CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Effect of Jute Fibers and Glass Fiber Reinforced Polymer Rebars in Concrete for Bridge Girder Applications

by

Abdul Wahab

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

in the

Faculty of Engineering
Department of Civil Engineering

2019

I want to dedicate this work to my family, who helped me throughout my education. This is likewise a tribute to our best teachers who guided us to go up against the troubles of presence with ingenuity and boldness, and who made us what we are today.

CERTIFICATE OF APPROVAL

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Acknowledgements

- I would like to thank Almighty Allah for his countless blessing.
- I would like to pay special gratitude to Dr. Engr. Majid Ali for his guidance and supervision, without which, this was not possible.
- I am also very thankful to Engr. M. Usman Farooqi for his Co- supervision during my research work.
- I also want to thank Department of Civil Engineering for partial financial assistance.
- I am grateful to all who assisted me during this study especially Engr. Sayed Ilyas Ahmad, Engr. Atif Khan, Engr. Fawad Ur Rehaman, Engr. Hassan Sabri, Engr. M. Affan, Engr. Fayaz Khan and Mr. M. Junaid for their kind help in lab work.
- I am also grateful to my family for their continuous moral support.

Abstract

Many aspects have been investigated previously in relation with the failure of concrete bridge girders. The main reasons for failure of bridge girders are cracking, heavy loads, crazing and mortar detaching. Among the aforementioned aspects, cracking is said to be the one which severly affects the strength and serviceability of concrete bridge girders. Cracking in concrete is due to high strength gained by cement content, water cement ratio and reduction strain. Cracking can be controlled by improving the mechanical properties of concrete. The use of jute fiber with GFRP rebar has achieved attention of researchers due to more ductility, resistance to heat and light weight. GFRP rebars can be used as alternatives for ordinary steel. This thesis presents the contribution of GFRP rebars and jute fiber to control cracking and improving the mechanical properties of concrete. Beamlets of reinforced concrete with different flexural GFRP rebars and shear steel bars, with and without jute fiber, were experimentally investigated to study the variation in properties due to introduction of jute fibers. Flexural strength of the concrete bridge girders was measured during the lab experiments. The experiments revealed significant increase in flexural strength, energy absorption, and toughness index of the gorders. Furthermore, integration of jute fiber showed better cracking control mechanism in GFRP rebars concrete. In conclusion concrete bridge girders having jute fiber are more durable and sustainable as compared to the concrete bridge girder having no jute fiber.

Key words: Jute fiber, Natural fibers, Concrete, GPRP rebars, Loading rate.

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Abbreviations

C.E1	Compressive energy absorbed up to first crack
C.E.P	Compressive energy absorbed post the maximum load
C.T.I	Compressive toughness index
F.E	Total flexural energy absorbed
F.E1	Flexural energy absorbed up to first crack
F.E.M	Flexural energy absorbed from the first crack to maximum load
F.E.P	Flexural energy absorbed post the maximum load
FRC	Fiber reinforced concrete
F.S	Flexural strength
F.T.I	Flexural toughness index
JF	Jute fiber concrete for flexure
JS	Jute fiber concrete for shear
GFRP	Glass fiber reinforce polymer
JFRC	Jute fiber reinforced concrete
L1	Loading rate one (i.e. 1.2 MPa/min)
L2	Loading rate two (i.e. 1.4 MPa/min)
Max	Maximum
MD	Mix Design
PC	Plain concrete
Pf	First crack load
PF	Plan concrete for flexure
Pm	Maximum load
PS	Plan concrete for shear
Pu	Ultimate load

kN	kilo-Newton
mm	Millimeter
MPa	Mega Pascal
s	Second
S.E1	Splitting-tensile energy absorbed up to first crack
S.E.P	Splitting-tensile energy absorbed post the maximum load
S.T.I	Splitting-tensile toughness index
UTM	Universal testing machine
w/c	water cement ratio

Symbols

Δ	Deflection
$\varnothing$	Diameter

Chapter 1

Introduction

1.1 Background

Failure behavior of bridge girders was experimentally studied and limited elements forming technique to calculate the behaviors are settled. This shows that important load carrying capacity is taken in ancient reinforced concrete bridges and investigation result shows that degraded support conditions of the bridge significantly affects stiffness of the bridge [1]. Shear span-to-depth and beam size were important parameters which significantly affects the failure mode of the bridge [2]. Bridge failure highlights the need to understand the real response of in service bridges and access future services life under the effect of various different environmental conditions [3]. Fire induces longitudinal movements in the bridge which was higher than the width of the expansion joints. The amount of live load substitute on the bridge had little effect on its fire response [4].

Natural fibers were environmentally friendly (bio-degradable). Jute fiber (being natural fiber) grown all over the world without any chemical (no need of pesticides and chemical fertilizer) [5]. As steel rebars are corrosive in moisture condition, and steel bars are adversely affected in varying environmental conditions. GFRP rebars were non-corrosive in moisture condition and also environment friendly. It cannot affect with environmental changes. To improve the compressive strength, flexural strength and nearly-age crack resistance jute fiber was good and can be added into cement based material. By adding jute fiber into cement based material flexural strength can be significantly improved with 30 mm length jute fiber at the mixing amount of 0.5-0.6 kg^{-3} [6]. Using different percentage of jute fibers (0.3%, 0.4%, 0.6%, 0.8%, 1%, 1.2%, 1.4%, 1.6%, and 1.8%) which can be cured for 3, 7 and 28 days can increase compressive strength from 8.8 MPa to a maximum of 44.44 MPa because of jute fiber [7]. Jute fiber had high tensile strength of 189 MPa and flexural strength of 127 MPa. The tensile strength can be increased because of high temperature due to better cross linkage [8]. The initial and final setting time were increased with increasing amount of jute fiber in cement matrix [9]. In hydration test the time required to reach max temperature for hydration of cement sample was approximately 860 minutes while that was 1020 in jute reinforced cement sample [10].

As compared to steel structures reinforced concrete structures were very commonly used in building because they were cheaper. Many concrete structures were damaged and to overcome this problem fiber reinforced polymer were used. Glass fiber reinforced polymer can improve the ability of girders in flexure much better than normal conditions [11]. GFRP bars were comparatively new developing technique to enhance the flexural capacities of existing RC elements. Flexural strengthening of reinforced concrete girder by using GFRP was effective [12]. Using GFRP in flexural concrete can cause two modes of failure i.e. flexure and shear. Flexural failure occurred due to tensile rupture of GFRP bars while the shear failure was started by a major crack within the girders span [13]. GFRP bars can deliver a construction system with high strength and suitable strength. The bending movement capacities at concrete crushing failure of GFRP reinforced polymer girders were 1.2-1.5% times greater [14]. The GFRP reinforced concrete beams fail either by concrete crushing at the dense zone or split of the GFRP reinforcement [15].

FRP rebars were involve in arrangement in the strengthened reinforced concrete girders and project philosophy for repair and recovery, mixing material properties with structural performance [16]. Fiber reinforced polymers (FRP) rebars had developed one of the most likely and inexpensive solution to the corrosion problems of steel reinforcement in structural concrete. The use of FRP rebars in new or damaged structure requires the development of design equation that must take into description the mechanical properties and the toughness index of FRP product [17]. The use of fiber in concrete structures had increased quickly in the last 10 years because of their excellent corrosion resistance, high tensile strength, and good non-magnetization properties. Illustrating fiber reinforced polymer (FRP) reinforcement in concrete creep and the number of cracks, and cracks width compare to steel samples was more significant [18].

There are four stages in which structure behavior can be predicted. Which includes (i) full-scale structure in real field conditions [19], (ii) full scale structural elements with precise boundary conditions [20], (iii) either scaling the prototype structure or typical structural elements, including the appropriate gradient for raw material size, loading conditions and end-limits [21], and (iv) small prototype structural elements with no scaling down technique for comparative comparison to check the effectiveness, only one variable provided all other conditions were similar [22, 23]. In current study, only simplified approach (i.e. stage iv) is adopted. In present research, the behavior of small prototype PC and JFRC having GFRP rebars bridge girders will be compared with main and transverse reinforcement configurations. To the best of author's knowledge, on the basis of limited revision of the literature, no study has been conducted on JFRC.

1.2 Research Motivation and Problem Statement

During earthquake most of the bridges suffered high damage and also to complete failure. A lot of financial resources are required for new structure in place of existing damages. This aim of this research is to increase the load carrying capacity of bridge girders in terms of structure load carrying capacity. Bridge girders are very critical element in the bridge structure. They are responsible to transfer load to pier or ground safely. Proper techniques of strengthening may be applied in order to improve the load transformation mechanism and ensuring the safety.

The verification of failure mechanism before and after fiber reinforced polymer (FRP) is also needed. In most cases, strengthening technique improve carrying capacity but also change failure mechanism. It is very old concept to use fibers and improve characteristics of concrete. The concrete beam reinforce with GFRP sections practiced a lower load carrying capacity and stiffness compare with the usual reinforced concrete beam. This was mostly because of the lower elastic modulus of the GFRP section compare with the steel reinforcement [15]. Therefore the investigation of experiment properties of jute fiber reinforced concrete (JFRC) related to bridge girder is important to consider. Thus, the problem statement is as follows:

"Efforts are required to use cheap and environment friendly material in construction. Steel rebars has corrosion problems, a big concern in developed countries. Glass fiber reinforced polymer (GFRP) rebars can be one option. Jute short discrete fibers are also environment friendly (as they are natural material). Behavior of GFRP rebars in jute fiber reinforced concrete (JFRC) is still needed to be explored for bridge girders."

1.3 Overall Objective and Specific Aim

The main objective of the research program is to replace longitudinal steel with GFRP rebars for bridge girders to upgrade performance.

In this MS study work, an examination has been done to study the behavior of horizontal members having GFRP rebars in JFRC for application of bridge girders.

1.4 Research Methodology

Experimental work will be done on PC and JFRC concrete to determine flexural strength, compressive strength, and splitting tensile strength. 1:2:3:0.6 is the mix design ratio for plain concrete (cement, sand, aggregate and water), respectively, While 5% of fiber content that have length of 50 mm will be added in concrete for making of JFRC. To calculate properties of each materials three sample from each will be casted separately. Two samples for every change in flexural and shear reinforcement will be casted to determine behavior of prototype from PC and JFRC. Beam size 100 mm x 100 mm x 450 mm will cast and test for flexural strength and energy absorption of PC and JFRC. The mix design ratio for PC and JFRC was same.

1.5 Thesis Outline

This research work has five chapter which are given as follows:

Chapter 1. This chapter includes introduction. This chapter explains Research Motivation and Problem Statement, Overall Objective, Specific Aim, Research Methodology and thesis outline.

Chapter 2. This chapter includes literature review segment. It explains background, failure in concrete bridge girder, natural fiber in concrete, GFRC rebars as flexural reinforcement, design equation for moment capacity.

Chapter 3. This chapter consists of experimental procedure. This chapter explains background, material, and mix design, procedure of casting, testing and summary.

Chapter 4. This chapter consists of analysis and test results. This chapter explains behavior of PC and JFRC, effects of loading rates on PC and JFRC beams having varying flexural and shear rebars and summary.

Chapter 5. This chapter explains conclusion and recommendation.

At the end references are given.

Chapter 2

Literature Review

2.1 Background

Failure behavior is the main cause which influence stability and serviceability of concrete bridge girders. The failure can be minimized by enhancing the mechanical properties of concrete bridge girders. These properties can be improved by adding natural fibers. Fiber reinforced concrete (FRC) improves concrete properties under dynamic and static loading. Natural fibers are also economical and environment friendly. Among other natural fibers, jute fiber is cultivated abundantly in Asian countries. The use of JFRC with flexural GFRP rebars and steel shear rebars gives good results in reducing failure in concrete bridge girders. This chapter consists of detail explanation on failure of concrete bridge girders, concrete having jute fibers with flexural GFRP rebars and shear steel rebars, and design moment equation for moment capacities.

