

CAPITAL UNIVERSITY OF SCIENCE AND  
TECHNOLOGY, ISLAMABAD



**Effect of Pre-Treatment  
Techniques and Contents of Jute  
Fibers on Mechanical Properties  
of Self-Compacting Concrete**

by

Haider Masaud

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

in the

Faculty of Engineering

Department of Civil Engineering

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



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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.

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**Haider Masaud**

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# *Abstract*

Self-compacting Concrete is known for its excellent flowability, allowing it to consolidate under its own weight without the need for mechanical vibration. However, its dependence on large quantities of cement leads to increased carbon emissions and reduces its compressive strength and resistance to cracking. The addition of pre-treated jute fibers to self-compacting concrete (SCC) offers an eco-friendly approach to addressing its limitations, such as brittleness and the environmental impact of high cement consumption. The overall aim is a step towards sustainable development by using eco-friendly alternatives in manufacturing / production of self-compacting concrete to avoid conventional issues in typical concrete. Considerable objectives of the research is to examining the impact of different pre-treatment techniques and contents applied to jute fibers on the mechanical properties of self-compacting concrete. To evaluate the effectiveness of jute fibers, three types of fibers were used: raw fibers, water-soaked fibers, and fibers treated with 5% sodium hydroxide (NaOH). The experimental program involved preparing SCC mixes with fiber of 0.125%, 0.25%, and 0.5% by volume. Fresh concrete tests, such as flow table test was conducted to assess workability. Hardened concrete was evaluated for compressive strength, flexural strength, hardened density and water absorption. Microstructural analysis using scanning electron microscopy (SEM) provided detailed insights into the bond between the fibers and the cement matrix. Using treated jute fibers not only minimize the cracking and improves strength of SCC but also reduces its environmental footprint. The findings showed that untreated (raw) fibers had limited impact on mechanical properties due to poor adhesion with the cement. NaOH-soaked fibers showed moderate improvements in bonding, but water-soaked fibers significantly enhanced the mechanical performance of SCC. Among the different mixes, the 0.5% Soaked-treated jute fiber mix delivered the best results, achieving an optimal balance of compressive and flexural strength, crack resistance, and workability. It achieves the highest compressive strength of 27.33 MPa, demonstrating excellent load-bearing capacity. The mix also exhibits a modulus of rupture (MOR) of 5.9 MPa, which highlights its strong resistance to bending forces. Additionally, it has an energy absorption (Fe) value of 10.77 J, indicating good impact resistance, and the good flexural toughness

index (FTI) of 1.22, showing much crack resistance. The enhanced SCC is particularly suitable for applications such as pavements, load-bearing elements, and other structural components requiring high durability and resistance to cracking. By reducing reliance on traditional materials, this research supports sustainable construction practices and aligns with global efforts to minimize carbon emissions and resource depletion. Future research should further investigate the long-term performance of raw, soaked, and chemically treated fibers in concrete under various environmental conditions.

**Keywords:** Self-compacting concrete, jute fiber, NaOH treatment, eco-friendly construction, concrete durability, SEM analysis

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# Abbreviations and Symbols

<b>CE</b>	Compressive Energy
<b>Cem</b>	Compressive Energy before Peak
<b>Cep</b>	Compressive Energy after Peak
<b>CTI</b>	Compressive Toughness Index
<b>Fe</b>	Flexural Energy
<b>Fem</b>	Flexural Energy before Peak
<b>Fep</b>	Flexural Energy after Peak
<b>FTI</b>	Flexural Toughness Index
<b>MOR</b>	Modulus of Rigidity
<b>PC</b>	Plain Concrete
<b>SCC</b>	Self Compacting Concrete
<b>JF</b>	Jute Fiber
<b>JFRSCC</b>	Jute Fiber Reinforced Self Compacting Concrete
<b>OPC</b>	Ordinary Portland Cement
<b>RHA</b>	Rice Husk Ash
<b>FA</b>	Fly Ash
<b>SF</b>	Silica Fume
<b>SEM</b>	Scanning Electron Microscopy
<b>NVC</b>	Normal Vibrated Cone
<b>GGBS</b>	Ground Granulated Glass Furnace Slag
<b>UT</b>	Untreated

# Chapter 1

## Introduction

### 1.1 Background

Concrete is a popular material used in building things like houses, roads, bridges, and dams. It is made by mixing small and large stones with water and a substance that holds everything together. Ordinary Portland Cement (OPC) is the most common material used to bind the mixture because it works well and is easy to use [1]. Self-compacting concrete (SCC) is a special type of concrete that can flow easily when fresh. Unlike regular concrete, which can be hard to pour and compact, SCC spreads on its own, filling molds evenly without leaving air pockets. This makes it stronger and more durable. It also resists water, chemicals, and tough weather conditions better than regular concrete [2]. The use of SCC is constrained by several factors, including its significant brittleness, susceptibility to cracking (such as shrinkage and early retraction cracking), elevated production costs, high carbon dioxide emissions, and environmental concerns. Additionally, challenges like bleeding, segregation, and excessive heat generation during hydration further limit its applications [3]. These shortcomings can be overcome by the utilization of fibers and secondary cementitious materials. When fibers are added to the concrete, they act as crack arrestors due to their random distribution in the concrete mix [4-6]. To improve SCC further, extra materials like fly ash (FA), rice husk ash (RHA), and silica fumes can be added to the mix. These materials provide several benefits, including better performance, cost savings, and environmental advantages [7-9].

Jute fibers are strong and are often used as a raw material for industrial textiles. They are made up of tiny cellulose strands held together by pectin and hemicellulose in a lignin framework. Pectin and lignin make the fibers stiff, but this stiffness can limit their flexibility and ability to handle loads effectively, which affects their overall strength [10]. Different methods like alkali treatment, bleaching, acetylation, and peroxidation are used to make natural fibers like jute stronger. Research shows that treating jute fibers with alkali, especially using 5% NaOH, can improve their strength when used in polymer materials. However, the results depend on how long the fibers are treated and at what temperature [11]. SCC is a type of concrete that flows very easily. It can move through barriers like reinforcement or small gaps in molds and settle on its own without needing vibration. It also doesn't separate into layers, which helps it stay uniform during mixing, transport, and placement [12, 13]. Because there were not enough skilled workers at the location in the 1980s, a Japanese researcher named Okamura developed the idea of SCC. This scarcity becomes a barrier to building structures of high quality [14]. Making SCC needs a lot of cement-like materials, especially Ordinary Portland Cement (OPC), to get its high flowability. It also uses a higher water-to-cement ratio compared to regular concrete [15, 16]. Using more SCC in construction would mean using more Portland cement, which could harm the environment and reduce the sustainability of SCC [17].

The building materials sector uses the greatest natural resources even though it is contributing significantly to the growth of the country. Sixty percent of the raw materials used in lithosphere construction come from infrastructure projects and building construction [18, 19]. The concrete industry is the third-biggest source of CO<sub>2</sub> emissions globally, producing 510% of all emissions, mostly from making concrete [20]. In an experiment, FA was used to replace cement in amounts of 25%, 30%, 35%, and 40%, while SF was used in amounts of 5%, 10%, 15%, and 20% to see how these materials affect the compressive strength of SCC. It was found that 15% SF replacement gave the highest compressive strength, followed by 40% FA replacement, and then SCC without FA or SF. Rice husk ash (RHA) is also useful in SCC because of its strong pozzolanic properties. It acts as an alternative binder, reducing the need for regular Portland cement in construction [21]. Using rice husk ash (RHA) in large amounts as a cement material can greatly reduce the

environmental impact of construction by lowering the carbon footprint [22]. Sinha and Rout [23], [24] studied the molecular structure, shape, and surface properties of untreated and 5% alkali-treated jute fibers using X-ray diffraction (XRD) and scanning electron microscopy (SEM) for treatment times of 2, 4, and 8 hours. These results were compared with the fibers' thermal and mechanical properties. The study also compared these properties to those of a composite material made with 15% fiber-reinforced unsaturated polyester.

## 1.2 Research Motivation and Problem Statement

The utilization of jute fiber in self-compacting concrete lies in its potential to address sustainability concerns in construction by offering a renewable, biodegradable, and cost-effective alternative to synthetic fibers. Additionally, exploring the performance of pretreatment techniques of jute fiber in self-compacting concrete can contribute to enhancing the mechanical properties, durability, and environmental friendliness of concrete structures, thus advancing the development of eco-friendly construction materials and practices. Thus, the problem statement of research work is given below as:

*SCC utilization is limited due its brittleness, cracking, high cement consumption etc. and its impacts on environment. To solve these issues, the utilization of fibers and waste materials like fly ash, silica fume etc. is deemed as a viable solution. Steel fibers in SCC face corrosion issue, while other synthetic fibers like poly propylene fibers give good results but are non-biodegradable and cause environmental issues. Natural fibers are the best alternative. Jute fibers is one of the most and cheap abundantly available natural fibers and have not been investigated in SCC so far.*

### 1.2.1 Research Questions

- How the different content of jute fiber influences the properties of self-compacting concrete?
- How the pre-treatment techniques enhance the mechanical properties of SCC?

- How the combination of jute fiber, fly ash, and silica fume affects the properties of self-compacting concrete?
- What are the optimum content of (treated and untreated fibers) and secondary cementations materials in SSC?
- What does the microstructural analysis of jute fiber-reinforced self-compacting concrete (treated with 0.125% NaOH or untreated) reveal?

### **1.3 Overall Objective and Specific Aim of Research Work**

The overall aim of this MS Thesis is a step towards sustainable development by using eco-friendly alternatives in manufacturing / production of self-compacting concrete to avoid conventional issues in SCC. Considerable objective of the research are given below as:

Examining the impact of different pre-treatment techniques and content applied to jute fibers on the mechanical properties of self-compacting concrete.

### **1.4 Scope of Work and Study Limitations**

The scope encompasses investigating pretreatment techniques of jute fiber's compatibility with self-compacting concrete, optimizing fiber dosages and lengths, evaluating mechanical properties, and proposing practical recommendations for sustainable and effective integration into construction practices. The mechanical and microstructural properties of jute fiber-reinforced self-compacting concrete will be studied. The tests will follow ASTM standards and include compressive strength, flexural strength and scanning electron microscopy (SEM). Cylinders will be made for the compressive strength test, and beams will be made for the flexural test. Jute fibers will be treated in three ways: in their natural form, soaked, or dipped in NaOH.

The mechanical properties will be investigated by taking the average of three specimens for each combination of jute fiber reinforced self-compacting concrete

(JFR-SCC). The specimen will be considered as a failure after the appearance of a first crack due to load application. Scanning electron microscopy SEM also has been performed. This study focuses exclusively on assessing the mechanical properties, and water absorption capabilities of specimens composed of natural fiber (Jute). A single combination of mix design, water cement ratio, and locally available jute fiber is considered.

In this study the properties of concrete are limited to the material of selected area and industry. Jute fiber needs to be treated for best use in self-compacting concrete. Separate industry or workplace is required to convert jute fiber into useable form at large scales for practical purposes. Secondly, only mechanical properties with some fresh and hard properties are part of this experimental work.

#### **1.4.1 Rationale Behind Variables' Selection**

The selection of jute fibers for self-compacting concrete (SCC) is driven by their eco-friendly nature, cost-effectiveness, and ability to enhance the mechanical properties of concrete. Muduli & Mukharjee, [27] reported that the utilization of various blends of cement substitute from 10% to 40% for FA and 5%10% for SF to create a mixed concrete gives better results and SCMs can improve initial and final concrete characteristics when added to combine concrete mixes. Zakaria et al. [28] reported that Jute fiber reinforcement enhances both tensile and flexural strengths of concrete. Jute fiber has better properties as compared to other natural fibers. Cho et al. [29] reported that the pre-treatment with 10% NaOH done to raw jute fibers played a positive role in the formation of jute-based carbon fibers. Pinto et al, [30] reported that by soaking fiber in water increased the modulus and water resistance of jute composites by 36 and 60%, respectively. Affan & Ali. [31] reported that jute is a cost-effective and abundant natural fiber with good tensile properties, making it a viable alternative to synthetic fibers in concrete. Ubayi et al. [34] added that shorter jute fibers (e.g., 10-15 mm) can enhance compressive strength at low volume percentages (e.g., 0.1-0.3%).Mittal and Chaudhary. (2021) [35] reported that an optimal jute fiber content of around 0.4-0.5% by volume for maximizing compressive and tensile strength in cementitious composites. As a natural and biodegradable material, jute fibers address

sustainability concerns while providing a renewable alternative to synthetic fibers, which are often non-biodegradable and have higher environmental costs [25]. By incorporating jute fibers, SCC can benefit from improved flexural capacity, and resistance to cracking, particularly in applications requiring high durability and cracking. Using different percentages of jute fibers allows for fine-tuning the balance between workability and mechanical performance, ensuring optimal results for various construction needs. However, raw jute fibers have inherent drawbacks, such as poor adhesion with the cement matrix and a tendency to absorb water, which can compromise the durability and structural integrity of the concrete. To address these issues, pretreatment methods, including water soaking and alkali treatment with fiber content of 0.125%, 0.25% and 0.5% , are employed [26]. These treatments modify the fibers' surface properties, improving their bonding with the cement and reducing water absorption. Alkali treatment, for instance, removes impurities and enhances the fibers' compatibility with the cement matrix, while water-soaked fibers exhibit better flexibility and adhesion. This approach not only enhances the performance of SCC but also ensures its long-term durability, making jute fiber-reinforced SCC a practical and sustainable solution for modern construction challenges [26].

## 1.5 Brief Methodology

Studies have investigated the essential mechanical and water absorption attributes of two distinct concrete compositions: plain self-compacting concrete (PC-SCC) and jute fiber reinforced self-compacting concrete (JFR-SCC). The investigation is conducted within a controlled laboratory environment. We incorporate jute fiber to manufacture fiber-reinforced self-compacting concrete (FRSCC) samples. The FRSCC preparation entails utilizing uniform jute fibers, each measuring 15mm in length, a parameter derived from relevant prior research [28-30]. Throughout the mixing process, tap water at ambient temperature is used in the production for PC and all JFR-SCCs. The manufacturing process entails two distinct water-cement ratios. For plain concrete and JFR-SCC alike, a W/C of 0.45 is adopted. Additionally, super-plasticizers are introduced at a concentration of 2% to enhance workability and flow characteristics. The critical role of workability in determining

the concretes ultimate properties, as well as its ease of handling during placement and transport, is acknowledged [31]. Consequently, we evaluate the workability of fresh plain concrete SCC and all JFR-SCCs compositions through the implementation of the flow table test.

In strict compliance of ASTM standards, a total of 60 specimens are carefully cast, encompassing both plain concrete and FRSCC samples. Within each FRSCC combination, a set of three beam lets and three cylinders are carefully cast. Among these, cylinders undergo testing to assess compressive properties of both plain concrete and FRSCC. Moreover, the flexural characteristics of each variant of PC and FRSCC are examined using a point loading setup on the cast beamlet specimens. Figure 1.1 shows that detailed methodology.

