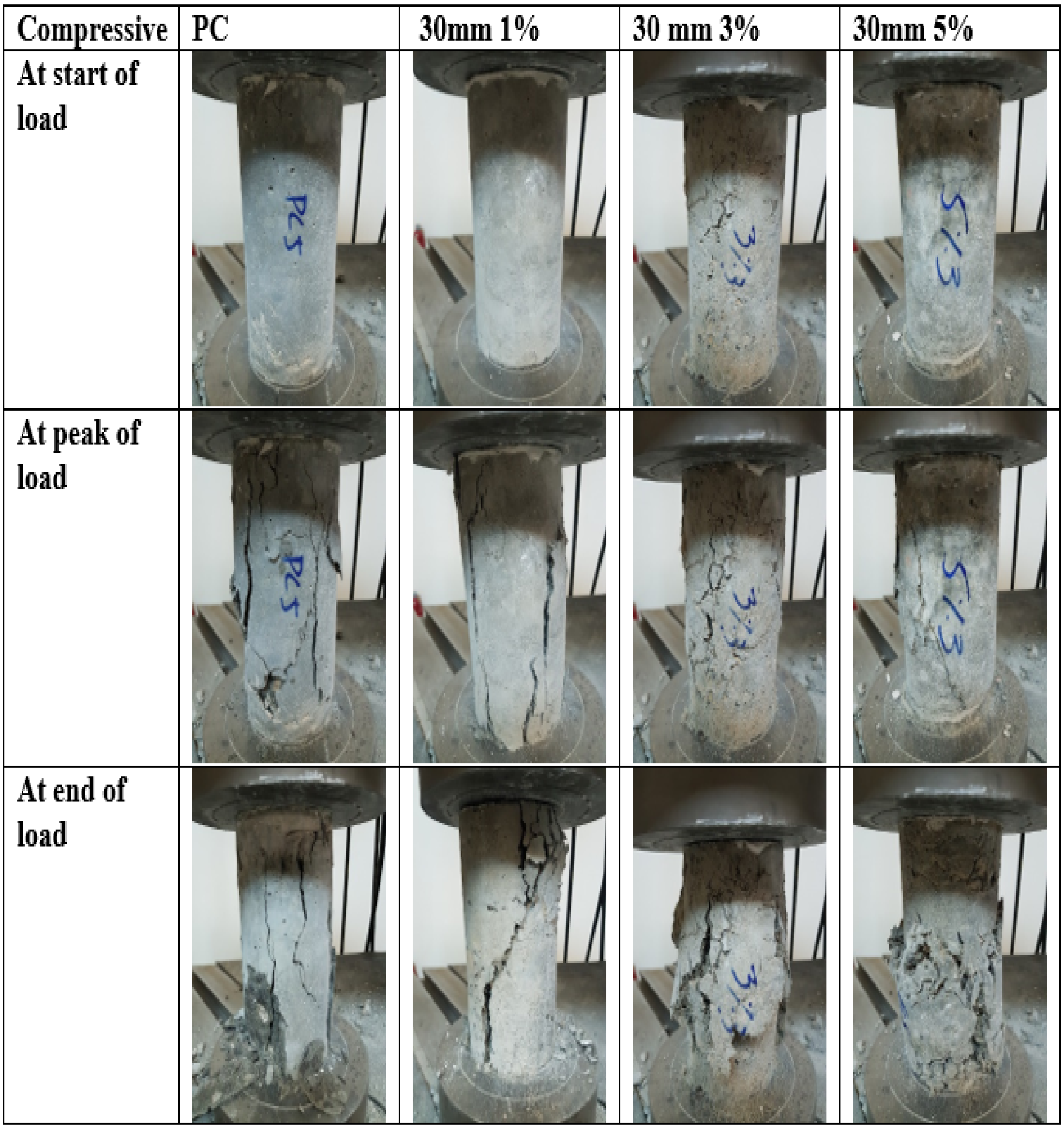


FIGURE 4.4: Cracking Behavior with different percentage and 30mm length of Jute fiber

strength (STS), splitting tensile pre-crack absorbed energy (SE1), splitting tensile post crack absorbed energy (SE2), splitting tensile total absorbed energy (STE) and splitting tensile toughness index (STI).

Table 4.3 is showing Tensile properties of plain concrete and all specimen of jute fiber reinforced concrete with different percentage of content and lengths. It can be clearly seen from the table that maximum strength value is 2.55 MPa of PC. In case of JFRC maximum strength value is A2 specimen which have highest value of 2.48 MPa. As the fiber length and percentage of fiber increases in jute fiber

TABLE 4.3: Tensile properties of PC and JFRC

	Tensile Properties				
Specimen	Strength (MPa)	STE1 (Nm)	STE2 (Nm)	SE (Nm)	STI
O0	2.54±0.49	25.36 ±2.53	0	25.36 ±5.53	1
A1	1.72±1.5	27.33±3.51	20.97±5.53	47.36±5.53	1.73±0.53
A2	2.48 ± 0.2	25.14±3.33	23.13±2.53	48.26±6.96	1.92±0.26
A3	2.01±0.7	19.07±1.53	31.29±2.03	50.64±6.53	2.62±0.59
B1	1.272±0.5	30.02±2.26	11.46±5.82	41.48±2.87	1.38±0.53
B2	1.43± 0.1	31.76±5.59	19.99±6.53	51.75±7.01	1.63±0.33
B3	1.466±0.75	25.87±3.56	29.29±5.55	55.16±2.03	2.13±0.53
C1	1.92± 0.5	43.55±4.53	21.68±9.51	64.89±9.9	1.49±0.33
C2	1.75± 0.2	27.53±1.51	39.50±1.51	67.03±2.03	2.43±0.59
C3	1.7± 0.1	20.27±7.57	48.23±6.96	68.5±9.01	3.37±0.53

reinforced concrete strength is decreasing but value of toughness Index increasing. Maximum toughness index is 3.37 which is C3 combination.