2.2 Failure in Concrete Bridge Girders

Shear span-to-depth and beam size are very important parameters which significantly affects the failure mode of the bridge. These parameters can greatly influence the failure mode of the bridge girder as shown in Figure 2.1. The shear resistance mechanism was also affected by length to depth ratio of bridge girders. Different effective length to depth ratio can cause failure in different ways. Increasing of girder length can cause reduction in ultimate load. The length of the girders not only influence the shear strength but also influenced characters of failure [2]. Failure behavior of bridge girders was experimentally studied and limited elements forming technique to calculate the behaviors were settled. This shown that important load carrying capacity is taken in ancient reinforced concrete bridges and investigated result shown that degraded supports conditions of the bridge significantly affect stiffness of the bridge. The poor support conditions greatly affect the expected reactions of the bridge capacity and also the bridge stiffness in old reinforced concrete bridges [1]. Bridge failure highlights the need to understand the real response of in-service bridges and access their remaining service life under the effect of various different deterioration conditions. Effects like punching shear and complex interaction between the structures elements cannot explain the capacity of bridge girders. The effect executed a failure tool to bridge girders and the specified characteristics in steel-concrete bridge girder are greatly affected by geometrical characteristics, properties of materials, loading capacity and also girder bond properties [3]. Fire adversely affects the longitudinal movements in the bridge which was higher than the width of expansion joints. The amount of live load substitute on the bridge had little effect on its fire response [4]. A number of same bridge overturning and failure accidents occurred recently in China. The main cause of these failure were heavily loaded transit as failure of bridge influenced by dynamic process. Failure began from support disconnection and as a result the entire bridge collapse. Bridge failure also enhanced by surrounding boundary contact conditions, quality of materials etc. Bridge with several support not collapse when few supports disconnects. However it collapsed when many supports disconnect and other were located along on line. This caused large rotation in bridge and leads to failure mode [25]. The deep beam with 0.5 of shear span to depth ratio, beam failure decreased when applied load increased. On other hand deep beam with shear depth ratio of 1.0 to 1.5, the beam failure was delayed applying load. When shear span to depth ratio decreased failure mode changed from shear to concrete crushing. Beam having less value of shear span to depth ratio, shown early failure because of concrete crushing [26].

FIGURE 2.1: Failure in concrete bridge girder

2.3 Using Natural Fibers to Improve the Mechanical Properties of Concrete

Natural fiber like wheat straw can be used in reinforced concrete (RC) to improve the performance and ability of RC for structural applications purposes. Concrete having wheat straw were more strong and sustainable. Natural fibers in concrete mix were environment friendly, sustainable and economical construction materials. Wheat straw using in concrete can improve the ability and performance of RC with flexural steel rebars and shear steel rebars. Using wheat straw in concrete, it was observed that F.S, F.E.P, F.E and F.T.I is noted up to 7.5%, 44.8%, 30.4% and 11.7%, respectively, improved significantly [27].

The natural fibers were receiving interest from researches and academician to use in polymer composites due to its friendly nature and maintainability. Chemical treatment of natural fiber can increase the adhesive property between polymer matrix and fiber surface. Chemical treatment also improve physiochemical and thermochemical characteristics of natural fibers reinforced polymer composites

(NFPCs). NFPCs were economical, having low density when compared to synthetics products. Natural fibers, shown good effect on the mechanical properties of polymers, when used as reinforcement [28]. Some natural fibers and their mechanical properties are shown in Table 2.1. The addition of jute fiber up to 0.5% in concrete shown adverse influence on properties of fresh concrete. But adding jute fiber up to 0.25% in concrete can impact positively on concrete hardened properties. The length and volume of jute fiber had great impact on hardened concrete properties when curing time was extended. Impact of jute fiber on flexural strength was greatly affected on fiber volume. Using of jute fiber in concrete up to 0.5% shown maximum increase in flexural strength. While minimum increase in flexural strength was noted when 0.25% of jute fiber was used in concrete. But when jute fiber was added up to 1.00% there was reduction in flexural strength [29].

2.4 Using GFRP Rebars to Enhance the Flexural Strength of Concrete

As compared to steel reinforcement, GFRP rebars were economical and can be used as alternative of steel in RC stucture. Many concrete structures having steel reinforcement were damaged under varying loading condition and to overcome this problem fiber reinforced polymer were used. GFRP polymers were used as external reinforcement and it was noted that glass fiber reinforced polymer can improve the ability of girders in flexure much better than normal conditions. Strength of GFRP rebars were enhanced upto 1.333 times than that of steel rebars.

Using GFRP rebars in beam there was increase of 43.95% in flexural strength. GFRP rebars were good solution for improving the strength and serviceability of concrete beam in building technology [11]. GFRP rebars are comparatively new developing technique to enhance the flexural capacities of existing RC elements. Flexural strengthening of reinforced concrete girder by using GFRP was effective. GFRP reinforced beam shown high flexural behavior as compared to

Table 2.1: Some natural fibers and their properties

Sr. No	Fibers	Properties	References
1	Wheat	High energy absorption, high toughness index, strong, high water absorption capacity, easily available	[27]
2	Jute	Lighter than steel , higher breaking strength, easily available, high energy absorption,	[30]
3	Coconut	High toughness index, high damping ratio, economical, good flexural strength	[23]
4	Flax	High tensile strength, elongation property up to 2.7-3.2%, biodegradable, cost effective	[31]

steel reinforced beam. Using GFRP rebars ductility, stiffness and energy absorption under applied load were significantly increased. Increasing in bond length of the braced GFRP rebars ultimate load, failure load and ductility index also increased [12]. GFRP bars can deliver a construction system with high strength and enhanced behavior. The bending movement capacities at concrete crushing failure of GFRP reinforced polymer girders were 1.2-1.5 times greater. GFRP rebars gave high strength, high sustainability and high durability when used in construction system. In flexural performance there was no significant effect of bar diameter. Generally while increasing the reinforcement ratio the performance of a beam also increased. Beams having similar reinforced ratio of GFRP rebars, nominal diameter shown insignificant effect on flexural strength [14]. The GFRP reinforced concrete beams fail either by concrete crushing at the dense zone or split of the GFRP reinforcement. The ultimate load carrying capacity of concrete beam can be increased by using GFRP reinforcement. GFRP rebar are non-corrosive in nature and good alternative of steel rebars. Number of cracks were higher in beam reinforced with GFRP rebars when compared with conventional beam. Also cracks spacing in beam reinforced with GFRP rebars were larger when compared to the control beam [15].

The comparison of steel and GFRP rebars is provided in Table 2.2. The percentage

TABLE 2.2: Comparison of tensile properties of steel and GFRP rebars

Description (1)	Steel (2)	GFRP (3)
Nominal yield stress, ksi (MPA)	40 to 75 (276 to 517)	N/A
Tensile strength, ksi (MPa)	70 to 100 (483 to 690)	70 to 230 (483 to 1600)
Elastic modulus, x10^3 ksi (GPa)	29.0 (200.0)	5.1 to 7.4 (35.0 to 51.0)
Yield strain, %	0.14 to 0.25	N/A
Rupture strain, %	6.0 to 12.0	1.2 to 3.1

of rupture strain of steel is greater than that of GFRP rebars. Rupture strain of steel is 6.0% to 12.0%, whereas that of GFRP rebars is 1.2% to 3.2%. Similarly, elastic modulus of steel is also greater when compared to that of GFRP rebars (i.e. 29.0 x 10^3 for steel and 5.1 x 103 to 7.4 x 10^3 for GFRP rebars). However, the tensile strength of GFRP rebars is greater than that of steel. The tensile strength of GFRP rebars is 70 MPa to 230 MPa, while that of steel is 70 MPa to 100 MPa.

2.5 Design Equations for Moment Capacities

Stress distribution of reinforced concrete at cross section of beam is shown in Figure 2.2a. Distribution of actual and equivalent stresses, which was limited only to reinforced concrete structure, and not applicable to concrete in which fibers were used to strengthen the concrete. The equation for normal reinforced concrete to find design moment capacity is as follow [32].

$$M_R = T_s(d - \frac{a}{2}) \text{ in N-mm} \qquad \text{Eq.(2.1)}$$

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

$$T_s = A_s \times f_y \text{ in N} \qquad \text{Eq. (2.1a)}$$

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

$$a = \frac{A_s \times f_y}{0.85 \times f_{c'} \times b} \text{ in mm} \qquad \text{Eq. (2.1b)}$$

Where,

A_s = Area of Steel (mm^2)

fc' = Compressive strength of concrete at 28 days

fy = Yield strength of steel in tension (MPa)

b = Cross sectional width (mm)

d = Effective depth (mm)

Stress and strain distribution for fiber reinforced concrete (FRC) is shown in 2.2b. Design moment capacity of fiber reinforced concrete can be calculated as follow[33]:

$$M_{F1} = T_s\left(d - \frac{a}{2}\right) + T_{f1}\left\{\left(t - \frac{tf}{2}\right) - \frac{a}{2}\right\} \qquad Eq.(2.2)$$

Where

t = Total depth of beam

tf = Effective height of equivalent stress of fibre reinforced concrete in tension region

T_{f1} = Tensile Strength of Fibre reinforced concrete

$$T_{fl} = \left[1.64\ V_f \left(\frac{l_f}{\Phi_f}\right) b\ t_f\right] \qquad \text{Eq. (2.2a)}$$

Where

V_f = Volume of fibre used In concrete

L_f = Length of fiber

Φ_f = Diameter of the steel fibers

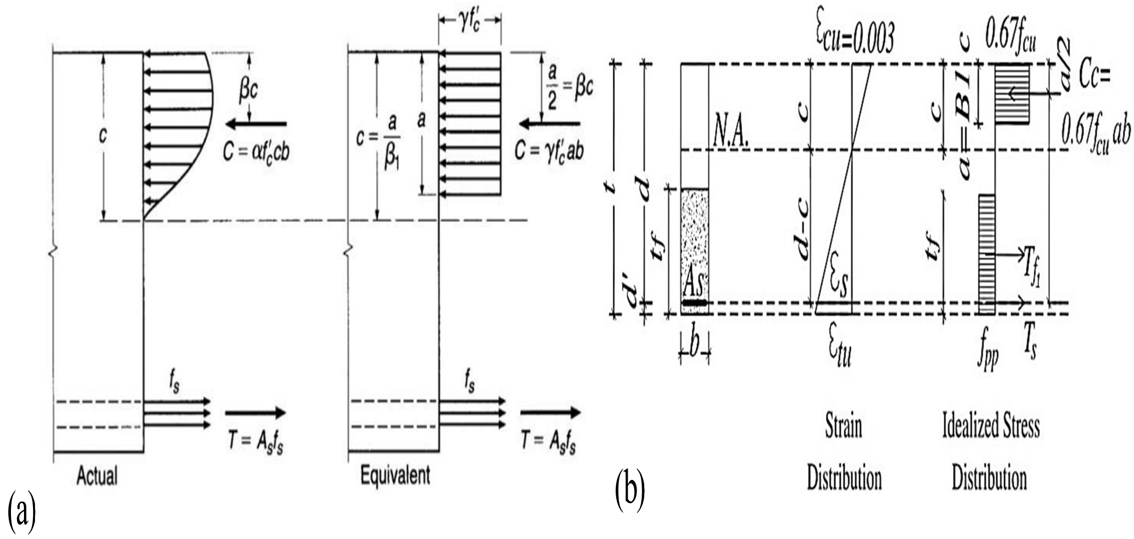


FIGURE 2.2: Stress distribution of concrete beam having steel rebars: (a) for plan concrete by [32], and (b) for fiber reinforced concrete by [33]

2.6 Summary

From the above discussion it is concluded that when mechanical properties of concrete are improved, the failure of bridge girder may reduce. To minimize the failure of concrete bridge girder the mechanical properties like compressive strength, split tensile strength and flexural strength of concrete are need to be increased. Natural fibers in concrete prevent the crack span and width. Natural fibers in concrete can increase load carrying capacity and stiffness. The design equations are also made by researches for predicting theoretical moment capacity of SFRC/PERC beams having GFRP rebars [13]. and examined the properties of JFRC to control EMAC in bridge-decks[14]. According to author knowledge, no research is conducted on JFRC with GFRP rebars for bridge girders. Beam-lets samples of PC and JFRC with flexural GFRP rebars are examined under flexural load. Cylinders are also tested for mechanical properties (compressive strength, flexural strength and split tensile strength).

