CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Investigation on Concrete Slab having Jute Fibers and GFRP Rebars for Bridge Deck Application

by

Abdullah Ejaz

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in the

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This effort is devoted to my respected and cherishing parents, who helped me through each troublesome of my life and yielded every one of the comforts of their lives for my brilliant future. This is likewise a tribute to my best teachers who guided me to go up against the troubles of presence with ingenuity and boldness, and who made me what I am today.

CERTIFICATE OF APPROVAL

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Abstract

Novel and innovative ideas and technologies are introduced in construction industry because the requirements from structure increase day by day. Enhancing strength characteristics of concrete has been a practice for long. Transportation departments face substantial maintenance cost because of repair or replacement of decks deteriorated from cracking and rusting. From the investigations of failed bridge structures, it can be inferred that initial assumptions in the design typically depend on bridge connections. As bridges degrade from environmental effects and aging the joints (that were designed to rotate or move longitudinally) become static. In this way, expected load transfer mechanism of reaction and internal forces change which initiates cracking. Cracking leads to the penetration of water to reinforcement bars that get rusted and area loss occurs that means loss in flexural moment capacity of the deck slab section.

This paper reveals a study of prototype concrete deck slabs reinforced with Glass Fiber Reinforced Polymer (GFRP) rebars and jute fibers to overcome the cracking and rusting issue. Comparison between prototype slab of Plain Cement Concrete (PC) and Jute Fiber Reinforced Concrete (JFRC) is made to find the effectiveness of jute fiber in improving the load carrying capacity and overall failure mechanism. Two different loading rates (3.3 and 6.6 kN/sec) are used to study their effect on prototype specimen. Twenty (20) prototype slabs with a width 225 mm, length 450 mm and 75 mm thick are tested with and without jute fibers, with varying shear and flexural GFRP rebars at two different loading rates. ASTM C 293 is followed to find flexural strength and corresponding deflection of slabs of PC and JFRC. Specimens are tested in servohydro testing machine (STM). Load-deflection curve is used to find flexural energy absorption and toughness. The mix design ratio for PC is 1:2:3:0.60 (cement: sand: aggregate: water). 1:2:3:0.70 mix is used with 5 cm long jute fibers and a fiber content of 5%, by mass of cement, are used for preparing JFRC. The mix design for JFRC is the same as that of the PC, only water cement ratio is increased to make it workable.

The test results show that flexural strength of prototype slabs is enhanced significantly. Also, toughness index and energy absorption were augmented by increasing the number of flexural and shear rebars. Inclusion of jute fibers improved crack behavior of concrete, increased flexural and splitting tensile strength of concrete. On microscopic level, it is seen that a stronger concrete matrix is formed by mixing jute fibers. An increase is observed in moment capacities by increasing flexural reinforcement as well as introducing Jute fibers. Theoretical moment capacity of the section with plain concrete is higher than the experimentally determined moment capacity of the same section. Whereas, this is in contrast to the trend found in the specimens reinforced with jute fibers. Further investigation should be carried out by varying diameter of GFRP as well as length of jute fibers. Other fibers may also be added.

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Abbreviations

C.E1	Compressive Energy Absorbed up to First Crack
C.T.I	Compressive Toughness Index
F.E	Total Flexural Energy Absorbed
F.E.M	Flexural Energy Absorbed from the First Crack to Maximum Load
F.E.P	Flexural Energy Absorbed Post the Maximum Load
F.E1	Flexural Energy Absorbed upto First Crack
F.S	Flexural Strength
F.T.I	Flexural Toughness Index
FRC	Fiber Reinforced Concrete
GFRP	Glass Fiber Reinforced Polymer
JF	Jute Fiber Concrete for Flexure
JFRC	Jute Fiber Reinforced Concrete
JS	Jute Fiber Concrete for Shear
kN	Kilo Newton
LR1	Loading Rate 1
LR2	Loading Rate 2
Max	Maximum
MD	Mix Design
mm	Milli Meter
MPa	Mega Pascal
PC	Plain Concrete
Pf	First Crack Load
PF	Plain Concrete for Flexure
Pm	Maximum Load

PS	Plain Concrete for Shear
Pu	Ultimate load
s	Second
S.E.P	Splitting Tensile Energy Absorbed Post the Maximum Load
S.E1	Splitting Tensile Energy Absorbed upto First Crack
S.T.I	Splitting Tensile Toughness Index
UTM	Universal Testing Machine
w/c	Water Cement Ratio

Symbols

$\triangle$	Deflection
Φ	Diameter
Φ_f	Diameter of Fibers Used
ξ_{cu}	Ultimate Failure Strain in Concrete
ξ_{fu}	Ultimate Failure Strain in Concrete
β_1	Equivalent Stress Block Parameter

Chapter 1

Introduction

1.1 Background

Transportation departments consume a lot of resources on the repair or replacement of bridge decks deteriorated by cracking and corroding of reinforcing bars. Studies of failed bridge structures show that preliminary assumptions in the design typically depend on bridge connections. As bridges degrade from weathering effects and aging the joints that were designed to rotate or move longitudinally become static. In this way predicted load transfer mechanism of reactions and forces internally changes which starts cracking. Cracking results in the water penetration and rusting of reinforcing bars. So, area loss occurs that means loss in flexural moment capacity of the deck slab section [1]. Response of the existing bridge structures and accessing their residual service life under deteriorating conditions can help in comprehension of failure of bridges [2]. Han et al. [3] described that the most common damage of bridges included shear-flexural failure of the deck.

Cracks in plain concrete present huge issue with the slabs as it increases water penetration and enhances the probability of corrosion and hence increasing failure chances. Razmi and Miryasar [4] report that mechanical properties of concrete were enhanced by mixing jute fiber. Traditional strengthened concrete is prepared by putting steel reinforcement in Portland cement concrete mix. The function of concrete is to take compressive stress whereas flexure and shear stresses are taken by steel bars. But steel bars have corrosion and high density. In order to overcome the issues caused by corrosion and high density of steel, GFRP bars are introduced in concrete. Fiber reinforced polymers (FRP) is a very promising class of additives.

Present study focuses on improving the strength and crack development by mixing natural fiber and confinement by adding GFRP bars. Natural fibers are environment friendly. Jute fiber is grown all over the world naturally without help of any chemical additive [5]. Fibers help in minimizing the crack in number as well as width. This increases section capacity as the concrete now takes more load before failure. Reason being the jute fibers present in the mix bridge the cracks and mitigate their development and expansion to a larger load. Jute fiber upon addition into concrete can considerably improve flexural strength. Using different percentage of jute fibers by weight of cement (0.3%, 0.4%, 0.6%, 0.8%, 1%, 1.2%, 1.4%, 1.6%, and 1.8%) which are cured for 3, 7 and 28 days have an increased compressive strength from 8.8 MPa to a maximum of 44.44 MPa [6]. Inclusion of jute fiber in the concrete increase initial and final setting times [7]. Also the slump value decrease by 30-50% by adding jute in concrete [8].

As steel bars corrode in moist condition, GFRP bars have evolved as an excellent alternative as they dont rust and have a very low weight and high tensile strength. In countries like Pakistan, where steel is a costly material, reinforced concrete (RC) structures are favored over steel structures being cost-effective. GFRP bars improve the capacity of slabs in flexure much better than Steel [9]. GFRP bars are introduced as a technique for flexural strengthening of existing RC elements [10]. Concrete reinforced with GFRP bars can have two types of failure under flexural loading i.e. flexure and shear. Flexural failure occurs due to tensile rupture of GFRP bars while the shear failure was started by a major crack in the span [11]. Construction system with GFRP offer high strength and durability. The crushing failure at flexural moment capacities of GFRP reinforced concrete slabs were 1.2-1.5% times greater than those with steel [12].

1.2 Research Motivation and Problem Statement

Bridge deck directly takes load from moving traffic, transfers the loads safely to ground through girders and piers. In conventional concrete, steel bars are used as reinforcement. But, in structures (like bridge deck) that are exposed to weathering conditions, steel bars may rust [13]. GFRP bars are a good alternative to steel bars because of low susceptibility to corrosion [26]. Often times, the strengthening systems enhance the loading capacities of structure but changes the mode of failure from ductile to brittle [10]. The concept to improve the properties of concrete by using fibers is very old [17]. The inclusion of fibers in the concrete tends to control cracking and spalling; which in result, causes increase in the overall toughness. Loading rate also affects the performance of GFRP bars and jute reinforced concrete. Two different loading rates for flexural testing are studied by various authors i.e., Min Li and Hongnan li (2012) [57]. Thus, the problem statement is as follows:

"Structures safety is associated with the materials used for construction. In concrete deck slabs, concrete is the main constituent that behaves very poor under tensile loadings and has less toughness. Corrosion associated with steel rebars is another problem. Flexural capacity of reinforced concrete is enhanced by replacing steel reinforcements with GFRP rebars that tends to be a convincing and reasonable solution to overcome the weathering issues [14]. At the same time, natural fibers (i.e., jute fibers, selected to start with) are used in concrete for having enhanced toughness. Different loading rates are also considered with high and low magnitudes as mentioned in ASTM standard of flexural testing [16]. Therefore, to attain adequate strength for the prototype bridge deck, the overall behavior of the prototype bridge deck is to be explored in detail."

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

The overall objective of research program is to replace longitudinal steel rebars with FRP rebars in concrete structures with additional use of natural fibers for improved durability and performance.

The specific aim of current study is to replace horizontal steel with GFRP rebars in JFRC for bridge deck application to improve the performance, serviceability and stability. The suitability of GFRP rebars and jute fibers is checked with main emphasis on corrosion free and enhanced toughness.

"In this research work, an investigation has been carried out to study the behavior of prototype concrete bridge deck slab having varying number of longitudinal and shear GFRP rebars in Jute fiber reinforced concrete at two different loading rates."

1.4 Scope of Work and Study Limitations

Twenty (20) specimens with five different reinforcing combinations are used for studying the behavior PC and JFRC at two loading rates. It may be noted that two loading rates have also been used in flexural testing by others e.g [57]. Comparison between PC and JFRC having GFRP rebars is done.

Single mix design ratio, fiber content and fiber length are used. Prototype testing is done with easy boundary conditions. Only two different loading rates are used for prototype testing.

1.5 Brief Methodology

In this experimental study, flexural strength of PC and JFRC are determined in lab. Comparison between prototype slab of PC and JFRC are made to find the effectiveness of jute fiber in improving the load carrying capacity and overall failure mechanism. Two different loading rates (3.3 and 6.6 kN/sec) are used for prototype specimen. These are being taken from ASTM C 293. [16] is followed to find flexural strength and corresponding deflection of slabs of PC and JFRC. Specimens are tested in servohydro testing machine (STM). Load-deflection curve is used to find flexural energy absorption and toughness. The mix design ratio for PC is 1:2:3:0.70 (cement: sand:aggregate: water). Qureshi and Ahmed (2013) use 1:1.5:3:0.60 mix and achieve a specific strength but to achieve more strength and confinement 1:2:3:0.70 mix is used 5 cm long jute fibers with a fiber content of 5% by mass of cement are used for preparing JFRC. The reason for selection of these fiber parameters is based on the fact that previous researches have reported optimum results. The mix design for JFRC was the same as that of the PC only water cement ratio was increased to make it workable. Slab panel of size 450 x 225 x 75 mm are casted and tested for flexural strength of PC and JFRC.

1.6 Thesis Outline

This research work has six chapters which are given as follows:

Chapter 1 covers introduction. It includes background, Research Motivation and Problem Statement, Overall Objective, Specific Aim, Scope of work, Research Methodology and thesis outline.

Chapter 2 encompasses literature review. It consists of background, failure in concrete bridge deck, natural fiber in concrete, GFRP rebars as flexural reinforcement in plain cement and jute reinforced cement, testing practice and summary.

Chapter 3 illustrates experimental procedure. It contains background, raw material, and mix design, procedure of casting, testing and summary.

Chapter 4 discusses analysis and test results. It covers background behavior of prototype PC and JFRC slab decks, effects of loading rates on PC and JFRC slabs having varying flexural and shear rebars and summary.

Chapter 5 covers discussion.

Chapter 6 covers conclusions and recommendations.

References are presented right after chapter 6.

Annexures are given at the end.

Chapter 2

Literature Review

2.1 Background

Use of natural fiber ages decades back to improve concretes behavior and properties. Concrete reinforced with natural fiber is proved to be better in durability, shrinkage and crack propagation is minimized. One of the positive aspects that encourage the use of the fiber on large scale is its availability and cost. Jute fiber is one of the natural fiber which is widely produced in tropical region and has better tensile properties. Concrete is very good in compression but behaves very poor under tensile loading. Steel reinforcement bars are added to the concrete to improve tensile resistance and make fracture ductile. Glass reinforced polymer (GFRP) bars are a good alternative for costly steel bars serving the same purpose.