In order to carry out the research work, the research methodology to be adopted is described as follows:

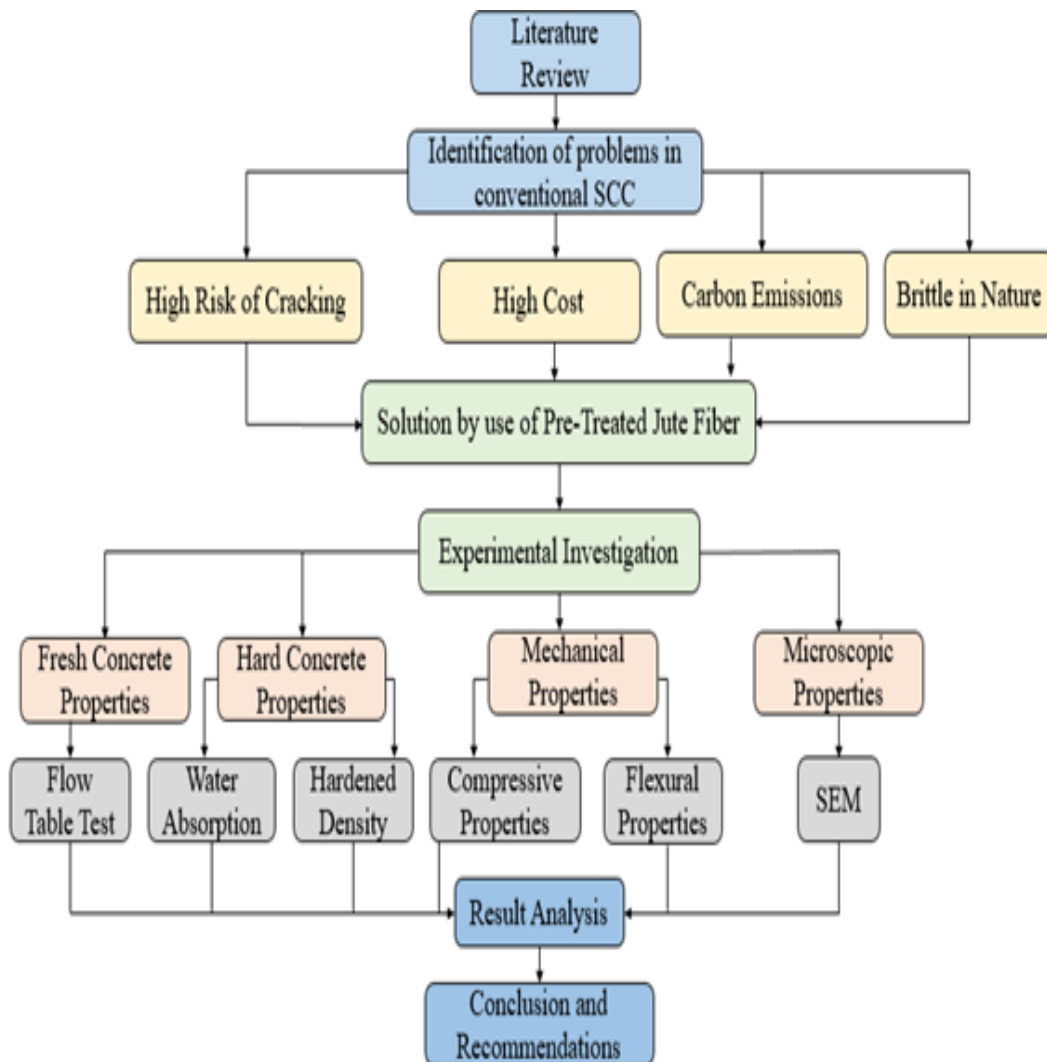


FIGURE 1.1: Adopted Methodology

TABLE 1.1: Summary of Mix Design and Testing

Test	Mix Design										Properties		
	SCC (1:1.5:2) w/c 0.37 2% SP	SCC+ FA+SF+ Raw JF 0.125%	SCC+ FA+SF+ Raw JF 0.25%	SCC+ FA+SF+ Raw JF 0.5%	SCC+ FA+SF+ Soaked JF 0.125%	SCC+ FA+SF+ Soaked JF 0.25%	SCC+ FA+SF+ Soaked JF 0.5%	SCC+ FA+SF+ NaOH JF 0.125%	SCC+ FA+SF+ NaOH JF 0.25%	SCC+ FA+SF+ NaOH JF 0.5%	Total number of Sam- ples for each test	Mechan- ical Prop- erties	Micro structure
Compression	3C	3C	3C	3C	3C	3C	3C	3C	3C	3C	30C	20C for Com- pressive strength 10C for Water Absorption	SEM
Flexural	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	30B	20B for Flexural Strength, 10 B for Water Absorption	

## 1.6 Research Significance

The research significance of utilizing pretreated jute fiber in self-compacted concrete (SCC) encompasses several important aspects that can positively impact concrete construction. Pretreatment processes, such as alkali treatment or soaked fibers, can enhance the compatibility between jute fibers and the cement matrix, leading to improved bonding and dispersion within the concrete mix. This improved compatibility aids in maintaining the workability and stability of SCC by minimizing water absorption tendencies that could adversely affect its rheological properties. Moreover, pretreated jute fibers have the potential to enhance the mechanical properties of SCC, including tensile and flexural strength, as well as impact resistance. By facilitating better load transfer mechanisms, the enhanced bonding contributes to a more ductile and durable concrete composite. Additionally, the mitigation of potential degradation issues, such as fiber decay or microbiological attack, through pretreatment processes improves the long-term durability and service life of SCC structures, particularly in harsh environmental or chemical exposure conditions.

## 1.7 Novelty of Research

Using treated jute fibers in self-compacting concrete (SCC) is a new and innovative idea. Although jute fibers have been used in concrete before, this research focuses on jute fibers in SCC. Moreover, by treating the fibers, they can bond better with the concrete and last longer. These treatments may involve using special chemicals or adjusting the fiber surface. They also help reduce water absorption and prevent the fibers from breaking down. This study supports the use of natural and eco-friendly materials in construction, helping to lower CO<sub>2</sub> emissions and reduce the environmental impact of concrete.

## 1.8 Thesis Outline

This thesis is organized into six chapters in order to explore the experimental research on material characterization.

**Chapter 1** provides an introduction, research motivation, problem statement, overall objective, specific aim, research methodology, and thesis outline.

**Chapter 2** offers a literature review on the flaws of self-compacting concrete, governing parameters in performance consideration, and remedial measures of these flaws. In addition, the incorporation of jute fiber in SCC for enhancing the mechanical properties is discussed.

**Chapter 3** comprises the experimental procedure. Background, materials used, optimization procedure of mix design, the procedure of casting and parameters to be considered for optimized mix design are explained.

**Chapter 4** Results and Analysis of mechanical properties and microstructural analysis including SEM are discussed in this chapter.

**Chapter 5.** This chapter discusses the optimization of mix design and structural capacity of jute fiber reinforced SCC in terms of enhanced mechanical properties and reduced flaws in self-compacting concrete.

**Chapter 6** This chapter includes the conclusion and future recommendations.

# Chapter 2

## Literature Review

### 2.1 Background

Concrete is a really useful man-made material that we use a lot for building stuff like buildings, roads, dams, and bridges. It's made up of different things mixed together, like small and big bits, water, and something that sticks it all together. Most of the time, we use something called Ordinary Portland cement to make it stick [1]. Self-compacting concrete (SCC) is a type of concrete known for its smooth flow and ease of use in construction. Regular concrete can be hard to handle and might end up with gaps or weak spots. But SCC solves these problems because it flows well and stays strong. It's also tougher against things like water and chemicals [17]. However, using SCC can have some drawbacks, like it being more likely to crack and being expensive to use. But we can fix these issues by adding things like fibers and other materials to the mix. These additions help stop cracks from spreading and make the concrete stronger and more eco-friendly [14]. SCC is concrete that, in its rheological state, demonstrates exceptional flowability properties [2]. SCC can flow through obstacles like reinforcement or small gaps in the formwork and compact on its own without needing mechanical vibration. It is also resistant to segregation, helping to maintain the concrete's uniformity during and after placement and transportation [5]. Because there were not enough skilled workers at the location in the 1980s, a Japanese researcher named Okamura developed the idea of SCC. This scarcity becomes a barrier to building structures of high quality [8]. Since then, SCC has been extensively employed in building

projects involving thick reinforcement or difficult construction sites, like viaduct girders and high-rise buildings [1]. However, the use of SCC is limited due to its high brittleness, cost, and increased risk of cracking, such as early shrinkage and contraction cracks [10]. Additionally, producing SCC requires a large amount of cementitious materials, particularly Ordinary Portland Cement (OPC), to achieve the desired flowability, often requiring higher water-cement ratios compared to regular concrete [11]. As the use of SCC materials in construction increases, the demand for Portland cement also rises, contributing to environmental concerns and limiting the sustainable development of SCC. Adding fibers to SCC is suggested as a way to reduce brittleness and the risk of cracking, with several solutions already proposed. Additionally, pozzolans are used as an alternative cement material in SCC mixtures to help reduce carbon dioxide emissions caused by the high demand for OPC in its production [18].

SCC is way easier to use than regular concrete. It flows really well and works great even in tight spots with lots of reinforcement. You don't need machines to press it down, and it doesn't separate when you're moving it around. But it has some downsides too, like being really brittle, expensive, and prone to cracking. Plus, it's not so great for the environment because it needs a lot of cement. But we can fix these problems by adding different fibers and other materials to the mix.

## 2.2 Flaws in Self-compacting Concrete

Self-compacting concrete (SCC) is a special type of concrete that flows and settles by itself, filling molds and covering reinforcements without needing external vibration. This technology was introduced in Japan in the late 1980s to overcome difficulties in building structures with heavy reinforcement and to reduce issues with vibration methods. SCC achieves its ability to self-consolidate by using high-range water reducers (super plasticizers) and viscosity-modifying agents, which improve its flow and stability. These qualities make SCC well-suited for complex molds, detailed architectural designs, and areas where traditional placement methods are difficult to use [3]. Although SCC has many benefits, it also presents challenges, especially in its mix design process. Developing a mix that balances flowability, stability, and strength is a careful process that often requires

many trial batches and lab tests. The mix design needs to carefully adjust the amounts of cement, aggregates, water, and chemical additives like superplasticizers and viscosity agents. Unlike regular concrete, SCC is highly sensitive to small changes in material properties, making the process time-consuming and complex. This complexity requires specialized knowledge, which can limit its widespread use [31].

Another major drawback of SCC is the increased lateral pressure it exerts on formwork during placement. Due to its high fluidity, SCC generates nearly hydrostatic pressures, which are significantly higher than those of conventional concrete. This necessitates the use of stronger, well-designed formwork systems to prevent failures such as formwork blowouts or deformation. As a result, the cost and labor associated with formwork construction may increase. Inadequate attention to this aspect can compromise structural integrity and pose safety risks during construction [32]. The higher material costs associated with SCC are also a concern. The specialized admixtures required, such as superplasticizers and viscosity-modifying agents, along with the potential need for higher cement content, contribute to its elevated production costs. While SCC reduces labor expenses by eliminating the need for vibration, the increased material costs and quality control requirements can offset these savings. For projects operating under tight budgets, this economic limitation can discourage its use, especially when conventional concrete can meet structural needs at a lower cost [33].

Durability concerns in SCC arise if its mix design and application are not properly managed. Improper proportions of water, cement, or admixtures can lead to issues such as shrinkage, cracking, or reduced resistance to environmental stressors. Additionally, inadequate curing can exacerbate these problems, affecting the long-term performance of the concrete. The sensitivity of SCC to variations in raw material quality underscores the need for stringent quality control measures during production and application. Neglecting these measures can result in compromised structural performance over time [34]. The environmental impact of SCC cannot be overlooked. The higher cement content often required in SCC formulations increases the carbon footprint of its production, which can be a disadvantage in terms of sustainability. Efforts to replace a portion of the cement with supplementary cementitious materials, such as fly ash or slag, can mitigate this impact, but

this requires additional optimization of the mix design. Addressing these sustainability challenges is essential to make SCC a more environmentally friendly option in construction [35].

## 2.3 Fiber Reinforced Self Compacting Concrete

Fiber-reinforced concrete imparts a distinct advantage over conventional concrete by significantly enhancing toughness and energy absorption capacities, as highlighted in reference [36]. This superiority becomes particularly pronounced when evaluating flexural strength [37]. In this context, the composite incorporating fiber-reinforced concrete demonstrates notably higher strength when compared to plain concrete. To elevate structural integrity and resistance against shrinkage cracks, a pivotal strategy emerges through the incorporation of a jute fiber into self-compacting concrete formulations [38]. Particularly in the realm of rigid pavements, this strategic integration assumes paramount significance [39].

TABLE 2.1: Comparison of Natural fibers

S/No	Fiber Type	Fiber Properties				Applications	References
		Tensile Strength (MPa)	Elastic Modulus (GPa)	Specific Gravity (kg/m <sup>3</sup> )	Density (g/cm <sup>3</sup> )		
1	Sisal	227–1002	10.9–26.7	1117–1167	0.75–10.70	Construction materials	[40-41]
2	Coir	126–148	1.7–2.3	1104–1370	0.87	Plastering	[42-43]
3	Jute	320–800	9.59	1400	1.3	Paver Blocks	[44-45]
4	Hemp	550–900	1.60–4.0	–	1.47	–	[46]
5	Wheat Straw	21.2–40	–	–	0.024–0.111	Radiation Shielding	[47]

The table presents a comparative analysis of natural fibers which include Sisal, Coir, Jute, Hemp, and Wheat Straw, based on their mechanical and physical properties, including tensile strength, elastic modulus, specific gravity, and density, along with their typical applications as referred by researchers [40-47]. Considering all the parameters, mechanical strength, density, and structural applicability, jute emerges as the most well-rounded and efficient natural fiber. Its combination of

strength, stiffness, and density makes it particularly suitable for civil engineering applications, marking it as a superior choice among the fibers compared.

Engineering properties of concrete undergo substantial augmentation through the synergistic amalgamation of jute fibers. The customization of these enhancements hinges upon various parameters, including fiber type, quantity, orientation, geometry, and distribution [39]. In this regard, steel fibers bring their remarkable reinforcing effects to bear, contributing to enhanced tensile strength and crack resistance [40]. Similarly, the inclusion of polypropylene fibers instills superior toughness and mitigates the development of minor shrinkage cracks [41]. Polyester fibers, on the other hand, offer the distinctive capability of further improving fatigue resistance and durability, especially within rigid pavement applications [42].

Nylon fiber play a pivotal augmenting the performance of FRCs for rigid pavements [43]. Their incorporation contributes to improved impact resistance and overall load-bearing capacity. Furthermore, the introduction of JG-FRCs stands out as a central strategy for retarding the onset of corrosion processes [44]. This notable benefit can be attributed to their exceptional crack resistance capabilities, effectively reducing the occurrence of minor shrinkage cracks, as detailed in references [45-47]. The utilization of numerous varieties of fibers, encompassing steel, polypropylene, polyester, and nylon, in the formulation of FRCs holds tremendous potential for enhancing the performance of rigid pavements. By harnessing the distinct attributes of these fibers, such as enhanced tensile strength, crack resistance, and durability, engineers can significantly improve the structural integrity and longevity of pavements, ensuring their resilience against various forms of stress and deterioration over time [40-43].

The judicious integration of waste materials, both from industrial and agricultural sources, into concrete formulations represents a noteworthy advancement towards sustainable development objectives [48]. This integration is particularly focused on enhancing early-age concrete strength and mitigating the occurrence of minor shrinkage cracks in rigid pavements [49]. Due to concrete's intrinsic susceptibility to low tensile strength, the incorporation of reinforcing constituents becomes

imperative to bolster its overall structural performance [50]. The assessment of cracks in rigid pavement systems is intricately linked to the strength capacity of concrete [51]. Tensile strain capacity denotes the magnitude to which a concrete rigid pavement can endure tensile deformation [52]. Consideration of tensile strain is imperative in conjunction with tensile strength when scrutinizing the crack initiation process, as the former parameter more precisely elucidates the stresses induced by fluctuations [53].

### **2.3.1 Utilization of Jute Fiber in Self-compacting Concrete**

Jute's main constituents, cellulose and lignin, give its fibers good tensile strength by nature. Furthermore, the uneven surface of jute fiber contributes to its good interfacial contact. Jute has become more advantageous than other natural fibers because of the previously mentioned qualities [86]. While steel fiber exhibits impressive strength, its susceptibility to corrosion in concrete poses challenges. Synthetic fibers offer strength and durability but lack environmental sustainability and cost-effectiveness in production. Therefore, natural fibers emerge as a viable alternative, with jute fiber standing out as a promising option. Jute fiber demonstrates competitive tensile strength and elastic modulus values comparable to other fibers, while also competitive water absorption rates. Its abundant availability, cost-effectiveness, and biodegradability make it a preferred choice for reinforcing composite materials, aligning well with both performance and sustainability considerations. Although jute fibers have many beneficial qualities, their durability in concrete is a concern. Natural fibers degrade in cement-based mixtures due to the reaction between alkaline pore water and the lignin and hemicellulose in the fibers' middle layers. This weakens the bonds between the fiber cells. Additionally, the alkaline reaction with cellulose molecules causes the breakdown of molecular chains, reducing polymerization and, consequently, weakening the fibers [87]. Toldo Filho, et al. [88] was conducted research on the durability of cellulose-based sisal and coconut fibers under various conditions, including exposure to tap water, alkaline solutions with calcium and sodium hydroxide, prolonged open-air weathering for 28, 180, and 322 days, and controlled wetting and drying cycles.