Chapter 3

Experimental Program

3.1 Background

Using of jute fiber in concrete with flexural GFRP rebars for improving the mechanical properties are increasing day by day. Jute fiber can increase flexural strength, toughness index and energy absorption of concrete. GFRP rebars gained good alternative to nominal steel rebars due to low density, high durability, more ductile, light weight, weather and fire resistant. In this chapter materials, concrete casting procedure, sample's details and testing procedure are discussed in detail.

3.2 Materials

The materials used in this research for preparing PC and JFRC are cement, sand, coarse aggregate, water, jute fibers and GFRP rebars. The cement is ordinary Portland cement which is available locally, good quality of sand is used as fine aggregate which is obtained from Lawerence-pur, crushed granite stone aggregate of Margallah is used and tap water of Capital University Lab is used. Jute fiber is a long, shiny, and soft natural fiber which is available commercially and belongs to plant of family corchorus. Jute fiber extracted from agriculture residues, collected from a near-by neighborhood source. The average length of jute fiber used is 50 mm approximately. The mechanical properties of jute fibers are examined practically. It has high tensile strength and low extensibility. The flexural and tensile strength of Jute fiber are 127 MPa and 189 MPa, respectively, [8]. Chemically jute fiber consists of cellulose, lignin, fat, wax, water soluble materials. These chemical (cellulose, wax, and lignin) can cause in weak connection in the middle of jute fiber and concrete mix. To remove these wax, lignin, cellulose and dust particle some cure is needed. A simple cure procedure is adopted so as to make the jute fiber as an economical building material. The jute fiber in this curing technique remained inside water tank for approximately twelve hours. After twelve hours the jute fiber is bring out of water and air dried out. The prepared jute fibers are utilized as scattered support for making PC and JFRC displayed in below Figure 3.1 (a).

a) b)

Figure 3.1: (a): Jute Fiber and (b): GFRP Rebars

Currently the construction industry all over the globe face a huge trouble because of decay in steel reinforcement due to corrosion. To avoid this problem Glass fiber reinforced polymer (GFRP) rebar is a good substitute to steel bars reinforcing concrete structure in serious condition. GFRP bars are relatively new emergent technique to improve the flexural capacities of existing structural elements. Flexural amplification of reinforced concrete girder by using GFRP is useful [12]. The GFRP rebars used in this research work is imported from China. The length of longitudinal reinforcement GFRP rebars used in both PC and JFRC beam-lets is 400 mm having diameter of 6 mm are shown in Figure 3.1 (b).

3.3 Mix Design and Procedure for Casting

For PC mix design ratio of cement, sand and coarse aggragate is 1, 2 and 3 recpectively. For preparation of PC water-cement ratio is 0.6. First of all coarse aggregates were poured into the drum mixer, then sand and then cement for making PC concrete mix. Water is added at final stage. Mixer machine is revolved for at least three to five minutes to achieved uniform PC concrete composite. But to prepare jute fiber reinforced concrete (JFRC), jute fiber is place in the mixer machine which have virgin PC. For preparation of JFRC 5% of jute fiber by mass of cement is added. The length of jute fiber is approximately 50 mm, 0.6 is the water cement ratio for JFRC. The mixer machine is again rotated for three to five minutes for achieving uniform JFRC concret. The JFRC concrete at this stage is very hard to be used. Again the mixer machine is revolved for few mintes to get better and homogenous mix. At this point flow from JFRC concrete can happen as an outcome of addition of extra water. To avoid addition of extra water the mixing period is greater than before, as a result it gives good result to get homogenous and workable JFRC mix. After getting homogenous mixture for both PC and JFRC slump test is conducted. Slump rate for PC is 60 mm while for JFRC is 40 mm. The reduction value in the slump of JFRC matches with PC due to the more quantity of water sucked by the air dried out jute fibers in JFRC concrete.

The made concrete JFRC and PC are now placed in beam-lets mould which have GFRP rebars fixed firmly with stirrups in three consecutive levels. To determine the flexural strength. The samples are compressed by 25 numbers of blows by temping rod when placing every level. Lifting and free falling of beam-let mould is done in case of JFRC to mitigate air voids. For compressive strength of JFRC the made concrete is placed in cylinders in three consecutive layers. Each layer is compressed by 25 number of blows by temping rod. The decembling of samples is done after 48 hours. Then the samples are place in water tank for 28 days of curing period. The samples are tested after 28 days of curing.

3.4 Samples

Total twenty beam-lets are cast for PC and JFRC to investigate flexure strength (i.e. ten for PC and ten for JFRC). For PC five beam-lets out of ten are tested under loading rate L1 and the remaining five beam-lets are tested under loading rate L2. The same procedure has been adopted for JFRC beam-lets. Beam-lets samples for PC and JFRC are cast with flexural GFRP reinforcement, and shear reinforcement to conduct flexural strength investigation, having width 100 mm, depth 100 mm, and length 450 mm. The purpose for making beam-lets samples is to receive a symbol for flexural strength of JFRC having GFRP reinforcement. The initial parameter in design of structural element, is to resist heavy loading. Keeping in mind that these beam-lets are considered as model. Single one sample for every arrangement is casted (PC and JFRC) for each loading rate i.e. one for L1 and one for L2. This arrangement has also been adopted by other researchers. The numbers of Ø6 GFRP rebars are arranged as 2, 3 and 4 bottom bars for flexural reinforcement. The Ø6 bars are used in all the samples placed in beam-lets moulds having 100 mm only. The spacing for strips are kept constant as 76 mm. The strips spacing for shear steel reinforcement are kept at 64, 76 and 89 mm as shown in Figure 3.2. However, the longitudinal reinforcement is kept constant, i.e. three rebars at bottom. The relationship among the GFRP mix concrete and jute fiber embedded GFRP mix concrete is made. The diameter of GFRP and steel rebar is different in each arrangement. The diameter of GFRP rebars are six mm while the diameter of steel rebar is three mm in each sample. The detailing of flexural GFRP reinforcement and shear steel reinforcement for PC and JFRC are displayed in Figure 3.2. Classification for PC and JFRC samples with shear steel rebars and flexural GFRP rebars are given in Table 3.1. To compare compressive strength and split tensile strength of PC and JFRC, four cylinders are cast (i.e. two samples for PC and two samples for JFRC).

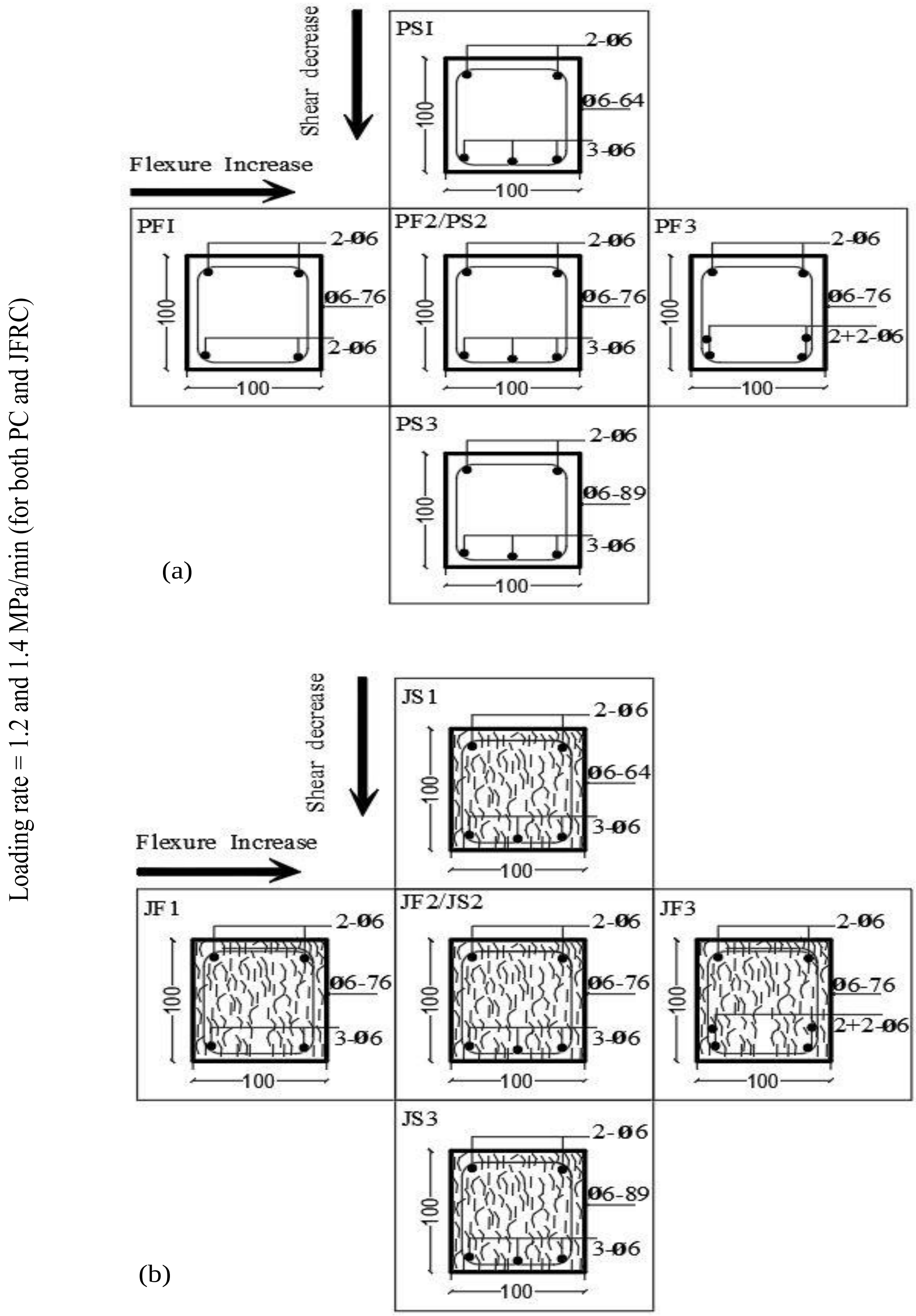


FIGURE 3.2: Structural details of beam-lets with GFRP rebars: (a) cross-sections of plan concrete, and (b) cross-sections of JFRC

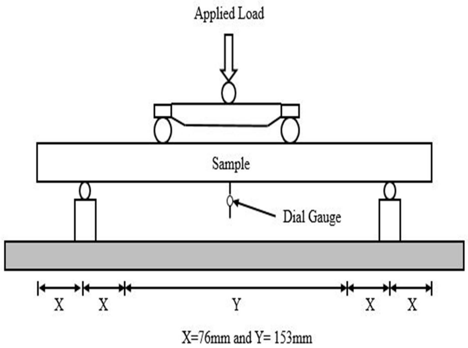
Table 3.1: Classification of beam-lets with GFRP rebars (2 samples for each)

			Labels		
S. No	Flexural	Shear	PC	JFRC	Loading Rates
1	2-Ø6	Ø6-76 mm	PF1	JF1	L1-L2
2	3-Ø6	Ø6-76 mm	PF2/PS2	JF2/JS2	L1-L2
3	2+2-Ø6	Ø6-76 mm	PF3	JF3	L1-L2
4	3-Ø6	Ø6-64 mm	PS1	JS1	L1-L2
5	3-Ø6	Ø6-89 mm	PS3	JS3	L1-L2