2.2 Failure in Concrete Bridge Deck

Every year, a lot of resources are consumed on bridge deck repair and replacement. Studies of failed bridge structures show that initial assumptions in the design typically depend on bridge connections. Some of the failed bridges are shown in Figure 2.1. As bridges degrade from weathering effects and aging the joints that were designed to rotate or move longitudinally become static. In this way,

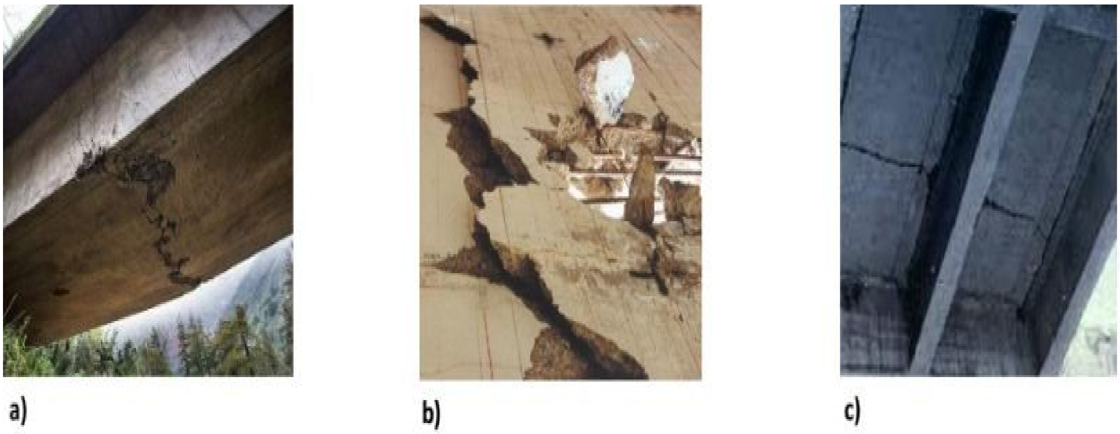

FIGURE 2.1: Failure in concrete bridge, a) Flexural cracking (Pfeiffer Canyon Bridge), b) Shear failure of a bridge deck., c) Crack in concrete bridge deck

predicted load transfer mechanism of reactions and forces internally changes which starts cracking. Cracking results in the water penetration and rusting of reinforcing bars. So, area loss occurs that means loss in flexural moment capacity of the deck slab section [1]. Response of the existing bridge structures and accessing their residual service life under deteriorating conditions can help in understanding failure of bridges [2].

2.3 Using Natural Fibers in Concrete

Mode of failure influences stability and serviceability of concrete bridge decks. The probability of failure can be reduced by improving the mechanical properties of concrete bridge deck. These properties can be improved by adding natural fibers. Use of natural fiber ages decades back to improve concretes behavior [17]. Concrete reinforced with natural fiber is proved to be better in durability, shrinkage and crack propagation is minimized. One of the positive aspects that encourage the use of the fiber on large scale is its availability and cost. Jute fiber is one of the natural fiber which is widely produced in tropical region and has better tensile properties. Zakaria et al. (2017) investigated the effect of jute fiber in concrete. Flexural strength, tensile strength were tested for the specimen of standard size. Major improvements in the mechanical properties was observed by the incorporation of jute fibers. Consequence of his research prove jute fiber to be very effective in enhancing concrete properties [18].

James et al. (2002) investigated that the mechanical properties can be enhanced by fiber reinforced concrete (FRC) and/or admixtures [19]. FRC is a composite material consisting of a matrix (i.e. concrete) containing a random dispersion of small discrete fibers, either artificial or natural. The dynamic and static properties of concrete are improved by the addition of small discrete fibers in the concrete matrix [20]. The presence of fibers in concrete reduces width of cracks; due to which stiffness and ultimate load carrying capacity is increased [21].

Ramakarishan and Sundarararajan studied durability of coconut, sisal, jute and hibicius and cannabinus fiber. They carried out alternate wetting and drying cycles as well as the immersed specimens in water saturated with lime and sodium hydroxide continuously for 60 days. They observed change in chemical composition of fiber. Coconut fiber was found best among the above considering its tensile properties. In this manner, the durability of natural fibers is evaluated.

Zia and Ali [15] studied the effect of natural fibers in canal lining crack propagation. Jute fiber reinforced concrete (JFRC), polypropylene fiber reinforced concrete (PPFRC) and nylon fiber reinforced concrete (NFRC) was tested for compression, flexure, split tension and shrinkage on standard cylinder and prism specimen. Enhanced energy absorption and toughness of JFRC was observed with respect to PC. Water absorption of JFRC was also increased by 8%. Their study concluded, that the crack width can be substantially reduced by inclusion of fibers.

Toledo and Filho et al. [22] experimented with concrete specimens reinforced with coconut fibers in three different pH ranges i.e, tap water, calcium hydroxide and sodium hydroxide. After 420 days immersing in sodium hydroxide the coconut fiber reinforced concrete retained 60.9% of their initial strength. They also studied the effect of different aging conditions. Properties of different natural fibers have been presented by [23] in Table 2.1.

TABLE 2.1: Properties of various natural fibers

Fibers (40 mm)	Tensile Strength (MPa)	Young's Modulus (GPa)	Failure strain (%)	Area (mm^2)
Jute	249±89	43±12.4	0.06±0.2	0.004±0.001
Coir	90±35	2.6±0.07	18.8±9.1	0.052±0.03
Sisal	484±135	19.5±4.5	3.3±1.6	0.023±0.007

2.3.1 Using Jute Fiber in Concrete

Jute fiber is found in abundance in South Asian countries. Razmi and Mirsyar [4] studied that, inclusion of jute fiber in concrete enhances the flexural properties of concrete. It further discusses the increase in fracture toughness and reduction of crack width. Chakraborty et al. [7] also verified the increase in strength by use of jute fiber [7]. Islam and Ahmed [24] also studied pull-out strength of concrete specimens reinforced with jute fiber. Research showed that bond strength increases significantly by length and volume of jute fibers [24].

Zakaria et al. [18] tested two mix design proportions 1:2:4 and 1:1.5:3 with varying fiber lengths from 10 to 25 mm. Overall strength of the concrete mix was significantly increased. Previous studies have shown that jute fibers absorb water when added to the concrete mix and reduce the water for hydration of cement. That is why, generally JFRC mix have w/c ratio more than the same mix of PC. Liu et al. [20] carried out investigation on two groups of concrete mixed with jute fibers. One of the group fiber length was kept constant and varied the volume of fiber while in the other group percentage additive was same and length varied from 10 to 50 mm. compressive strength increased by 20.44% and flexural strength was increased 53.5%.

Table 2.2 shows that fiber length affects the properties of concrete. For different mix designs, there is a different optimum content and different lengths of fiber. Sen et al. [25] studied the durability of mechanical properties of jute fibers composite with concrete in different conditions. He reported that salt water adversely affects the durability and mechanical properties of concrete reinforced with jute fiber.

Table 2.2: Effect of Length of Jute fiber on the Moment of Rupture (MOR) of JFRC as compared to PC

Sr. No.	Reference	Fiber Length mm	MOR (%)
1	Zakaria et. al. (2016)	15	90
2	Razmi and Miryasar (2017)	20	103
3	Kundu et. al. (2012)	50	111
4	Zia and Ali (2017)	50	108

2.4 Fiber Reinforced Polymer Rebar

The FRP rebars are made from high strength glass fiber reinforced with vinyl ester resin. FRP rebars as an alternative for steel bars have arisen as a genuine and inexpensive solution to overcome the corrosion and self-weight issues. The FRP has many benefits over steel bars, including a density of one-quarter to one fifth that of steel, greater tensile strength than steel, and no corrosion even in cruel situations [26].

As compared to steel reinforced concrete, the construction cost of GFRP is expected to be 20% less because of having low density than the normal reinforced concrete [27]. Davalos et al. [28] studied that FRP reinforced concrete is quite complex and moderately reinforced. The use of FRP rods together with high-strength concrete, particularly in highly corrosive locations, will solve some problems due to its non-corrosive and lightweight FRP rods, as well as high water and moisture content [29].

2.4.1 Using GFRP as as Flexural Reinforcement in PC and JFRC

GFRP rebars are reasonably developing technique to increase the flexural capacities of RC elements. Flexural strengthening of reinforced concrete deck by using GFRP was effective. The FRP has many benefits over steel bars, including a density of 20-25% of steel, greater tensile strength than steel, and no rust even in humid situations [20]. GFRP reinforced slab exhibited better flexural strength as compared to steel reinforced slab. Using GFRP rebars ductility, stiffness and energy absorption under applied load were significantly increased. Increase in bond length of the braced GFRP rebars ultimate load, failure load and ductility index also increased [16]. Hosen et al. [10] investigated GFRP rebars for increasing the flexural capacity of reinforced concrete members by using side near-surface mounted (SNSM) technique. It was proved that improved flexural performance from the tested specimen compared with the control specimen. The first crack and ultimate loads of energy absorption capabilities, ductility and stiffness were also augmented.

Maranan et al. [12] evaluated the flexural strength and serviceability performance of geopolymer concrete members having GFRP rebars under four-point loading in a bend test. It was determined that, based on experimental results, the performance of a beam amended when the reinforcement ratio of glass fiber increased. The bending capacity of the GFRP strengthened geopolymer concrete beams shows up to be higher than GFRP exhilarated concrete beams basically due to the improved mechanical properties of the geopolymer concrete than the conventional concrete of the same review. Increase in the reinforcement ratio of GFRP rebars resulted in improved performance, including post-crack stiffness, load capacity, and flexibility (or deformation) [30].

Zhu et al. [31] investigated the flexural behavior of partially steel fiber reinforced high strength concrete with GFRP rebars. GFRP bars can deliver a construction system with high strength. The bending moment capacities at concrete crushing failure of GFRP bars reinforced slabs were 1.2-1.5 times greater [12]. GFRP rebars gave high strength, high sustainability and high durability when used in construction system. Bar diameter did not affect the flexural strength significantly. Generally, while increasing the reinforcement ratio the performance of a beam also enhanced. The GFRP reinforced concrete beams fail either by concrete crushing at the dense zone or split of the GFRP reinforcement.

GFRP rebar are non-corrosive in nature and good alternative of steel rebars. Number of cracks increased in concrete reinforced with GFRP rebars when compared with conventional concrete [32]. Generally, jute fibers enhance the mechanical properties like splitting tensile strength, flexural strength and flexural toughness index as discussed in previous section. And GFRP bars are mainly used because of corrosion free properties. Combination of GFRP rebars and jute fibers may provide a concrete better in corrosion and toughness at the same time.

2.5 Testing Practice Using Prototypes

There are four stages to foresee the behavior of any structure which are

(i) full scale structure in actual field circumstances [33].

(ii) fully scaled structural member with accurate boundary conditions [34].

(iii) either scaling the prototype structure or typical structural elements, including the suitable gradient for raw material,size, loading conditions and end-limits [35].

(iv) small prototype structural elements for comparative reasons to check the effectiveness of only one variable keeping all other conditions constant [36, 20].

In the current study, only an easy method (i.e. stage iv) is adopted. The behaviors of a small prototype of PC and JFRC bridge slab fixed with various longitudinal GFRP and shear steel reinforcement configurations are compared.

2.6 Moment Capacities using Stress Block

2.6.1 Whitney's Stress Block

In 1930s, Whitney (1937) proposed the use of rectangular compressive stress distribution to replace the parabolic stress distribution as shown in figure 2.2.

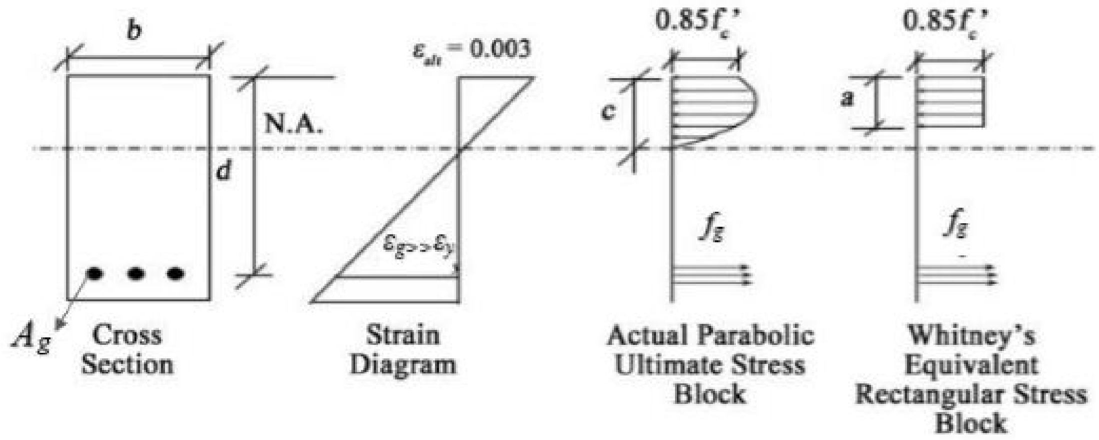

FIGURE 2.2: Stress distribution using Whitney's Stress Block

b = Cross sectional width (mm)

A_s = Area of steel rebar (mm^2)

f_s= Yield strength of Steel rebars in tesnion (MPa)

f_c = compressive strength of concrete at 28 days (MPa)

d = Effective Depth of section (mm)

a = Equivalent depth of whitneys stress block (mm)

T_s = Tensile force in Steel rebars (N)

An average stress of $0.85f_c$ is used with the rectangular depth of a = β_1c. Concrete below the neutral axis is ignored and total tension T is due to Reinforcing bars. Whitneys equation takes plain concrete reinforced with steel rebars in to consideration. The equation for normal reinforced concrete to find design moment capacity is as follows [37].

$$M_n = T_s \left(d - \frac{a}{2}\right) \ , \tag{2.1}$$

The strength of Steel in tension can be calculated with equation as follows:

$$T_s = A_s x f_s N \ , \tag{2.2}$$

Equivalent compressive stress depth (a) can be calculated as:

2.6.2 Besharas Equation

In Whitneys stress block, concrete strength in tension zone is neglected. That is true for normal concrete. But, for concrete reinforced with fiber in tension zone concrete does show tensile capacity. To consider this, Beshara et. al. [38] proposed new equation for concrete reinforced with fibers as well as steel rebars. Modified stress strain diagram according to Beshara is shown in figure 2.3.