The study found a significant reduction in toughness after six months of outdoor exposure or when the fibers were subjected to wetting and drying cycles.



FIGURE 2.1: Jute yarn of different cut lengths [92]

Jute fiber, like other natural fibers, could be a viable alternative due to environmental and energy-related considerations [90]. Due to the growing global focus on environmental issues, jute fibers have been increasingly explored for use in normal vibrated concrete (NVC) in recent years [25, 26, 91, 92]. In order to enhance the characteristics of NVC incorporating jute fiber, Zakaria et al., [89] used fiber lengths of 10, 15, 20, and 25 mm and concentrations of 0.1%, 0.25%, 0.50%, and 0.75% by weight. Their study found that a 0.25% concentration of 15 mm jute fibers greatly improved the mechanical properties of the concrete mix, increasing tensile strength by 35% compared to the control mix. With a fiber length of 20 mm, Islam and Ahmed [25] examined three volumetric dosages of 0.1%, 0.30%, and 0.50% and discovered that Jute Fiber Reinforced Concrete (JFRC) demonstrated superior resistance ability against crack initiation compared to plain concrete. Kurda [93] investigated the effect of SF and jute fibers in concrete to check the mechanical properties and life cycle impact of concrete. Using 10% SF to replace cement and adding 0.3% jute fibers with lengths between 12 and 18 mm resulted in an approximately 28% increase in compressive strength. Zhou, et al. [94] studied the effect of jute fibers (1% content and 20 mm length), FA (with 50% cement replacement), and GGBS (with 50% cement replacement) to evaluate the mechanical properties of concrete. It was observed that JFRC with GGBS had the highest compressive strength, followed by JFRC with FA, and then normal concrete. Gupta, et al. [95] investigated the effect of jute fibers (0.1%, 0.2%, and 0.3% content and 13 mm length) and RHA (with 5%, 10%, and 15% cement replacement) to evaluate the mechanical properties of concrete. It was found that concrete with 0.2% fiber and 10% RHA increased compressive strength by 3% compared to normal concrete. Studies have shown that jute fibers typically improve the compressive strength of concrete. In most cases, the compressive strength

increased when the fiber length ranged from 6 mm to 18 mm [96]. Ahmad et al. [98] reported that Jute fibers present challenges in concrete applications due to their high water absorption, poor adhesion to the cement matrix, and susceptibility to degradation in alkaline environments. Ali et al. [99] also investigated that pre-treatment can significantly enhance the properties of plant fibers and their composite materials. Fresh jute fibers were soaked in a 5% NaOH solution for two hours to remove wax, impurities, and reduce the water absorption of the fibers.

For applications that require strong bonding between the fiber and resin matrix, jute fibers are often treated with alkali in a process called mercerization. This method, originally developed for cotton fibers to improve their reaction with dyes, has been applied to jute in various studies. When jute fibers were treated with NaOH solutions at concentrations of 1%, 8% for 48 hours, and 2% for 1 hour, improvements in fiber properties of 130% and 13% were observed, respectively [97]. The study found that treating jute yarns with a 25% NaOH solution for 20 minutes resulted in a 120% increase in tensile strength and a 150% increase in modulus. Additionally, the jute/epoxy composite reinforced with these treated yarns showed a 60% improvement in properties. These improvements were linked to the increased reactivity of the treated fibers with the resin, leading to better bonding [98]. The effect of treating jute fibers with a 5% NaOH solution for up to 8 hours as a reinforcing material for vinyl ester resin has been studied. The mechanical properties of the resulting composites, with varying fiber weight percentages, were assessed. Changes in these properties were examined through microstructural analysis of the fractured surfaces [98]. It can be concluded that fibers (steel

TABLE 2.2: Chemical Compositions of Raw Jute and Alkali-Treated Jute Fibers [39]

Sample Type	Weight Loss (%)	$\alpha$ -Cellulose (%)	Hemicellulose (%)	Lignin (%)
Untreated	0	63	22	13.7
2-h alkali-treated	9.63	62.7	12.9	13.48
4-h alkali-treated	10.06	62.6	12.65	13.4
6-h alkali-treated	10.43	62.52	12.4	13.35
8-h alkali-treated	10.45	62.5	12.4	13.35

fibers at initial stage) were introduced to overcome different shortcomings of SCC

but due to corrosion issue of steel fibers, synthetic fibers were utilized. The later performed well but causes environmental issues because of their production and processing. So, to have sustainable SCC, natural fibers (like jute fibers) are the viable option. In addition, different additives such as SF, FA, enhance the properties of SCC and also contribute to reduce the environmental degradation.

TABLE 2.3: Mechanical properties of untreated and alkali treated jute composites [76].

Jute (wt.%)	Type of fiber	Modulus (Gpa)	Flexural strength (MPa)	Breaking energy (J)
0	untreated	2.915	120.7	0.8227
	untreated	4.22	106.3	0.2948
	treated 2h	3.446	96.27	0.2497
8	treated 4 h	4.205	121.2	0.3634
	treated 6 h	3.967	101.8	0.227
	treated 8 h	3.13	93.97	0.2488
15	untreated	5.544	128.6	0.3399
	treated 2h	6.024	134.7	0.353
	treated 4 h	6.539	146.5	0.4016
23	treated 6 h	5.546	121.5	0.2569
	treated 8 h	5.337	127.6	0.3351
	untreated	7.355	145.7	0.3531
30	treated 2h	8.065	157.7	0.4048
	treated 4 h	9.384	172.7	0.4198
	treated 6 h	8.542	155.4	0.3553
35	treated 8 h	7.132	145.8	0.3762
	untreated	10.03	180.6	0.4799
	treated 2h	10.99	189.4	0.4816
30	treated 4 h	12.85	218.5	0.5061
	treated 6 h	12.49	195.9	0.4319
	treated 8 h	11.17	197.5	0.5042
35	untreated	11.89	199.1	0.5543
	treated 2h	12.7	205.2	0.457
	treated 4 h	14.69	238.9	0.5695
35	treated 6 h	14.89	232	0.5678
	treated 8 h	12.32	204.2	0.5099

## 2.4 Incorporation of Secondary Cementitious Materials and Fibers in Self-compacting Concrete

The building materials sector uses the greatest natural resources even though it is contributing significantly to the growth of the country. Sixty percent of the raw materials used in lithosphere construction come from infrastructure projects and

building construction [18]. It is the third-largest manufacturing sector in the world in terms of CO<sub>2</sub> emissions, accounting for between 5 and 10% of all CO<sub>2</sub> emissions worldwide, with the majority of this pollution coming from the production of concrete [20]. Environmentally friendly building materials are therefore crucial. SCC can be used in challenging construction scenarios, like seismic zones with densely packed reinforcement [54]. However, the high powder content, admixtures, and large amounts of cementitious materials come at an extra cost [55]. The high cement content frequently necessitates significant hydration heating, autogenous shrinkage, and financial outlays. In addition, the production of cement has a large environmental impact and uses a tremendous amount of energy—roughly 7.36\*10<sup>6</sup> kJ per ton of cement [56].

Due to the increased demand for SCC due to its high-performance qualities, researchers are attempting to make it more environmentally friendly by utilizing waste materials [57-59]. Pozzolans are a substitute cementitious material that has been added to SCC mixtures in order to lessen the carbon dioxide emissions linked to the high demand for OPC in SCC production [7-9]. Meanwhile, the disposal of mineral wastes poses serious environmental risks because it reduces farmlands, pollutes water supplies, and destroys biodiversity because there are more landfills [9, 60]. Mineral waste disposals, following suitable processing and/or treatment, have been used more frequently as pozzolans in order to take advantage of the resources of solid wastes from the mining industry [61, 62]. Several studies have explored the use of agricultural by-products, including tobacco waste ash, sugarcane straw ash, rice husk ash (RHA), eggshell ash, palm oil fuel ash, groundnut shell ash, and other similar materials, as partial substitutes for cement in concrete. These by-products have demonstrated strong pozzolanic properties and potential for enhancing concrete quality [62-67].

Turk, et al. [21] used FA with a percentage of 25, 30, 35, and 40 and SF with a percentage of 5, 10, 15, and 20 as a replacement of cement to check the additions of these cementitious materials on compressive strength of SCC. It was observed that SF with 15% replacement of cement in SCC produced the highest compressive strength followed by FA with 40% replacement followed by SCC without FA and SF. Rice Husk Ash (RHA) is considered a valuable precursor in Self-Compacting Concrete (SCC) because of its significant pozzolanic properties. By leveraging

these characteristics, RHA can reduce the reliance on traditional Ordinary Portland Cement (OPC) as the main binding agent in construction. The use of RHA as an alternative binder offers an opportunity to minimize the environmental impact of cement production, ultimately helping to lower the carbon footprint associated with construction activities. The widespread adoption and mass production of RHA could serve as a sustainable solution in the cement industry [22].

Fibers have been used to reinforce brittle materials since the Roman era, when clay was mixed with straw or horsehair to create stronger bricks [68]. The same concept is continued in fiber-reinforced concrete (FRC). In order to lessen the brittleness of concrete under tensile stress, fibers were first added to concrete in the early 1960s. The random embedding of fibers in FRC of all orientations serves to limit and postpone the development of microcracks, micro voids, and microslips into broad, continuous cracks. Polyvinyl alcohol fibers offer biodegradability and chemical resistance. Natural fibers like sisal, coconut, palm, and jute provide renewable, biodegradable options with varying strengths and water absorption capacities, contributing to sustainable construction. According to Das et al. [69], Akid et al. [70] corresponding tensile and flexural strength, respectively, drove the increase in FRC's compressive strength. The addition of fibers to SCC may stop or slow the start and spread of cracks, Table 2.1 shows the properties of natural fiber reinforced concrete. Furthermore, it is expected that fiber will split large, significant cracks into multiple smaller cracks from the viewpoint of structural durability and safety [71].

TABLE 2.4: Properties of Natural Fiber Reinforced Concrete

Natural Fibers	References	Properties	Values (MPa)
Jute	Kunda et al., [50]	a.Compressive strength	27.5
		b.Flexural strength	4.9
Hemp	Polytanovic [51]	a.Compressive strength	23.9
		b.Flexural strength	5.7
Wheat Straw	Mansur et.al [52]	a.Compressive strength	31-32.1
		b.Fracture energy	122.5
Sisal	Ramakrishna [53]	a.Compressive strength	21-26
		b.Flexural strength	5.8
Coir	Gowripal et.al [53]	a.Compressive strength	2.95
		b.Flexural strength	1.07

Research has also looked into using a mix of different types of fibers, including both artificial and natural fibers, in Fiber-Reinforced Self-Compacting Concrete (FRSCC).[76-81]. The properties of fibers, such as their length, diameter, aspect ratio, and shape, have a major impact on the flow and strength of concrete [82, 83]. Aslani [82], Pajk and Ponikiewski [83] demonstrates that adding fibers can impact the workability of Self-Compacting Concrete (SCC), so it's essential to control the water-to-binder ratio carefully. The degree to which workability is reduced depends on factors like the type, size, shape, and amount of fibers used. Steel fibers are the most widely used type of artificial fiber in the production of Steel Fiber-Reinforced Self-Consolidating Concrete (SFR-SCC). According to Abdelrazik and Khayat [81] adding steel fibers to SCC alters its flow characteristics, especially its workability in the liquid state. The extent of workability reduction depends on factors like the type of fiber, its concentration, and the cement mix. When steel fibers are added at volumes ranging from 0.25% to 1.00%, they have a noticeable impact on the mixture's workability, according to da Silva et al., 2020 [14]. Conversely, it was discovered that there was a positive correlation between flexural strength and toughness. In their study, Mastali and Dalvand [84] studies the looked at the hardened properties of recycled SFR-SCC with fiber concentrations of 0.25%, 0.5%, and 0.75% by volume. They found improvements in compressive, tensile, and flexural strength by 18%, 14%, and 25%, respectively. However, steel fibers are prone to corrosion, which limits their use today. To overcome this problem, both steel and synthetic fibers are often used. However, because synthetic fibers are expensive and energy-intensive to produce, their production costs are very high [25]. Under these conditions, using natural fibers as a substitute to make FR-SCC could be an option. A number of studies also suggest that high-fluidity concrete composites can be made with natural fibers like sisal, abaca, and coir [76, 77]. Table 3 shows the utilization of natural fibers in SCC. The natural fibers length in SCC ranges from 10 mm to 30 mm reported in the available literature. In case of JFR-SCC, 20 mm length has been reported by Hasan, et al. [85].

## 2.5 Summary

This chapter explores the key concepts, challenges, and advancements related to self-compacting concrete (SCC) and the incorporation of jute fibers for enhanced

performance. The chapter begins with an overview of SCC, highlighting its ability to flow and settle under its own weight without mechanical vibration. SCC is particularly beneficial in scenarios involving dense reinforcements or complex structures. However, its use is limited by brittleness, high material costs, cracking issues, and environmental concerns due to high cement consumption. The flaws of SCC are discussed comprehensively. The mix design process of SCC is noted to be complex and sensitive, requiring precise proportions of materials and admixtures to achieve a balance of flowability and stability. SCC exerts higher lateral pressures on formwork, necessitating robust and costlier formwork systems. Durability concerns arise from improper mix proportions and curing, which may lead to cracking and reduced long-term performance. Additionally, the environmental impact of high cement content in SCC is significant, contributing to carbon emissions and energy consumption.

To address these challenges, the use of fibers, especially natural fibers like jute, is highlighted as a promising solution. Jute fibers improve mechanical properties, such as tensile and flexural strength, and enhance resistance to cracking. Their natural availability, biodegradability, and cost-effectiveness make them a sustainable alternative to synthetic and steel fibers, which pose environmental and durability issues. The chapter also reviews the potential of secondary cementitious materials, like fly ash, silica fume, and rice husk ash, as partial cement replacements in SCC. These materials reduce cement consumption, mitigate environmental impacts, and enhance mechanical properties like compressive strength. Incorporating jute fibers and supplementary materials together offers a balanced approach to improving SCC's sustainability and performance. The chapter examines pre-treatment methods for jute fibers, such as alkali and water soaking, to enhance their adhesion to the cement matrix. These treatments remove impurities and modify fiber surfaces, improving bonding, reducing water absorption, and increasing durability. The chapter concludes by emphasizing the potential applications of fiber-reinforced SCC in structural and pavement engineering, offering a sustainable path forward for the construction industry.

# Chapter 3

## Materials and Methods

### 3.1 Background

The use of dispersed fibers in self-compacting concrete is an effective way to improve the mechanical properties of concrete, counteract crack development and propagation and increase its strength. Natural fibers in self-compacting concrete gives the most optimal engineering properties while being cost-efficient. Number of researches have already been done on the mechanical properties of jute fiber self-compacting concrete but not on the pretreatment of Jute fiber. Thus, further studies should be conducted to examine the effects of varying fiber lengths on the mechanical characteristics of jute fiber self-compacting concrete. The use of pretreated jute fibers in self-compacting concrete may lead to improved mechanical characteristics of the material, including increased compressive and flexural strength. Additionally, the use of fibers may also enhance toughness and impact resistance, which can be beneficial against tension or impact scenarios. The use of fibers may result in a concrete with improved mechanical properties and enhanced performance in a variety of applications. In order to gain an extensive understanding of the behaviour of pretreated jute fibers in self-compacting concrete for a variety of civil engineering applications, a comprehensive investigation is carried out. The effects of varying percentages of jute fibers (0.125%, 0.25%, and 0.5% by volume of wet concrete) to optimize the mix design are studied along with control samples of plain self-compacting concrete. The influence of fiber addition on the energy absorption capacity of concrete under compressive and flexural loadings are also determined experimentally. Scanning electron microscopy is used to

study the fiber bond matrix mechanism of the tested specimens in order to gain a deeper insight of the behavior. Furthermore, materials collection, preparation, mix proportions, casting, specimen details and testing are conducted in sequence. In Section 3.2, materials and methods are outlined. Section 3.3 contains tests and the standards followed for each test.