3.5 Testing procedures

3.5.1 Flexural test

ASTM standard C78 / C78M-15b) has been fallowed for all beam-lets 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 steel shear reinforcement. For applying the varying loading rates i.e. loading rate (L1) and loading rate (L2), Universal Testing Machine (UTM) is used. To explore the deflections and loading rates the UTM machine is connected with computer, which displayed the results on screen. The system diagram is shown in Figure 3.3. Under loading rates L1 and L2 the deflection curves and crack transmission are noted with optical examination. The first crack is recorded with the help of naked eyes and resultant loading rates are noted. From this evidence the first crack occurrence load (Pf), max load (Pm), ultimate load (Pu), max deflection (Δ), amount of cracks at final load and failure mode are obtained.



a)

b)

FIGURE 3.3: Testing of beam-lets with rebars: (a) representation diagram, and (b) testing setup

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 both PC and JFRC. 5% of jute fiber by mass of cement is added to prepare JFRC samples. The length of jute fiber used in this research work is 50 mm. GFRP rebars having Ø6 mm are used in specimen to prepare PC and JFRC beam-lets samples to study flexural behavior. A total of 20 specimens are cast. As per ASTM standards, slump, density, compressive strength, splitting tensile and flexural are also examined. For JFRC the same ASTM standards are followed. To study the behavior of GFRP reinforced beams, 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 mass 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 Behavior of PC and JFRC

4.2.1 Slump and Density for PC and JFRC

The slump of fresh concrete and density of hard concrete are given in Table 4.1. The slump value of PC is more than that of JFRC. The slump of PC is more than JFRC by 20 mm water cement ration of 0.6 for both. The decrease in slump value of JFRC is because of absorption more water by jute fiber. The density of PC is 2530 kg/m^3 while JFRC has density of 2453 kg/m^3. The reduction of 50 kg/ m^3 is noted in density of JFRC. The percentage reduction in JFRC density is 1.98%. This reduction is because of the scattered jute fiber in concrete.

TABLE 4.1: Slump, Density and W/C ratio of PC and JFRC

Description	W/C ratio	Slump (mm)	Density (kg/m^3)
Plain Concrete	0.6	60	2530
Jute-Fiber-Reinforced-Concrete	0.6	40	2465

4.2.2 Compressive Behavior of PC and JFRC

Compressive stress-strain graph, appearance of first crack, crack at maximum load, compressive of percentage increase or decrease of CS, C.P.E, C.E and C.T.I of PC and JFRC are shown in Figure 4.1a. The behavior of PC and JFRC are examined during conducting compressive strength test. At 81% and 79% of maximum load, the first crack of PC and JFRC are calculated, respectively. While increasing load, number of cracks in PC and JFRC increases. At maximum load, the PC samples breaks into two pieces while in JFRC at max load only the crack span and width increases. This is due to the presence of jute fibers. In JFRC samples 20% of jute fiber are wrecked and 80% are dragged out. The broken aggregate is 3% and 5% for PC and JFRC, respectively, due to less compressive strength on fracture surface. A significant decrease in Pf of JFRC is absorbed as compared to PC. Value of C.E1, C.S, C.E.P and C.T.I of JFRC also decreases when compared to PC. The percentage decrease of C.E1 and C.S, are 8.4%, 24.03%, respectively. Similarly increasing percentage of C.P.E and C.T.I are 35.8%, 41.3%, respectively, (Table 4.2).

TABLE 4.2: Compressive Properties of PC and JFRC Samples with MD ratio of 1:2:3

Specimen	Intended Properties			
	Strength (MPa)	C.E1 (MJ/m^3)	C.E.P (MJ/m^3)	C.T.I (-)
PC	30.29	0.154	0.825	5.35
JFRC	23.01	0.141	1.285	9.12

4.2.3 Splitting tensile Behavior of PC and JFRC

The splitting-tensile load-deflection curves first crack, crack at max load, splitting-tensile increase or decrease percentage S.S, S.P.E, S.E and S.T.I of PC and JFRC samples are given in Figure 4.1b. During splitting-tensile strength, first crack of JFRC is noted 97% at maximum load. The PC sample at peak load splits into two pieces, while JFRC span and width of cracks increased. JFRC samples are purposely separated in two piece to identify the failure of fibers. It is noted that 15% of fibers dragged out and 85% of fibers are wrecked. The shorter length gives less grip to surrounding concrete mix. Due to appropriate fiber length, the fiber wrecked on application of load. With the help of naked eye, the damage on fracture surface of PC and JFRC are 15% and 10%, respectively. While S.E1, S.E.P of JFRC are increased when compared to PC. There is increase of 10.8%, 71.8%, and 55% in S.E1, S.P.E and S.T.I, respectively, when compared to their respective PC samples (Table 4.3). The addition of jute fiber in concrete composite is the cause of improvement in S.E1, S.P.E and S.T.I.

Table 4.3: Splitting-tensile Properties of PC and JFRC Samples with MD ratio of 1:2:3

Specimen	Intended Properties			
	Strength (MPa)	S.E1 (J)	S.P.E (J)	S.T.I (-)
PC	4.10	35.68	35.68	1.0
JFRC	4.21	39.55	61.30	1.55

4.2.4 Flexural Behavior of PC and JFRC

The flexural load-deflection curve, appearance of first crack, cracks at max load, F.E1, F.S, F.E.P and F.T.I of PC and JFRC are shown in Figure 4.4. Up to the first crack area under curve is considered as F.P.E. The total area under load-deflection curve is F.E1. F.T.I is the ratio of F.E1 to F.P.E (i.e. F.E1/F.P.E).

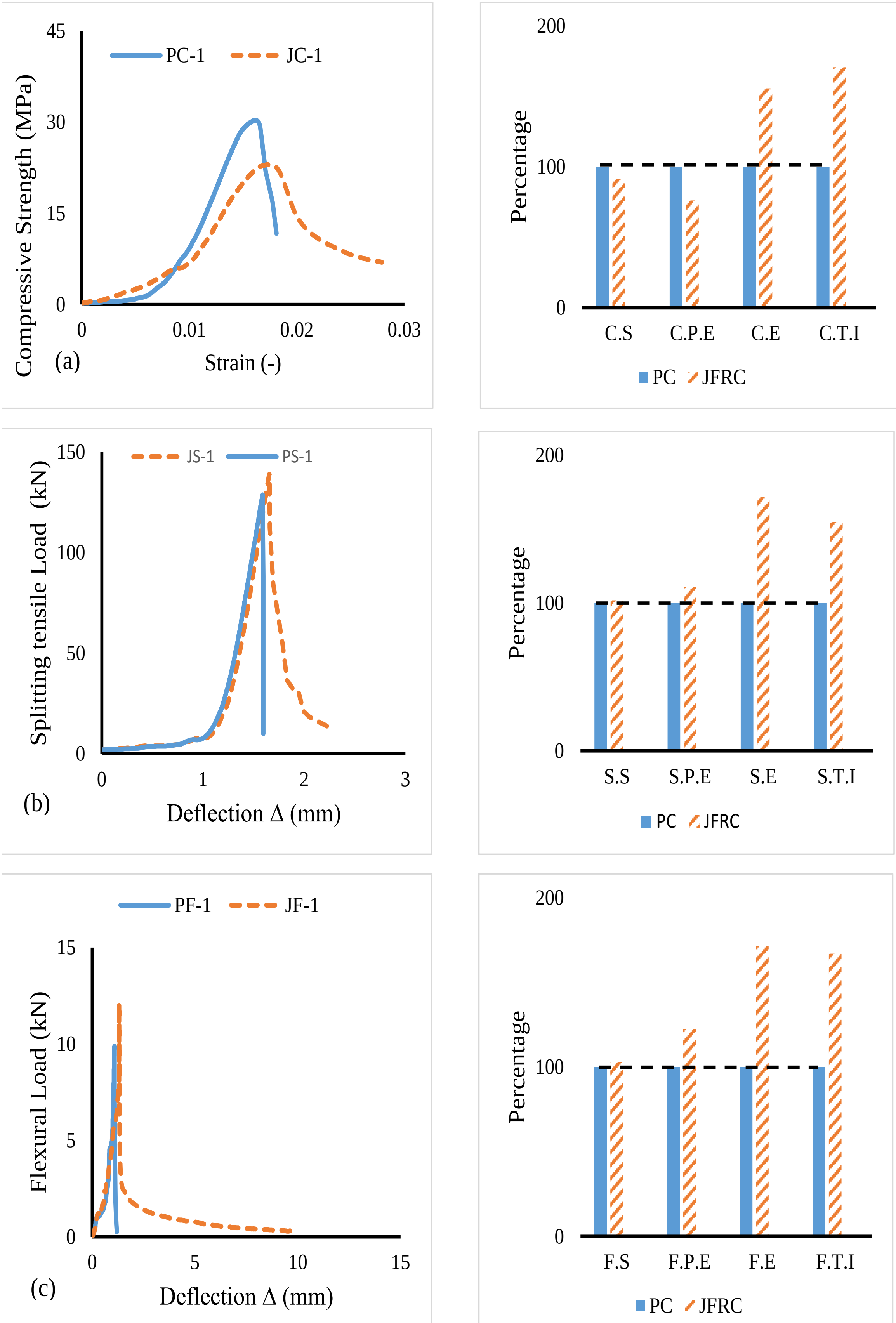


Figure 4.1: Material properties of PC and JFRC specimens with MD ratio of 1:2:3 ; a) under compression, b) under split-tension and c) under flexure.

First crack in JFRC samples during flexural strength are noted as 93% of the maximum load. At max load the PC sample breaks into two pieces. But in JFRC samples the crack length increase at max load and not splits into two pieces because of jute fiber. It is noted with the help of naked eye that in JFRC samples 30% of jute are pulled out and 70% fiber are wrecked. The damage surface in PC is 10% while 5% in JFRC is noted. The value of F.E.P, Pm, F.E1 and F.T.I are increased when compared to PC samples. The percentage increase in F.E.P, F.S, F.E1 and F.T.I of JFRC are 41.6%, 18.43%, 2.74% and 67%, respectively, (Table 4.4). The F.E1 and F.T.I of JFRC is more when compared to that of PC. Therefore JFRC is better to be used in concrete as crack arrester.

TABLE 4.4: Flexural Properties of PC and JFRC Samples with MD ratio of 1:2:3

Specimen	Intended Properties			
	Strength (MPa)	F.E1 (J)	F.E.P (J)	F.T.I (-)
PC	6.20	2.84	2.84	1.0
JFRC	6.35	2.92	4.87	1.67

4.3 Effect of Loading Rates on Beam with Changing Flexural GFRP Rebars

4.3.1 Behavior during Testing

Load deflection curve for PC and JFRC are shown in Figure 4.2. Beam-lets having different numbers of flexural GFRP reinforcement and same number of shear steel rebars i.e. (Ø6-76 mm). The tested beam-lets 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 steel rebars are shown in Figure 4.3. The flexural GFRP reinforcement is improved by 2- Ø6, 3-Ø6 and 2+2-Ø6 for both PC and JFRC concrete. In all the load deflection curves the linear manners is noted until the first crack is seemed. Post the first crack there is positive improvement in behavior of JFRC samples i.e. less abruptness in curve and extra deflection before the ultimate load as matched to PC samples. This shows the strong performance of JFRC. In JFRC the samples with (2+2-Ø6) GFRP flexural rebars indicate much strong behavior when compared with other JFRC samples. Under flexural loading behavior of plan concrete and JFRC samples having flexural GFRP reinforcement are also observed. Specific evidence like first crack span, quantity of cracks at max load and the final load are discovered. The first crack of PF1, JF1, PF2, JF2, PF3 and JF3 are presented at 21.1%, 21.5%, 21.7%, 27.4%, 30.1% and 18.3%, respectively, of their corresponding highest values of L1. Similarly the first crack of PF1, JF1, PF2, JF2, PF3 and JF3 are exposed at 22.9%, 15.1%, 19.5%, 22.3%, 26.1% and 24.6%, respectively, of their corresponding highest values of L2. The sharpness of cracks in case of JFRC samples observed with the help of naked eye is minor as compare to PC samples. The span of cracks in JFRC samples is also less as compared to their particular PC samples. With increasing the number of flexural reinforcement the span of crakes decrease. For PC the span of very first crake is almost 72, 67, and 52 mm for PF1, PF2 and PF3, respectively, under loading rate (L1) and for JFRC the span of first crack for JF1, JF2 and JF3 are almost 60, 45 and 40 mm, respectively, under L1. Similarly for PC the span of first crack is almost 75, 72, and 60 mm for PF1, PF2 and PF3, respectively, under loading rate (L2) and for JFRC the span of first crack for JF1, JF2 and JF3 are almost 65, 52 and 50 mm, respectively, under L2. At maximum loading the number and width of crakes are greater in PC concrete as compared to JFRC concrete. At ultimate load the numbers and width of cracks are slightly more than maximum load. Crakes are similar or slightly more in JFRC concrete than PC concrete in some cases. But when observed with naked eye cracks in PC are more when compared with JFRC samples. The serviceability of JFRC concrete beam-lets samples are more than PC concrete beam-lets samples. It is concluded when jute fiber is used in concrete it improve the cracking behavior of tested beam-lets samples.