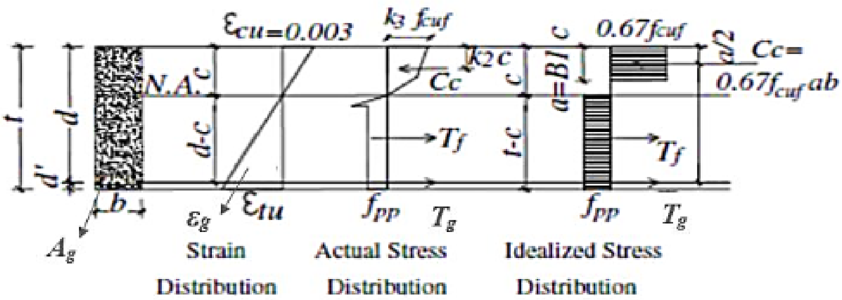

Figure 2.3: Stress distribution using Beshara's et al [2012]

Design moment capacity of fiber reinforced concrete can be calculated as follows:

$$M_f = T_s\left(d - \frac{a}{2}\right) + T_f\left\{\left(t - \frac{t_e}{2}\right) - \frac{a}{2}\right\} N.mm \ , \tag{2.3}$$

$$T_f = 1.64 V_f \left(\frac{L_f}{\phi_f}\right) b.t_f N \ , \tag{2.4}$$

Where:

t = Total depth of slab(mm)

t_f = Effectice height of equivalent stress of fiber reinforced concrete in tension zone(mm)

T_f= Tensile force of Fiber reinforced Concrete(N)

V_f = Volume Fraction of fiber used in concrete

L_f = Length of fiber used in concrete(mm)

ϕ_f= diamter of fiber used in concrete

But in the present study an easier approach is used to determine the tensile force in jute fiber that is $T_f = \left(\frac{P_m f - P_m c}{2}\right)$where $P_m f$ and $P_m c$ are maximum flexural load taken by the JFRC and PC. This can be explained by the concept that the concrete mix in the PC and JFRC are the same so the additional load taken by JFRC can be associated to the presence of Jute fiber in it. PC at peak load starts cracking and section is reduced supporting lesser loads whereas in JFRC these cracks are bridged to a higher load therefore takes more load.

2.6.3 Urgessas Equation

In the present research, GFRP rebars are used for which ACI equation is not valid. For concrete reinforced with GFRP rebars moment capacities can be computed using Urgessa et al. [39] and W.K. Feeser and L.K. Brown [40] approach. The stress distribution by these methods are shown in Figure 2.3. They state that a design approach to design FRP reinforced concrete member is set to a lower limit on FRP reinforcement to achieve and compression controlled failure in concrete. This is in contrast to the design methodology for steel. Concrete sections that are reinforced with single layer of GFRP rebars should be designed as tension controlled sections recommended by ACI guide, ultimate strength limits rather than the crack width criteria. Equations for design are as follows:

$$M_n = A_f . f_{fu} \left(d - \frac{\beta_1 . c_b}{2} \right) N.mm \tag{2.5}$$

Where c_b is depth of compression zone at balanced strain condition; "f_u is ultimate tensile strain of FRP.

$$c_b = \left(\frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{fu}} \right) dmm \tag{2.6}$$

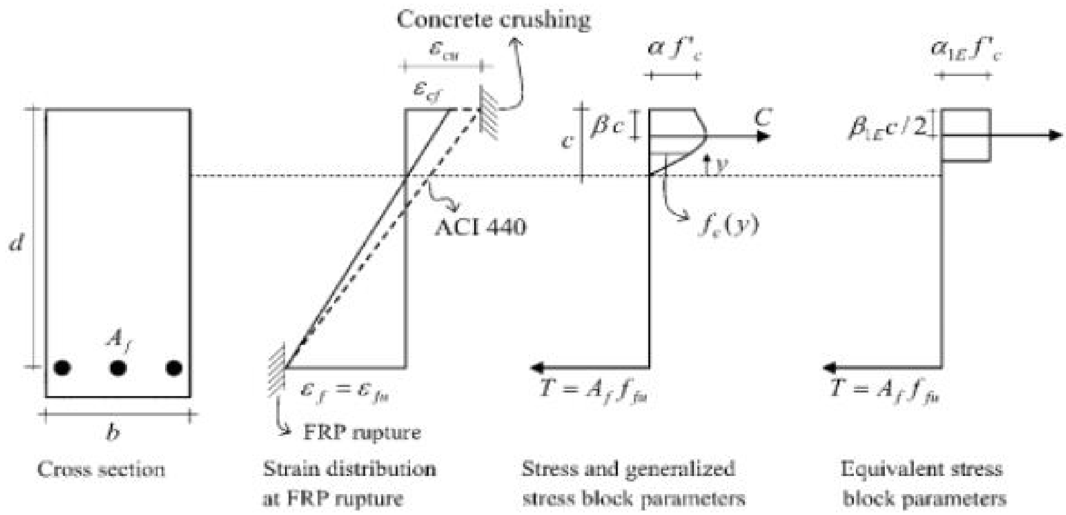

FIGURE 2.4: Stress distribution using Urgessa et al. [2008]

2.7 Summary

In this chapter, we understood fiber can be used to enhance properties of concrete. Jute fibers have high tensile strength, low cost, and richly existing in tropical areas. Jute fibers had a positive effect on hardened concrete properties. Glass fiber reinforced polymer rebars are more effective and efficient as compared to steel reinforcement with a subject to their mechanical properties including low density, higher tensile strength than steel, and no erosion even in harsh environment.

From the above discussion, it is concluded that when mechanical properties of concrete are improved, the chances of failure of bridge deck may reduce. To minimize the failure of concrete bridge deck the mechanical properties like compressive strength, split tensile strength and flexural strength of should be increased. Natural fibers in concrete increases the crack span and reduces the width. Natural fibers in concrete can increase load carrying capacity and stiffness. Slab samples of PC and JFRC with flexural GFRP rebars are examined under flexural load.

Chapter 3

Experimental Program

3.1 Background

Use of jute fiber in concrete with GFRP reinforcement to enhance the mechanical properties are common these days. Increase in mechanical properties, toughness, and energy absorption are the main returns of fiber reinforced concrete. Performance of jute fiber for enhancing the resistance with GFRP rebars is discovered through the experimental work. GFRP rebars gained good alternative to conventional steel rebars due to low density, high durability, more ductile, light weight, weather and fire resistant. This chapter demonstrates in detail the selection of mix design, raw materials, mix design, and casting procedure, specimens, testing procedures.

3.2 Raw Material

In the present study, lawrencepur coarse aggregate, sand, ordinary portland cement, fresh water, jute fibers and GFRP rebars are used for the preparation of PC and JFRC mixtures. The maximum size of the coarse aggregates is 10 mm. Jute fibers are available in a raw form which are prepared by hand at the rate of 50 mm length. It has high tensile strength and low extensibility. Physical properties of jute fibers are experimentally determined by [23]. Tensile strength ranges from 160 MPa to 338 MPa. Its density ranges from 1200 to 1400 kg/m^3 and absorbs water upto 13%. Chemical constituents of jute fiber are cellulose, lignin, fat, wax, water soluble materials [41]. These chemical (cellulose, wax, and lignin) can be a reason of weak connection between jute fiber and concrete mix. A simple pre-treatment is adopted in which jute fibers are soaked in water to remove dust and wax content inside water tank for approximately half an hour. After that the jute fiber is brought out of water and air dried. Prepared and hand cut length of jute fibers are shown in (Fig. 3.1.b) 5 cm length and 5% content of fibers are chosen based on past researches (Table 2.2).

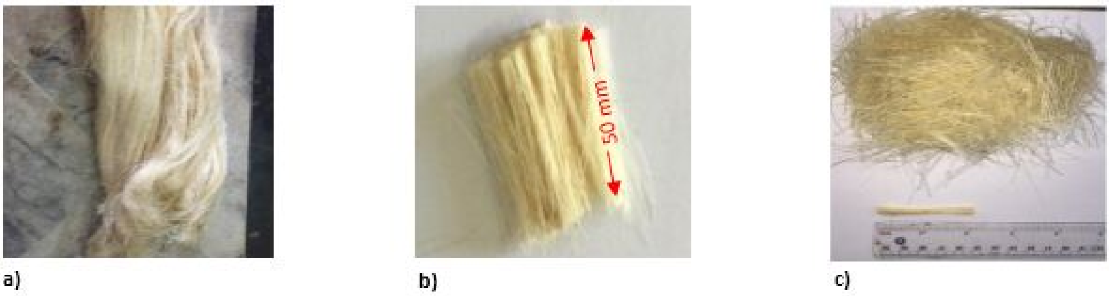

FIGURE 3.1: Jute Fibers, a) Raw Fiber, b) Cut Length, c) Dispersed Fiber

GFRP rebars are imported from china having 6 mm diameter and 400 mm length (Fig.3.2). Physical properties are determined experimentally (Table 3.1). The tensile strength and ultimate tensile strain of glass fiber reinforced polymer rebars are 896 MPa and 1.94 %, respectively; whereas density is 2200 kg/m^3.

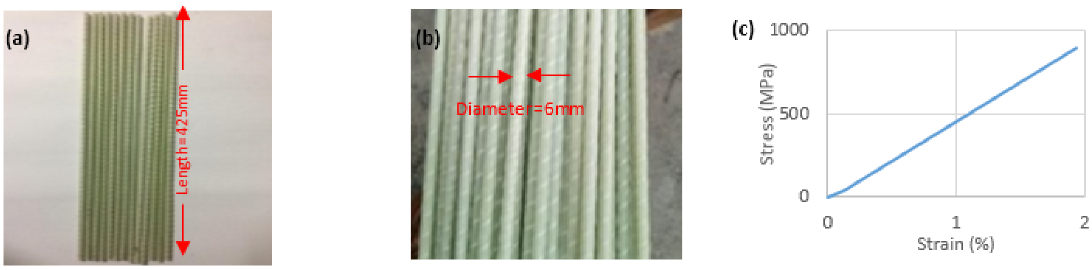

FIGURE 3.2: Glass Fiber Reinforced Polymer Rebars, a) Cut length of Bar, b) Diameter of bar, c) Tensile Stress-strain curve

Table 3.1: Mechanincal Properties of Glass Fiber Polymer Bars

Dimensions	Value	Unit
Diameter	6	mm
Cross-Sectional Area	28.27	mm^2
Density	2200	kg/m^3
Weight	0.051	kg/m
Ultimate Tensile Load	28.34	kN
Tensile Strength	896	MPa
Ultimate Shear Strength	150	GPa
Elastic Modulus	46	GPa
Ultimate Shear Strain	1.94	%

These days corrosion is the main problem associated with steel reinforcement bars in moist conditions. To avoid this problem, GFRP rebars are a good substitute to steel bars in concrete structures in humid conditions as they are corrosion free and show great strength. Similarly, jute fibers can enhance toughness of concrete. In present study, GFRP and jute fibers are combined so that the mix exhibits better resistance to corrosion, enhanced toughness as well as better crack control. GFRP bars are an emergent way to improve the flexural capacities of structural elements. The GFRP rebars used in this research work are imported from China. The length of longitudinal reinforcement GFRP rebars used in both PC and JFRC slabs is 400 mm having diameter of 6 mm are shown in Figure 3.2 (a).

3.3 Mix Design and Casting Procedure

Different mix design proportions have been used in literature i.e, Razmi and Mirsayar(2017) [4] used 1:2.77:2.46 and Zia and Ali chose 1:3:1.5. So, in present study, the mix design ratio for PC is 1:2:3:0.65 (cement: sand: aggregate: water). Mix design ratio 1:2:3:0.70 is used with 5 cm long jute fibers with a fiber content of 5% by mass of cement (Table 3.3). The increase in w/c ratio in JFRC mix is done to cover the additional water required by the jute fibers in the concrete mix. High w/c ratio in the JFRC mix also increases the workability of the mix. All the dry constituents are put in the concrete mixing drum for preparing mix and water is added in the end. The mixer is rotated for about 3-4 minutes to achieve a homogenous mix. However, jute fiber is mixed in the concrete after adding water. The mixer is further rotated for two minutes to get JFRC mix. The paste seems harder so to make it workable mixer is rotated for two more minutes. This additional mixing time saves the mix from bleeding by adding extra water to enhance workability.