## **3.2 Raw Materials for Self-compacting Concrete**

Raw materials of concrete needs to be discussed to evaluate its elements and their replacements. Concrete is usually made from cement, sand, and aggregate. Water is added to activate cement in binding cause. In this research program raw materials are increased by ceramic waste powder, eggshell powder, wheat straw fibers, and super plasticizer. Increasing materials might affect properties of concrete, therefore materials with good results in previous research were selected.

### **3.2.1 Cement**

Cement is a key ingredient in concrete, and it comes in various types depending on the manufacturing process. For this study, Ordinary Portland Cement (OPC) from Bestway Cement, sourced locally, was used. OPC is known for its high resistance to cracking and shrinkage, though it is less resistant to chemical attacks. The initial setting time of OPC is shorter compared to Portland Pozzolana Cement (PPC), making it suitable for projects where formwork removal is needed quickly. Additionally, OPC sets and cures faster than PPC, reducing curing costs, which is beneficial in projects where curing expenses are a concern. Bestway Cements OPC production complies with EN 197-1: 2011 CEM I 42.5N standards, achieving a 28-day strength of 52.3 MPa, as specified by the manufacturer. The chemical composition of the cement is provided in Table 3.1

### **3.2.2 Fine Aggregates**

Fine aggregate is essential for producing high-quality concrete. It improves the workability of the concrete mixture by promoting consistency, reducing the amount

of cement and water required, and enhancing the mechanical strength of the hardened concrete. Additionally, fine aggregate aids in binding the cement paste around coarse aggregate particles, preventing segregation during transportation. It also minimizes shrinkage in the binding material and fills the gaps in the coarse aggregate, thereby increasing the overall density of the concrete. Another important function of fine aggregate is that it prevents the development of cracks in concrete by improving its overall strength and durability. In this study, sand obtained from Lawrencepur has been used as fine aggregate, which passed through a 4.75 mm sieve size and retained in sieve number #100. This sand has been carefully selected based on its particle size distribution and other relevant properties to ensure high-quality concrete production. It is worth noting that the quality and properties of the fine aggregate used in concrete production can have a significant impact on the final product. Using appropriate fine aggregate not only benefits the quality of concrete, but can also minimize the environmental impact of production by reducing resource consumption.

### **3.2.3 Coarse Aggregates**

Aggregates are added in concrete to gain strength. Locally available aggregates are collected in different sizes. Aggregates passing from 25mm and retained on 9.75mm are separated from bulk. These aggregates are then washed thoroughly in mixer to remove impurities and dust. After washing aggregates are air dried properly and used in concrete making. Aggregates used were varying in size between 10mm to 20mm.

### **3.2.4 Water**

Potable tap water is used in the preparation of Specimen. It has pH 6.5-8.5.No impurity or suspended particle in it is observed.

### **3.2.5 Jute Fibers**

Jute fibers are a sustainable and eco-friendly material that can be incorporated into self-compacting concrete (SCC) to improve its mechanical and durability properties. The inclusion of jute fibers in SCC enhances its ability to resist cracking and

improves toughness, making it suitable for applications requiring higher ductility. Additionally, jute fibers contribute to better energy absorption, reduced shrinkage, and improved impact resistance. However, to optimize the performance of SCC reinforced with jute fibers, factors such as fiber length, content, and treatment need to be carefully considered to ensure proper dispersion and bonding within the concrete matrix. Jute Fiber used in present research is in Dry state having Brown colour and the optimum length considered for jute fiber is 15 mm.

### 3.2.6 Super Plasticizer

2% super plasticizer Viscocrete-3110 PK by mass of cement from Sika Company is used. It is a high range viscosity modifying admixture and set retarding concrete admixture which is used to give long lasting control of slump loss and improves workability without adding more water. Viscocrete-3110 complies with ASTM C-494 Type G and EN 934-2: 2001. Chemical composition of super plasticizer is mentioned in Table 3.2 provided by manufacturer. Figure 3.1 shows picture of Viscocrete-3110 PK. All the chemical composition of super plasticizer shown in table 3.2 were obtained from the manufacturer company named as SIKA Pakistan.

TABLE 3.1: Technical Data of Super-Plasticizer

Technical Data of Super Plasticizer	
Density	1.16-1.2 kg/lit
PH Value	Approximately 7
Product Color	Transparent
Liquid Type	Organic polymer



FIGURE 3.1: Sika Viscocrete 3110

### **3.3 Pretreatment Techniques of Jute Fibers**

The study focuses on the comparison of utilization of untreated jute fibers (raw form) and treated jute fibers (NaOH dipped and water soaked).

#### **3.3.1 Alkali treatment of Jute Fiber**

In many practical applications, it is essential to pre-treat natural fibers to improve their bond strength and surface characteristics. Several researchers have utilized various methods to alter the physical and chemical properties of the fiber surfaces. These studies have shown that pre-treatment can significantly enhance the properties of plant fibers and their composite materials [111]. Fresh jute fibers were soaked in a 5% NaOH solution for two hours to remove wax, impurities, and reduce the water absorption of the fibers. After soaking, the fibers were thoroughly rinsed until the water was clear, indicating no further adhesion between the fibers. Any excess water on the fiber surfaces was removed by drying. Following the alkali treatment, the ends of the fibers appeared black and brown, while the centers remained light brown. Additionally, the natural scent and resin of the fibers were no longer detectable.

#### **3.3.2 Water Soaked Treatment of Jute Fiber**

This process involves immersing jute fibers in water for a specified duration to modify their physical and chemical characteristics. The soaking helps to remove impurities, reduce the lignin and hemicellulose content, and increase the fibers' flexibility. Through this treatment, the fibers achieve better wettability and adhesion to the cement matrix, which enhances the overall bond strength. Additionally, water-soaked jute fibers are less prone to forming clumps, ensuring uniform dispersion throughout the concrete. This uniformity is crucial for maintaining the workability and self-compacting properties of SCC while also improving its mechanical performance, such as tensile strength and crack resistance. The soaking time and water quality are key factors in determining the effectiveness of the treatment. Over-soaking may lead to fiber degradation, while insufficient soaking may leave impurities intact, reducing the desired benefits. Properly optimizing these parameters ensures the treated jute fibers enhance both the durability and sustainability of the concrete.

### 3.4 Mix Proportions and Casting Procedure

The mix proportions for plain concrete are set at a ratio of 1:1.5:2 (cement: sand: aggregate), with a water-to-cement ratio ranging from 0.32 to 0.38. For the preparation of jute fiber-reinforced concrete, jute fibers of approximately 15 mm in length are added in quantities of 0.125%, 0.25%, and 0.5% by volume of wet concrete, along with 2% superplasticizer as an additive. The study observed three conditions of jute fibers: untreated raw jute fiber used in varying percentages, jute fiber soaked in a 5% NaOH solution for 2 hours, and jute fiber soaked in water for 2 hours. The required amounts of cement, sand, and aggregates for each batch are 15.5 kg, 25 kg, and 34.74 kg, respectively. In preparing the self-compacting concrete (SCC) mix, cement, sand, and aggregates are placed together in the drum mixer, followed by the addition of water. The mixer is then operated for five minutes. For the preparation of jute fiber-reinforced concrete, the materials cement, sand, aggregates, and fibers are added in layers, with one-third of each material placed in the drum mixer initially. The remaining cement, sand, and aggregates are then added using the same layering method. Two-thirds of the water is added, and the mixer is rotated for three minutes. The final third of the water is added, and the mixer is operated for another two minutes. At this stage, the mix is not yet fully homogeneous or workable, so the mixer is run for an additional three minutes to achieve a more uniform blend. The extended mixing time is necessary because adding water too early could lead to bleeding in the high-fiber content mix.

The extended mixing time proved to be an effective method for achieving a workable jute fiber-reinforced concrete (JFRC). Both plain concrete (PC) and JFRC were tested for slump to assess their fresh properties. After preparing the homogeneous mixture, it was poured into molds to create specimens. Each layer of the mixture was compacted with 25 tamping rod blows. To remove air voids, the mold containing JFRC was lifted to a height of approximately 100-150 mm and then dropped freely. After 24 hours, the specimens were demolded and left to cure for 28 days. Once the curing period was complete, the water absorption test was conducted on the hardened PC and JFRC specimens.

TABLE 3.2: Mix Design

Mix Design	Cement		SF		w/b	Volume	Fine A		CA	SP+VMA	JF (%)
	Kg	%age	Volume	%age			Kg	Kg			
C100SF10FA10	408	10	18.38	10	0.37	181.3	720	1000	1	0	
C100SF10FA10J0.125	408	10	18.38	10	0.37	181.3	720	1000	1	0.125	
C100SF10FA10J0.25	408	10	18.38	10	0.37	181.3	720	1000	1	0.25	
C100SF10FA10J0.5	408	10	18.38	10	0.37	181.3	720	1000	1	0.5	
C100SF10FA10J0.125	408	10	18.38	10	0.37	181.3	720	1000	1	0.125	
C100SF10FA10J0.25	408	10	18.38	10	0.37	181.3	720	1000	1	0.25	
C100SF10FA10J0.5	408	10	18.38	10	0.37	181.3	720	1000	1	0.5	
C100SF10FA10J0.125	408	10	18.38	10	0.37	181.3	720	1000	1	0.125	
C100SF10FA10J0.25	408	10	18.38	10	0.37	181.3	720	1000	1	0.25	
C100SF10FA10J0.5	408	10	18.38	10	0.37	181.3	720	1000	1	0.5	

## 3.5 Testing Methods

### 3.5.1 Fresh State Properties

#### 3.5.1.1 Flow Table Test

The flow table test is a commonly used method to assess the flowability and consistency of self-compacting concrete (SCC). SCC is a highly flowable type of concrete that can spread into place, fill formwork, and encapsulate reinforcements without the need for mechanical consolidation. The flow table test helps evaluate its workability. The flow table test for self-compacting concrete (SCC) is standardized under ASTM C1611/C1611M-18. This standard outlines the procedure for determining the slump flow of self-consolidating concrete, which is an essential measure of the flowability and filling ability of SCC.



FIGURE 3.2: Flow Table Test Setup



FIGURE 3.3: Specimens for each casting

### 3.5.1.2 Water Absorption

The ASTM standard C1585 [131] is used to determine the water absorption capacity of samples. Specimens were taken out from the tank after 28 days and oven dried at 100c. Dry weight of the cylinders were taken. After that, cylinders were submerged in water for 24 hours. After the time has elapsed, the cylinders are taken out and their weight is taken again to determine the amount of water that the concrete mix has absorbed. Difference of wet weight and dry weight was divided by wet weight to get the water absorption of cylinders. The incorporation of jute fibers into concrete mixes presents a challenge due to the fibers' inherent high water absorption capacity.

This characteristic can negatively impact the concrete's long-term durability and mechanical strength, as increased water absorption can contribute to issues like reduced bond strength between the fiber and the cement matrix and increased susceptibility to deterioration from environmental factors. However, studies have explored methods to mitigate these drawbacks, such as chemical treatments of the jute fibers. For instance, research has shown that alkali treatments can modify the fiber surface, reducing water absorption and improving the fiber-matrix interface, ultimately enhancing the composite's performance (Zhang et al.,) [132].

### 3.5.1.3 Hardened Density Test

The ASTM standard C642 is used to determine the hardened density test for self-compacting concrete (SCC) evaluates the concrete's density after it has set and hardened [101]. It involves measuring the weight and volume of a cured specimen, such as a cube or cylinder, and calculating the density using the formula:  $\text{Density} = \text{Mass}/\text{Volume}$ . This test helps assess the concrete's quality, as density influences properties like strength, durability, and compactness. It also ensures consistency in the mixing and curing process. By meeting the specified density requirements, SCC's performance and suitability for its intended application are validated effectively.

## 3.5.2 Mechanical Testing

### 3.5.2.1 Compression Test

A Universal Testing Machine (UTM) equipped with a highly accurate displacement transducer, which has a measurement range of 0-1500 mm and a resolution of 0.001 mm, is used to evaluate the compressive strength, absorbed compressive energy, energy absorption up to peak stress (CBE), energy absorption after peak stress (CPE), and compressive toughness index (CTI) of cylindrical specimens [102]. To ensure uniform load distribution during testing, the cylinders are capped with sulfur. The compressive strength of the cylinders is tested according to ASTM C39/C39M-20, which is the standard test method for assessing the compressive strength of cylindrical concrete specimens.



FIGURE 3.4: Compressive Strength Test Setup

### 3.5.2.2 Flexural Test

The flexural strength test on the 30 beam-lets is conducted following ASTM C293/C293M-16 (Standard Test Method for Flexural Strength of Concrete - Using a Simple Beam with Center-Point Loading). A flexural testing machine is employed to assess the flexural behavior, modulus of rupture (MOR), flexural energy absorption, and flexural toughness index (FTI) [102].



FIGURE 3.5: Flexural Strength Test Setup

### 3.5.3 Microstructural Analysis

#### 3.5.3.1 Scanning Electron Microscope (SEM) Test

The microstructural analysis of the optimized jute fiber-reinforced concrete (JFRC) is conducted using scanning electron microscopy (SEM) to examine the bond between the fibers and the concrete, as well as the pull-out behavior of the fibers and the nature of failure or cracking. Scanning electron images are captured using a VEGA3 TESCAN microscope, operating at a voltage of 10 kV. Prior to testing, plasma coating is applied to the samples.

## 3.6 Summary

The mechanical properties including compressive and flexural properties, of PC-SCC and JFRSCC are determined through a mixture of cement, sand, coarse aggregate with a ratio of 1:1.5:2 and w/c ratio of 0.32-0.38 with varying percentages of 15mm long jute fibers keeping a fiber content of 0.125%, 0.25%, 0.5% respectively by volume of wet concrete. SEM analysis is then performed to evaluate the results in accordance with ASTM standards. The findings of the testing are presented and discussed in Chapter 4.

# Chapter 4

## Results and Analysis

### 4.1 Background

The mechanical and microstructural testing is conducted in accordance with ASTM standards. To optimize the fiber content of natural fibers, the mechanical properties of Jute Fiber Reinforced Self-Compacting Concrete (JFRSCC) with various natural fiber ratios are compared to those of plain self-compacting concrete. This chapter provides a comprehensive experimental investigation of both the fresh and hardened state properties, including mechanical and microstructural analyses, of JFRSCC. Additionally, scanning electron microscopy (SEM) is performed to examine the matrix bonding in the microstructural analysis of JFRSCC.

### 4.2 Fresh Properties

#### 4.2.1 Flow Table Test

The flow table test for self-compacting concrete (SCC) is used to evaluate its flowability and ability to deform. First, the flow table surface and mold are cleaned and dampened to prevent the mix from sticking. The conical mold is positioned at the center of the table, filled with the fresh SCC mixture, and leveled without applying external vibration. The mold is then carefully lifted, allowing the SCC to flow freely. Immediately after, the table is dropped vertically from a height of 40 mm about 25 times in 15 seconds to help spread the concrete. The spread diameter is

then measured in two perpendicular directions, and the average is recorded as the flow spread of the SCC. A large and uniform spread with no segregation indicates good flowability and stability of the SCC mix, offering crucial data for assessing its suitability in construction applications. The flowability measurement is shown in Figure 4.1. The self-compacting concrete (SCC) without any fiber reinforcement showed a flow spread of 625 mm, indicating moderate flowability suitable for applications where high fluidity is not required. However, the inclusion of natural fibers reduces the flow of concrete, which in turn decreases its workability. The addition of jute fibers, in particular, results in a decrease in flow, likely due to the absorption of water by the air-dried fibers in the jute fiber reinforced concrete (JFRC) mix. After treatment, the fibers are exposed to air, causing moisture to evaporate. The results from the Slump Flow Test show variation in the spread diameter for different mixes, indicating that the fiber content significantly influences the workability of the concrete. For flow and passing ability, experimental methods such as the Slump Flow, J-Ring, and U-Box tests demonstrate that concrete mixes with lower fiber content of jute fibers are more favorable for maintaining workability [76] The incorporation of jute fibers, silica fume, fly ash and super plasticizer into the SCC significantly decreases its flowability, resulting in a spread of 610 mm maximum of soaked JF with 0.25%. Table 4.1 shows slump for all mixes altogether.