4.4.1 Results on The Basis of Fixed Percentage and Varying Length

The graph that is shown above in figure 4.5 (a) demonstrates the split tensile behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 1% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation curve split tensile strength (STS) of plain concrete is maximum 2.8 MPa. In case of JFRC maximum STS is with 1% content and 30mm length of fiber which is 2.48 MPa and reduces as length of fiber increase in mixture. Second graph is showing Split tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI)

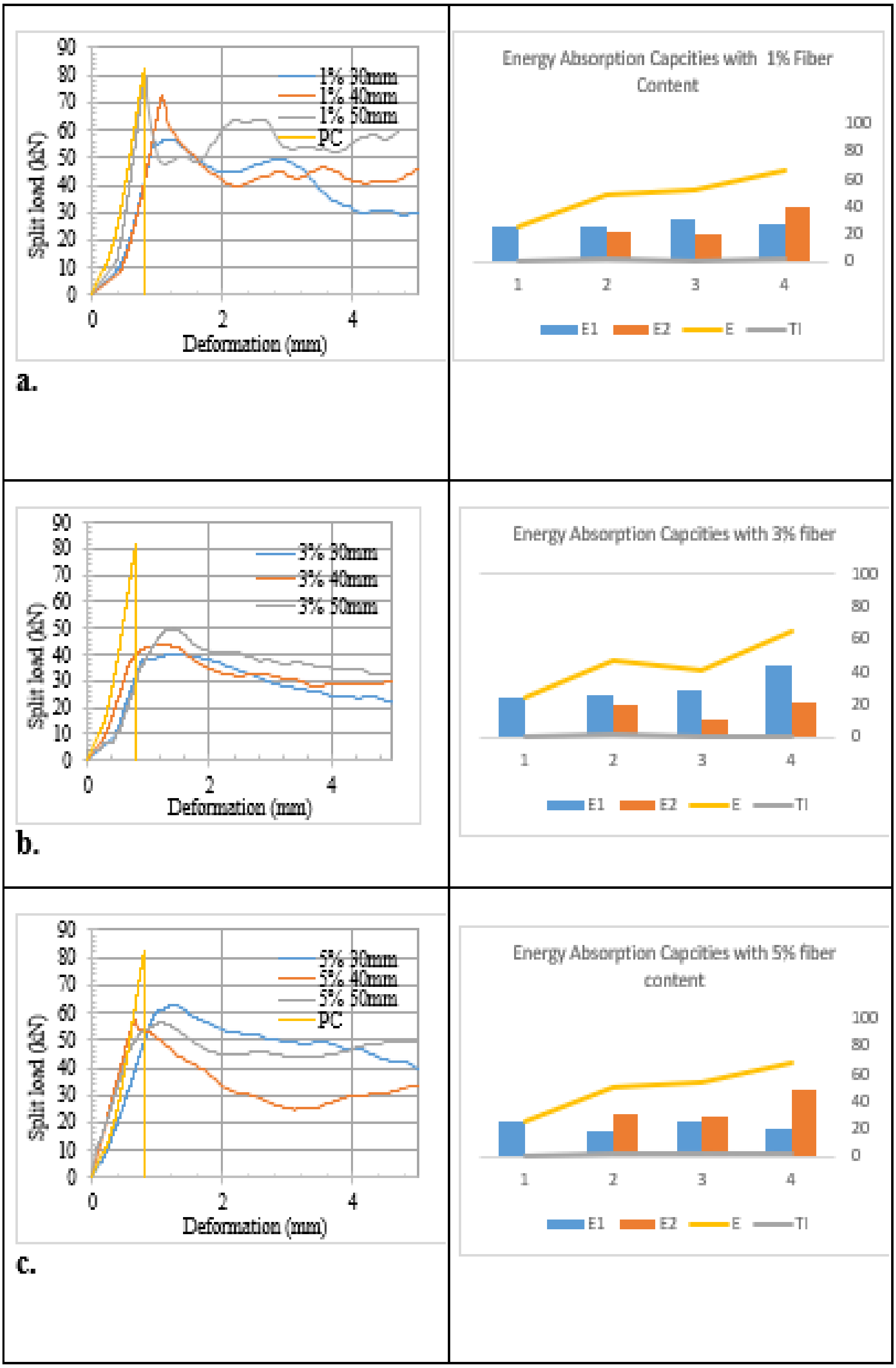


FIGURE 4.5: Split Tensile properties of PC and JFRC with a) 1% b)3% c)5% content

is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.025 Nm. This value is increase in case of JFRC. As length of fiber increases in mixture C-E increases it is because of change is post cracking behavior of plain concrete due to availability of fiber in it. Figure 4.5 (b) demonstrates the split tensile behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 3% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation curve split tensile strength (STS) of plain concrete is maximum 2.8 MPa. In case of JFRC maximum STS is with 3% content and 50mm length of fiber which is 1.75 MPa and reduces as length of fiber increase in mixture but it is less than 1% 30mm. Second graph is showing Split tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.025 MJ/m^3. This value is increase in case of JFRC. As length of fiber increases in mixture STE increases it is because of bridging effect fiber in plain concrete. Figure 4.5 (c) determines the split tensile behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 5% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation curve split tensile strength (STS) of plain concrete is maximum 2.8 MPa. In case of JFRC maximum STS is with 5% content and 30mm length of fiber which is 2.1 MPa and reduces as length of fiber increase in mixture but it is less than 1% 30mm and 3% 50mm. Second graph is showing Split tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.025 Nm. This value is increase in case of JFRC. As length of fiber increases in mixture STE increases it is because of bridging effect fiber in plain concrete. The JFRC energy absorption capacity before cracking STE1 = 0.13 Nm and energy after cracking STE2 = 6.2 Nm and the total energy is CE = CE1 + CE2 = 6.33 Nm and the compressive toughness index is STI = SE/SE1 = 18.6.

4.4.2 Results on The Basis of Fixed Length and Varying Percentages

The graph that is shown above in figure 4.6 (a) demonstrates the split tensile behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 30mm length and 1%, 3% and 5% content of fiber. It can be seen in strain-deformation curve split tensile strength (STS) of plain concrete is maximum 2.8 MPa. In case of JFRC maximum STS is with 30mm length and 1% content of fiber which is 2.48 MPa and reduces as content of fiber increase in mixture. Second graph is showing Split tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.025 MJ/m^3. This value is increase in case of JFRC. As content of fiber increases in mixture STE increases keeping length of fiber constant. It is because of change is post cracking behavior of plain concrete due to availability of fiber in it. As content of fiber increases in mixture STE increases it is because of bridging effect fiber in plain concrete. The JFRC energy absorption capacity before cracking STE1 = 0.13 Nm and energy after cracking STE2 = 6.2 Nm and the total energy is CE = CE1 + CE2 = 6.33 MJ/m^3 and the compressive toughness index is STI = SE/SE1 = 18.6. figure 4.6 (b) demonstrates the split tensile behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 40mm length and 1%, 3% and 5% content of fiber. It can be seen in strain-deformation curve split tensile strength (STS) of plain concrete is maximum 2.8 MPa. In case of JFRC maximum STS is with 40mm length and 1% content of fiber which is 2.45 MPa and reduces as content of fiber increase in mixture. Second graph is showing Split tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.025 MJ/m^3. This value is increase in case of JFRC. As content of fiber increases in mixture STE increases keeping length of