Table 4.5 shows maximum deflection (δ), total quantity of cracks in the ultimate failure modes of failure of PC and JFRC having different flexural GFRP rebars with constant shear steel rebars. The first cracking load (Pf) is obtained from load deflection curve of examined beam-lets samples. Load (Pf) is noted with the help of corresponding time of the arrival of the very first crake and load deflection curve. The first crack occurs in PF1, PF2 and PF3 at load 7.17 kN, 8.62 kN and 8.20 kN under L1. Similarly the first crack under L1 is 7.72 kN, 8.75 kN and 9.12 kN for JF1, JF2 and JF3, respectively. The first crack occurs in PF1, PF2 and PF3 at load 4.90 kN, 5.56 kN and 6.40 kN under L2. Similarly the first crack under L2 is 6.70 kN, 9.92 kN and 8.76 kN for JF1, JF2 and JF3, respectively. In L1 the load at which the very first crack occurs of JF1, JF2 and JF3 are improved by 0.72 kN, 0.13 kN and 0.92 kN, respectively. Similarly for L2 the cracks occur in JF1, JF2 and JF3 are improved by 1.8 kN, 4.36 kN and 2.36 kN, respectively. From the above value it is proved that JFRC samples are more resistant 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 beam-lets samples. The maximum load (Pm) is similarly obtained from the load deflection curves of tested samples. The maximum load (Pm) of PF1, PF2, PF3, JF1, JF2 and JF3 are 34.0 kN, 39.8 kN, 30.3 kN, 35.9 kN, 31.9 kN and 44.9 kN, respectively, under loading rate L1. Similarly the maximum load (Pm) for PF1, PF2, PF3, JF1, JF2 and JF3 are 29.2 kN, 28.5 kN, 24.5 kN, 32.4 kN, 30.7 kN and 35.6 kN, respectively, under loading rate L2. With the help of computer screen the maximum deflection (δ) is noted and these values are given in Table. 4.5. The value of maximum deflection (δ) noted is greater in JFRC samples than PC samples. The value of maximum deflection for PF1, PF2, PF3, JF1, JF2 and JF3 are 12.6, 11.5, 13.7, 16.5, 19.3 and 15.5 mm, respectively, under L1. Similarly under L2 maximum deflection (δ) for PF1, PF2, PF3, JF1, JF2 and JF3 are 16.5, 23.2, 15.5, 19.6, 18.8 and 23.5 mm, respectively. The reduction in the median length deflection is detected in samples with increasing flexural GFRP rebars. Increase in toughness of particular beam lets samples are reason for decrease in deflection. Because toughness of beam lets samples are related with steel ratio.

At ultimate load the quantity of cracks in tested samples are also noted given in Table 4.5. The number of crakes in PF1, PF2, PF3, JF1, JF2 and JF3 are 6, 4, 4, 5, 3 and 4, respectively, under L1. Similarly these value under loading rate L2 are 7, 5, 4, 6, 4 and 3 for PF1, PF2, PF3, JF1, JF2 and JF3, respectively. The cracks length and width in JFRC samples are less than PC samples. This decrease in cracks length and width in JFRC samples are due to the dispersed jute fiber in JFRC samples. The jute fiber resisted cracks. The failure mood phenomenon is observed in tested beam-lets on basis cracks formation shown in Table 4.5.

TABLE 4.5: Experimental results (loads and deflections) of tested specimens with changing flexural rebars and constant shear rebars (Ø6-76 mm)

Specimens	Load rate	First crack load P_f (kN)	Max Pm (kN)	Ultimate loadPu (kN)	Max Δ (mm)	No.of cracks at the ultimate load (-)	Failure mode at first crack (-)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PF1 (2-Ø6)	L1	7.2	34.1	21.5	12.6	6	Flexure
	L2	6.7	29.2	17.1	16.5	7	Flexure
JF1 (2-Ø6)	L1	7.7	35.9	24.5	15.6	5	Flexure
	L2	4.9	32.4	17.7	19.6	6	Flexure
PF2 (3-Ø6)	L1	6.6	29.3	22.1	12.8	4	Flexure
	L2	5.6	30.7	22.6	13.0	5	Flexure
JF2 (3-Ø6)	L1	8.7	38.6	20.5	16.5	3	Shear
	L2	9.9	36.0	21.5	16.5	4	Shear
PF3(2+2-Ø6)	L1	9.1	30.3	25.1	13.7	4	Flexure
	L2	6.4	24.5	15.0	15.5	4	Flexure
JF3(2+2-Ø6)	L1	8.2	44.9	30.1	15.5	4	Shear
	L2	8.8	35.6	17.5	25.0	3	Flexure

The noted failure modes for PF1 and JF1 are flexural, PF2 and JF2 are balanced while PF3 and JF3 are shear. The cause of flexural failure is because of reasonably less reinforcement. The origin of shear failure is relatively less shear reinforcement. Failure that is caused by flexural cracks is indicated by flexural failure mood. Similarly shear failure mood shows that the failure is due to the shear cracks (circulated at 45°). The balance failure mood shows that at ultimate failure the numbers of shear cracks and flexural cracks are nearly same.

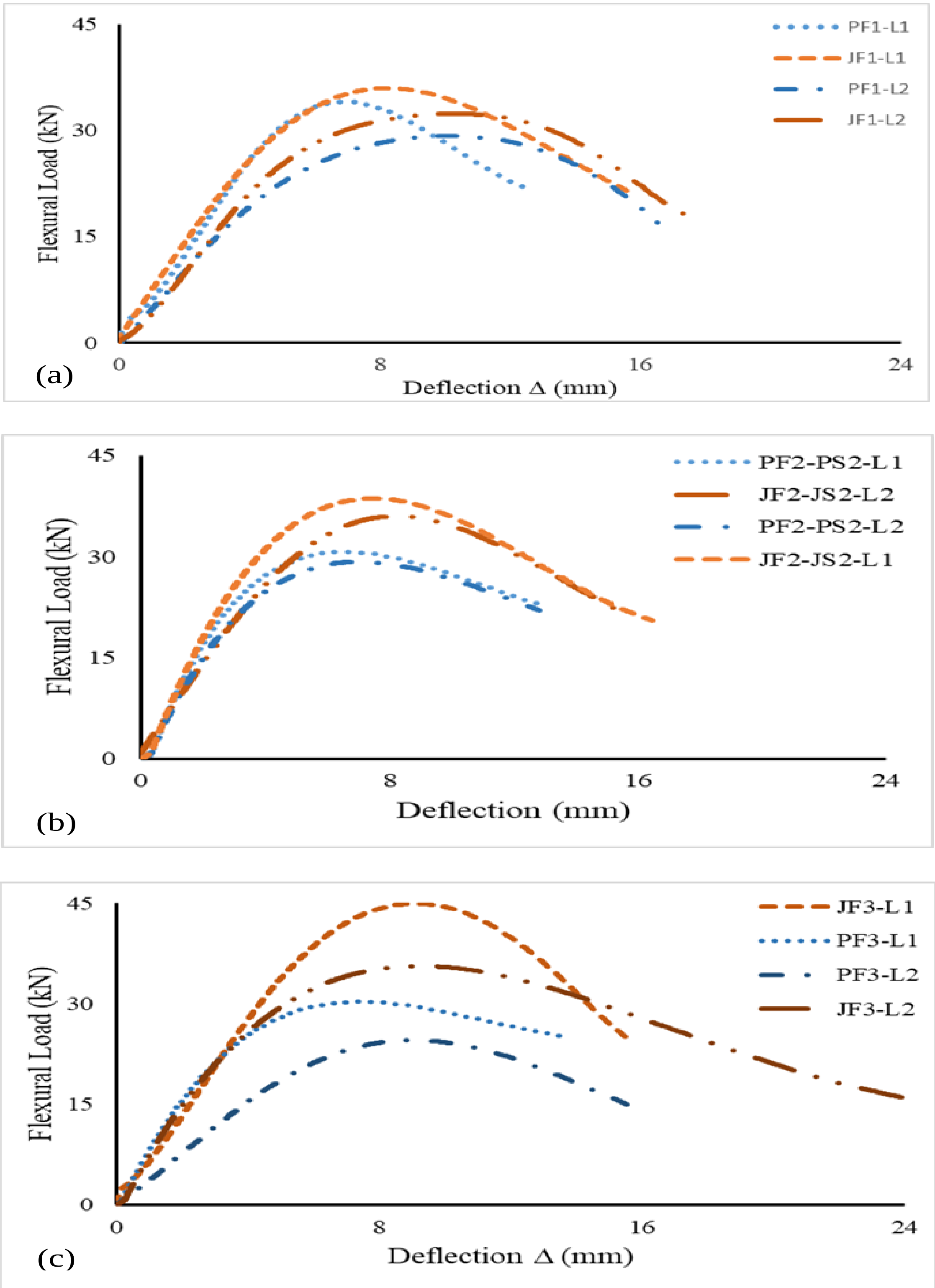


FIGURE 4.2: Load-deflection curve of samples with changing flexural rebars and constant shear rebars: 2-Ø6, 3-Ø6, 2+2-Ø6 and Ø6-76 mm, respectively.