TABLE 3.2: Mix Design Proportions for PC 1:2:3:0.65 and for JFRC 1:2:3:0.7:0.05 for 1 m^3

Material	Cement kg	Fine Aggregate kg	Coarse Aggregate kg	Water Litre	Jute Fibers kg
PC	370	740	1110	222	-
JFRC	351.5	703	1054.5	246.06	18.5

The slump test of PC and JFRC is done, value of Slump came out to be 40 mm and 30 mm respectively. JFRC mix slump is lower than PC even after adding extra water in mix, this is because of the water absorbing capacity of jute fibers in JFRC mix. The PC and JFRC made in the mixer are put in the slab moulds in which GFRP rebars are already laid in successive three layers. Each layer is given 25 blows by tamping rod to remove air and voids from the concrete. Whereas lifting and free falling of the slab mould is done to remove air. The dissembling of sample moulds is done after 48 hours. Specimens are placed in water tank for 28 days for curing as per ASTM C192/C192M. Cylindrical samples of 100 mm diameter and 200 mm height are casted to determine compressive and splitting tensile strength and for flexural strength test prisms of 100 x 100x 450 mm are casted plain concrete as well as concrete reinforced with jute fiber. Three different minimum loading rates are considered for compressive test 0.15 MPa/s, splitting-tensile test 0.78 MPa/min and for flexural test 0.86 MPa/min as per ASTM standards C-39M-18, C-496M-17 and C-293M-16 respectively. Cracking behavior, stress-strain curve, strength, energy absorption, and total toughness index parameters for these three tests at 28 days are shown in chapter 4.

3.4 Samples

Total twenty (20) slabs are casted for PC and JFRC of 450 mm x 225 mm x 75 mm, to investigate flexure strength (i.e. ten (10) for PC and ten for JFRC). Five (05) PC slabs are tested under loading rate LR1 and the remaining five slabs are tested under loading rate LR2. The same procedure is done with jute reinforced concrete. One slab for every arrangement is casted (PC and JFRC) for each loading rate i.e. one for LR1 and one for LR2. This technique has also been adopted by many other researchers [22-24]. The numbers of ϕ2 GFRP rebars are 3 and 4 as flexural reinforcement at bottom. The ϕ2 rebars are used as shear reinforcement at a spacing of 76 mm and 64 mm keeping the longitudinal reinforcement constant (Table 3.3). The detailing of flexural reinforcement and shear reinforcement for PC and JFRC are displayed in Fig. 3.3

TABLE 3.3: Labeling Schedule

Sr. No	PC		JFRC		Reinforcement Detail	
	LR1	LR2	LR1	LR2	Longitudinal	Transverse
1	PA	PB	JA	JB	-	-
2	3PA	3PB	3JA	3JB	3-ϕ2	-
3	3P76A	3P76B	3J76A	3J76B	3-ϕ2	ϕ2-76
4	4P76A	4P76B	4J76A	4J76B	4-ϕ2	ϕ2-76
5	3P64A	3P64B	3J64A	3J64B	3-ϕ2	ϕ2-64

3.4.1 Mechanical Properties

Cylindrical samples of 100 mm diameter and 200 mm height are casted to determine compressive and splitting tensile strength and for flexural strength prisms of 100 x 100x 450 mm are casted of PC as well as JFRC. Three different minimum loading rates are considered for compressive test 0.15 MPa/s, splitting-tensile test 0.78 MPa/min and for flexural

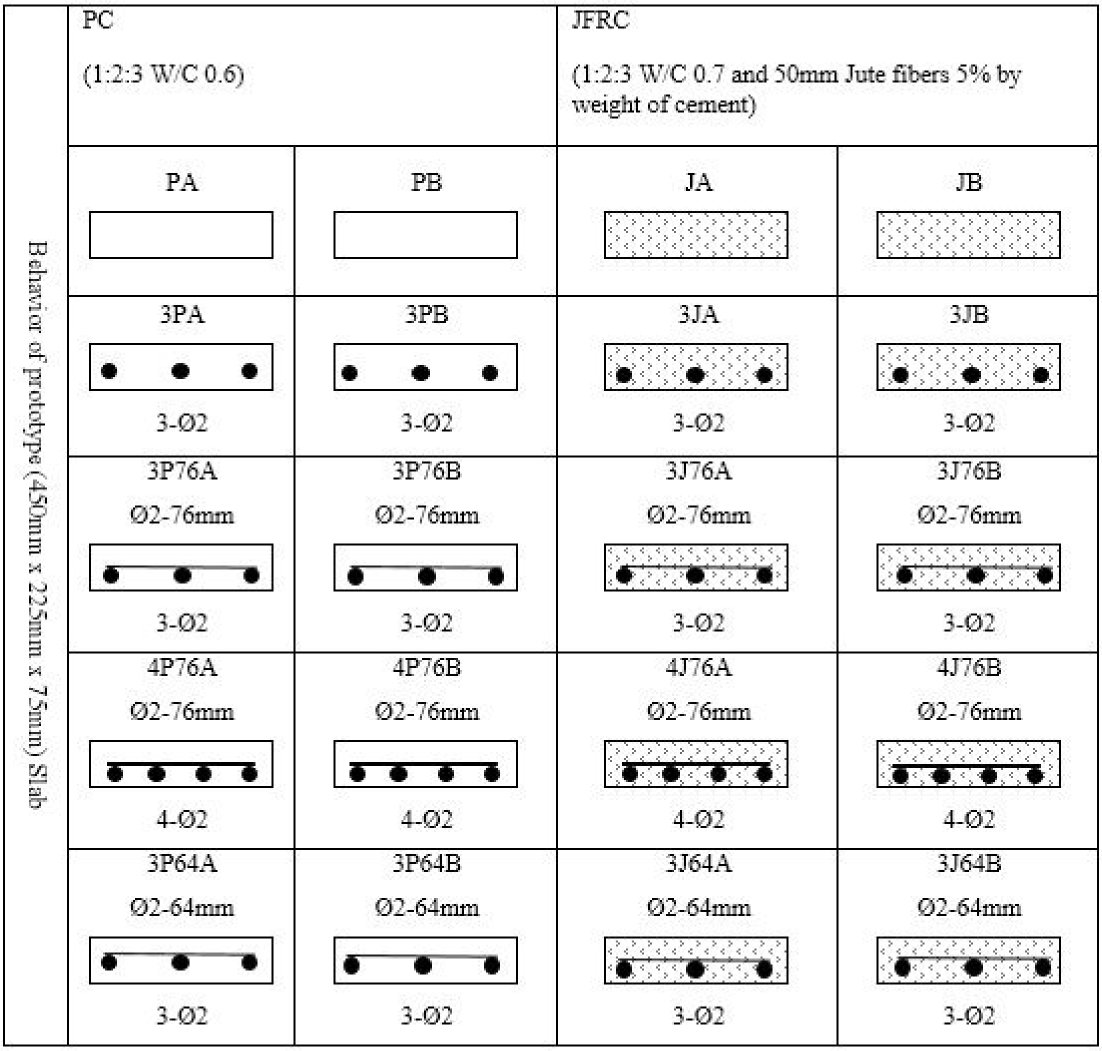

FIGURE 3.3: Structural Details of slabs

test 0.86 MPa/min as per ASTM standards C-39M-18, C-496M-17 and C-293M-16 respectively. Cracking behavior, stress-strain curve, strength, energy absorption, and total toughness index parameters for these three tests at 28 days are shown in Figure 3.4 and Table 3.4. Compressive strength is observed to decrease by the inclusion of jute fibers. There is an increase observed in flexural as well as splitting tensile parameters by the addition of concrete.

Table 3.4: Compressive, Flexural and Splitting tensile Properties of PC and JFRC fo MD 1:2:3

Properties	Compressive		Splitting Tensile		Flexural	
	PC	JFRC	PC	JFRC	PC	JFRC
Strength MPa	24.18 ±0.2	20.13 ±0.2	2.56 ±0.1	2.67 ±0.2	6.14 ±0.1	8.27 ±0.2
E_m	0.11 ±0.001 MJ/m^3	0.15 ±0.005 MJ/m^3	24.7 ±0.05 J	35.9 ±0.08 J	6.34 ±0.5 J	5.72 ±0.2 J
TE	0.21 ±0.001 MJ/m^3	0.51 ±0.005 MJ/m^3	24.7 ±0.05 J	69.1 ±0.06 J	6.34 ±0.05 J	16.96 ±0.02 J
TTI	1.92 ±0.05	3.56 ±0.005	1 ±0.05	1.93 ±0.05	1 ±0.1	3.03 ±0.1

Pmax= Maximum load, Em= Energy-absorption up to maximum load,

Cr. E= Cracked energy-absorption after maximum load,

TE= Total energy absorbed,

TTI= E / Em = Total toughness index an average of three readings is taken.

3.5 Testing Procedures

ASTM standard C293/C293M-16a has been fallowed for all slabs to determine flexural strength, flexural toughness index (F.T.I) and flexural energy absorption (i.e. F.E, F.E1, F.E.M, and F.E.P) of PC and JFRC with GFRP longitudinal reinforcement and shear reinforcement. For applying the varying loading rates i.e. LR1 (3.3 kN/sec) and LR2 (6.6 kN/sec), Universal Machine (UTM) is used. Data acquisition system was used to have the data for deflections at time during loading.

The schematic diagram is shown in Figure 3.5. Under loading rates LR1 and LR2, the deflection curves and crack transmission are noted with visual examination. The first crack is recorded with the help of naked eyes and resultant loading rates are noted.

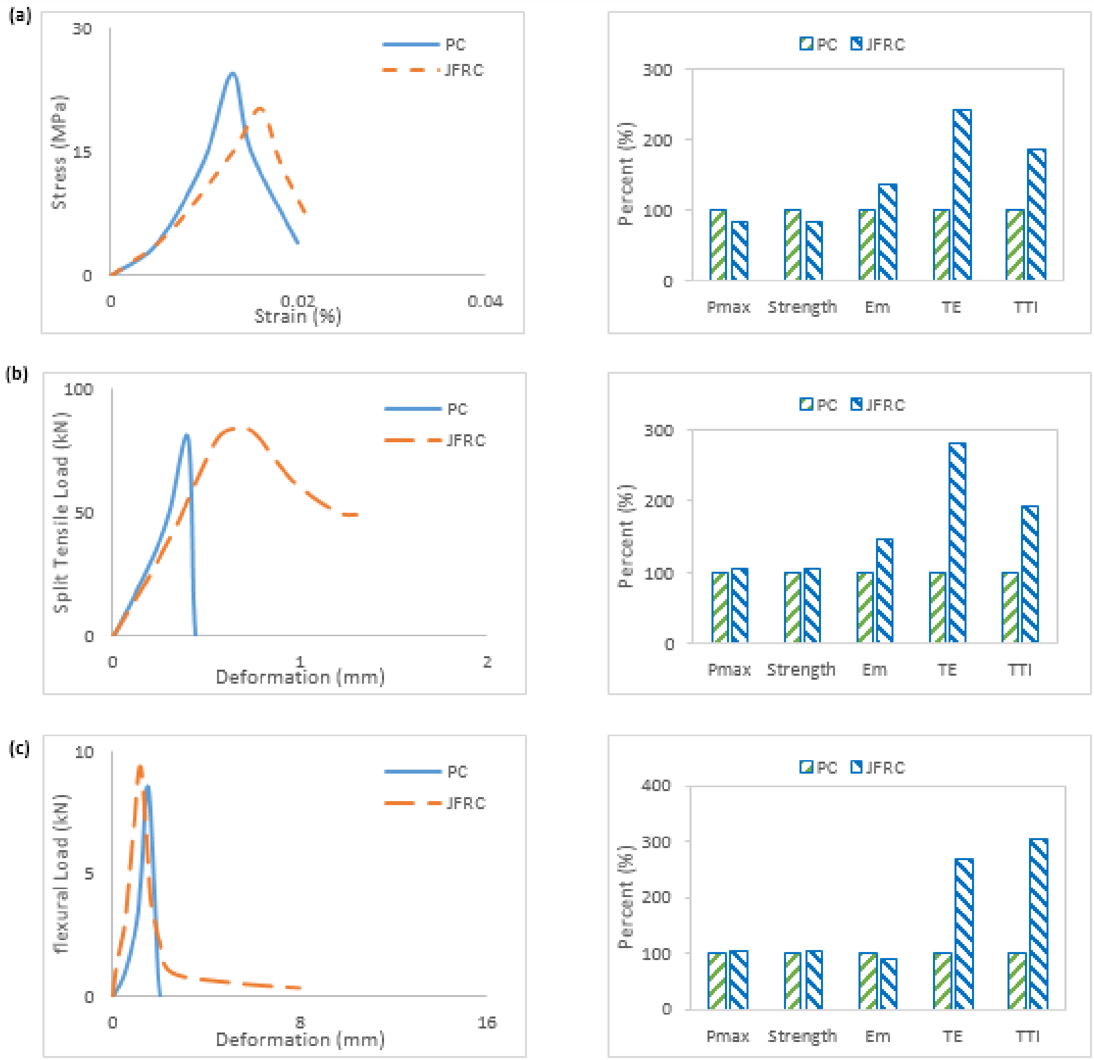

FIGURE 3.4: Comparison of Mechanical Properties of PC and JFRC in, a) Compressive Strength Test, b) Splitting Tensile Strength Test, c) Flexural Strength Test

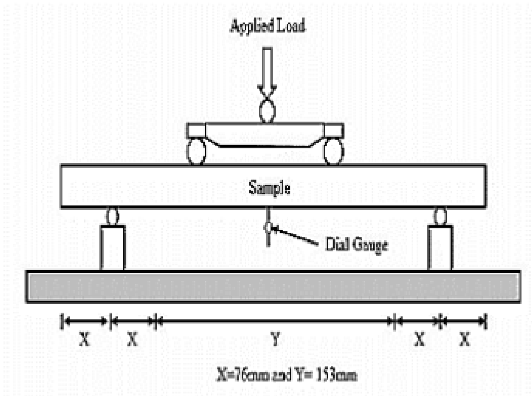

FIGURE 3.5: Schematic Sketch for testing Prototype slab

From this procedure the first crack occurrence load (P_f), max load (P_m), ultimate load (Pu), max deflection (Δ), amount of cracks at final load and failure mode are obtained.