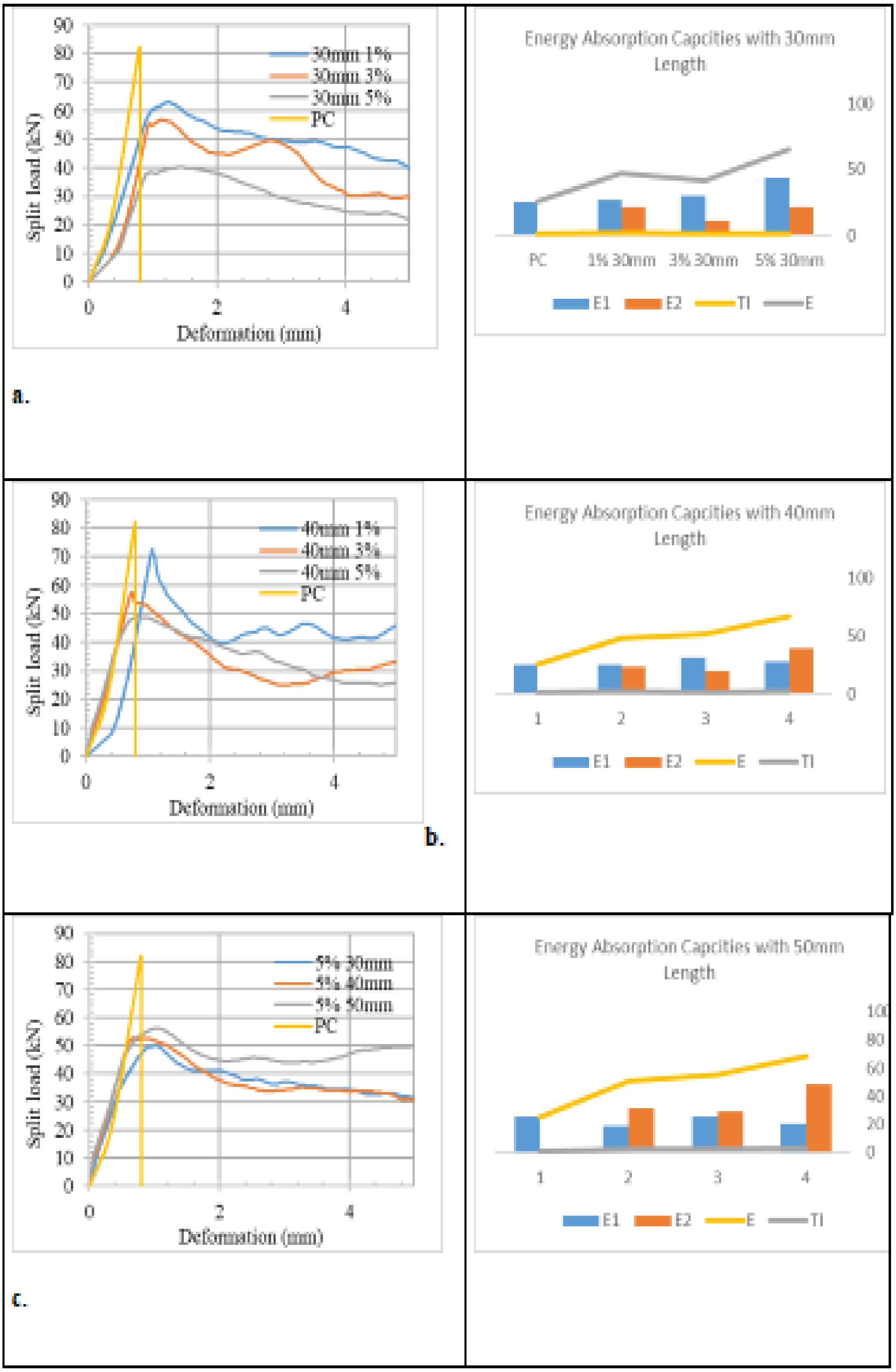


FIGURE 4.6: Splitting tensile properties of PC and JFRC with a) 30mm b)40mm c)50mm length

fiber constant. It is because of change is post cracking behavior of plain concrete due to availability of fiber in it. As content of fiber increases in mixture STE increases it is because of bridging effect fiber in plain concrete. The JFRC energy absorption capacity before cracking STE1 = 0.13 Nm and energy after cracking STE2 = 7.1 Nm and the total energy is STE = STE1 + STE2 = 7.23 Nm and the compressive toughness index is STI = SE/SE1 = 21.6. Figure 4.6 (c) demonstrates the split tensile behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 50mm length and 1%, 3% and 5% content of fiber. It can be seen in strain-deformation curve split tensile strength (STS) of plain concrete is maximum 2.8 MPa. In case of JFRC maximum STS is with 50mm length and 5% content of fiber which is 1.75 MPa and reduces as content of fiber increase in mixture. Second graph is showing Split tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the compressive energy of PC plain concrete in graphs is 0.025 MJ/m^3. This value is increase in case of JFRC. As content of fiber increases in mixture STE increases keeping length of fiber constant. It is because of change is post cracking behavior of plain concrete due to availability of fiber in it. As content of fiber increases in mixture STE increases it is because of bridging effect fiber in plain concrete. The JFRC energy absorption capacity before cracking STE1 = 0.4 Nm and energy after cracking STE2 = 4.1 Nm and the total energy is STE = STE1 + STE2 = 4.5 Nm and the compressive toughness index is STI = SE/SE1 = 11.25.

4.5 Flexural Properties

Flexural is measured from strain-deformation curves. Area under the curve is measured as energy absorption capacity of specimen. Modulus of rupture defines bending stress a material can bear before it yields. If MoR of concrete improved it enhances bending moment capacity structural element. Flexural strength (FS), Flexural pre-crack absorbed energy (FE1), Flexural post crack absorbed energy (FE2), Flexural total absorbed energy (FTE) and Flexural toughness index (FTI).

These properties are measured for each specimen. Table 4.4 is showing flexural properties of plain concrete and all specimen of jute fiber reinforced concrete with different percentage of content and lengths. It can be clearly seen from the table that maximum strength value is 2.55 MPa of PC. In case of JFRC maximum strength value is A2 specimen which have highest value of 2.48 MPa. As the fiber length and percentage of fiber increases in jute fiber reinforced concrete strength is decreasing but value of toughness Index increasing. Maximum toughness index is C1 combination.