FIGURE 4.1: Flow Table Test

TABLE 4.1: Flow ability of different mixes

Labelling of Specimen	Flowability (mm)
SCC PC	625
NaOH 0.125%	605
NaOH 0.25%	580
NaOH 0.5%	560
Soaked 0.125%	600
Soaked 0.25%	610
Soaked 0.5%	550
Raw 0.125%	540
Raw 0.25%	525
Raw 0.5%	520

### 4.2.2 Water Absorption

Water absorption, which describes the liquid transport through capillary action, is measured by dividing the mass of water absorbed by the specimen by its actual mass after being oven-dried, as per ASTM standard C642-13[112]. The purpose of the test is to estimate the increase in sample density brought on by water absorption over the time period. Water contains many hazardous elements that soaks into concrete that is why concrete disintegrates and absorbs more water. Natural fibers like jute have the characteristics to absorb water. The water absorption of SCC PC and all JFRSCC is given in Table 4.3. SCC Soaked JF 0.5% has maximum water absorption and PC has minimum water absorption value. It is evident from the literature that natural fibers have high water absorption capacity than synthetic fibers [25]. It can be seen that as far as JF content is increased in Raw JF 0.125%, 0.25% and 0.5% respectively, water absorption capacity is increased. In comparison to control specimen SCC PC, Jute fibers has more water absorption. Composites made with surface-treated jute, such as those soaked and dipped in NaOH, exhibit lower water absorption compared to untreated ones, like raw jute fiber. This behavior can be attributed to the enhanced interfacial adhesion between the jute fibers and the matrix resulting from the chemical surface treatment [113]. Tabular data depicts the water absorption capacity of all the specimens.

The bar chart shows the water absorption of various self-compacting concrete (SCC) mixes, with plain cement (PC) SCC set as the baseline at 100%. The different SCC mixes include variations treated with NaOH at concentrations of 0.125%

TABLE 4.2: Water Absorption (%)

Specimens	Wet Weight (kg)	Dry Weight (kg)	Water Absorption %	Change in % w.r.t PC (%)
SCC-PCC	13.8	13.6	1.32	100
SCC Raw JF 0.125%	12.4	12.2	1.96	73
SCC Raw JF 0.25%	11.9	11.6	2.57	108
SCC Raw JF 0.5%	12.7	12.2	2.9	112
SCC Soaked JF 0.125%	12.3	12.1	1.85	141
SCC Soaked JF 0.25%	12.4	12.1	1.96	149
SCC Soaked JF 0.5%	12.3	12.3	2.06	156
SCC NaOH JF 0.125%	12.4	12.3	1	149
SCC NaOH JF 0.25%	12.3	12.1	1.43	195
SCC NaOH JF 0.5%	12.6	12.5	1.35	217

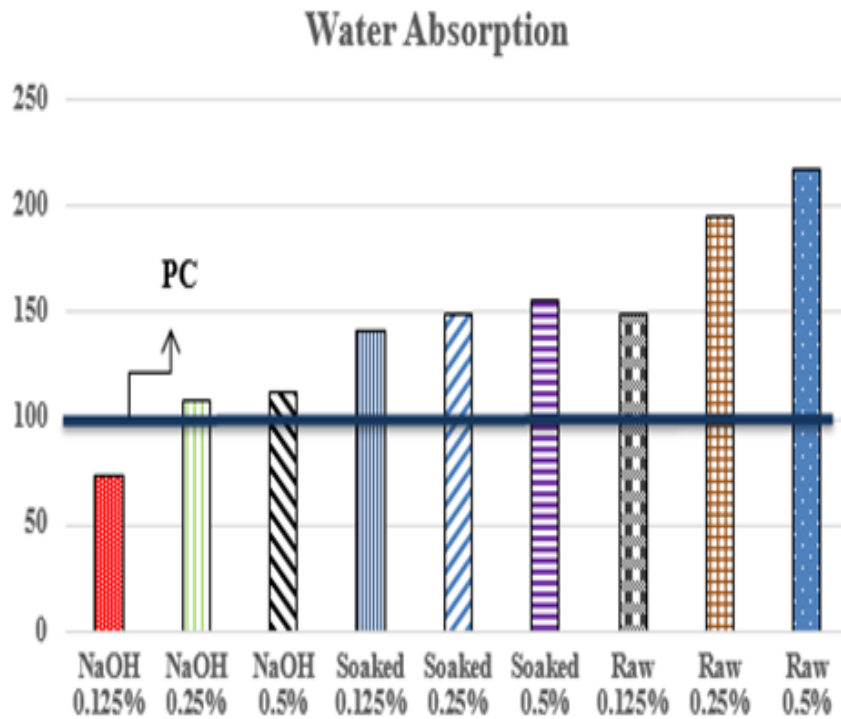


FIGURE 4.2: Comparison of different mixes with PC

and 0.25%, as well as mixes labeled as "Soaked" and "Raw" with fiber contents of 0.125%, 0.25%, and 0.5%. The chart reveals that water absorption tends to increase with higher fiber content, particularly in the "Raw" and "Soaked" conditions. For instance, the SCC mixes with "Raw" fibers at 0.5% demonstrate the highest water absorption, reaching around 200% relative to the PC SCC mix. Comparatively, the "NaOH" treated mixes show lower water absorption levels, with NaOH 0.125% having the lowest absorption among the modified mixes, indicating that NaOH treatment could reduce water absorption in SCC. This trend suggests that untreated fibers increase porosity and thus water uptake, while the

NaOH treatment could help mitigate this effect. According to literature review, the control mix shows a water absorption (WA) percentage of 2.57%. With the incorporation of jute fiber (JF) into the concrete, the WA increases due to the properties of the fibers. When 0.10% JF is added, the WA rises by 12.45%. With 0.25% JF, the WA increases by 20.62%. Moreover, adding 0.50% JF increases the water absorption by 36.18%, and a 0.75% JF addition leads to a 46.30% increase in absorption. These findings suggest a direct correlation between the amount of JF in the concrete and the water absorption, with the absorption increasing as the JF content rises [114].

### 4.2.3 Hardened Density Test

To conduct a hardened density test on self-compacting concrete (SCC), casted the SCC in a standard-sized mold and cure it according to specified conditions (usually 28 days). After curing, dry the concrete sample in an oven at 105°C until it reaches a constant mass. Accurately measure the dimensions of the sample (length, width, height) for volume calculation. Record the dry mass of the sample using a precision balance. Calculate the hardened density using the given formula and express the density in kg/m<sup>3</sup>.

$$\text{Density} = \text{Mass of Sample} / \text{Volume of Sample}$$

The table 4.3 presents data on the wet and dry weights, as well as the wet and dry densities, for various samples of concrete, including plain concrete (PC) and jute fiber-reinforced self-compacting concrete (SCC) treated under different conditions. The samples have undergone treatments using different concentrations of sodium hydroxide (NaOH) or soaking processes, with the NaOH concentrations labeled as 0.125%, 0.25%, and 0.5%. Additionally, the samples are categorized based on whether they were soaked or untreated (raw).

The wet and dry weights are provided in kilograms (kg), and the densities are calculated in kilograms per cubic meter (kg/m<sup>3</sup>) for both wet and dry states. Plain concrete (PC) shows the highest density, with a wet density of 2465.179 kg/m<sup>3</sup> and a dry density of 2433.036 kg/m<sup>3</sup>, indicating that the untreated sample has higher compactness compared to the fiber-reinforced samples. For samples

TABLE 4.3: Properties of Hardened Density

Sample	Wet Weight (kg)	Dry Weight (kg)	Wet Density (kg/m <sup>3</sup> )	Dry Density (kg/m <sup>3</sup> )
PC	13.8	13.6	2465	2433
NaOH 0.125%	12.4	12.3	2229	2208
NaOH 0.25%	12.3	12.1	2208	2176
NaOH 0.5%	12.6	12.5	2265	2234
Soaked 0.125%	12.3	12.1	2209	2168
Soaked 0.25%	12.3	12.1	2213	2175
Soaked 0.5%	12.3	12.1	2206	2161
Raw 0.125%	12.4	12.2	2224	2181
Raw 0.25%	11.9	11.6	2133	2079
Raw 0.5%	12.5	12.2	2245	2182

treated with NaOH, densities decrease as the concentration increases, with the 0.5% NaOH concentration sample showing a wet density of 2265.179 kg/m<sup>3</sup> and a dry density of 2234.821 kg/m<sup>3</sup>. This trend suggests that higher concentrations of NaOH may lead to a reduction in density, possibly due to fiber degradation or weakening of the concrete matrix.

The soaked samples exhibit a similar trend, where increased soaking time (from 0.125% to 0.5%) correlates with a slight reduction in density. The wet and dry densities for soaked samples range from 2209.286 kg/m<sup>3</sup> to 2213.036 kg/m<sup>3</sup> for wet density and 2168.75 kg/m<sup>3</sup> to 2175.893 kg/m<sup>3</sup> for dry density, indicating a minor but noticeable reduction in compactness. In the untreated (raw) samples, densities are higher than the soaked samples but still lower than the PC sample. The raw sample with 0.125% concentration shows a wet density of 2224.107 kg/m<sup>3</sup> and a dry density of 2181.25 kg/m<sup>3</sup>, with densities slightly increasing as the concentration increases to 0.5%.

Overall, this data indicates that both chemical treatment with NaOH and soaking lead to reduced densities in the fiber-reinforced SCC samples, likely due to structural changes or degradation of fibers in the concrete matrix. This reduction in density may affect the mechanical properties and durability of the concrete, and

thus understanding these effects is essential for optimizing the composition and treatment of jute fiber-reinforced SCC in practical applications.

## 4.3 Mechanical Properties

### 4.3.1 Properties under Compressive Loading

The stress-strain graph presented illustrates the compressive behavior of self-compacting concrete (SCC) reinforced with jute fibers subjected to different pretreatment methods and concentrations. This analysis captures the influence of fiber treatments, such as alkali (NaOH) treatment and fiber conditioning (raw, soaked) on the compressive strength and ductility of SCC. The various curves on the graph represent different treatment methods and fiber concentrations, including untreated (raw) jute, NaOH-treated fibers, and fibers soaked in water, each at different ratios (e.g., 0.125, 0.25, and 0.5). The plain concrete (PC) line, represented by the solid blue line, serves as the control mix, which enables comparison between the baseline SCC and the fiber-reinforced mixes.

As the fiber concentration increases, the strain at peak stress also tends to increase. For instance, the soaked 0.5 and NaOH 0.5 samples exhibit higher strain values before failure compared to lower concentration samples, indicating improved ductility. This phenomenon is consistent with existing literature, which shows that fibers with optimal pretreatment and concentration can contribute to improved strain distribution within the concrete, allowing the material to absorb more energy before reaching peak stress. Studies have shown that this energy absorption capacity is critical in improving the ductility and toughness of fiber-reinforced concrete, making it more resilient to cracking and sudden failure. The use of NaOH-treated fibers in concrete helps distribute loads more evenly, thus delaying crack propagation and improving overall ductility, a trend that matches the increased strain at peak stress seen in the NaOH 0.5 mix in the current results [110].

The inclusion of untreated (raw) jute fibers at varying concentrations (0.125, 0.25, and 0.5) shows a trend where higher fiber concentrations, such as raw 0.5, achieve higher peak stresses compared to lower dosages. This indicates that untreated



FIGURE 4.3: Spalling under compression



FIGURE 4.4: Bridging effect caused by JFRSC

fibers can improve compressive strength to an extent, with additional fibers acting as crack-arresters that enhance load distribution. However, the untreated fibers may not bond optimally with the concrete matrix, leading to limited strength improvements compared to other treatments. The raw fiber mixes exhibit some

improvement in strain at peak stress, but their effect on ductility is not as pronounced as with treated fibers, possibly due to the smoother surface and lower interaction with the cement matrix. Lower concentrations of raw, soaked, and NaOH-treated fibers (e.g., 0.125) showed limited improvements in compressive strength compared to higher concentrations [111].

Alkali-treated (NaOH) fibers demonstrate the most significant impact on compressive performance. For instance, NaOH 0.5 achieves a stress of approximately 18.52 MPa, outperforming both the control and other fiber types. This enhanced performance is attributed to the alkali treatment, which removes impurities and roughens the fiber surface, promoting better bonding between fibers and the cement matrix. This stronger bond allows for effective stress transfer and resistance to crack propagation, thus increasing both compressive strength and strain capacity. Lower concentrations, like NaOH 0.125, offer less pronounced strength gains, suggesting that both fiber concentration and bonding quality play crucial roles in achieving optimal performance in fiber-reinforced SCC. Alkali treatment improved the interaction between jute fibers and the cement matrix, resulting in better load transfer and resistance to micro-cracking. This increased bonding strength due to alkali treatment is consistent with the observed performance in the present study, where NaOH-treated fibers, particularly at higher concentrations, yielded the highest compressive strength and strain capacity [112].

Soaked fibers (0.125, 0.25, and 0.5) provide intermediate results between raw and NaOH-treated fibers. Soaked 0.5, for example, reaches around 27.33 MPa in peak stress, surpassing the raw 0.5 mix but falling short of NaOH 0.5. The soaking process likely improves the compatibility between fibers and the mix by preventing excessive water absorption, which might otherwise disrupt the concrete's water-cement balance. However, unlike NaOH treatment, soaking does not roughen the fiber surface, so the bond strength with the cement matrix remains lower than that of alkali-treated fibers. Therefore, soaked fibers moderately improve both compressive strength and strain capacity, but they do not reach the level of performance seen with NaOH-treated fibers at comparable concentrations. Soaking fibers can improve their compatibility with the cement matrix by controlling the rate of water absorption, which helps maintain the concrete's water-cement ratio [113].

The results in this study align closely with findings from previous research on the effects of natural fiber reinforcement in self-compacting concrete (SCC) and conventional concrete. Past studies have demonstrated that natural fibers, when incorporated into concrete, generally improve the material's toughness, ductility, and crack resistance. For instance, investigations on jute fiber-reinforced concrete have shown that fiber pretreatment can significantly enhance the bonding between fibers and the cementitious matrix, leading to improved mechanical properties. In line with this, researchers have frequently found that alkali treatment (such as NaOH treatment) is particularly effective for improving the performance of jute and other natural fibers in concrete, as it removes surface impurities like lignin and hemicellulose, increasing fiber roughness and thereby enhancing fiber-matrix adhesion. Natural fiber reinforcement enhances concrete ductility by bridging cracks and delaying failure, a benefit observed in the current study where higher fiber concentrations of both soaked and NaOH-treated fibers contributed to greater strain capacity at peak stress compared to plain concrete [67].