3.6 Summary

The mix design ratio of cement, sand and aggregate for PC and JFRC are 1:2:3. The water cement ratio is kept 0.6 for PC and 0.7 for JFRC. 5% of jute fiber by weight of cement is added to prepare JFRC samples. Total of 20 slabs were casted. The length of jute fiber used in this research work is 50 mm. $\phi 2$ GFRP rebars are used in specimen to prepare PC and JFRC slab samples to study flexural behavior as per ASTM standards, slump, density and flexural are also examined. For JFRC the same ASTM standards are followed. To study the behavior of GFRP reinforced slabs, the load deflection and failure mode are noted.

Chapter 4

Experimental Evaluation

4.1 Background

The specimen are cast with ratio of 1:2:3 having water cement ratio of 0.6 for PC as well as for JFRC. 5% jute fiber by weight of cement is added. The length of jute fiber is 50 mm. The test conducted on PC and JFRC having flexural GFRP rebars are discussed in detail in this chapter.

4.2 Effect of Loading Rates on Slabs (Changing Flexural GFRP Rebars)

4.2.1 Behaviour During Testing

Slabs having different numbers of flexural GFRP reinforcement and same number of shear rebars i.e. (ϕ2-76 mm). Total number of cracks in the ultimate failure, deflection and failure modes of PC and JFRC having different flexural GFRP rebars with constant shear rebars are given in Table 4.1. The first cracking load (P_f) is obtained from load deflection curve (Figure 4.1) of examined slabs. Load (P_f) is noted with the help of corresponding time of the arrival of the very first crack and load deflection curve. Increase in the first crack load is observed for the loading rate 6.6 kN/s as compared to the loads at 3.3 kN/s. Also substantial increment is seen by introducing jute in the concrete mix. When number of flexural bars is increased from 3-ϕ2 to 4-ϕ2 a rise in first crack load is observed.

Around 11.1%, 11.2%, 7.7% and 8.01% rise is observed in specimens 4P76A, 4P76B, 4J76A and 4J76B respectively as compared to corresponding slabs with 3 GFRP rebars.

With the help of computer screen, the deflection ($\triangle$) at maximum load is noted and these values are given in Table. 4.1. The value of deflection ($\triangle$) is greater in JFRC samples than that of PC samples. An overall decrease is observed in deflection by increasing load rate and increasing flexural rebars. From the above values it is proved that JFRC samples are more resilient to cracks as compared to PC samples. This crack resistant property is due to the dispersed jute fiber in concrete mixture. With increasing flexural reinforcement linear growth is noted of load in which the initial crack occurs in both PC and JFRC samples.

The maximum load (P_m) is similarly obtained from the load deflection curves (figure 4.1) of tested samples. Increase in the maximum load is noticed for the LR2 as compared to the loads at LR1. Also considerable increment is witnessed by mixing jute fibers in the concrete mix. Also, when number of flexural bars is increased from 3-ϕ2 to 4-ϕ2, a rise in maximum load is observed. Around 11.1%, 21.06%, 6.4% and 6.03% rise is observed in specimens 4P76A, 4P76B, 4J76A and 4J76B respectively as compared to corresponding slabs with 3 GFRP rebars.

The mode of failure is observed in slab specimen. The tested slab samples, cracks at final loading, cracks at max loading and first crack for PC and JFRC with different numbers of flexural GFRP rebars and same numbers of shear rebars are shown in Figure 4.2.

Table 4.1: Experimental results of tested specimens with changing flexural rebars and constant shear reinforcement

Specimen Detail	Loading Rate	First Crack Load (kN)	Max P_m (kN)	Ultimate Load P_m P_m (kN)	No. of Cracks at Ultimate Load	Deflection (mm)	Failure Mode at first crack
3P76A 3-ϕ2	LR1	10.52	26.7	13.9	6	12.4	Flexural
3P76B 3-ϕ2	LR2	10.71	28.44	14.23	7	12.7	Flexural
3J76A 3-ϕ2	LR1	11.23	35.63	24.1	4	14.1	Flexural
3J76B 3-ϕ2	LR2	11.48	38.36	24.52	5	15.3	Flexural
4P76A 4-ϕ2	LR1	11.69	29.66	23.85	4	10.23	Flexural
4P76B 4-ϕ2	LR2	11.91	34.43	26.92	5	12.8	Flexural
4J76A 4-ϕ2	LR1	12.1	37.92	27.03	3	16.2	Shear
4J76B 4-ϕ2	LR2	12.4	40.68	28.18	4	14.8	Shear

The flexural GFRP reinforcement is enhanced from 3-ϕ2 to 4-ϕ2 for both PC and JFRC concrete. In all, the load deflection curves until the first crack linear trend is noted. After the first crack, there is an improvement in the behavior of JFRC samples i.e. less suddenness in curve and elongated deflection before the ultimate load as compared to PC samples.

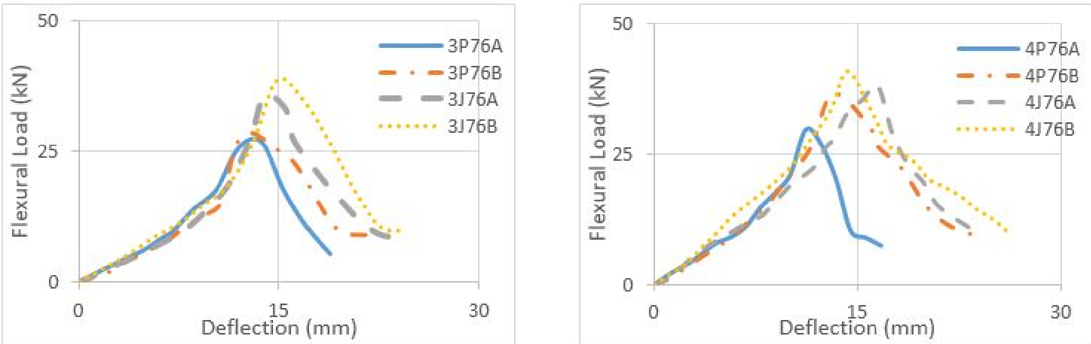

Figure 4.1: Load Deflection Curves of Slabs with changing Flexural Rebars

The crack width when observed with naked eye appeared to be lesser for JFRC as compared to PC. At maximum loading, the number and width of cracks are greater in PC concrete as compared to JFRC concrete. It is concluded that when jute fiber is used in concrete it improves the cracking behavior of tested slab samples.

Crack development is also minimized by increasing reinforcement. Table 4.1 shows that, by increasing the flexural rebars, the slab behaves better in flexure. That is why, failure mode shifts to shear failure. Crack propagation and failure modes in specimens can be seen in figure 4.2.

FIGURE 4.2: Crack Propagation of PC and JFRC Specimens with changing Flexural rebars

4.2.2 Effect of Change of Flexural Reinforcement on F.S and Flexural Energies Absorbed (F.E1, F.E.M, F.E.P, and F.E) and F.T.I

A detailed assessment of F.S , F.E.P, F.E, F.T.I and maximum deflection (δ) of plain concrete and JFRC using different GFRP flexural rebars (i.e. 3-ϕ2 and 4-ϕ2) and same shear reinforcement (ϕ2-76 mm) is shown in Figure 4.3. It is noted that the JFRC samples show good results as matched with respective plain concrete samples. All behavior of JFRC samples i.e. flexural strength (F.S), post cracking and flexural toughness index (F.T.I) are noted when compared to plain concrete. Additional displacement in JFRC samples with flexural GFRP rebars are also absorbed.

The F.S, flexural energy absorption (F.E1, F.E.M, F.E.P, and F.E) and F.T.I of slab samples using constant shear rebars and different flexural rebars are shown in Table 4.2. The area under curve (where first crack happens under load deflection curve up to max load) is selected as energy absorption F.E1. The space beneath load deflection curve from F.E1 to max load (F.E.M) is noted as energy absorption. The F.E.P of JFRC is more than PC samples. The entire area under curve is sum of F.E1, F.E.P, and F.E.M is derived as entire F.E.

In JFRC, the same increase in energies absorption is noted as compared to PC samples It is noted that overall value of F.S, F.E1 and F.E are improved with when number of GFRP flexural reinforcement are increased. It is also noted that, the value of F.E.M, F.E.P and F.T.I is reduced. F.E.M is reduced due to opening reduction between Maximum load and first crack load.

An increase is observed in the values of Total Energy (FE) by increasing the flexural rebars and introducing jute fibers on both loading rates. On LR2 (6.6 kN/s) the values of FE1 are higher than those on the LR1 (3.3 kN/s). Details are in table 4.2.

TABLE 4.2: Energy Computations of tested specimens with changing longitudinal rebars and constant Shear rebars

Specimen Detail		Loading Rate	FS (kN)	F.E1 (J)	F.E.M (J)	F.E.P (J)	F.E (J)	F.T.I
3P76A	3-ϕ2	LR1	26.7	9.33	190.67	149.68	349.68	37.48
3P76B	3-ϕ2	LR2	28.44	10.57	205.1	200.7	416.37	39.39
3J76A	3-ϕ2	LR1	35.63	10.97	230.4	195.34	436.71	39.81
3J76B	3-ϕ2	LR2	38.36	12.28	242.9	254.4	509.58	41.50
4P76A	4-ϕ2	LR1	29.66	10.99	177.8	220.11	408.9	37.21
4P76B	4-ϕ2	LR2	34.43	11.78	218.2	222.27	452.25	38.39
4P76A	4-ϕ2	LR1	37.92	12.12	227.9	247.7	487.72	40.24
4P76B	4-ϕ2	LR2	40.68	12.78	259.2	265.5	537.48	42.06

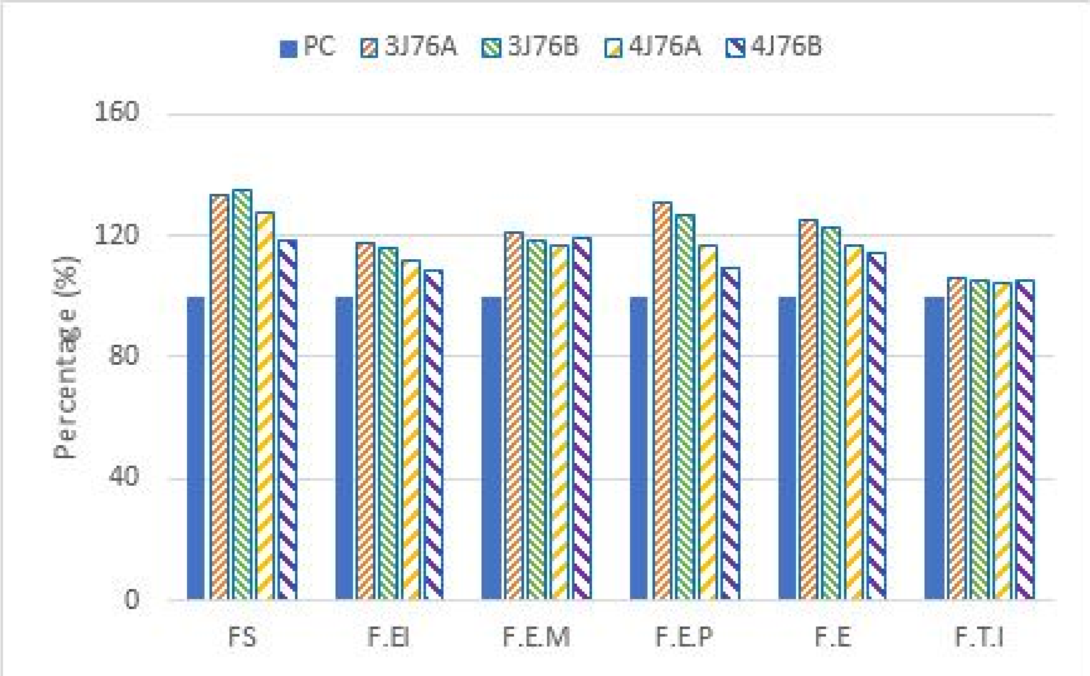

FIGURE 4.3: Relationship of F.S, F.E1, F.E.P, F.E.M, F.E, F.T.I of PC and JFRC with changing Flexural rebars and constant shear rebars

4.3 Effect of Loading Rates on Slabs (Varying Shear Rebars)

4.3.1 Behaviour During Testing

Slabs having different numbers of flexural GFRP reinforcement and same number of shear rebars i.e. (ϕ2-76 mm). Total number of cracks in the ultimate failure, modes of failure of PC and JFRC having different shear rebars are in Table 4.3. Also, deflections are discussed in Table 4.3. The first cracking load (P_f) is obtained from load deflection curve (Figure 4.4) of examined slabs. Load (P_f) is noted with the help of corresponding time of the arrival of the very first crack and load deflection curve. Increase in the first crack load is observed for the loading rate 6.6 kN/s as compared to the loads at 3.3 kN/s.