TABLE 4.4: Flexural properties of PC and JFRC

	Flexural Properties				
Specimen	**Strength (MPa)**	**FE1 (Nm)**	**FE2 (Nm)**	**FE (Nm)**	**FTI**
O0	3.33 ± 0.6	4.72 ± 0.20	0	4.72 ± 0.20	1
A1	0.783±0.08	2.77± 0.2	9.72± 1.2	12.5± 1.6	4.51± 0.20
A2	1.71± 0.16	7.46± 0.6	1.4± 0.6	8.86± 1.2	1.19± 0.04
A3	1.6± 0.15	5.64± 0.5	0.89± 0.6	6.53± 0.6	1.16± 0.01
B1	0.992±0.03	3.49± 0.4	8.84± 1.4	12.33± 1.1	3.53± 0.2
B2	0.68± 0.04	2.56± 0.2	1.7± 0.2	4.26± 0.6	1.66± 0.03
B3	0.57± 0.02	4.81± 0.3	3.22± 0.6	8.02± 1.0	1.67± 0.08
C1	1.3± 0.04	1.14± 0.1	5.23± 0.9	6.37± 0.99	5.32± 1.2
C2	1.21± 0.11	3.37± 0.3	4.8± 0.4	8.17± 0.6	2.42± 0.10
C3	0.9± 0.01	2.45± 0.1	3.42± 0.1	5.86± 1.6	2.4± 0.10

4.5.1 Results on the Basis of Fixed Percentage and Varying Length

The graph that is shown above in figure 4.7 (a) demonstrates the Flexural behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 1% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation

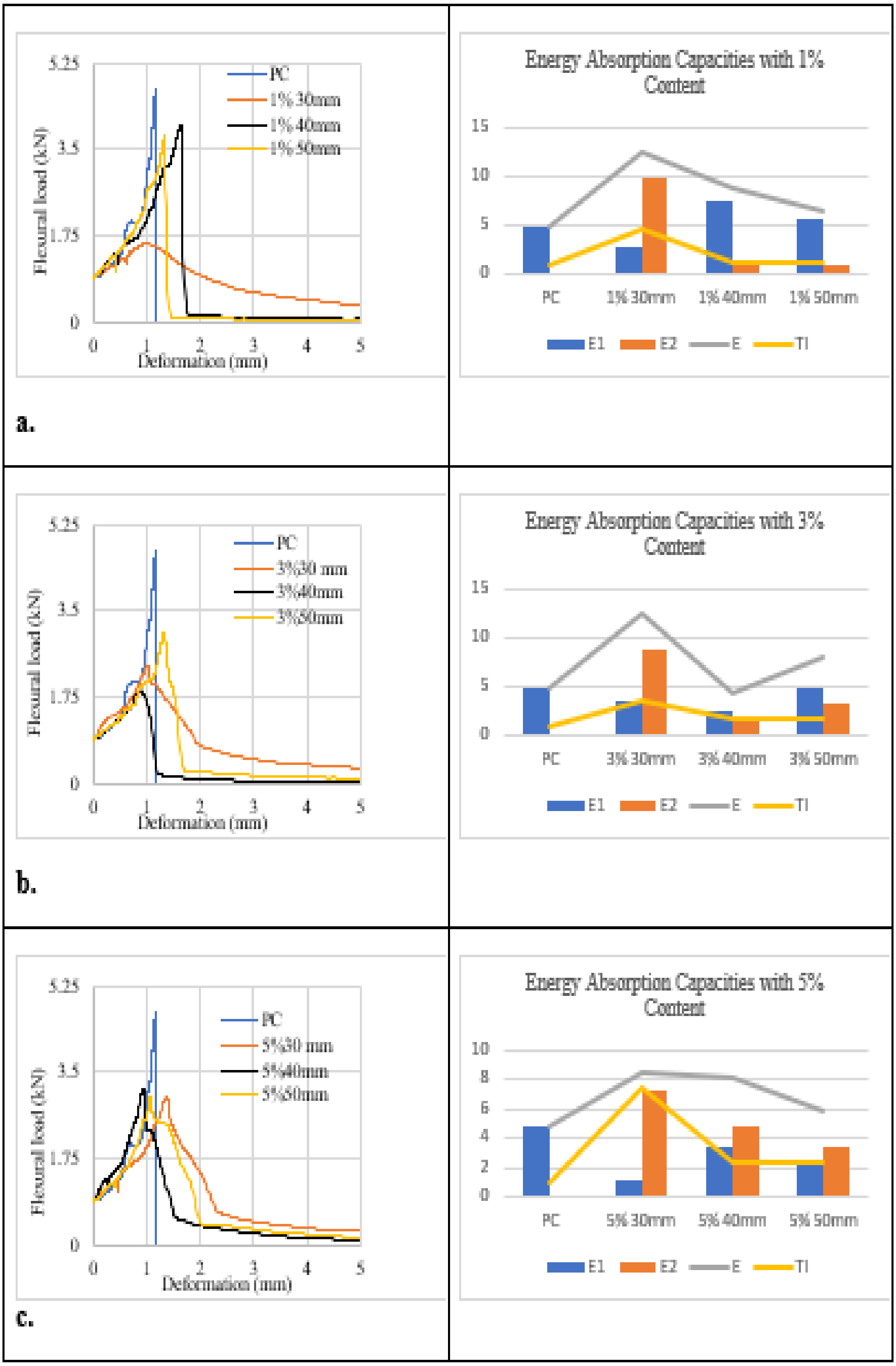


FIGURE 4.7: Flexural properties of PC and JFRC with a) 1% b)3% c)5% content

curve flexural strength (FS) of plain concrete is maximum 3.33 MPa. In case of JFRC maximum FS is with 1% content and 40mm length of fiber which is 2.7 MPa and reduces as length of fiber decrease in mixture. Second graph is showing Flexural tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the Flexural energy of PC plain concrete in graphs is 4.72 MJ/m^3. This value is increase in case of JFRC. As length of fiber increases in mixture FEE increases it is because of bridging effect fiber in plain concrete. The JFRC energy absorption capacity before cracking FE1 = 2.77MJ/m^3 and energy after cracking FE2 = 9.72 MJ/m^3 and the total energy is FE = FE1 + FE2 = 12.5MJ/m^3 and the flexural toughness index is FEI = FE/FE1 = 4.5. Figure 4.7 (b) demonstrates the Flexural behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 3% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation curve flexural strength (FS) of plain concrete is maximum 3.33 MPa. In case of JFRC maximum FS is with 3% content and 50mm length of fiber which is 1.9 MPa and reduces as length of fiber decrease in mixture. Second graph is showing Flexural tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the Flexural energy of PC plain concrete in graphs is 4.72 MJ/m^3. This value is increase in case of JFRC. As length of fiber increases in mixture FEE decrease. The JFRC energy absorption capacity before cracking FE1 = 3.33MJ/m^3 and energy after cracking FE2 = 8.72 MJ/m^3 and the total energy is FE = FE1 + FE2 = 12.05MJ/m^3 and the flexural toughness index is FEI = FE/FE1 = 1.5. figure 4.7 (c) demonstrates the Flexural behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 5% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation curve flexural strength (FS) of plain concrete is maximum 3.33 MPa. In case of JFRC maximum STS is with 5% content and 30mm length of fiber which is 1.9 MPa and reduces as length of fiber increase in mixture. Second graph is showing

Flexural tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the Flexural energy of PC plain concrete in graphs is 4.72 MJ/m^3. This value is increase in case of JFRC. As length of fiber increases in mixture FEE decrease. The JFRC energy absorption capacity before cracking FE1 = 1.33MJ/m^3 and energy after cracking FE2 = 7.72 MJ/m^3 and the total energy is FE = FE1 + FE2 = 9.05MJ/m^3 and the flexural toughness index is FEI = FE/FE1 = 6.8.

4.5.2 Results on the Basis of Fixed Length and Varying Percentages

The graph that is shown above in figure 4.8 (a) demonstrates the Flexural behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 1% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation curve flexural strength (FS) of plain concrete is maximum 3.33 MPa. In case of JFRC maximum FS is with 1% content and 40mm length of fiber which is 2.7 MPa and reduces as length of fiber decrease in mixture. Second graph is showing Flexural tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the Flexural energy of PC plain concrete in graphs is 4.72 MJ/m^3. This value is increase in case of JFRC. As length of fiber increases in mixture FEE increases it is because of bridging effect fiber in plain concrete. The JFRC energy absorption capacity before cracking FE1 = 2.77MJ/m^3 and energy after cracking FE2 = 9.72 MJ/m^3 and the total energy is FE = FE1 + FE2 = 12.5MJ/m^3 and the flexural toughness index is FEI = FE/FE1 = 4.5. Figure 4.8 (b) demonstrates the Flexural behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 3% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation curve flexural strength (FS) of plain concrete is maximum 3.33 MPa. In case of

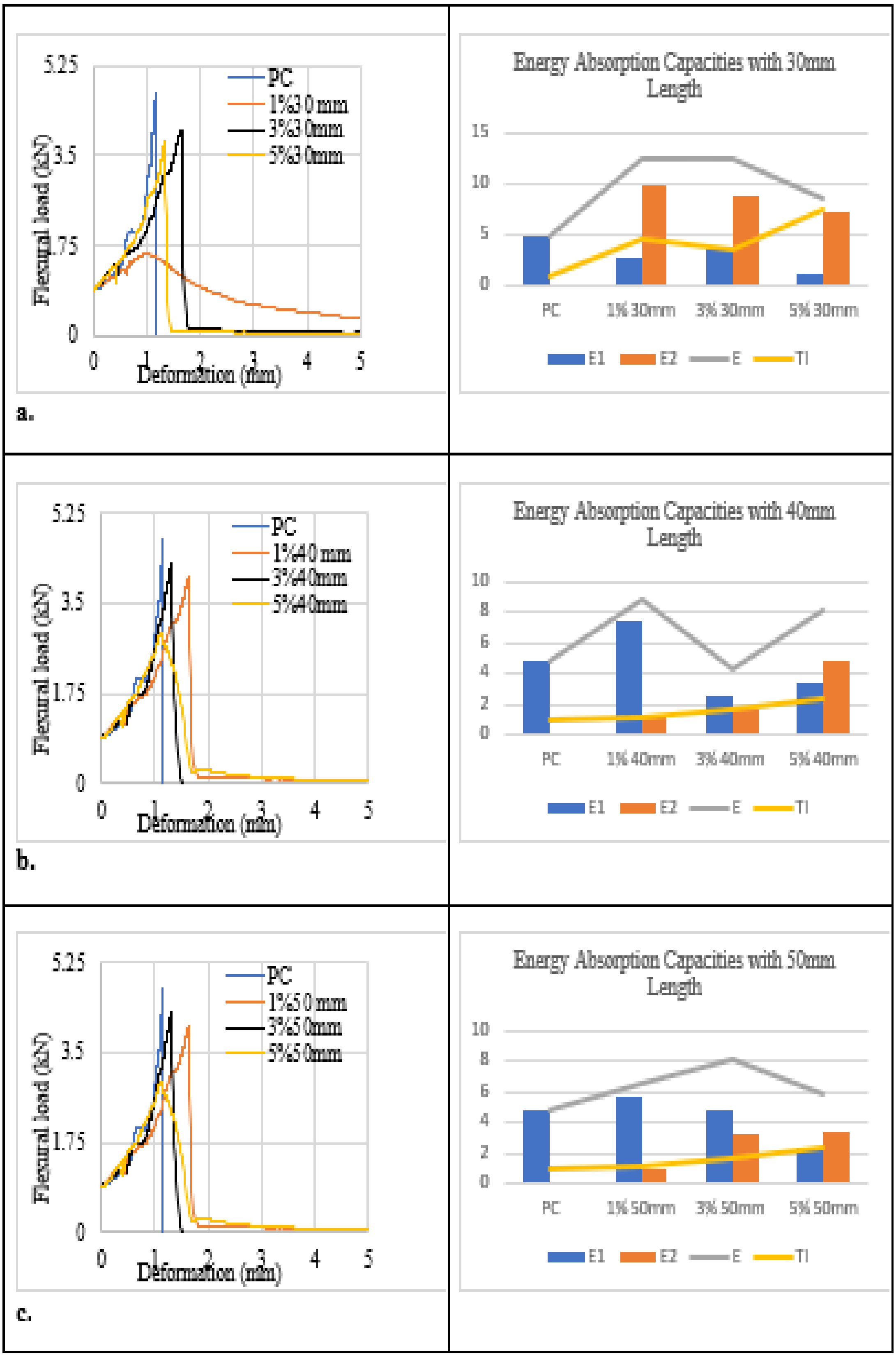


Figure 4.8: Flexural properties of PC and JFRC with a) 30 mm b)40 mm c)50mm length