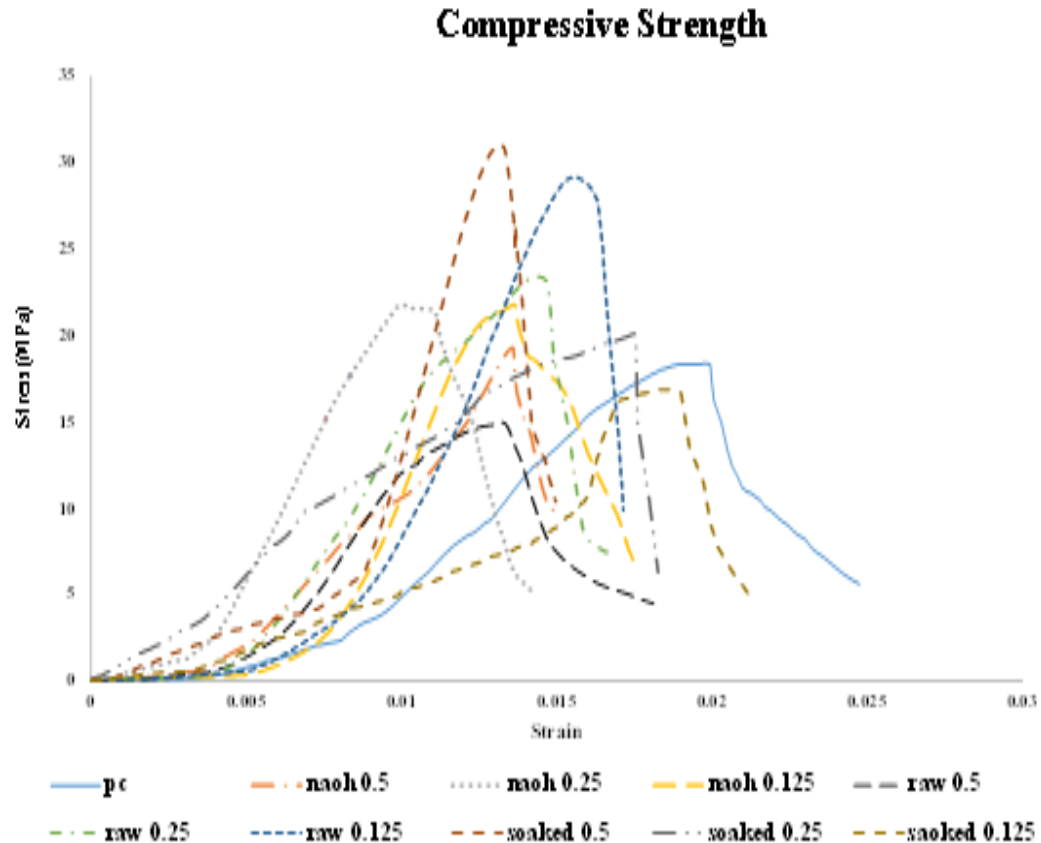


FIGURE 4.5: Compression response of PC-SCC and pretreated JFR-SCC

TABLE 4.4: Mechanical properties of PC and other Mixes, Modulus of Elasticity (E), After peak (CeP), Before peak (CeM), Total Energy (Ce) and Compression Toughness Index (CTI)

Sample	C.S (MPa)	MoE (GPa)	(E)	CeM (MJ/m <sup>3</sup> )	CeP (MJ/m <sup>3</sup> )	Ce (MJ/m <sup>3</sup> )	CTI
PC	18.49±1.34	0.92±0.2		0.05±0.003	0.004±0.001	0.05±0.002	1.07±0.003
NaOH 0.125%	21.96±0.09	1.60±0.3		0.08±0.004	0.005±0.003	0.08±0.001	1.07±0.005
NaOH 0.25%	19.84±3.42	2.16±1.1		0.07±0.001	0.01±0.001	0.09±0.005	1.17±0.004
NaOH 0.5%	18.52±1.34	1.42±0.5		0.002±0.004	0.07±0.003	0.07±0.003	1.02±0.007
Soaked 0.125%	14.28±3.87	0.92±0.1		0.02±0.002	0.002±0.001	0.02±0.003	1.10±0.001
Soaked 0.25%	17.81±3.45	1.14±0.4		0.08±0.002	0.001±0.001	0.08±0.004	1.01±0.009
Soaked 0.5%	27.33±5.65	2.36±1.1		0.08±0.006	0.019±0.004	0.01±0.001	1.22±0.002
Raw 0.125%	23.60±1.23	1.87±0.8		0.12±0.001	0.01±0.001	0.13±0.006	1.09±0.005
Raw 0.25%	21.65±2.77	1.63±0.5		0.12±0.004	0.003±0.001	0.12±0.003	1.02±0.003
Raw 0.5%	13.86±1.75	1.12±0.3		0.04±0.002	0.003±0.001	0.05±0.001	1.07±0.008

Values of stress, Cem, Cep, Ce, and CTI are mentioned in Table 4.4. Compressive energy absorption (Ce) for all blends is computed using the area under stress-strain curves, and this has also been done by [110-112]. The energy absorption per cubic metre of concrete is measured in MJ/m<sup>3</sup> [113, 114]. The remaining two parts of this total energy are the energy absorbed up to the maximum stress (Cem) and the energy absorbed from the maximum stress to the maximum strain (Cep). However, the toughness index is derived using the Ce/Cem ratio (CTI). Compressive toughness index is higher in case of soaked with 0.5% jute fiber. Soaked 0.25% mix shows lower toughness index as compared to all other mixes.

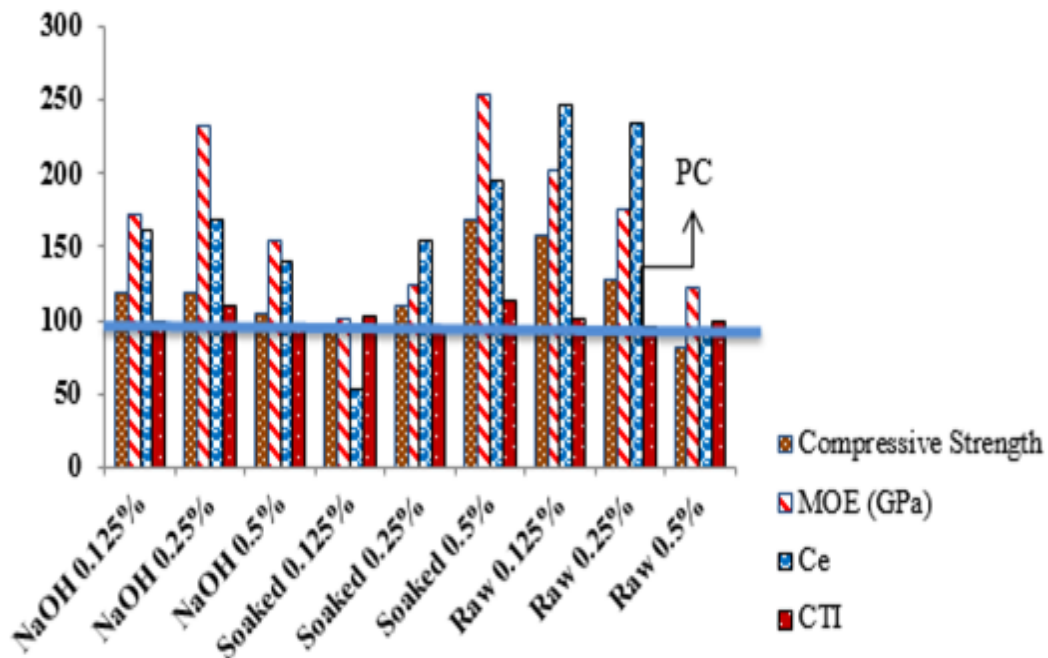


FIGURE 4.6: Comparison of Compressive Results

The figure 4.5 compares the results of compression tests for jute fiber-reinforced composites subjected to different treatments and concentrations. The parameters analyzed include Stress, Modulus of Elasticity (MOE), Ce (Compression Energy), and CTI (Crack Tip Index). These properties provide an understanding of the compressive strength, stiffness, energy absorption, and crack resistance of the material. The fibers were either treated with NaOH, soaked in water, or used in their untreated (raw) form, at concentrations of 0.125%, 0.25%, and 0.5%.

For NaOH-treated fibers, at 0.125% concentration, the Stress and MOE are relatively moderate, with values near 100 and 150, respectively. The Ce, representing energy absorption, is higher at approximately 175, whereas the CTI, indicating resistance to crack propagation, is notably low at around 50. When the fiber concentration increases to 0.25%, the MOE reaches its peak at 250, while Stress and Ce remain stable at around 100 and 175, respectively. There is only a slight improvement in CTI. At 0.5% concentration, all parameters exhibit a significant decline, with Stress and Ce dropping below 100, MOE decreasing to about 150, and CTI falling further. This indicates that excessive NaOH treatment may degrade fiber-matrix bonding, leading to reduced performance.

For water-soaked fibers, the results show superior performance across most parameters. At 0.125% concentration, Stress and MOE are approximately 100 and 150, respectively, while Ce is notably high at 200, indicating excellent energy absorption. The CTI is relatively good at around 100, suggesting better crack resistance compared to NaOH-treated fibers. At 0.25%, the performance is exceptional, with Ce exceeding 250, Stress and MOE both reaching around 200, and CTI achieving its highest value at approximately 150. These results highlight the effectiveness of water-soaked fibers in enhancing compression performance. At 0.5%, there is a slight reduction in all parameters, though the values remain higher than those for NaOH-treated and raw fibers, demonstrating the stability of water-soaked fibers even at higher concentrations.

For raw fibers, the results are moderate. At 0.125% concentration, Stress and MOE values are close to 100, while Ce and CTI are around 125. At 0.25%, the performance improves, with Ce reaching 200, MOE around 175, and CTI remaining stable. However, the Stress value does not improve significantly. At 0.5% concentration, all parameters decrease, with Stress and Ce falling below 100

and CTI dropping to around 75. This suggests that untreated raw fibers may not perform effectively at higher concentrations, possibly due to poor fiber-matrix interaction.

In conclusion, compression test results clearly indicate that water-soaked fibers at 0.5% concentration provide the best overall performance, with superior values for energy absorption (Ce), crack resistance (CTI), and compressive strength (Stress). These fibers effectively balance stiffness and ductility, making them ideal for compression applications. NaOH-treated fibers demonstrate high stiffness (MOE) at 0.25% concentration, but their poor CTI values suggest limited crack resistance, especially at higher concentrations. Raw fibers perform moderately, with optimal results at 0.25%, but exhibit significant declines at 0.5% concentration due to inadequate fiber dispersion or weak bonding with the matrix. Overall, water-soaked fibers are the most effective treatment for enhancing compressive performance, provided the concentration is optimized to 0.25%.

### 4.3.2 Properties under Flexural Loading

The flexural strength graph shown in Figure 4.7 presented the load-displacement behavior of self-compacting concrete (SCC) and jute fiber-reinforced SCC under various treatments. The vertical axis represents the load in kilonewtons (kN), indicating the force applied to the sample, while the horizontal axis shows the displacement in millimeters (mm), reflecting the samples deformation under load. This test illustrates the flexural capacity and ductility of each sample, highlighting the influence of jute fiber treatments on the materials performance. Natural fibers added to concrete mixtures could enhance post-cracking strength and ductility, as the fibers act as bridges across cracks, preventing sudden brittle failure [115].

Plain concrete PC (SCC without any fiber reinforcement). As shown, plain concrete reaches a peak load of around 13 kN at a displacement close to 1.8 mm. Following this peak, the load suddenly drops, indicating a brittle failure. This behavior is typical for plain concrete, which lacks the tensile reinforcement needed for ductility. When the load reaches a certain limit, the material fractures suddenly without much plastic deformation, which results in a steep decline on the



FIGURE 4.7: Beam Failure under Loading

graph. This characteristic is a limitation in structural applications, as plain concrete cannot absorb much energy before breaking.

The other lines represent SCC samples with varying dosages of jute fibers, both treated and untreated, showing distinct patterns in load-bearing capacity and ductility. The dashed lines labeled "raw" indicate SCC with raw (untreated) jute fibers at different dosages: 0.5, 0.25, and 0.125, respectively. These samples demonstrate an improvement in load-bearing capacity compared to plain concrete, though the enhancements are limited. For instance, the raw 0.5 sample reaches a peak load near 12 kN, slightly lower than plain concrete but with a somewhat slower decline after peak displacement, suggesting a minor improvement in energy absorption. Despite these improvements, raw jute fibers do not significantly enhance post-peak behavior. The rapid drop after peak load indicates limited ductility, with the material failing soon after reaching maximum load capacity.

The samples with NaOH-treated fibers show a marked improvement in both load-bearing capacity and ductility. NaOH treatment, which involves soaking fibers in sodium hydroxide, alters the fiber surface by roughening it, which enhances bonding with the cement matrix. The NaOH 0.5 sample reaches a peak load comparable to that of plain concrete, around 13 kN, but unlike plain concrete, it maintains a gradual decline in load capacity after the peak. This behavior indicates that NaOH-treated fibers provide better energy absorption and crack-bridging abilities, preventing the concrete from sudden brittle failure. Even at lower concentrations, such as naoh0.125, the NaOH-treated fibers show an improvement over raw fibers,

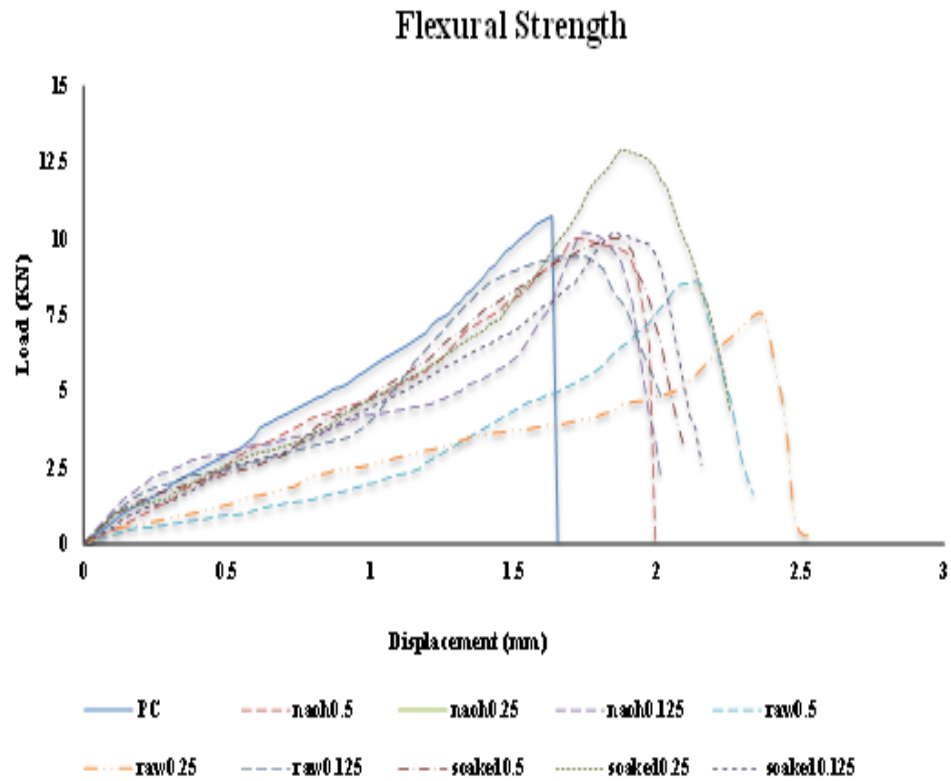


FIGURE 4.8: Flexural Response of SCC PC and JFR-SCC

underscoring the benefits of chemical treatment for enhancing both strength and ductility. Fiber treatment with NaOH resulted in enhanced fiber-matrix bonding and increased the flexural performance of the composite [53].

TABLE 4.5: Flexural strength properties

Sample ID	MoR (MPa)	Fe (J)	Fep (J)	Fem (J)	FTI
PC	6.35±2.31	8.25±3.21	0±0.0	8.2±4.7	1±0.2
NaOH 0.125%	6.04±3.02	9.26±4.67	2.2±0.9	7.0±2.8	1.3±0.3
NaOH 0.25%	5.25±1.32	6.35±2.43	0.09±0.1	6.2±1.9	1.0±0.05
NaOH 0.5%	6.51±3.18	10.0±3.55	2.5±1.04	7.5±3.4	1.3±0.7
Soaked 0.125%	6.04±2.09	10.5±4.03	2.3±1.01	8.1±3.1	1.2±0.6
Soaked 0.25%	7.63±3.13	13.3±5.27	3.8±1.7	9.4±4.7	1.4±0.1
Soaked 0.5%	5.91±1.97	10.7±3.71	1.9±0.7	8.8±3.5	1.2±0.7
Raw 0.125%	5.56±1.03	10.0±4.08	2.3±0.9	7.7±2.6	1.3±0.2
Raw 0.25%	4.48±1.01	7.8±2.17	0.6±0.01	7.1±2.1	1.0±0.1
Raw 0.5%	5.12±2.01	7.3±2.36	1.0±0.02	6.3±2.5	1.1±0.7

The effect of natural fibers on the flexural properties of SCC and found that

soaking fibers in water before mixing slightly improved the bonding, though the effect was not as pronounced as chemical treatments [116]. The soaked jute fiber-reinforced SCC samples exhibit a moderate improvement in performance over raw fibers, although they are not as effective as NaOH-treated fibers. Soaking involves immersing fibers in water before mixing, which may help to swell the fibers slightly and improve their integration into the cement paste. The green, black, and brown dashed lines represent samples with soaked fibers at 0.5, 0.25, and 0.125 dosages, respectively. These samples demonstrate moderate peak loads and a relatively gradual decline after the peak, though they fall short of the ductility improvements achieved by NaOH-treated fibers. The soaked 0.25 sample peaks around 12 kN and shows a smoother decline compared to raw fibers, indicating that soaking has some positive effect on bonding, though it is less effective than chemical treatment.