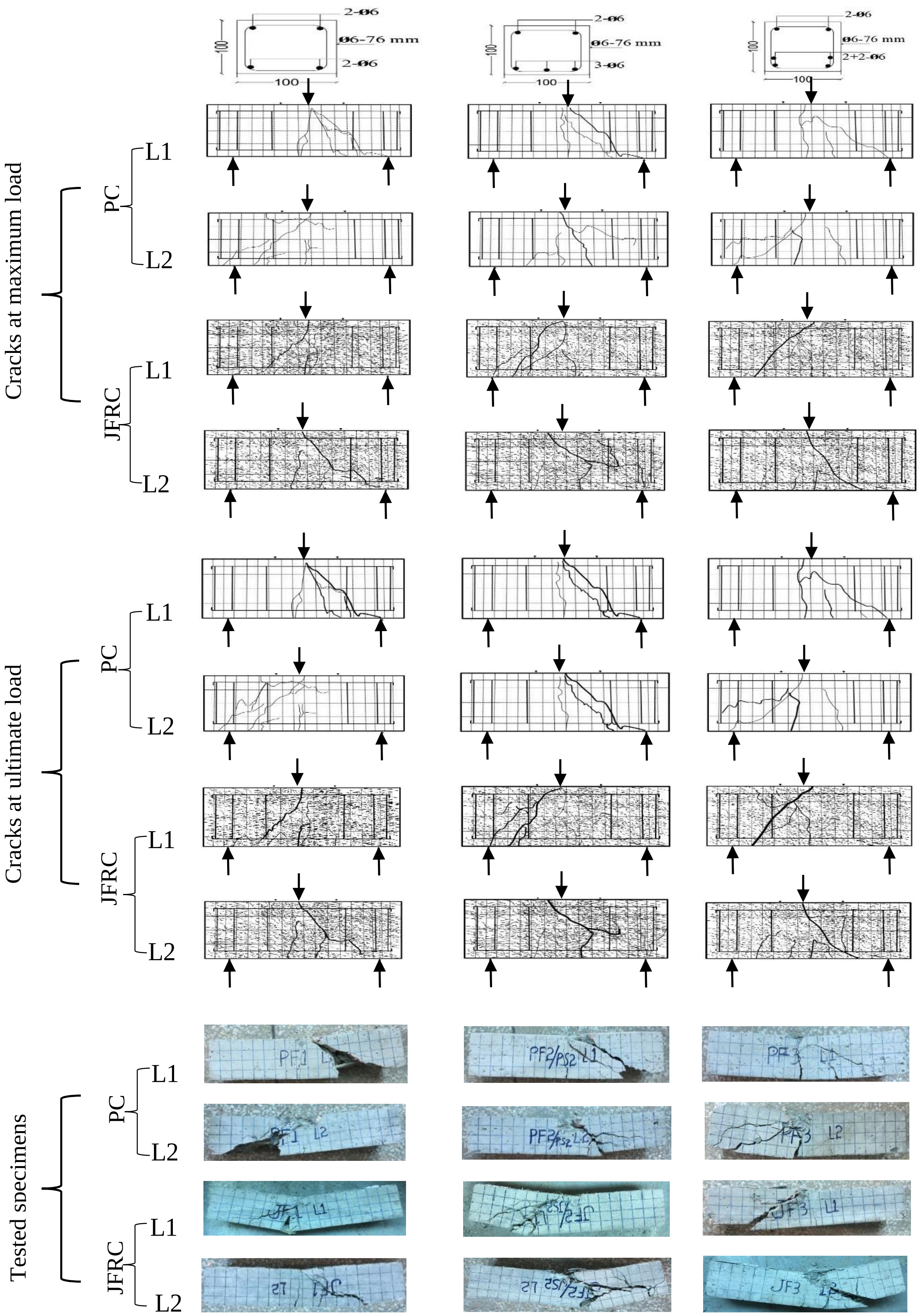


FIGURE 4.3: Crack propagation of PC and JFRC specimens with changing flexural rebars and constant shear rebars (i.e.Ø6-76 mm) during varying flexural loading rates.

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

The F.S, flexural energy absorption (F.E1, F.E.M, F.E.P, and F.E) and F.T.I of beam-lets samples using constant shear rebars and different flexural rebars are shown in Table 4.6. Using maximum load-deflection curves of particular samples, flexural strength of PF1, PF2, PF3, JF1, JF2 and JF3 are calculated. The value for flexural strength of PF1, PF2, PF3, JF1, JF2 and JF3 are 34.05 kN, 29.3 kN, 30.3 kN, 35.9 kN, 38.6 kN, and 44.9 kN, respectively, in loading rate L1. Similarly for loading rate L2 the flexural strength of PF1, PF2, PF3, JF1, JF2 and JF3 are 29.2 kN, 30.7 kN, 24.5 kN, 32.4 kN, 36.0 kN and 35.6 kN, respectively. Area at which first crack happens under load deflection curve up to max load is selected as energy absorption to F.E1. The value for energy absorption of JF1, JF2 and JF3 are improved by 1.9 J, 9.3 J and 14.6 J after comparison with PF1, PF2 and PF3, respectively, in loading rate L1. The value of energy absorption of JF1, JF2 and JF3 are increased by 3.2 J, 5.3 J and 11.1 J when the comparison is done with PF1, PF2 and PF3, respectively, in loading rate L2. The increase in first crack for both plan concrete and JFRC samples are noted while increasing flexural GFRP rebars. The space beneath load deflection curve from F.E1 to max load (F.E.M) is noted as energy absorption. F.E.M of JF1, JF2 and JF3 are improved by 38%, 28% and 63%, respectively, compared to that of PF1, PF2 and PF3, respectively, under loading rate L1. Similarly F.E.M for loading rate L2 the energy absorption of JF1, JF2, and JF3 are increased by 14% 47% and 62%, respectively, when compared PF1, PF2 and PF3. For both PC and JFRC the convex reduction is absorbed in F.E.M because of growth in GFRP flexural rebars. F.E1, F.E.M, F.E.P, and F.E from maximum load to final load are occupied as an area below load deflection curve from extreme load to final load. The F.E.P of PF1, PF2, PF3, JF1, JF2 and JF3 are 163.54 J, 152.8 J, 175.6 J, 220.2 J, 269.2 J and 238.4 J, respectively, under loading rate L1. Similarly the value for F.E.P of PF1, PF2, PF3, JF1, JF2 and JF3 under loading rate L2 are 161.4 J, 175.1 J, 135.2 J, 119.1

J, 205.4 J and 406.2 J, respectively. 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. The F.E of JF1, JF2 and JF3 are increased by 35%, 60% and 48%, respectively, when compared to PF1, PF2 and PF3 under L1. The F.E of JF1, JF2 and JF3 are increased by 17%, 31% and 85%, respectively, when compared to PF1, PF2 and PF3 under L2. The flexural toughness index is define as F.E/F.E1. The F.E/F.E1 of PF1, PF2, PF3 JF1, JF2 and JF3 are 58.7, 5, 62.6, 93.2, 94.0 and 75.8, respectively, under loading rate L1. Similarly the F.E/F.E1 for loading L2 of PF1, PF2, PF3 JF1, JF2 and JF3 are 64.1, 43.9, 105.7, 159.9, 91.2 and 135.5, respectively. The F.E/F.E1 of JF1, JF1 and JF3 are increased by 58 %, 74 % and 21%, respectively, for L1. Similarly the F.E/F.E1 of JF1, JF1 and JF3 are increased by 149%, 108 % and 28%, respectively, for L2 and similarly. 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.

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. 2-Ø6, 3-Ø6, and 2+2-Ø6) and same shear reinforcement (Ø6-76 mm) is shown in Figure 4.4. 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. Only the F.E.P in case of 3-Ø6 flexural reinforcement samples and Ø6-76 mm shear steel rebars of JFRC are considerably greater than other considered JFRC samples. Beside these properties other properties are more or less similar with small difference i.e. increase in behavior with increasing number of GFRP flexural rebars.

TABLE 4.6: Experimental results (loads and deflections) of tested samples with changing flexural rebars and constant shear steel rebars (i.e. Ø6-76 mm)

Specimens	Load rate	F.S (kN)	F.E1 (J)	F.E.M (J)	F.E.P (J)	F.E (J)	F.T.I (-)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PF1 (2-Ø6)	L1	34.1	5.2	137.8	163.5	306.6	58.7
	L2	29.2	5.6	195.5	161.3	362.6	63.9
JF1 (2-Ø6)	L1	35.9	4.4	190.3	220.2	415.1	93.2
	L2	32.3	2.6	221.9	199.1	423.7	159.5
PF2 (3-Ø6)	L1	29.3	5.4	134.9	152.8	293.2	54.1
	L2	30.7	7.1	131.2	175.1	312.3	43.9
JF2 (3-Ø6)	L1	38.3	4.9	175.4	269.2	468.5	94.1
	L2	35.5	4.5	192.5	205.3	410.2	91.1
PF3(2+2-Ø6)	L1	30.3	5.3	152.3	175.6	333.2	62.5
	L2	24.5	2.6	137.3	135.2	275.1	105.6
JF3(2+2-Ø6)	L1	44.9	6.5	249.4	238.4	494.3	75.7
	L2	35.6	4.6	222.8	406.2	633.7	135.5

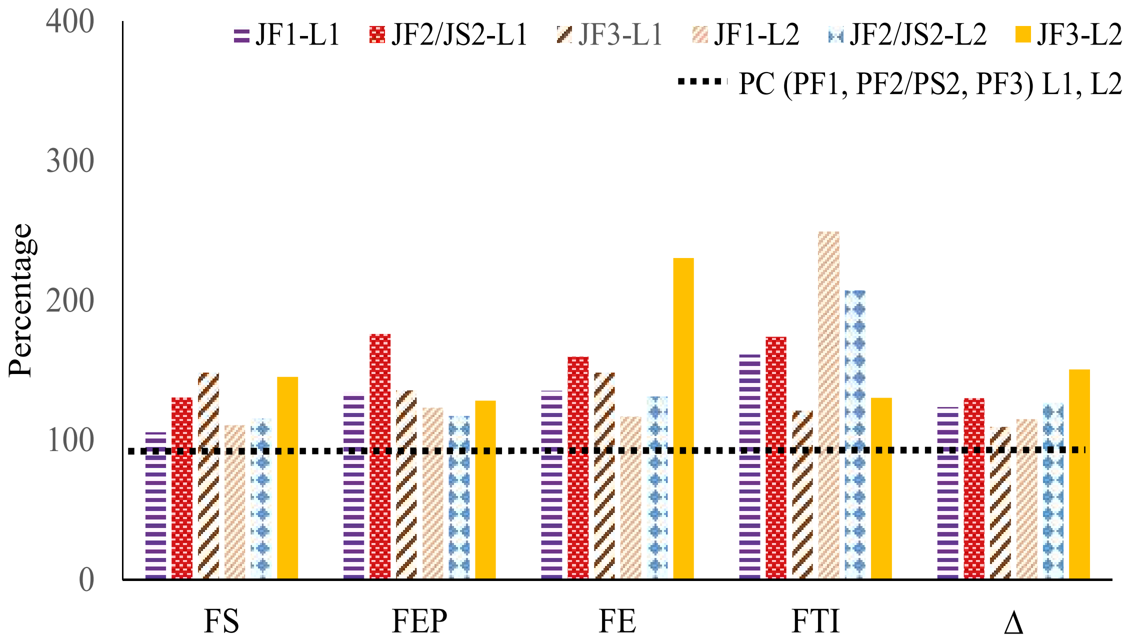


FIGURE 4.4: Relationship of F.S, F.E.P, F.E, F.T.I and deflection of PC and JFRC with changing flexural rebars (i.e. 2-Ø6, 3-Ø6, and 2+2Ø6) and with constant shear rebars (i.e. Ø6-76 mm).

4.4 Effect of Loading Rates on Beam with Varying Shear Rebars

4.4.1 Behavior during Testing

Figure 4.5 shows the load deflection curves for plan concrete and JFRC having varying shear steel rebars (i.e. Ø6-64 mm), (Ø6-76 mm) and (Ø6-89 mm). The first crack (Pf), cracks at max loading (Pm), cracks at ultimate loading (Pu) and the tested samples for PC and JFRC are shown in Figure 4.6. For both cases i.e. plan concrete and JFRC the shear rebars are reduced by (Ø6-64 mm), (Ø6-76 mm) and (Ø6- 89 mm). The flexural performance and stiffness of JFRC samples having shear steel reinforcement is noted here again in comparison with load deflection curves to their particular PC samples. In case of JFRC samples great displacement is noted with shear reinforcement. This is because of the scattered jute fiber. Because of crack stunning behavior and resistant to cracking the JFRC samples show great displacement and tolerate great load as compared to their respective PC samples. The samples of JFRC having Ø6-64 mm shear reinforcement show good behavior as compared to other measured JFRC samples. In this case the developed behavior is noted after the Maximum loading. During testing the cracking mechanism with shear steel reinforcement in PC and JFRC are also examined. The appearance of the cracks at varying stages i.e. first crack (Pf) at Maximum loading (Pm), and first crack at ultimate loading (Pu) is discovered. The cracks seemed in JFRC samples are relatively less in width and strictness, when matched with cracks of their respective plan concrete samples. Samples having more shear reinforcement (Ø6-64) are more resistive to cracks than all other considered samples. With the help of naked eye when the lengths of first crack of JFRC sample are observed, they are less than that of their respective PC samples. Also the crack span, width and quantity of cracks are more in plan concrete samples when matched to their particular JFRC samples after observation with naked eye. It is also observed that crack resistance behavior in JFRC samples with shear rebars are greater than PC samples. In all the JFRC samples, the samples with

Ø6-64 mm shear reinforcement and 3-Ø6 flexural reinforcement show good crack resisting when matched to other measured JFRC samples. The improvement in the post cracking performance is because of scattered jute fibers.