Also, substantial increment is seen by introducing jute in the concrete mix. When number of shear bars is increased from ϕ2-76 mm to ϕ2-64 mm, a rise in first crack load is observed. Around 17.3%, 24.1%, 17.1% and 22.4% rise is observed in specimens 3P64A, 3P64B, 3J64A and 3J64B respectively as compared to corresponding slabs with 3 GFRP rebars. From the above values, it is proved that JFRC samples are more resilient to cracks as compared to PC samples. This crack resistant property is due to the dispersed jute fiber in concrete mixture. With increasing shear reinforcement linear growth is noted of load in which the initial crack occurs in both PC and JFRC samples.

The maximum load (P_m) is similarly obtained from the load deflection curves (figure 4.4) of tested samples. Increase in the maximum load is noticed for the LR2 as compared to the loads at LR1. Also considerable increment is witnessed by mixing jute fibers in the concrete mix. Also, when number of shear bars is increased from ϕ2-76 mm to ϕ2-64 mm a rise in maximum load is observed. Around 25.65%, 24.1%, 10.58% and 12.77% rise is observed in specimens 3P64A, 3P64B, 3J64A and 3J64B respectively as compared to corresponding slabs with 3 GFRP rebars.

TABLE 4.3: Experimental results of tested specimens with changing shear rebars and constant flexural reinforcement

Specimen Detail		Loading Rate	First Crack Load (kN)	Max P_m (kN)	Ultimate Load P_m P_m (kN)	No. of Cracks at Ultimate Load	Deflection (mm)	Failure Mode at first crack
3P76A	ϕ2@76	LR1	10.52	26.7	13.9	6	12.4	Flexural
3P76B	ϕ2@76	LR2	10.71	28.44	14.23	7	12.7	Flexural
3J76A	ϕ2@76	LR1	11.23	35.63	24.1	4	14.1	Flexural
3J76B	ϕ2@76	LR2	11.48	38.36	24.52	5	15.3	Flexural
3P64A	ϕ2@64	LR1	10.742	33.55	16.8	5	9.5	Flexural
3P64B	ϕ2@64	LR2	11.294	35.29	17.49	6	9.9	Shear
3J64A	ϕ2@64	LR1	12.16	39.4	23.848	3	10.05	Flexural
3J64B	ϕ2@64	LR2	13.06	43.264	24.88	4	12.23	Flexural

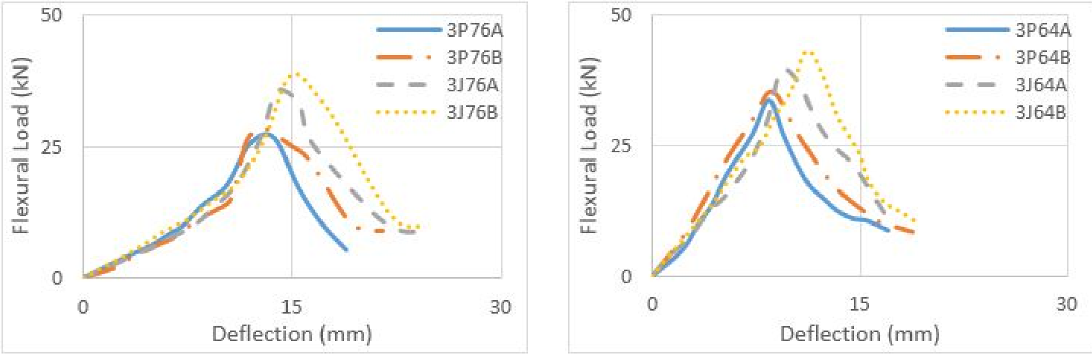

FIGURE 4.4: Load deflection curve of slabs with changing shear rebars

The tested slab samples, cracks at final loading, cracks at max loading and first crack for PC and JFRC with different numbers shear GFRP rebars and same numbers of flexural rebars are shown in Figure 4.5. The shear GFRP reinforcement is improved by ϕ2-76 mm, ϕ2-64 mm for both PC and JFRC concrete.

In all the load deflection curves until the first crack, linear trend is noted. After the first crack, there is an improvement in the behavior of JFRC samples i.e. less suddenness in curve and elongated deflection before the ultimate load as compared to PC samples.

With the help of computer screen, the deflection ($\triangle$) at maximum load is noted and these values are given in Table. 4.3. The value of deflection ($\triangle$) is greater in JFRC samples than that of PC samples. An overall decrease is observed in deflection by increasing loading rate and increasing shear rebars. The crack width when observed with naked eye appeared to be lesser for JFRC as compared to PC.

At maximum loading, the number and width of cracks are greater in PC concrete as compared to JFRC concrete. It is concluded when jute fiber is used in concrete it improve the cracking behavior of tested slabs samples improves. Crack propagation in specimens can be seen in figure 4.5.

4.3.2 Effect of Change of Shear Reinforcement on F.S and Flexural Energies Absorbed (F.E1, F.E.M, F.E.P, and F.E) and F.T.I

A detailed assessment of F.S , F.E.P, F.E, F.T.I and maximum deflection (δ) of plain concrete and JFRC using different GFRP shear rebars (i.e. ϕ2-76 mm and ϕ2-64 mm and same flexural reinforcement (3-ϕ2) is shown in Figure 4.6.

Figure 4.5: Crack propagation of PC and JFRC specimens with changing shear rebars

It is noted that the JFRC samples show good results as matched with respective plain concrete samples. All behavior of JFRC samples i.e. flexural strength (F.S), post cracking and flexural toughness index (F.T.I) are noted when compared to plain concrete. Additional displacement in JFRC samples with flexural GFRP rebars are also absorbed. The F.S, flexural energy absorption (F.E1, F.E.M, F.E.P, and F.E) and F.T.I of slab samples using constant flexural rebars and different shear rebars are shown in Table 4.3. The area under curve (where first crack happens under load deflection curve up to max load) is selected as energy absorption F.E1. The space beneath load deflection curve from F.E1 to max load (F.E.M) is noted as energy absorption. The F.E.P of JFRC is more than PC samples.

TABLE 4.4: Energy Computations of tested specimens with changing shear rebars and constant flexural rebars

Specimen Detail		Loading Rate	FS (kN)	F.E1 (J)	F.E.M (J)	F.E.P (J)	F.E (J)	F.T.I
3P76A	ϕ2-76 mm	LR1	26.7	9.33	190.67	149.68	349.68	37.48
3P76B	ϕ2-76 mm	LR2	28.44	10.57	205.1	200.7	416.37	39.39
3J76A	ϕ2-76 mm	LR1	35.63	10.97	230.4	195.34	436.71	39.81
3J76B	ϕ2-76 mm	LR2	38.364	12.28	242.9	254.4	509.58	41.50
3P64A	ϕ2-64 mm	LR1	33.55	10.89	203.8	220.11	434.9	39.57
3P64B	ϕ2-64 mm	LR2	35.29	11.53	218.2	242.27	472.25	40.09
3J64A	ϕ2-64 mm	LR1	39.4	12.32	237.9	257.7	507.92	41.23
3J64B	ϕ2-64 mm	LR2	43.264	12.91	243.8	286.2	539.23	42.18

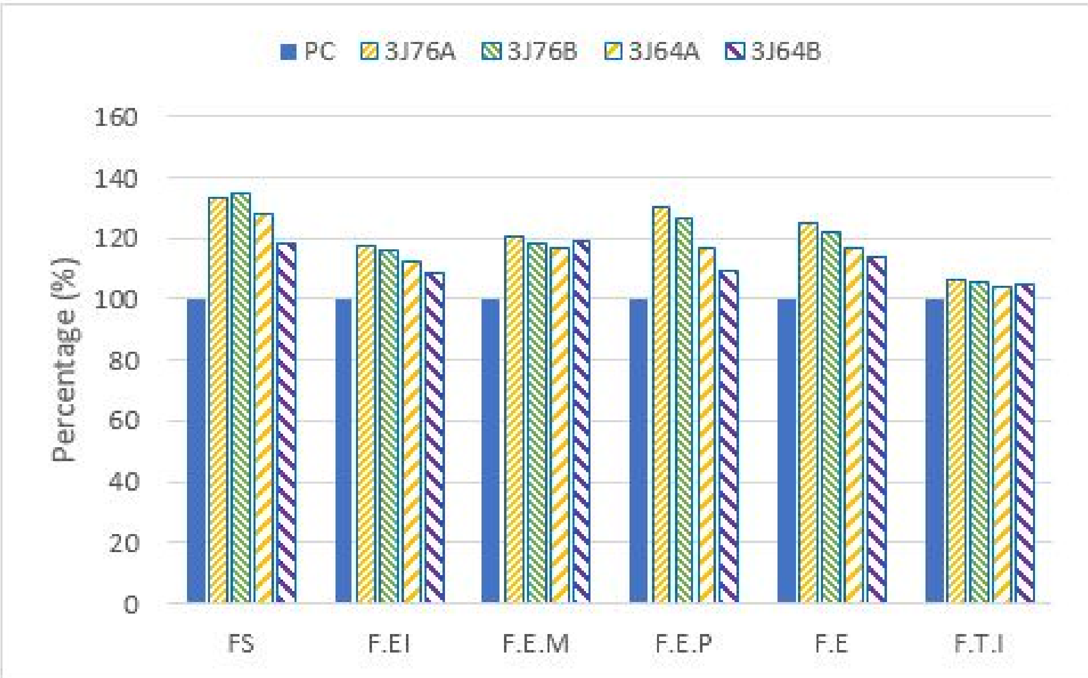

FIGURE 4.6: Relationship of FS,F.EI,F.E.M,F.E.P,F.E,F.T.I of PC and JFRC with changing shear rebars and constant flexural rebars

The entire area under curve is sum of F.E1, F.E.P, and F.E.M is derived as entire F.E. In JFRC the same increase in energies absorption is noted as compared to PC samples It is noted that overall value of F.S, F.E1 and F.E are improved with when number of GFRP shear reinforcement are increased. It is also noted that the value of F.E.M, F.E.P and F.T.I is reduced. F.E.M is reduced due to opening reduction between Maximum load and first crack load.

An increase is observed in the values of Total Energy (FE) by increasing the shear rebars and introducing jute fibers on both loading rates. On LR2 (6.6 kN/s) the values of FE1 are higher than those on the LR1 (3.3 kN/s). Details are given in Table 4.4

4.4 SEM Analysis

SEM analysis of PC slab (Figure 4.8) indicates a homogenous mix. There are some air voids in the mix as well as some micro-cracks after failure of slabs. On higher magnification needle like structure of Ettringite can also be observed.

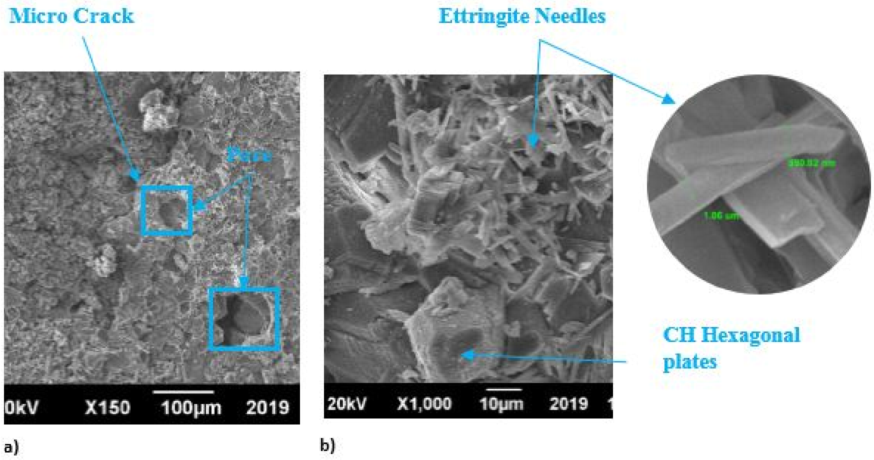

Figure 4.7: SEM analysis of hardened plain concrete, a) Micro-cracking and pores in concrete mix, b) Structure of concrete mix on micro level

JFRC under SEM shows jute fibers in different states after failure of slab. In the pictures, circumferential de-bonding around jute fiber can be seen (Figure 4.9 a).

In Figure. 4.9(b) a jute fiber ruptured can be seen which is still well embedded in the concrete matrix that indicates a good bond between these two.