JFRC maximum FS is with 3% content and 50mm length of fiber which is 1.9 MPa and reduces as length of fiber decrease in mixture. Second graph is showing Flexural tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the Flexural energy of PC plain concrete in graphs is 4.72 MJ/m^3. This value is increase in case of JFRC. As length of fiber increases in mixture FEE decrease. The JFRC energy absorption capacity before cracking FE1 = 3.33MJ/m^3 and energy after cracking FE2 = 8.72 MJ/m^3 and the total energy is FE = FE1 + FE2 = 12.05MJ/m^3 and the flexural toughness index is FEI = FE/FE1 = 1.5. Figure 4.8 (c) demonstrates the Flexural behavior of plain concrete (PC) and Jute fiber reinforced concrete (JFRC) with 5% content and 30mm, 40mm and 50mm length of fiber. It can be seen in strain-deformation curve flexural strength (FS) of plain concrete is maximum 3.33 MPa. In case of JFRC maximum STS is with 5% content and 30mm length of fiber which is 1.9 MPa and reduces as length of fiber increase in mixture. Second graph is showing Flexural tensile energy absorption capacities of PC and JFRC. E1 is pre-cracking energy absorption capacity, E2 is post cracking energy absorption capacity and E is total sum of both energies E = E1+E2. Toughness index (TI) is the ratio between E and E1. It was determined that the Flexural energy of PC plain concrete in graphs is 4.72 MJ/m^3. This value is increase in case of JFRC. As length of fiber increases in mixture FEE decrease. The JFRC energy absorption capacity before cracking FE1 = 1.33MJ/m^3 and energy after cracking FE2 = 7.72 MJ/m^3 and the total energy is FE = FE1 + FE2 = 9.05MJ/m^3 and the flexural toughness index is FEI = FE/FE1 = 6.8.

4.6 SEM Analysis of Specimens

After the stress strain curve, compressive properties and comparison of mechanical properties the results are analyzed through SEM images at failure surface, refer Fig. 4.9 (a). These images assisted in studying fiber and concrete matrix bonding under different types of loading. SEM images shows the conditions resulted at tested surface of JFRC specimen under compressive load. Fiber pull-out is clearly evident from the SEM images. It can also be noted that there is a circumferential debonding at fiber. Similarly, fiber break length wise is visible from SEM images. While analyzing images cavity near fiber is observed.

In case of tensile the specimens under splitting loading showed sudden failure and broken into two pieces are plain concrete while bridging effect was noticed for JFRC specimens. This bridging effect enhances energy absorption capacity of composite which results high toughness index. Small cavities near fiber shows entrapped air between concrete matrix and fiber. SEM images at failure surface of tested JFC specimen are shown under splitting load as shown Fig. 4.9 (b). The cause of failure observed through analysis is fiber pull-out. The visible cavity at the toe of fiber is indication of improper bonding of fiber and concrete matrix. On the other hand, cavity is not much deep, so it can be assumed that the reason behind the cavity is air entrapped near the surface of fiber.

Application of flexural load resulted in pull-out of fibers and along with splitting of fiber as shown fig 4.9 (c). The splitting of fiber is like threads. Existence of concrete matrix is clearly visible through SEM images. Presence of small cavity on tested surface indicates good bonding among concrete and fiber, whereas propagation of cavity resulted.

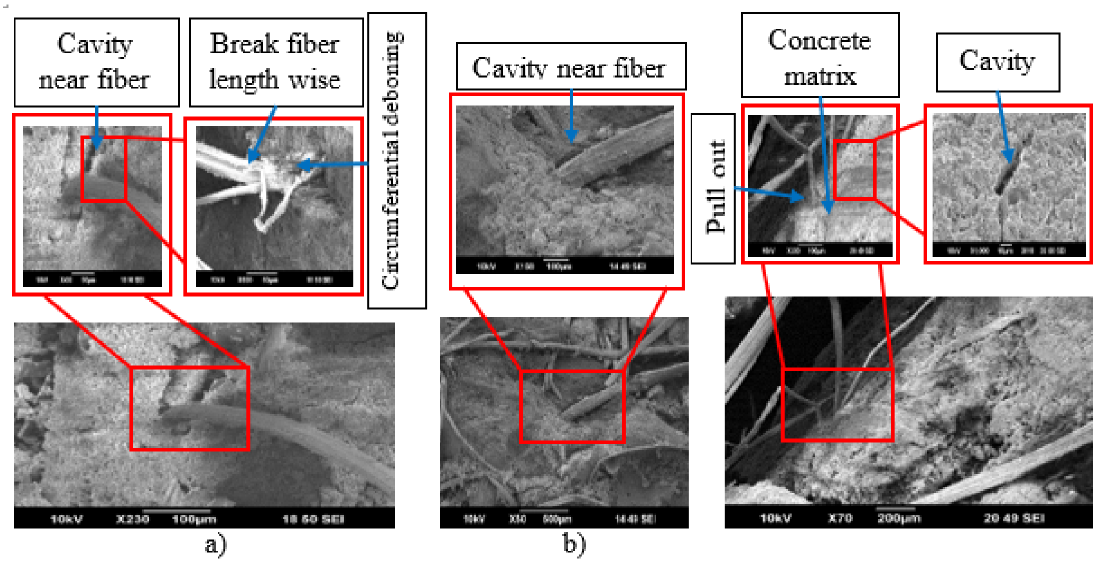


FIGURE 4.9: SEM analysis of mechanical specimens under; a) compressive load, b) split load and c) flexural load test

4.7 Summary

In this chapter, the mechanical properties and dynamic behavior of both plain concrete and jute fiber reinforced concrete (JFRC) were studied and evaluated at different percentages and lengths. A mix design ratio of 1:2:3 with a 0.6 W/C ratio was used to calculate the properties of both plain concrete (PC) and JFRC. The results showed that while the mechanical strength of JFRC was lower than that of PC, the toughness index was improved in all cases. Furthermore, the dynamic modulus of rigidity was enhanced with the increase in jute fiber length and content. However, the workability of all JFRC was decreased as compared to PC with the addition of jute fibers at different lengths and percentages. The increased tensile and flexural strength and toughness of JFRC were attributed to the tendency of jute fibers to absorb both pre-crack and post-crack energy. The compressive energy absorption capacity was also improved, but with a compromise in compressive strength. Fiber pullout and fiber breakage were also observed during the testing.