Table 4.7 shows loads, deflections (δ), quantity of crack happened at final failure and mode of failure for tested plan concrete samples and JFRC samples having constant flexural GFRP rebars 3-Ø6 and different shear steel reinforcement (Ø6-64 mm), (Ø6-76 mm) and (Ø6-89 mm). For first crack of PS1, PS2, PS3 JS1, JS2 and JS3, the loads are 6.7 kN, 6.6 kN, 7.6 kN, 7.8 kN, 8.7 kN, and 8.3 kN, respectively, under loading rate L1. Similarly under loading rate L2 the first crack load for PS1, PS2, PS3 JS1, JS2 and JS3 are 6.9 kN, 5.5 kN, 7.8 kN, 7.8 kN, 9.9 kN, and 8.4 kN, respectively. First cracks load under L1 of JS1, JS2 and JS3 are improved by 16.4%, 32% and 9.2%, respectively. Correspondingly the first crack load of JS1, JS2 and JS3 are improved by 13%, 80% and 7.6%, respectively, under L2. The improved value for crack resisting is because of the embedded jute fiber in PC mix. Decreasing in shear rebars the crack resistance also decreases. The max load is also taken from the load deflection curve of the tested samples. The maximum load under loading rate L1 for PS1, PS2, PS3, JS1, JS2 and JS3 are, respectively, 30.9 kN, 29.3 kN, 38.9 kN, 34.4 kN, 38.6 kN, and 41.8 kN. Similarly, for loading rate L2 the maximum load for PS1, PS2, PS3, JS1, JS2 and JS3 are 28.5 kN, 30.7 kN, 26.8 kN, 32.3 kN, 35.9 kN, and 33.7 kN, respectively. The maximum load is increased by 3.5 kN, 9.3 kN, and 2.9 kN, of JS1, JS2 and JS3 when compare to their respective PC samples under L1. Similarly the maximum load is increased by 3.8 kN, 5.2 kN, and 6.9 kN, of JS1, JS2 and JS3 when compare to their respective PC samples under L2. Simply the load bearing capacity of JFRC samples are much better that PC samples. The maximum deflection values are also shown in Table 4.7. The maximum deflection in JFRC samples are more than that of PC samples. When the deflection of JS1, JS2 and JS3 are compared to their respective PC samples, the deflection in JS1, JS2 and JS3 are more by 44%, 29%, and 75%, respectively, under L1. Similarly under L2 When the deflection of JS1, JS2 and JS3 are compared to their respective PC samples, the deflection in JS1, JS2 and JS3 are more by 12%, 27%, and 36%, respectively. At ultimate failure in the samples, the numbers of cracks are also noted with the help of naked eye and are shown in Table 4.7. The quantity of cracks for PS1, PS2, PS3 JS1, JS2 and JS3 samples are 5, 5, 5, 4, 4 and 5, respectively, under L1. Similarly under L2 the number of cracks in PS1, PS2, PS3 JS1, JS2 and JS3 samples are 6, 5, 6, 5, 5 and 3, respectively. In PC samples the cracks span and width are more than their respective JFRC samples. Again here, because of jute fiber in concrete the crack arresting and bridging phenomenon are noted. The jute fiber resist the first crack production and also resists the crack propagation in all JFRC samples having flexural GRFP reinforcement and shear steel rebars. The failure mode of the tested samples on the basis of cracks formation is also noted shown in Table 4.7. The recorded failure mode of PS1 and JS1 are oblique tension. For PS2 and JS2 the failure mode are balanced while the failure mode for PS3 and JS3 are shear. The shear and longitudinal stress combination are indicated by diagonal tension failure mode.

4.4.2 Effect of Shear Rebars on Flexural Strength (F.S), Flexural Energies Absorbed (F.E1, F.E.M, F.E.P, and F.E), and Flexural Toughness Index (F.T.I)

The (F.S), flexural energies absorbed and F.T.I having different shear rebars (i.e. Ø6-64 mm), (Ø6-76 mm) and (Ø6-89 mm) and constant flexural GFRP rebars (3-Ø6) for PC samples and JFRC samples are shown in Table 4.8. The flexural strengths of PS1, PS2, PS3, JS1, JS2 and JS3 are calculated from their respective samples using the Maximum load from load deflection curves. The flexural strength under loading rate L1 of PS1, PS2, PS3, JS1, JS2 and JS3 are 30.9 kN, 29.3 kN, 38.9kN, 34.4, 38.6 kN and 41.8kN, respectively. Similarly the flexural strength under loading rate L2 of PS1, PS2, PS3, JS1, JS2 and JS3 are 28.5 kN, 30.7 kN, 28.6kN, 32.3 kN, 35.9 kN and 33.7 kN, respectively. The flexural strength value of JS1, JS2 and JS3 are improved by 11%, 32%, and 8%, respectively, under L1. Similarly under L2 the flexural strength value of JS1, JS2 and JS3 are improved by 13%, 17%, and 26%, respectively.

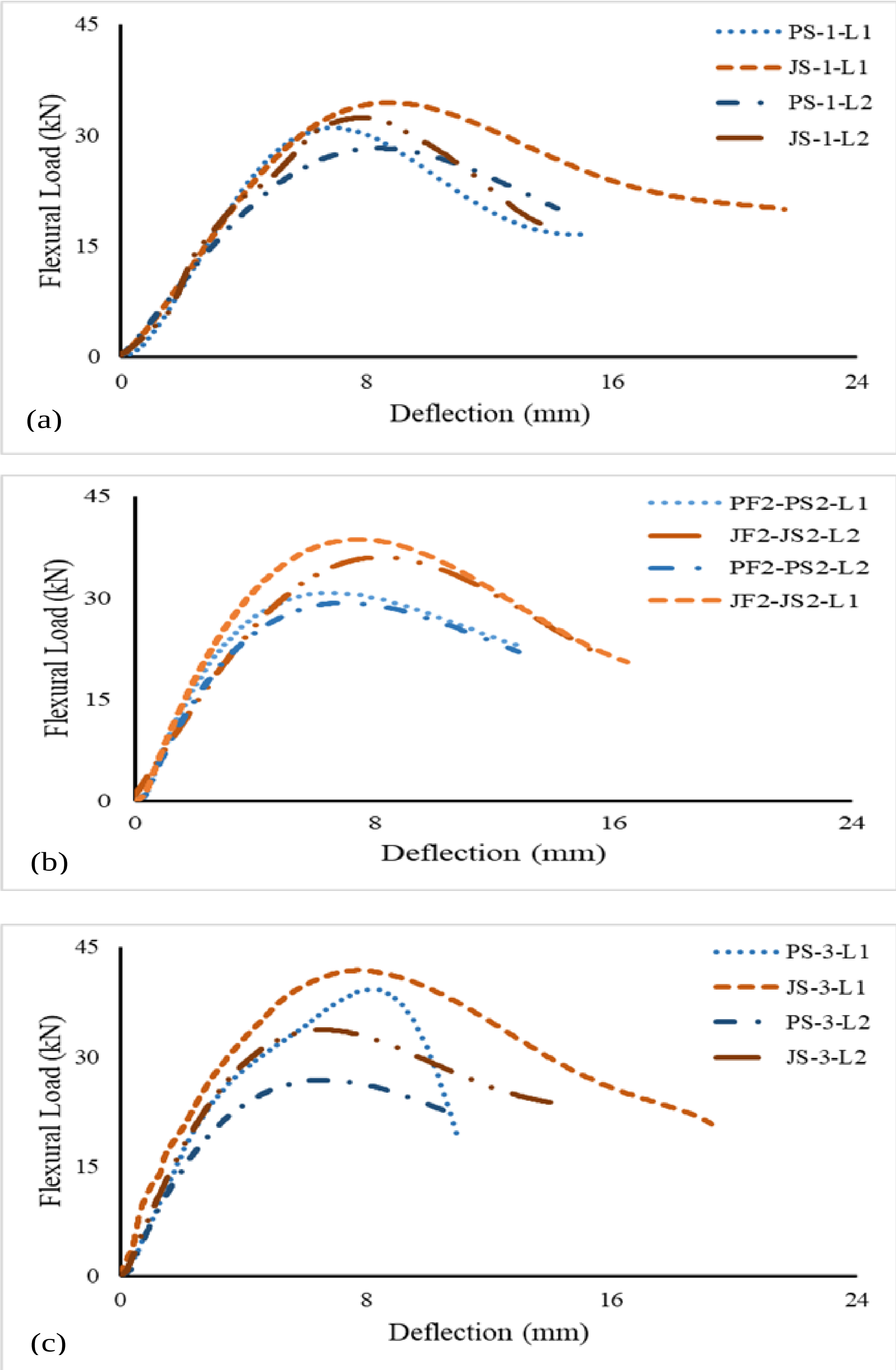


FIGURE 4.5: Load deflection curve of PC and JFRC with shear rebars: (a) Ø6-64mm, (b) Ø6-76mm, and (c) Ø6-89mm and constant flexural rebars (i.e. 3- Ø6).