This flexural strength test reveals that both the presence and treatment of jute fibers influence the performance of SCC. Chemically treated fibers showed improved flexural strength compared to untreated fibers [116]. While untreated jute fibers provide a marginal improvement in flexural strength and post-peak behavior, they do not significantly enhance ductility. NaOH treatment, particularly at higher concentrations, proves to be the most effective in increasing both load-bearing capacity and energy absorption, suggesting improved fiber-matrix interaction. Soaked fibers also perform better than raw fibers but are not as effective as NaOH-treated fibers. Fibers treated with NaOH exhibited enhanced durability and bonding properties, which increased the toughness and ductility of the concrete [67]. Findings suggest that for applications requiring enhanced flexural strength and toughness, chemically treated jute fiber-reinforced SCC could be a viable solution, as it combines the workability of SCC with the reinforced durability provided by the treated fibers. The chemical treatment of jute and other natural fibers significantly improves the flexural strength and ductility of concrete composites. The enhanced fiber-matrix bonding due to NaOH treatment has been shown to contribute to higher load-bearing capacity, improved crack-bridging, and a more gradual failure mode. This collective evidence suggests that chemically treated jute fiber-reinforced SCC can offer substantial benefits in applications requiring improved flexural performance, confirming the viability of this approach in structural applications [54, 117].

The figure 4.8 illustrates the flexural performance of jute fiber-reinforced materials under varying treatment methods and concentrations, focusing on four key parameters: Load, Modulus of Rupture (MOR), Flexural Energy (Fe), and Flexural Toughness Index (Fti). The treatments include jute fibers processed with NaOH, soaked in water, and left untreated (raw fibers), with fiber concentrations of 0.125%, 0.25%, and 0.5%. Each parameter reflects the material's response to flexural loading and its ability to resist deformation. For NaOH-treated fibers, at

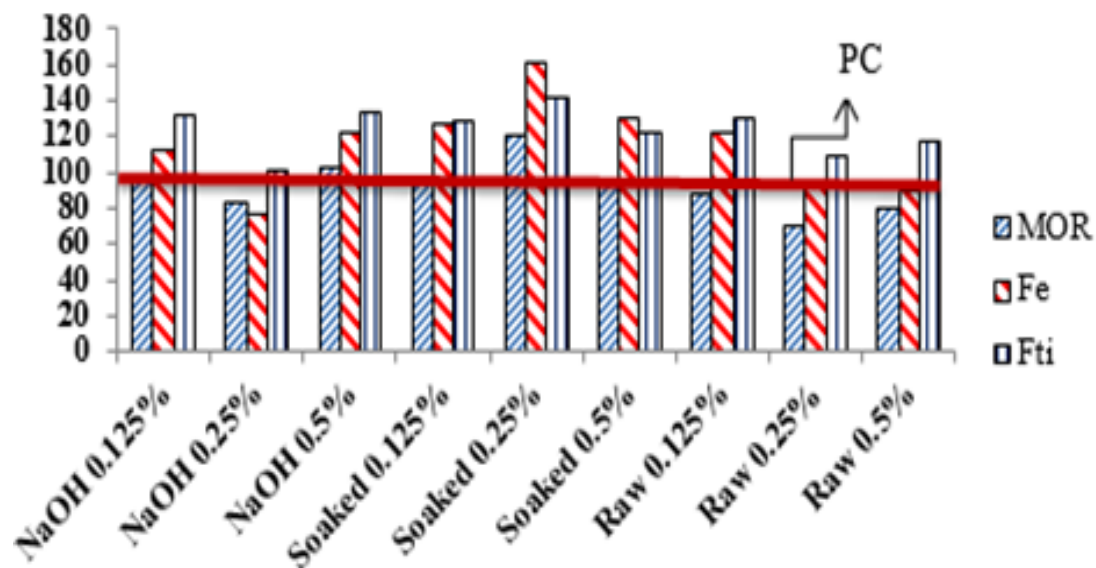


FIGURE 4.9: Comparison of Flexural Results

a concentration of 0.125%, the Load and Fti values are relatively high, around 100 and 120, respectively, while MOR and Fe are slightly lower at approximately 80 and 110. As the concentration increases to 0.25%, there is a noticeable decline in the Load, MOR, and Fe values, indicating reduced performance, although Fti remains marginally higher. At the highest concentration of 0.5%, the performance further deteriorates, with all parameters dropping significantly. This suggests that excessive NaOH treatment might weaken the fiber-matrix bond or alter fiber properties detrimentally.

The water-soaked fibers show superior performance compared to the other treatments. At 0.125% concentration, the Load and Fti values are around 110 and 120, respectively, while MOR and Fe are slightly lower, close to 90 and 100. The peak performance occurs at 0.25%, where Fe exceeds 160, Fti reaches approximately 140, and both Load and MOR are around 120. This indicates an optimal fiber concentration that allows for enhanced bonding and effective stress transfer

between fibers and the matrix. However, at 0.5% concentration, all parameters decrease, though they still remain higher than the NaOH-treated and raw fiber samples, demonstrating the relative effectiveness of water-soaked fibers.

For raw fibers, at 0.125% concentration, the Load and Fti values are comparable to those of NaOH-treated fibers, at approximately 100, while MOR and Fe are slightly lower. At 0.25%, all parameters improve, with Fti rising to 120 and Fe reaching 110, indicating better reinforcement at this concentration. However, at 0.5%, similar to the other treatments, the performance declines, likely due to issues such as poor fiber dispersion or excessive fiber content disrupting the matrix continuity.

In conclusion, the chart reveals that water-soaked fibers at a concentration of 0.25% deliver the best flexural performance across all parameters, particularly in terms of energy absorption (Fe) and toughness (Fti). In contrast, both NaOH-treated and raw fibers exhibit lower flexural performance, especially at higher concentrations. The consistent decline in performance at 0.5% fiber concentration across all treatments highlights the importance of optimizing fiber dosage to maintain a balance between reinforcement effectiveness and matrix integrity. These findings suggest that water-soaked fibers, due to their enhanced bonding and compatibility with the matrix, are the most effective for improving flexural properties when used at an appropriate concentration.

The Modulus of Rupture (MoR) is determined based on the maximum load recorded in the load-displacement curve during flexural testing [123, 124]. As per ASTM C293/C293M-16, the Modulus of Rupture (MoR) is calculated using the maximum load observed in the load-displacement curve during flexural testing. The MoR for all mixtures is determined using the following equation  $MOR = 3Pl/2bd^2$  (Standard Test Method for Flexural Strength of Concrete - Using Simple Beam with Centre-Point Loading). In this calculation, P represents the maximum load, while L, b, and d are the dimensions of the beam specimens, specifically the length, breadth, and depth, with the span length L being 406 mm. Among all the jute fiber-reinforced self-compacting concrete (JFRC) specimens, the highest Modulus of Rupture (MoR) is observed in the soaked 0.25% JF mix (7.637 MPa), which is 18.36% higher than that of the plain concrete (PC). The energy absorbed by the specimen under flexural loading up to the maximum load is referred to as

Fem, which corresponds to the area beneath the load-displacement curve up to the highest point of the load. The energy absorbed after the peak load, until the conclusion of the test, is denoted as Fep. The total flexural energy absorbed (Fe) is the sum of Fem and Fep, which represents the entire area under the flexural load-displacement curve. The flexural toughness index (FTI) is calculated as the ratio of total energy absorption to the energy absorbed up to the maximum flexural load (Fe/Fem). When compared to plain concrete, all mixes show an increase in the toughness index.

## 4.4 Microstructural Analysis

### 4.4.1 SEM

In Figure 4.10 (a), the rough texture of fiber shows that it has a bond with concrete. Applied load overcome bond between fiber and concrete, as one end of fiber is broken. This might be the reason behind lower compressive strength. Figure 4.10 (b) shows air voids with fibers in them. This clearly explain the reason behind bridging effect. Higher water absorption is also because of voids. Cluster of concrete with fiber at one end. Improper distribution of fibers, reason behind lower compressive strength as compared to PC and other JFR-SCC mixes, can be seen in Figure 4.10 (c). Figure 4.10 (d) shows improper breakdown of fiber. This shows that fiber has resisted applied load up to some extent. Potential reason behind bridging effect. Energy absorption after peak point shows sequence. Cluster of concrete is seen in one of the views of Figure 4.10 (e) which shows brittleness of jute fiber incorporated mix with lower energy absorption. Voids along with fiber addition. Reason behind higher water absorption and lower density as compared to PC, observed in Figure 4.10 (f).

In Figure 4.11 finer internal structure is observed, higher water absorption resulted. Fine structure was observed, as jute fiber came out to be finer material from cement. In Figure 4.11 (a) pullout of fiber is observed. Fiber internal capacity is greater than load applied, reason behind energy after peak. Figure 4.11 (b) shows fiber with only small piece removed, bonded with concrete from both ends, justifying bridging effect and delayed failure time. In Figure 4.11 (c) hairline and finer internal structure are observed as compared to JFR-SCC NaOH 0.125%;

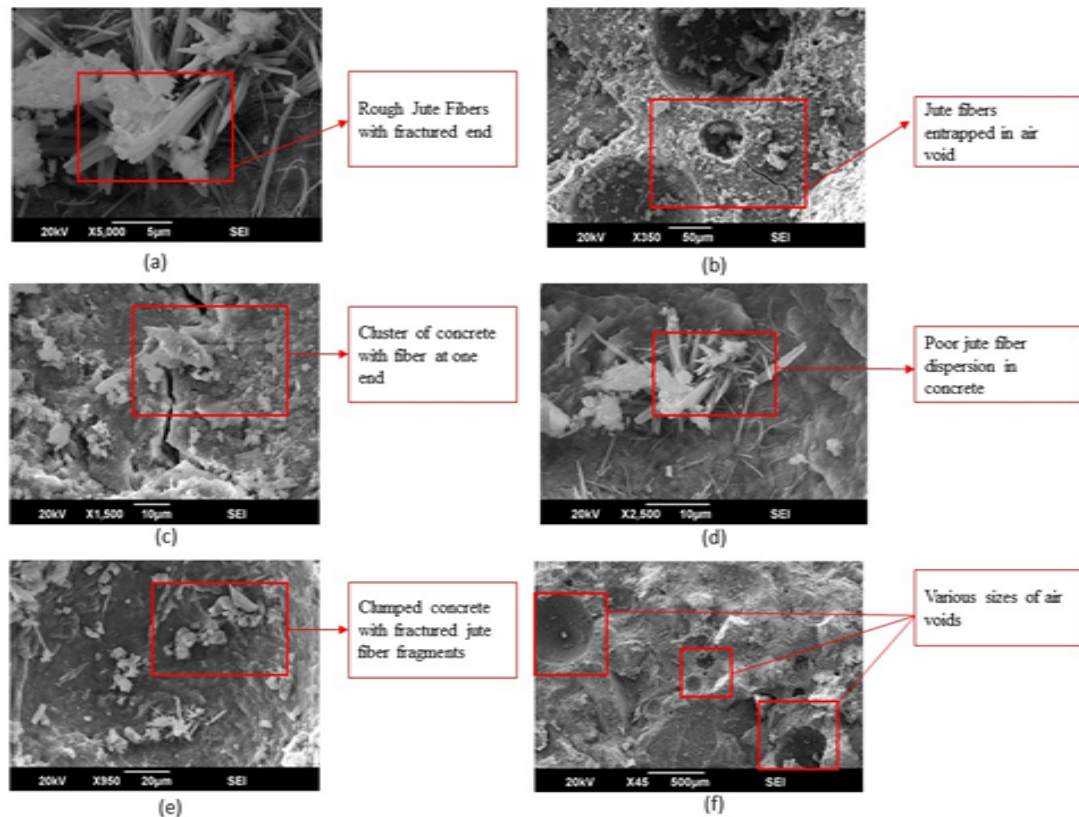


FIGURE 4.10: SEM of JFRSCC-NaOH 0.125%

higher water absorption resulted. Concrete was clearly observed as porous from internal view, aggregate size and non-uniform mixing, reason behind lower compressive strength, higher water absorption also resulted, shown in Figure 4.11 (d). In Figure 4.11 (e) fibers are not visible, improper distribution. This can be the reason behind an irregular drop in strength as fibers are not uniformly displaced. In Figure 4.11 (f), it shows clusters of concrete with small voids, lower density with increased water absorption. SEM analysis shows voids in both the specimens. JFR-SCC NaOH 0.125% and JFR-SCC Raw 0.125% showed maximum water absorption than PC, voids can be potential reason in case of both samples. Improper distribution of fiber is observed in both samples, showing human error during casting, reason behind irregular trends in results.

The SEM images of raw jute fiber and NaOH treated jute fiber shown in Figure 4.10 and 4.11 respectively, which shows that the surface of NaOH treated is comparatively very much better than the surface of untreated raw jute fiber. SEM of NaOH treated jute fibers shows rough jute fibers with fractured end, cluster of concrete with fibers at one end and various sizes of air voids, this may be because of improper mixing whereas SEM analysis of Raw JF shows the bunch of fibers

at several places, fibers with broken pieces stuck to concrete, and the air voids of different sizes were also observed in SEM of Raw JF and concrete clumps were also observed. Similarly, Hossain et al. [126] reported that the dust particles are removed from the jute surface by soaking them in NaOH for a specified period. It is also obvious that the jute fibers that were added to the concrete caused bonding and interlocking contacts between the fibers and the concretes components. This bonding helped to transmit stress away from the normal axis and decreased the growth of microcracks, which increased the concretes strength. Specimens for SEM analysis were selected based on mechanical performance, failure mechanisms, and fiber treatment variations. Optimized samples with 0.25% NaOH-treated jute fiber were analyzed for fiber-matrix inter- action. Broken cylindrical specimens from compression tests were used to examine crack patterns and fiber dispersion.