Chapter 5

Guidelines for Practical Implementation

5.1 Background

The tests performed on the specimens revealed valuable information about the influence of jute fiber of varying lengths (30 mm, 40 mm, and 50 mm) and percentages (1%, 3%, and 5%) on the properties of reinforced concrete. The graphs illustrating stress-strain, load deflection, and load deformation demonstrate the impact of jute fiber on the mechanical characteristics of concrete. The findings from the dynamic and mechanical testing were then used to determine the optimal combinations of jute fiber lengths and percentages. The mechanical properties of plain concrete were used as a comparison to assess the impact of different fiber lengths and content on JFRC. The minimum compressive strength of concrete specified by the ACI (American Concrete Institute) code for structural purposes is 17.5 MPa. To attain strengths greater than 17.5 MPa, it is necessary to modify the concrete mix design. This chapter provides in-depth analysis on the practical application of this study, as well as recommendations for using jute fiber of varying lengths and percentages in real-world situations.

5.2 Optimum Combinations of Different Lengths and Percent of Jute Fibers

Optimization of concrete mix is to have a mix design so as to get the favorable different properties at the same time. It is not necessary to get the maximum values of all properties with one mix design. There will be a gain and loss in properties. The maximum gain and minimum losses in few properties may be regarded as optimization.

Table 5.1 provides the maximum and minimum values obtained through mechanical and dynamic testing, respectively. This study found that for compression members such as columns, the combination of jute fibers with a 30 mm length and 1% content in concrete offers lower compressive strength compared to plain concrete, but a higher compressive toughness index. As the fiber length and content in concrete increase, the compressive strength decreases, but the toughness index significantly increases, indicating a high capacity for post-cracking energy absorption. The split tensile strength reaches its maximum value when using a fiber length of 30 mm and a fiber content of 3%, suggesting that smaller fiber lengths and more discrete fiber particles produce better bonding with concrete. The maximum split tensile toughness value was obtained using a fiber length of 30 mm and a fiber content of 5% in concrete. The flexural strength was highest with a fiber content of 5% and a fiber length of 30 mm. The maximum flexural toughness index was achieved with a fiber length of 30 mm and a fiber content of 3%. Thus, for maximum flexural properties in JFRC, it is recommended to use 30 mm length fibers with 3% to 5% content.

Table 5.1 provides the JFRC mix design combinations that offer the best strength and toughness values. For strength, a fiber content of 1% provides the best results for compressive and tensile strength, while a fiber content of 5% provides the highest flexural strength. It is recommended to use fiber lengths of 30 to 40 mm to achieve the best possible strengths. For toughness, a fiber content of 5% provides the highest values.

Table 5.1: Optimum Combinations of Varying Length and Percentage of Jute Fiber Concrete

Concrete type	**Compressive**			**Splitting Tensile**			**Flexural**		
	C-S (MPa)	**CTE (MJ/m^3)**	**CTI (-)**	**STS (MPa)**	**STE (Nm)** .	**STI (-)**	**F-S (MPa)**	**FTE (Nm)**	**FTI (-)**
PC's Value	14.26± 1.49	0.17 ± 0.01	2.12±0.7	2.54 ± 0.49	25.36 ± 5.53	1	3.33 ± 0.6	4.72 ± 0.20	1
Jute fiber with a min value	4.181±0.2 C3	0.217± 0.02 A1	2.22±0.04 A1	1.466±1.5 B3	2.363±9.8 A1	1.38±0.6 B1	0.76±0.1 A1	6.53±0.4 A3	1.15±0.02 A3
Jute fiber with a max value	13.42±1.2 A1	0.37±0.02 B3	4.4±0.3 B3	2.48 ± 0.1 A2	5.97±10.7 C1	3.37±0.53 C1	3.177 ±0.4 C1	12.32±0.88 B1	3.53±0.3 B1
Recommendation For Specific Property									
a.From strength point of view	A1 (1% 30 mm)			A2 (1% 40 mm)			C1 (5% 30 mm)		
	13.42	0.217	2.22	2.48	3.10	1.92	3.177	8.02	1.66
b.From toughness point of view	B3 (3% 50 mm)			C3 (5% 30 mm)			B1 (3% 30 mm)		
	9.3	0.37	4.4	1.92	5.97	3.37	1.10	12.32	3.53

Concrete type	Compressive			Splitting Tensile			Flexural		
	C-S (MPa)	**CTE (MJ/m^3)**	**CTI (-)**	**STS (MPa)**	**STE (Nm)**	**. STI (-)**	**F-S (MPa)**	**FTE (Nm)**	**FTI (-)**
Recommendation For Specific Application									
a.A1 for columns/compression members	13.42	0.22	2.22	1.772	47.36	1.73	0.78	12.5	4.51
b.A2 for slabs and beams	10.86	0.28	2.69	2.48	48.26	1.92	1.71	8.86	1.19
c.C1 for the structure stressed by lateral loading	7.42	0.29	3.4	1.92	64.89	1.49	1.9	8.87	7.32

The above results can be compared with prior research to obtain an understanding of the optimal mix design for desired results in various applications. Most prior studies have employed a 5% fiber content and 50 mm fiber length for all applications. However, this study provides varying mix design options for different applications and can inform future research.

5.3 Guideline for Large-Scale Production of Optimized JFRC in Industry

The production of optimized Jute Fiber Reinforced Concrete (JFRC) on a large scale in the industry requires careful attention to certain guidelines to ensure that the final product meets the desired quality standards. To start, it is important to use high-quality jute fibers that meet specific tensile strength and elongation criteria. The fibers should be thoroughly mixed into the concrete mixture using appropriate equipment to ensure uniform distribution. Proper curing methods must be followed to ensure maximum strength gain. The length and percentage of fiber in JFRC have a significant impact on its properties. A small length and percentage of fiber tend to provide good compressive, tensile, and flexural strength, while a higher length and percentage of fiber can improve the energy absorption capacity and toughness index of the JFRC. This is because the fibers act as reinforcements and help distribute stress more evenly, leading to improved mechanical properties. It is important to note that the optimal fiber length and percentage will depend on the specific requirements of the end application. The optimal fiber content and length should be determined through trial and error and/or theoretical calculations to ensure that the JFRC meets the desired specifications for each specific application. Additionally, the use of proper admixtures, such as water-reducing agents and air-entraining agents, can help optimize the properties of the JFRC. Proper quality control measures, such as regular testing of concrete samples, should be implemented to ensure that the JFRC meets the desired specifications. By following these guidelines, the industry can produce high-quality JFRC that meets the demands of various applications.