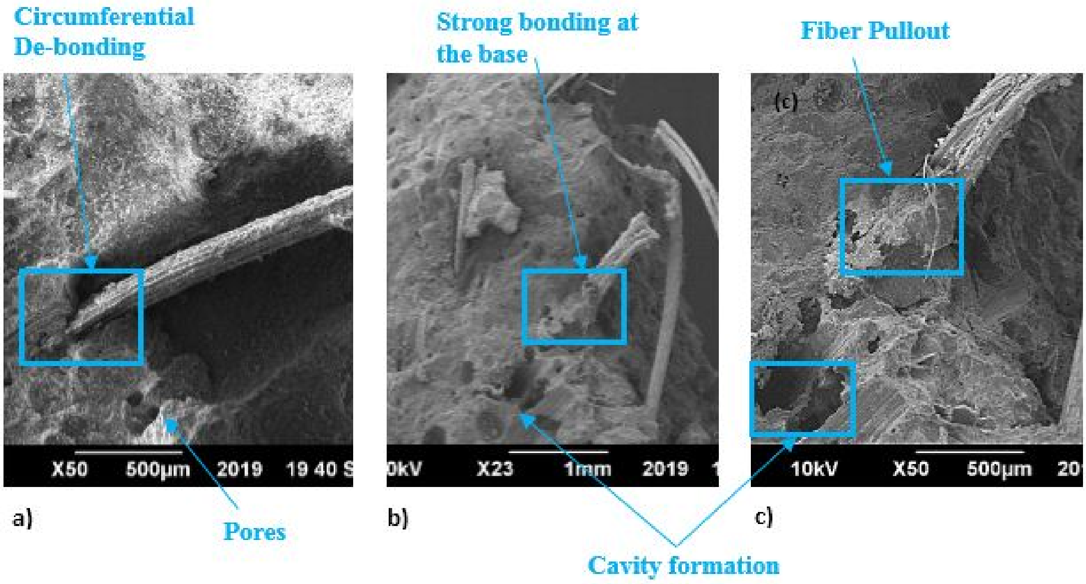

FIGURE 4.8: SEM analysis of hardened Jute Fiber reinforced concrete a) Fiber embedded in concrete, b) Strong bonding of concrete matrix and Jute Fiber, c) Fiber Pullout from concrete mixture

A cavity made by pulling out of fiber from its place in the mix can be observed in Fig.4.9(c). An increased density of Ettringite needles can be seen for JFRC specimens which indicates densified concrete. A homogenous dispersion of jute fibers can be seen in JFRC mix as the dosage is low (5% by weight of cement) and considerable number of these fibers are well anchored in the concrete matrix.

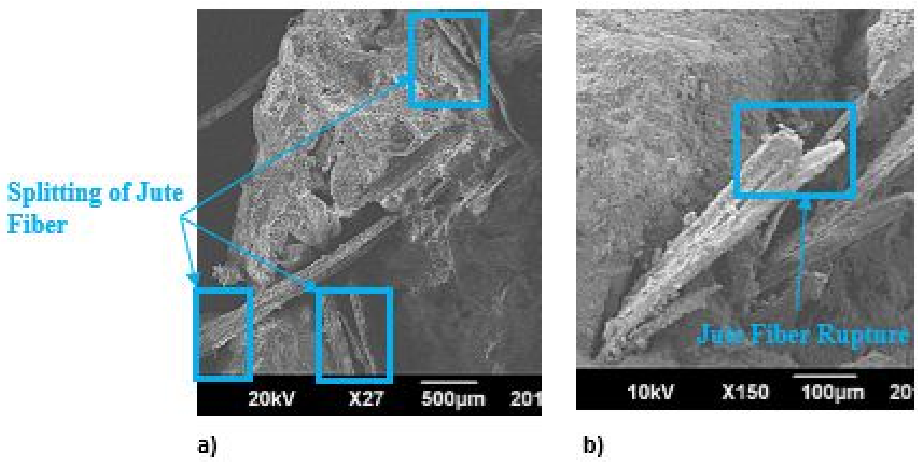

FIGURE 4.9: SEM analysis of hardened Jute fiber reinforced concrete, a) at LR1 (3.3 kN/s), b) at LR2 (6.6 kN/s)

By analyzing the SEM images at failure surfaces of JFRC specimens (Figure 4.10), it can be concluded that fiber pull-out and cavity formation occur under higher LR2 (6.6 kN/s) whereas jute fiber had tensile rupture at lower LR1 (3.3 kN/s).

4.5 XRD Analysis

The XRD patterns of PC and JFRC are shown in Figure 4.11 The 2theta values are presented on x-axis ranging from 10o to 50o and absolute intensity values on y-axis from 0 to 400 and 240 respectively for PC and JFRC. PC sample shows peaks at calcium silicate hydrate that indicates hydration. XRD confirms the finding that Ettringite structure increases by adding Jute in the concrete mix. Also, quartz has a proportion higher in JFRC than PC.

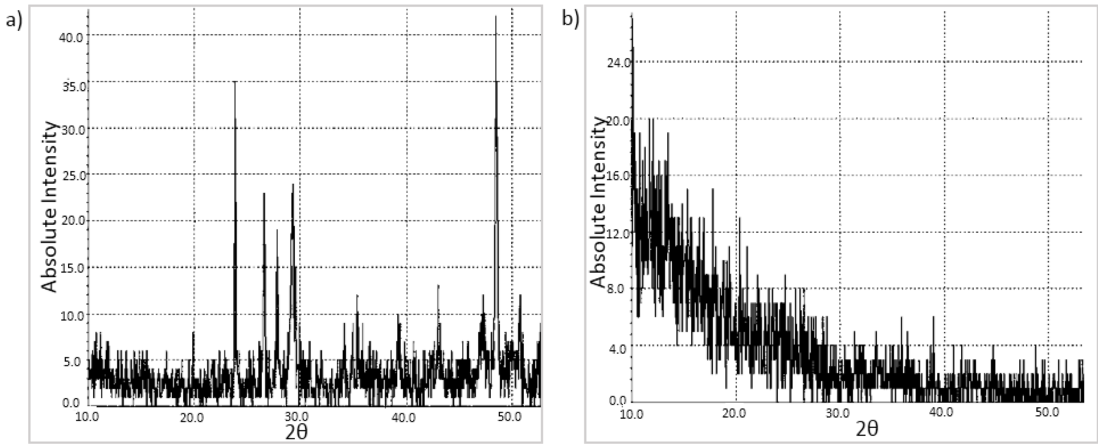

FIGURE 4.10: XRD analysis,a) Plain Cement Concrete, b) Jute fiber reinforced concrete

4.6 Summary

The jute fibers with flexural and shear GFRP reinforcement are studied in this research work for good application and for reducing failure in bridge decks. Jute fibers of length 50 mm and 5% by weight of cement are mixed in concrete composite. Using mix design ratio of 1:2:3 the material properties are studied. Slump and density are decreased of JFRC when compared to that of PC. The use of JFRC with GPRP flexural rebars, the load carrying capacity like flexural strength, total energy absorption and toughness index are improved when compared to their respective PC samples [34]. Therefore using JFRC with GFRP rebars is good solution for minimizing failure in bridge decks.

Chapter 5

Discussion

5.1 Background

The results of experimental testing have been discussed in chapter 4. It is observed that a significant increase in the flexural strength, energy absorbed and toughness index by increasing no. of bars in shear and flexure and by including jute fiber in the mix. Also a decrease in the crack development is also experienced by jute fibers. In this chapter moment capacities will be computed using some theoretical and experimental approaches. Also an equation has been modified to be used for concrete reinforced with GFRP rebars and Jute fibers at a time.

5.2 Relationship Between Material Properties and Prototype Behavior

Mechanical properties in Flexure, splitting tensile and flexure are determined for plain concrete and jute reinforced concrete cylinders casted. From the results, it can be seen that flexural strength of jute reinforced concrete increases by 2.1% as compared to the PC. Similarly, the maximum energy at maximum load and total energy absorption of the Jute reinforced concrete specimens is amplified by 4.4%

and 167.7% respectively. The overall index of toughness has also been raised up to 161.6% as compared to PC.

Prototype concrete deck slabs have been made with JFRC and PC and are reinforced with GFRP rebars longitudinally and transversely. These slabs when tested under flexure exhibited behavior similar to the material behavior mentioned above. The slabs without Jute fibers started cracking earlier and their number of cracks at failure are more, showing a brittle kind of behavior. Whereas, in the jute reinforced slabs crack appearance is delayed as well as the total number of cracks are lesser than the PC slabs. Under flexure load, the slab is deflected and bottom concrete has a tensile strain. In case of PC slabs cracks start to appear but in presence of jute fibers, they bridge the cracks and delay their appearance as well as reduce their number. That is the reason, higher loads are taken by JFRC prototype concrete slabs and fail at a higher strain. Energy absorption and toughness indices also increase for the prototype GFRP reinforced slabs by addition of jute fibers.

From the results of compressive strength test it is found out that compressive strength of JFRC is reduced by 16% as compared to the PC and the energy absorbed till peak load and total energy absorption of the JFRC specimen is increased by 35% and 145.7% respectively. The overall index of toughness has also been increased up to 85.8% as related to PC. From discussion, it can be determined that although there was slight decrease in compressive strength, however, the values for energy absorption and total toughness index have considerable increase in all the JFRC specimens.

The splitting tensile strength of JFRC is increased by 4.41% as related to the PC. In evaluation with PC, the maximum energy at maximum load and total energy absorption of the JFRC specimen is increased by 45.25% and 79.34% respectively. The overall index of toughness has also been increased up to 93.19% as related to PC.

These material properties show that, introduction of jute fibers in PC mix enhances its toughness. Similar trends are noted in the prototype slab samples.

Additionally, presence of GFRP rebars in the sample slabs makes it corrosion free. In this way, use of jute fibers and GFRP rebars at the same time in the concrete makes it more durable against the flexural loading.

5.3 Empirical Modeling

From the literature review 2.8 topic a background is developed for the computation of moment capacities in different cases. Equation 2.6 taken from [39-40] is developed for plain concrete that is reinforced with GFRP bars. In the present study this equation is modified to take effect of jute fiber into consideration. In original equation by Beshara [37], first part is for capacity coming from the steel rebars. For GFRP reinforced concrete, this part is replaced with the contribution from GFRP rebars from Urgessa et.al (eq 2.6) [39].

A comparison is made in theoretical and experimental moment capacities of slab section is tables 5.1 and 5.2 under loading rate 1 and 2 respectively. Theoretical moment capacity for sections with GFRP rebars is computed using eq. 2.6. Similarly, eq.5.2 is used for the section reinforced with Jute and with GFRP rebars. Experimental moment capacity has been determined by computing areas of shear capacities.

TABLE 5.1: Comparison of theoretical and experimental moment capacities for slab under LR1 (3.3 kN/s)

Specimen	Rebar Details	Theoretical Moment Capacity $\boldsymbol{M_{th}}$[1] (kN.m)	Experimental Moment Capacity $\boldsymbol{M_{exp}}$[2] (kN.m)	$\boldsymbol{M_{th}/M_{exp}}$
3P76A	3-φ2	3.36	3.00	1.12
4P76A	4-φ2	4.49	3.34	1.34
3J76A	3-φ2	3.39	4.01	0.84
4J76A	4-φ2	4.51	4.60	0.98

Note: 1. $M_{th} = A_f \ x \ f_{fu} \left(d - \frac{\beta_1 c_b}{2}\right)$ where $c_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{fu}}.d$

2. $M_f = A_f.f_f\left(d - \frac{\beta_1 c_b}{2}\right) + T_f\left\{\left(t - \frac{t_e}{2}\right) - \frac{a}{2}\right\}$

3. $M_{ex} = \frac{p_m\ x\ L}{4}$

4. f_y = 896 MPa, d=46 mm, f_c'= 24.18 MPa, b=225 mm, t=450 mm

TABLE 5.2: Comparison of theoretical and experimental moment capacities for slab under LR1 (3.3 kN/s)

Specimen	Rebar Details	Theoretical Moment Capacity $\boldsymbol{M_{th}}$ (kN.m)	Experimental Moment Capacity $\boldsymbol{M_{exp}}$ (kN.m)	$\boldsymbol{M_{th}/M_{exp}}$
3P76B	3-φ2	3.36	3.20	1.05
4P76B	4-φ2	4.49	3.87	1.16
3J76B	3-φ2	3.39	4.32	0.78
4J76B	4-φ2	4.51	4.55	0.99

Note: 1. $M_{th} = A_f\ x\ f_{fu}\left(d - \frac{\beta_1 c_b}{2}\right)$ where $c_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{fu}}.d$

2. $M_f = A_f.f_f\left(d - \frac{\beta_1 c_b}{2}\right) + T_f\left\{\left(t - \frac{t_e}{2}\right) - \frac{a}{2}\right\}$

3. $M_{ex} = \frac{p_m\ x\ L}{4}$

4. f_y = 896 MPa, d=46 mm, f_c'= 24.18 MPa, b=225 mm, t=450 mm

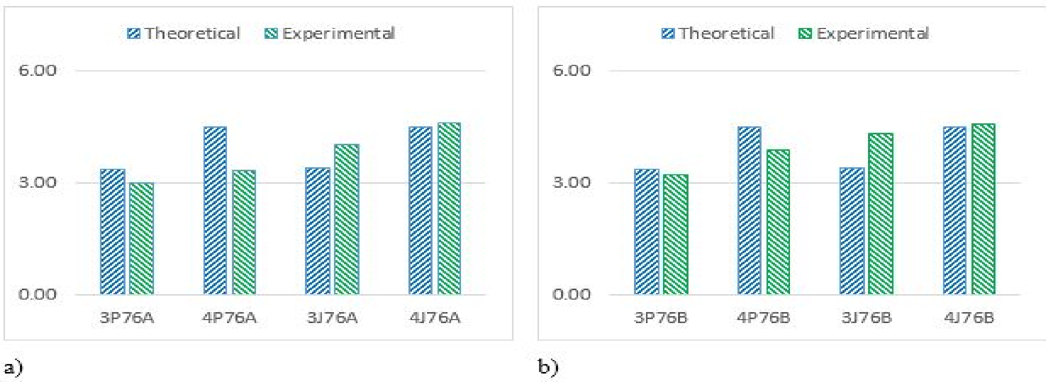

FIGURE 5.1: Comparison of theoretical and experimental moment capacity, a) LR1 ,b) LR2

From tables 5.1 and 5.2, an increase is observed in moment capacities by increasing flexural reinforcement as well as introducing Jute fibers. Theoretical Moment capacity of the section with plain concrete is higher than the experimentally determined moment capacity of the same section. Whereas, this is in contrast to the trend found in the specimens reinforced with jute fibers.