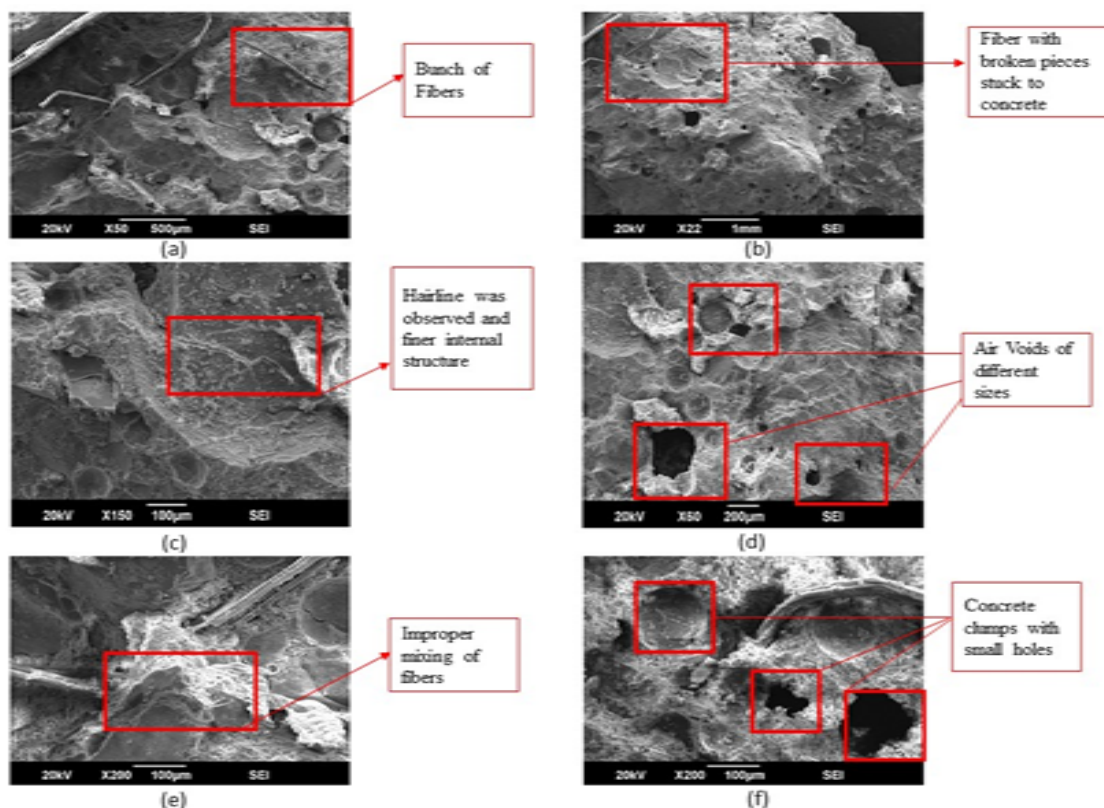


FIGURE 4.11: SEM of JFR-SCC, Raw 0.125%

## 4.5 Summary

Chapter 4 presents a detailed analysis of the experimental results, focusing on both the fresh and hardened properties of jute fiber-reinforced self-compacting

concrete (JFR-SCC). The fresh-state evaluation includes flowability tests, highlighting the impact of fiber addition on workability, with variations in fiber treatment methods influencing the concretes consistency and self-compacting ability. The hardened-state analysis examines mechanical properties such as compressive, flexural strength and energy absorption, emphasizing the role of fiber content and pretreatment in enhancing performance. Water absorption and density tests provide insights into the materials porosity, indicating the influence of fiber reinforcement on moisture resistance and structural integrity. Microstructural analysis using scanning electron microscopy (SEM) further investigates fiber-matrix bonding, revealing the effects of different fiber treatments on adhesion and crack resistance. The findings contribute to optimizing JFR-SCC by balancing workability, strength, and durability, offering a sustainable alternative for construction applications.

# Chapter 5

## Discussion and Practical Implementation

### 5.1 Background

Chapter 4 suggests the potential use of pre-treated and untreated (raw form) jute fiber in structural applications based on evidence of improved properties discussed in Chapters 3 and 4. To further investigate the behavior and capacities of fiber reinforced self-compacting concrete that incorporates jute fiber, research needs to be conducted. However, rare study has been conducted yet. Furthermore, optimization of the mix design should consider aspects such as economy, environment and social sustainability. Results are obtained from after performing physical and mechanical testing on specimens of all mixes. Quantity of jute fiber is changed in all mixes. There are total 10 mixes i.e, PC, raw with 0.25%, 0.125% and 0.5% jute fiber, NaOH dipped with 0.25%, 0.125% and 0.5% jute fiber and soaked with 0.25%, 0.125% and 0.5% jute fiber, respectively. Data from above mentioned testings is utilized to evaluate optimized mix. Comprehensive discussion on practical implementation of this study and optimized mix is done in this chapter.

### 5.2 Optimum Combination of Pre-treated Jute Fiber on SCC

The optimization of self-compacting concrete (SCC) reinforced with jute fibers involved analyzing key fresh and hardened properties to achieve an ideal balance between workability and mechanical performance. Flowability and passing

ability were assessed through fresh-state tests to ensure the concrete maintained its self-compacting characteristics while incorporating fiber reinforcement. Mechanical properties, such as compressive and flexural strength, were evaluated to determine the impact of different fiber treatments and dosages on structural performance. Additional parameters, including crack resistance, energy absorption, and toughness, were examined to assess the durability and long-term stability of fiber-reinforced SCC. The effects of fiber modification techniques, such as water soaking and alkali treatment, were also considered to improve fiber-matrix bonding and reduce potential issues like water absorption and dispersion inconsistency. Microstructural analysis provided insights into the interfacial adhesion between fibers and the cement matrix, further aiding in the selection of optimal fiber treatments. These studied properties played a crucial role in optimizing the SCC mix, ensuring improved performance while maintaining sustainability in construction applications.

Results obtained from physical testing are analyzed in Table 5.1. Results from compressive and flexural testing are mainly observed in selection of optimized mix along with other properties.

TABLE 5.1: Comparison of all Mixes

Sample ID	C.S (MPa)	Ce (MJ/m <sup>3</sup> )	CTI	MOR (MPa)	Fe (J)	FTI
PC	18.49±1.34	0.05±0.002	1.07±0.003	6.35±2.31	8.25±3.21	1±0.2
NaOH 0.125%	21.96±0.09	0.08±0.001	1.07±0.005	6.04±3.02	9.26±4.67	1.3±0.3
NaOH 0.25%	19.84±3.42	0.09±0.005	1.17±0.004	5.25±1.32	6.35±2.43	1.0±0.05
NaOH 0.5%	18.52±1.34	0.07±0.003	1.02±0.007	6.51±3.18	10.0±3.55	1.3±0.7
Soaked 0.125%	14.28±3.87	0.02±0.003	1.10±0.001	6.04±2.09	10.5±4.03	1.2±0.6
Soaked 0.25%	17.81±3.45	0.08±0.004	1.01±0.009	7.63±3.13	13.3±5.27	1.4±0.1
Soaked 0.5%	27.33±5.65	0.01±0.001	1.22±0.002	5.91±1.97	10.7±3.71	1.2±0.7
Raw 0.125%	23.60±1.23	0.13±0.006	1.09±0.005	5.56±1.03	10.0±4.08	1.3±0.2
Raw 0.25%	21.65±2.77	0.12±0.003	1.02±0.003	4.48±1.01	7.8±2.17	1.0±0.1
Raw 0.5%	13.86±1.75	0.05±0.001	1.07±0.008	5.12±2.01	7.3±2.36	1.1±0.7

TABLE 5.2: Optimized Mix

Sample (ID)	C.S (Mpa)	Ce (MJ/m <sup>3</sup> )	CTI	Load kN	MOR (MPa)	Fe (J)	FTI
Soaked 0.5%	27.33	0.01	1.23	10.00	5.9	10.77	1.22

The Soaked 0.5% mix is identified as the most optimized option based on its superior mechanical and durability properties. It achieves the highest compressive strength of 27.33 MPa, demonstrating excellent load-bearing capacity. The mix

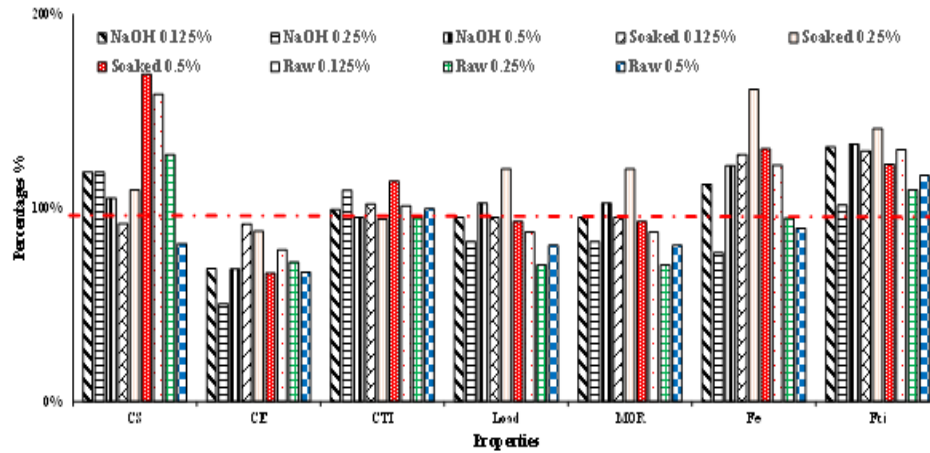


FIGURE 5.1: Comparison of All Mixes

also exhibits a modulus of rupture (MOR) of 5.912 MPa, which highlights its strong resistance to bending forces. Additionally, it has an energy absorption (Fe) value of 10.770 J, indicating good impact resistance, and the good flexural toughness index (FTI) of 1.226, showing improved ductility and crack resistance. The high performance of this mix is attributed to the water-soaked pre-treatment of jute fibers. This treatment improves the fibers by removing impurities, enhancing dispersion, and promoting better bonding with the cement matrix. This results in efficient stress distribution within the concrete, enhancing its strength and durability. The Soaked 0.5% mix is particularly suitable for applications that require high strength, durability, and the ability to resist cracking, making it a sustainable and effective choice for self-compacting concrete.

TABLE 5.3: Cost Comparison of PC-SCC and JFRSCC

S/No	Construction Cost (PKR)	Cost Reduction	Remarks
PC-SCC	23,410	-	Without fibers
JFRSCC	22,967	2%	With 0.5% fibers in concrete

In conclusion, Soaked 0.5% treatments provide optimal performance enhancements for SCC, with their specific strengths catering to different application priorities. The optimized mix design was selected due to its superior mechanical performance compared to the other mixes evaluated. The mix containing 0.5% soaked

and treated jute fiber emerged as the optimal choice, offering a well-rounded combination of mechanical strengths. It recorded the highest compressive strength at 27.33 MPa, reflecting excellent load-bearing capabilities. Furthermore, it achieved a modulus of rupture (MOR) of 5.91 MPa, highlighting its flexural strength. The mix also showed an energy absorption (Fe) of 10.7 J, indicating strong impact resistance, and a flexural toughness index (FTI) of 1.2, suggesting enhanced ductility and resistance to cracking. Its mechanical behavior, particularly the high compressive strength along with enhanced flexural strength, energy absorption, and toughness, reflects a well-balanced and durable material. These qualities make it a strong for applications that demand both strength and resistance to cracking or impact. Soaked 0.5% is ideal for applications requiring greater toughness and flexural performance. These findings underscore the potential of pre-treated jute fibers in producing sustainable, high-performance SCC, aligning with the goals of ecofriendly and resilient construction.

### **5.3 Utilization of Optimized JFRSCC for Pavement and Other Real Life Applications**

Jute fiber-reinforced self-compacting concrete (JFRSCC) has shown great potential for use in pavement construction due to its enhanced durability and crack resistance. The inclusion of jute fibers in self-compacting concrete improves its mechanical properties, including tensile strength and resistance to shrinkage, making it a suitable material for roads and pavements that are subjected to heavy traffic loads and varying weather conditions. Studies have demonstrated that JFRSCC can effectively reduce the occurrence of cracks and surface deterioration, which are common issues in traditional pavement materials. The ability of JFRSCC to self-compact further enhances its suitability for pavement applications, as it can be placed in intricate molds without the need for vibration, ensuring a smoother surface finish [125]. The sustainability aspect of using jute fibers also contributes to the environmental benefits of road construction, as jute is a renewable, biodegradable material. This combination of durability, ease of placement, and sustainability positions JFRSCC as an innovative alternative for improving the longevity and performance of pavements in urban infrastructure [126]. Jute fiber-reinforced self-compacting concrete (JFRSCC) has found several

real-life applications across various sectors due to its sustainable properties and enhanced performance. One significant area is sustainable construction, where JFRSCC is utilized in eco-friendly building projects. The natural fibers in jute help reduce the carbon footprint of concrete production, making it a more environmentally responsible material for construction [114]. In road construction, JFRSCC has shown promise in improving the durability and crack resistance of pavements. The incorporation of jute fibers helps the concrete withstand heavy traffic loads and adverse weather conditions, offering a sustainable alternative to traditional road materials [114]. In the realm of building construction, JFRSCC is particularly useful for non-load-bearing walls and floors, where its self-compacting ability facilitates easy placement in intricate formworks without the need for vibration. This makes it a cost-effective option in modern construction techniques [127].

Additionally, JFRSCC is being applied in the production of precast concrete products, such as panels, beams, and columns. The material's flowability and workability make it ideal for precast applications, where uniformity and ease of casting are essential [127]. Jute fibers also enhance the tensile strength of concrete, which has led to its use in reinforcing structural elements like beams and columns. This application is particularly valuable in improving the performance of concrete in areas with high tensile stress [128]. In water-retaining structures, such as reservoirs and dams, JFRSCC has shown potential for improving the durability and water resistance of concrete, making it suitable for use in these critical applications [129]. JFRSCC is being explored in low-cost housing projects, especially in developing countries, due to its affordability and the availability of jute fibers. The use of this material helps reduce construction costs while maintaining adequate strength and durability [130].

Additionally, the integration of JFR-SCC in precast concrete elements offers significant advantages in modern construction practices. Elements such as facade panels, parapet walls, and pavement blocks can be manufactured with this innovative material, achieving lightweight yet durable components. The combination of sustainability, enhanced mechanical properties, and versatility in design positions JFR-SCC as a transformative material for the construction industry, catering to both environmental and structural demands.

# Chapter 6

## Conclusions and Future Recommendations

### 6.1 Conclusions

This study successfully demonstrated the potential of incorporating pre-treated jute fibers into self-compacting concrete (SCC) to address significant challenges such as brittleness, cracking, and environmental sustainability. The experimental results revealed that jute fibers enhanced the compressive and flexural strength of SCC, offering better resistance to cracking and improved mechanical performance.

- The addition of jute fibers impacted the workability of SCC. The flow table test results indicated a slight reduction in flowability with the addition of fibers. The highest flowability was recorded for the SCC mix containing 0.25% water-soaked jute fibers, achieving a spread diameter of 610 mm, demonstrating improved workability compared to other fiber treatments.
- The 0.5% Soaked-treated jute fiber mix exhibited the highest compressive strength at 31.08 MPa, reflecting excellent load-bearing capacity. The value of MoE is 2.36 (GPa), The 0.5% soaked-treated mix exhibited a peak energy absorption CeP of 0.019789 MJ/m<sup>3</sup>, The same mix demonstrated 0.0105875 MJ/m<sup>3</sup> of energy absorption after the peak. With a CTI of 1.229, the 0.5% soaked-treated mix displayed the greatest resistance to cracking and failure.

- Flexural testing revealed that SCC reinforced with 0.5% water-soaked jute fibers achieved the maximum modulus of rupture (MOR) of 5.912 MPa, showcasing exceptional bending resistance. The 0.5% water-soaked fiber mix exhibited the highest  $F_e$ , which is 10.77 J. The highest  $F_eP$  was recorded in the 0.5% water-soaked fiber mix, confirming strong peak performance.
- SEM analysis revealed enhanced bonding between the cement matrix and pretreated fibers, especially in soaked and NaOH-treated fibers, confirming their contribution to improved mechanical properties.

Additionally, the use of supplementary cementitious materials, such as fly ash and silica fume, reduced the cement content in the mix, aligning with global efforts to minimize the environmental impact of construction materials. The optimized mix design provided a sustainable solution by lowering carbon emissions and utilizing renewable materials without compromising strength and workability. These advancements make jute fiber-reinforced SCC (JFR-SCC) a cost-effective and eco-friendly alternative for various construction applications.

## 6.2 Future Recommendations

Keeping in mind conclusions extracted from this research many future recommendations can be made. Following are the future recommendations on the basis of research work:

- Further investigation into the long-term durability of jute fiber-reinforced SCC (JFR-SCC) is essential. Studies should focus on the material's behavior under real-world conditions, including freeze-thaw cycles, prolonged moisture exposure, and resistance to chemical attacks, to evaluate its long-term viability in various climates and environments.
- Future research should explore advanced fiber treatment methods, such as chemical modifications, to enhance the bond between jute fibers and the cement matrix. This could improve the fiber dispersion, increase fiber-matrix adhesion, and mitigate issues related to fiber degradation in alkaline environments.

- The use of hybrid fiber systems (combining natural fibers like jute with synthetic fibers) should be explored to balance the benefits of natural fibers with the enhanced mechanical performance provided by synthetic alternatives. This could further improve the strength, durability, and sustainability of the mix.
- It is recommended to conduct large-scale field tests to validate the practical application of JFR-SCC in real construction projects, such as pavements, roads, and industrial flooring. This would provide valuable data on the performance, durability, and ease of implementation of JFR-SCC in various infrastructural applications.

These recommendations aim to further advance the potential of jute fiber-reinforced SCC in both practical applications and research, ensuring its sustainability, performance, and economic feasibility in the future.

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