5.4 Summary

It appears that there is a consistent trend that as the fiber content in plain concrete increases, the mechanical strength of the concrete decreases, but the toughness index improves. This makes it possible to determine which fiber content and length would be most suitable for future research to achieve optimal results. The study has identified the optimal combinations of jute fibers with varying lengths and percentages that provide the best results in terms of toughness and strength. Figure 5.1 displays the maximum values of strength and toughness index achieved through the use of six different combinations of JFRC. Based on these results, recommendations have been made for the use of jute fiber in real-life applications, particularly for non-structural elements such as pavers, plain concrete floorings ornamental elements of building. The best combination of strength and toughness has been identified as the most suitable option.

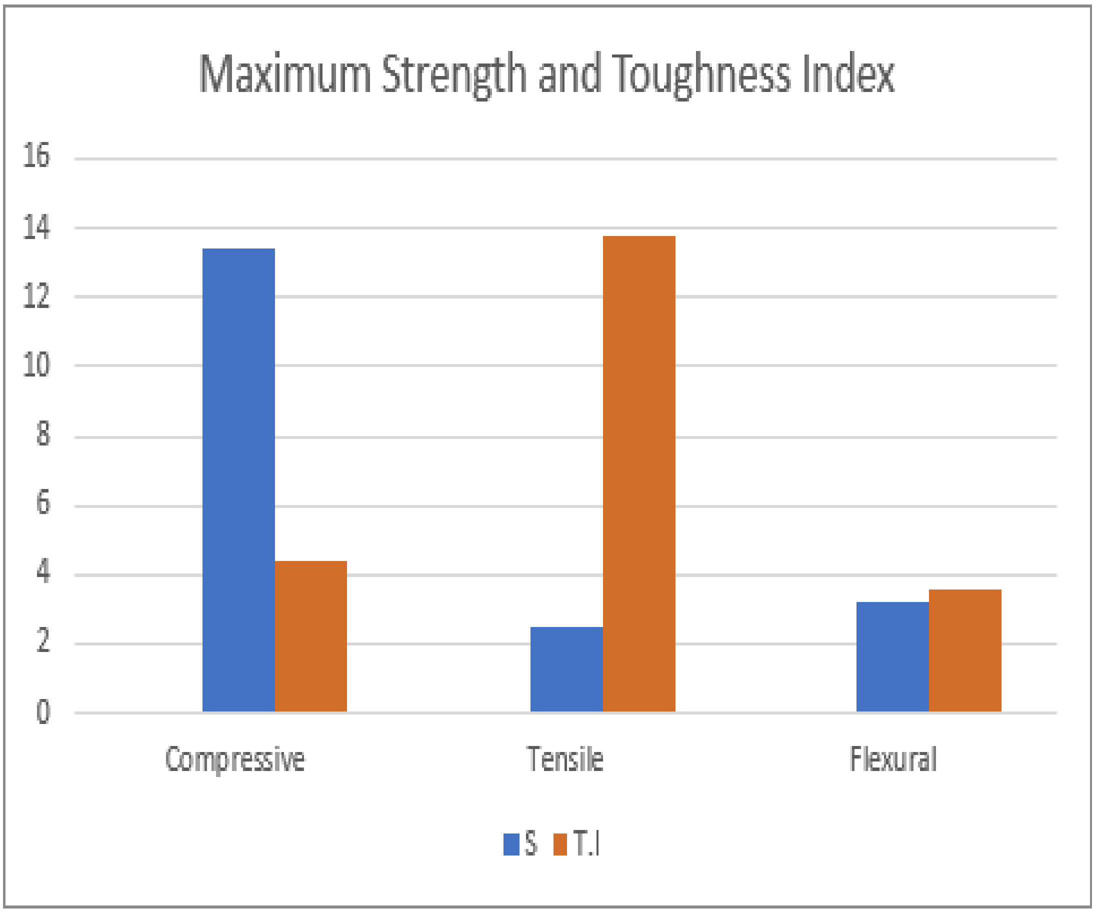


FIGURE 5.1: Maximum Values of Strength and Toughness Index of JFRC

Chapter 6

Conclusion and Recommendations

6.1 Conclusions

The practice of repurposing discarded materials is gaining widespread recognition as a crucial step in mitigating the harm caused to the environment by burning or disposing of agricultural waste. This type of waste often disrupts the delicate balance of ecosystems, making it imperative to find alternative, sustainable uses for it. One such promising solution is the use of jute fiber in concrete. Jute, a readily available resource in areas where it is grown in large quantities, has been found to enhance the mechanical properties of concrete composites when incorporated in optimal lengths and volume concentrations. Through extensive research and experimentation, the best combination of jute fiber and concrete has been determined for various non-structural applications, including building ornamental elements, sculptures, and on-grade flooring. By employing this eco-friendly strategy, a positive effect on the environment can be made and sustainable development can be adopted.

- The increased damping ratio in jute fiber reinforced concrete indicates its superior ability to absorb and dissipate energy, making it a suitable material for applications where improved vibration resistance is desired.

- The results of low fiber content and small fiber length in concrete show a minimal impact on compressive strength. By accepting a slight compromise in compressive strength, the toughness of the concrete can be greatly increased, making it ideal for use in members where compressive toughness is a priority over strength, such as on-grade slab, parking lots and jogging tracks etc.
- The addition of 5% fiber content with a length of 40mm results in a 4-fold increase in split tensile toughness index, leading to a significant increase in post-cracking energy and a higher capacity for elongation before break, even after yielding strength is reached.
- Similarly, the use of jute fiber in concrete improves the material's flexural properties, toughness index, and dynamic properties, though at the cost of some flexural strength.
- Jute fiber also increases the material's resistance to cracking, and SEM analysis has shown a stronger connection and improved bonding and bridging between the fiber and concrete matrix.

Concretes having short length and low percentage jute fibers have least compromised on strengths with reasonable gain in toughnesses compared to plain concrete. On the other hand, concretes having longer length and high percentage jute fibers have little more compromised on strengths with significant gain in toughnesses compared to plain concrete. Thus, depending upon the required properties of concrete product or the performance of non-structural element (i.e. strength or toughness preference), the relevant optimized jute fiber reinforced concrete can be used.

6.2 Future Work

- Further investigation is required to assess the capabilities of locally sourced jute fiber for commercial use.

- Efforts should be made to develop optimized JFRC on an industrial scale and to put its practical applications into effect.

- The findings from this study could be confirmed through analytical modelling.

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