5.4 Summary

In this chapter, experimental and theoretical moment capacities have been computed. The moment capacity increases with increase in number of bars in shear and flexure as well as by the introduction of jute fibers. Increase in the moment capacity and toughness is observed by the addition of jute fibers. Similarly, the addition of GFRP bars also increases the moment capacity. This is the aspect that encourages use of GFRP rebars instead of steel bars as they do not rust [13] and moment capacity does not reduce (current study). Theoretical moment capacity of the section with plain concrete is higher than the experimentally determined moment capacity of the same section. Whereas, this is in contrast to the trend found in the specimens reinforced with jute fibers. Experimental capacity is more than the theoretical determined by eq. 5.2, it means Besharas equation for the jute fiber consideration underestimates the tensile capacity increased by presence of fibers.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

Plain (PC) and Jute fiber reinforced concrete (JFRC) with flexural and shear GFRP reinforcement in slabs is studied in this experimental research for possible application of bridge decks. For the preparation of JFRC, the jute fibers of 5% fiber content, by mass of cement, having a 50 mm length are incorporated in the concrete mix (i.e. 1:2:3) as that of PC. The behavior of PC and JFRC slabs with flexural and shear reinforcements are investigated. The conclusions are as follows.

- The slabs with same shear reinforcement (ϕ2-76 mm) and changing flexural reinforcement (i.e, 3- ϕ2 to 4- ϕ2) Flexural strength is increased by 6.5% and 16.1%for plain cement slab when loading rate is increased from 3.3 kN/s to 6.6 kN/s. Similarly 7.7% and 7.3% rise is observed for jute reinforced concrete slab is observed.

- Keeping the Flexural reinforcement (3-ϕ2) constant and changing shear reinforcement (i.e, ϕ2-76 mm to ϕ2-64 mm) in specimens Flexural strength is increased by 6.5% and 5.18%for plain cement slab when loading rate is increased from 3.3 kN/s to 6.6 kN/s. Similarly, 7.7% and 9.8% rise is observed for jute reinforced concrete slab is observed.

- Maximum deflection is observed to decreased by increasing flexural reinforcement by (i.e, 3- ϕ2 to 4- ϕ2) by 0.7 mm and 2.94 mm for PC and JFRC under LR1(3.3 kN/s). Similarly, 4.14 mm and 3.64 mm for PC and JFRC under LR2 (6.6 kN/s). Hence, for greater loading rate, reduction in deflection is more for both mixes.

- Reduction in the maximum deflection by increasing Shear reinforcement by (i.e, ϕ2-76 mm to ϕ2-64 mm) by 5.5 mm and 4.081 mm for PC and JFRC under LR1(3.3 kN/s). Similarly 4.69 mm and 3.52 mm for PC and JFRC under LR2 (6.6 kN/s).

- The value of energy absorbed of PC slabs is increased by 3.12% and 3% when loading rate is increased keeping flexural bars constant and varying shear reinforcement. Furthermore, JFRC slabs observed an increase of 20% and 5% from LR1 to LR2.

- By increasing flexural reinforcement keeping shear reinforcement constant energy absorbed of PC slabs is increased by 3.1% and 3.24% when loading rate is increased from LR1 to LR2. Similarly, for JFRC observed rise is 19% and 17%.

- Keeping the flexural reinforcement (3-ϕ2) constant and changing shear reinforcement (i.e, ϕ2-76 mm to ϕ2-64 mm) in specimens. Flexural strength is increased by 6.5% and 5.18% for plain cement slab when loading rate is increased from 3.3 kN/s to 6.6 kN/s. Similarly 7.7% and 9.8% rise is observed for jute reinforced concrete slab.

- The slabs with same shear reinforcement (ϕ2-76 mm) and changing flexural reinforcement (i.e, 3- ϕ2 to 4- ϕ2) flexural toughness index is increased by 6.3% and 11.7% for plain cement slab when loading rate is increased from 3.3 kN/s to 6.6 kN/s. Similarly, 28.2% and 15.5% rise is observed for jute reinforced concrete slab is observed.

- Keeping the Flexural reinforcement (3-ϕ2) constant and changing shear reinforcement (i.e, ϕ2-76 mm to ϕ2-64 mm) in specimens. Flexural strength is increased by 6.28 and 11.72% for plain cement slab when loading rate is increased from 3.3 kN/s to 6.6 kN/s. Similarly 22.7% and 12.95% rise is observed for jute reinforced concrete slab.

- Presence of jute fibers and GFRP rebars at the same time in concrete enhances the toughness and reduces the corrosion susceptibility of the concrete.
- JFRC specimen show more Ettringite needles as compared to PC specimen.
- Broken and ruptured well embedded fibers at the failure surface show good bond between jute fibers and concrete matrix.
- Empirical model computes moment capacity of jute reinforced section having longitudinal and transverse GFRP reinforcement closer to the theoretical value. Experimental moment capacity for jute reinforced specimen is more than theoretical.

So based on the current research we understand that GFRP rebars in concrete behaves better at higher loading rates. And jute fibers enhance toughness and GFRP bars reduce chances of corrosion. Jute Fiber and GFRP added in the concrete at the same time make it more durable.

6.2 Recommendations

Recommendations based on the study for future works are:

- Different mix proportions, fiber length and content may be used.
- The material properties of JFRC with admixtures may be studied.
- Numerical behaviour of JFRC with flexure and shear reinforcement using ABACUS and ANSYS may be investigated.

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Annexure A

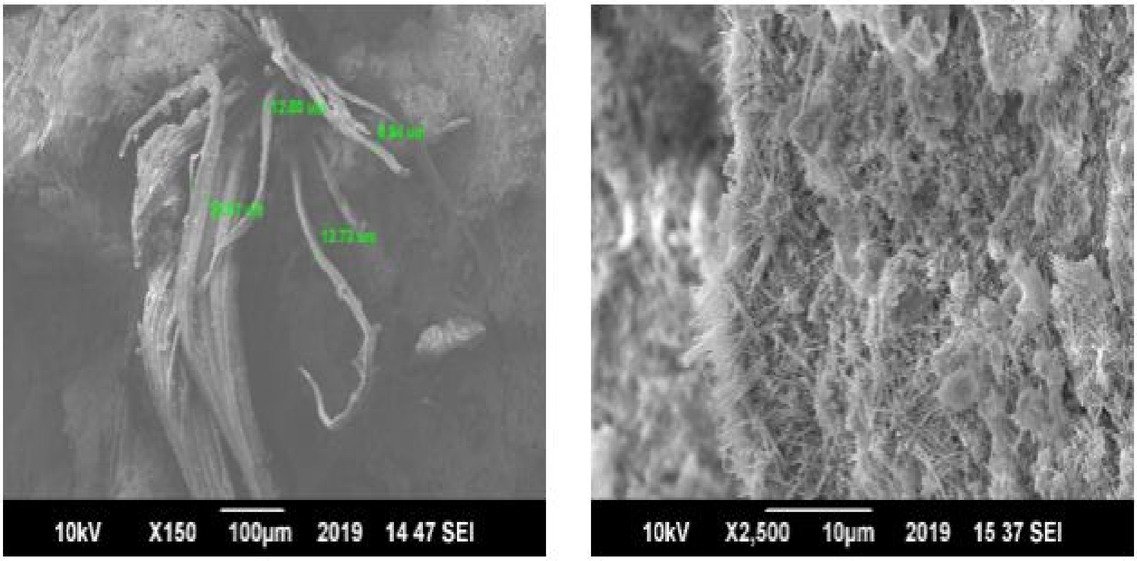

Figure A.1: SEM of failure surface of jute reinforced concrete

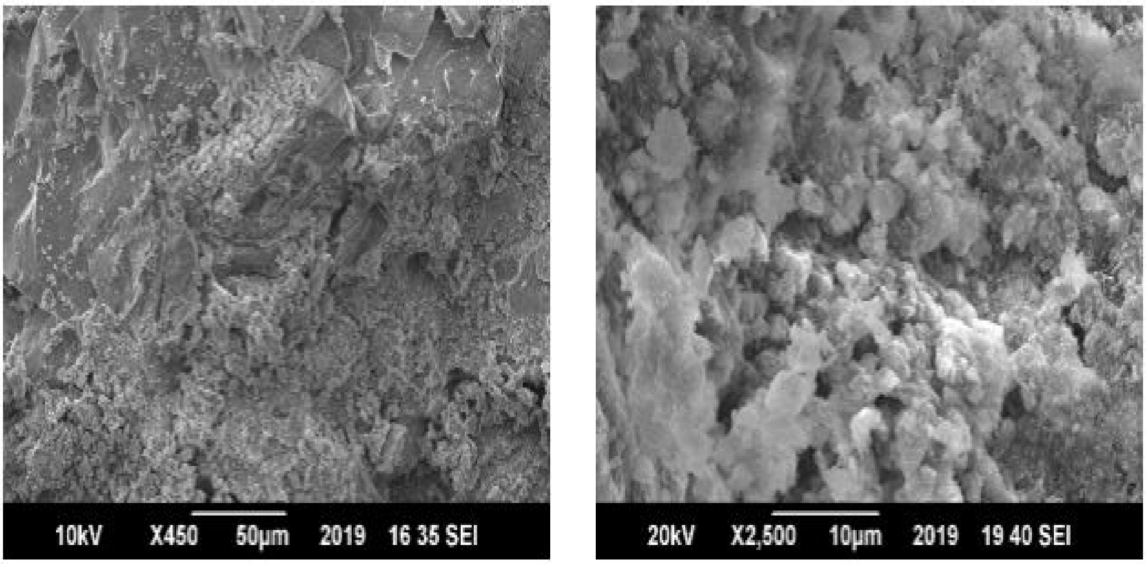

Figure A.2: SEM of failure surface of plain concrete

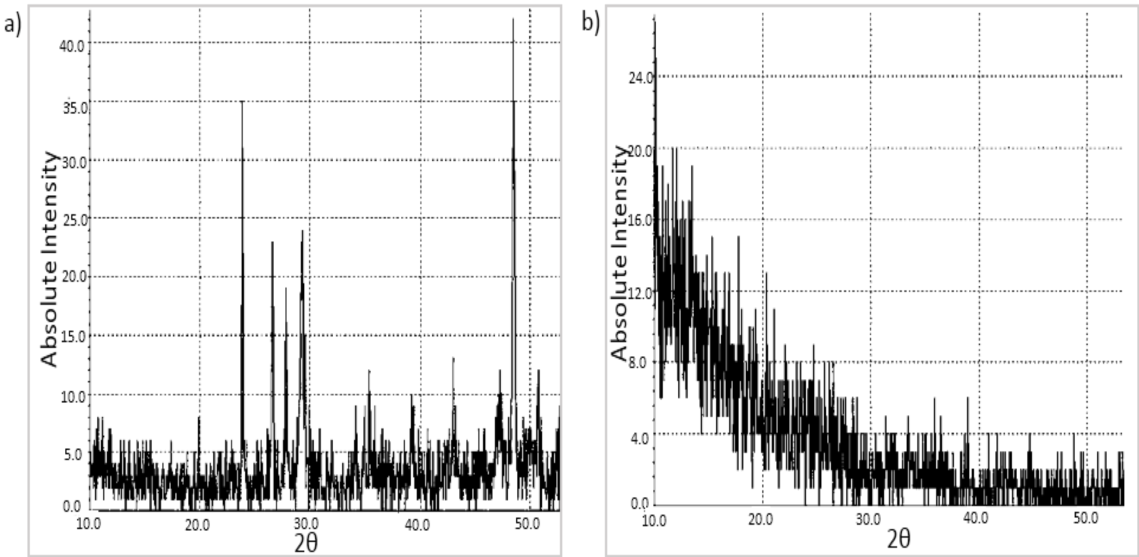

FIGURE A.3: XRD results of a) PC, b) JFRC