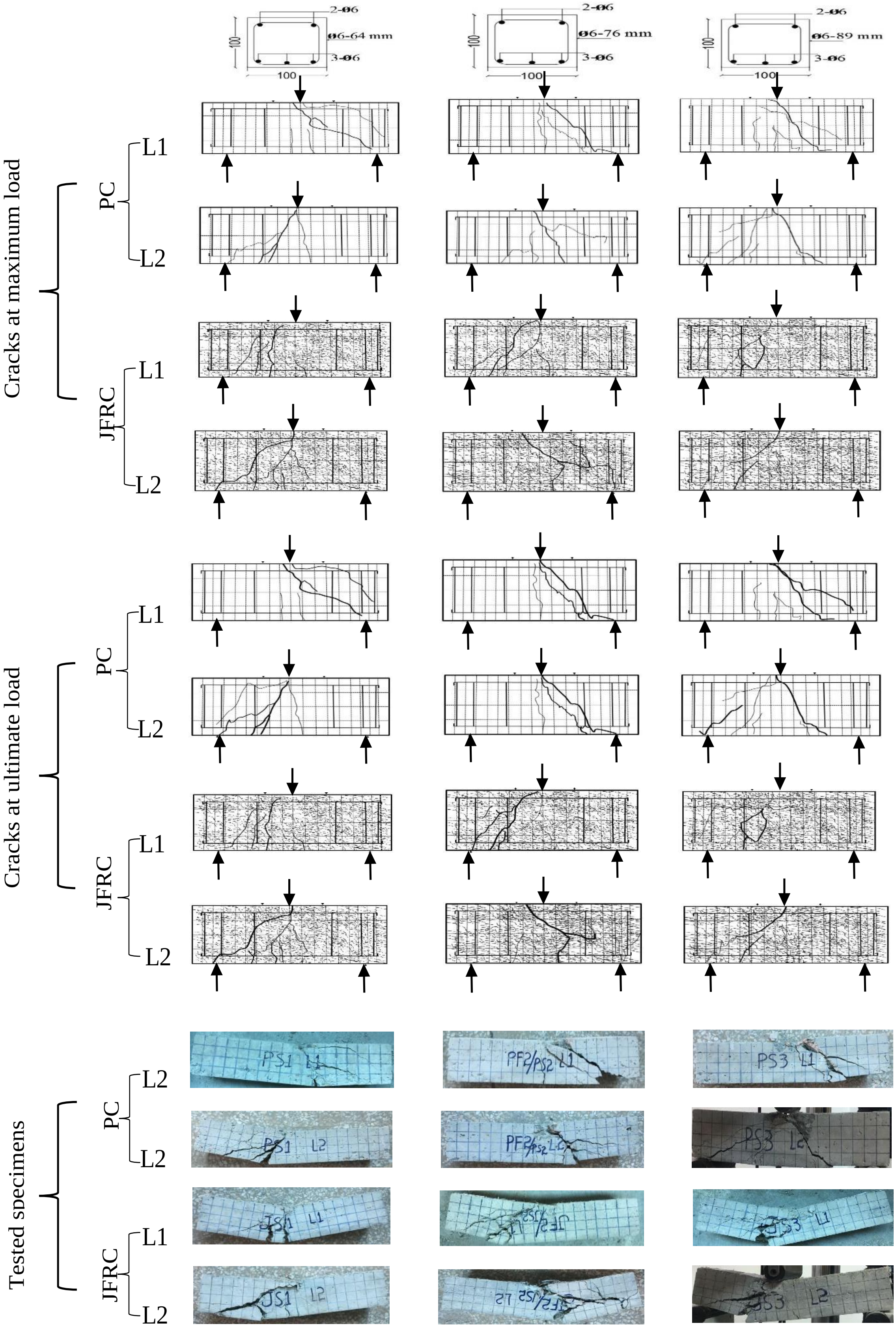


FIGURE 4.6: Crack propagation of PC and JFRC specimens with changing shear reinforcement and constant flexure rebars (i.e.3-Ø6) during varying flexural loading rates

The decrease in shear strength is noted because of reduction in shear rebars. F.E.M and F.E values of JS1, JS2 and JS3 samples, when compared with their respective samples of PS1, PS2 and PS3, F.E.M values are increased by 48%, 30% and 48% and F.E values are increased by 79%, 60% and 57%, respectively, under L1. Similarly under L2 F.E.M and F.E values of JS1, JS2 and JS3 samples, when compared with their respective samples of PS1, PS2 and PS3 F.E.M are increased by 24%, 47% and 13% and F.E are increased by 3%, 31% and 68%, respectively.

TABLE 4.7: Experimental results (loads and deflections) of tested samples having changing shear reinforcement and constant flexural rebars (3-Ø6)

Specimens	Load rate	First crack load pf (kN)	Max Pm (kN)	Ultimate load Pu (kN)	Max Δ (mm)	No.of cracks at the ultimate load (-)	Failure mode at first crack (-)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PS1 (Ø6-64 mm)	L1	6.7	30.9	16.5	15.0	5	Flexure
	L2	6.9	28.5	19.3	13.0	6	Shear
JS1 (Ø6-64 mm)	L1	7.8	34.4	20.1	21.6	4	Flexure
	L2	7.8	32.3	20.0	14.5	5	Flexure
PS2 (Ø6-76 mm)	L1	6.6	29.3	22.1	12.8	5	Flexure
	L2	5.5	30.7	22.6	13.0	5	Flexure
JS2 (Ø6-76 mm)	L1	8.7	38.6	20.5	16.5	4	Shear
	L2	9.9	35.9	21.4	16.5	5	Shear
PS3 (Ø6-89 mm)	L1	7.6	38.9	18.6	11.0	5	Flexure
	L2	7.8	26.8	22.5	10.6	6	Shear
JS3 (Ø6-89 mm)	L1	8.3	41.8	20.8	19.3	5	Flexure
	L2	8.4	33.7	23.4	14.4	3	Flexure

The F.E.P values of JFRC samples when compared with their respective PC samples, there is an increase of 48%, 76% and 62%, respectively, under L1. Similarly the F.E.P values of JFRC samples under L2 when compared with their respective PC samples, there is an increase of 7%, 17% and 16%, respectively. However, while decreasing the shear reinforcement from (Ø6-64 mm), to (Ø6-89 mm) the energy absorbed is also decrease. The same case is noted in flexural toughness index (F.T.I) of JFRC samples with shear steel reinforcement. The JS1, JS2 and JS3 flexural toughness index are improved by 69%, 74%, and 82%, respectively, when matched with PS1, PS2 and PS3 respective samples under L1. Similarly the JS1, JS2 and JS3 flexural toughness index are improved by 9%, 107%, and 25%, respectively, when matched with PS1, PS2 and PS3 respective samples under L2. The flexural toughness index (F.T.I) of sample with shear rebars of (Ø6-64 mm) is increased when compared to other JFRC samples. In overall the flexural behavior of JFRC are improved while increasing in shear rebars. Under flexural loading JFRC with shear rebars (Ø6-64 mm), (Ø6-76 mm) and (Ø6-89 mm) with flexural rebars of (3-Ø6) do much better.

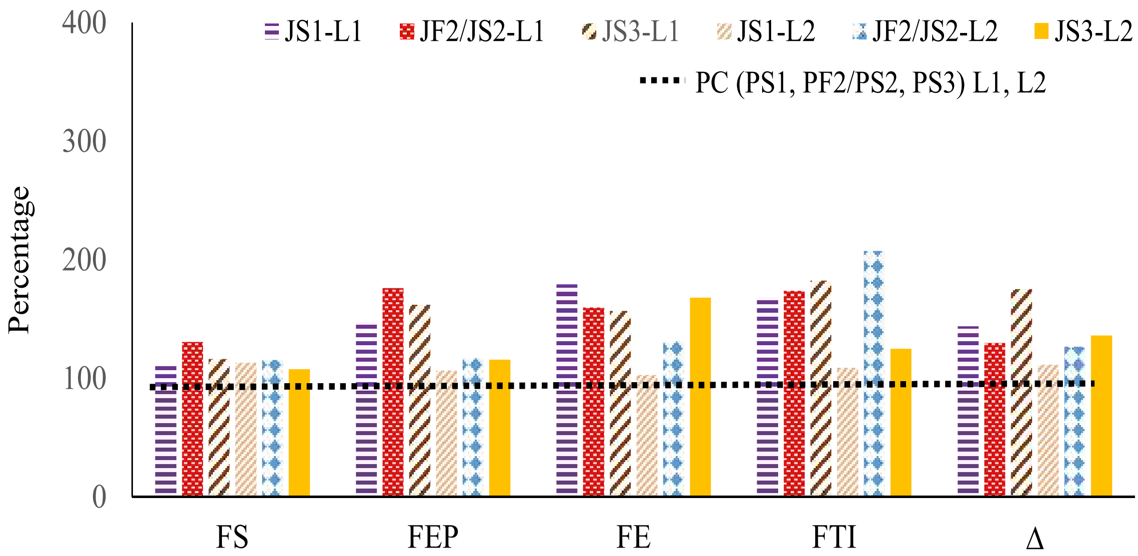


FIGURE 4.7: Relationship of F.S , F.E.P, F.E, F.T.I and δ of PC and JFRC with changing shear rebars (i.e. Ø6-64, Ø6-76, and Ø6-89 mm) and having constant flexural rebars (i.e. 3-Ø6)

The comparison with changing shear rebars (i.e. Ø6-64 mm), (Ø6-76 mm) and (Ø6-89 mm) and having constant flexural rebars (3-Ø6) of F.S , F.E.P, F.E, F.T.I and deflection (δ) of PC and JFRC are given in Figure 4.7. The JFRC samples with shear steel rebars show good result as matched to their respective plan concrete samples. The improved flexural strength (F.S), the post cracking performance, and flexural toughness index of JFRC samples having shear steel reinforcement are noted in relationship to plan concrete samples. When the result of shear rebars in JFRC samples are concerned, reduction in flexural behaviors with the reduction in shear steel rebars are noted.

TABLE 4.8: Experimental results (loads and deflections) of tested samples with constant flexural rebars (i.e. 3-Ø6) and changing shear steel rebars

Specimens	Load rate	F.S (kN)	F.E1 (J)	F.E.M (J)	F.E.P (J)	F.E (J)	F.T.I (-)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PS1 (Ø6-64 mm)	L1	30.9	5.0	115.3	183.0	308.6	61.7
	L2	28.5	4.6	150.0	145.2	297.7	64.0
JS1 (Ø6-64 mm)	L1	34.4	5.3	170.3	270.2	553.2	104.3
	L2	32.3	4.4	185.2	154.8	306.5	69.7
PS2 (Ø6-76 mm)	L1	29.3	5.4	134.9	152.8	293.2	54.1
	L2	30.7	7.10	131.2	175.1	312.3	43.9
JS2 (Ø6-76 mm)	L1	38.6	4.9	175.4	269.2	468.5	94.1
	L2	35.9	4.5	192.5	205.3	410.2	91.1
PS3 (Ø6-89 mm)	L1	38.9	4.8	143.6	223.2	372.4	67.0
	L2	26.8	3.5	180.3	190.5	221.6	62.3
JS3 (Ø6-89 mm)	L1	41.8	5.5	212.13	361.52	584.7	122.2
	L2	33.7	4.8	203.8	220.5	372.4	77.9

4.5 Summary

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 flexural strength of JFRC and splitting tensile strength of JFRC are improved when compared to their respective PC. It was also witnessed from the previous study [34]. 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. Therefore using JFRC with GFRP rebars is good solution for minimizing failure in bridge girders.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

The jute fiber with flexural GFRP reinforcement are studied in this research work for good application of eliminating failure in bridge girders. Jute fibers of 5% content to the total weight of cement and span of 50 mm are mixed in concrete composite. The ratio for JFRC and PC is 1:2:3. The influence of jute fiber is considered for enhancing the performance of concrete composite reinforced with GFRP flexural rebars and shear steel reinforcement when used in bridge girders. In this research study jute fiber reinforced concrete (JFRC) and plain concrete (PC) with flexural GFRP reinforcement and shear steel rebars are studied. The conclusions are as follows.

- JFRC with GFRP flexural rebars show improvement up to 32%, 76%, 60% and 82% in flexural strength, energy absorbed from the maximum load to the ultimate load, total flexural energy absorbed and flexural toughness index, respectively, in loading rate L1. Futhermore increase of 26%, 17%, 85% and 25% in flexural strength, energy absorbed from the maximum load to the ultimate load, total flexural energy absorbed and flexural toughness index, respectively, was absorved in loading rate L2.

- JFRC samples having shear reinforcement are measured the maximum increase in total flexural energy absorbed, energy absorbed from the maximum load to the ultimate load, energy absorbed from the first crack to the maximum load and flexural toughness index 79%, 76%, 48% and 82%, respectively, in loading rate L1. Futhermore, maximum increase in total flexural energy absorbed, energy absorbed from the maximum load to the ultimate load, energy absorbed from the first crack to the maximum load and flexural toughness index 68%, 16%, 47% and 57%, respectively, in loading rate L2.

- Here again in JFRC samples when matched to their respective plan concrete samples, the cracks length, width and quantity decrease up to 17%, 33% and 23%, respectively, under loading rate L1. Similarly under loading rate L2 again in JFRC samples when compared to that of PC samples, the cracks length, width and quantity decrease up to 14%, 28% and 17%, respectively.

- Improvement in flexural strength, energy absorbed from the maximum load to the ultimate load, total flexural energy absorbed and flexural toughness index of JFRC samples with shear steel reinforcement to 32%, 76%, 60% and 74% with, respectively, to that of their respective PC samples are absorbed under L1. Similarly under L2 the flexural strength, energy absorbed from the maximum load to the ultimate load, total flexural energy absorbed and flexural toughness index of JFRC samples with shear steel reinforcement to 17%, 17.5%, 31% and 57% with to that of respective PC samples.

- The values of flexural strength, energy absorbed from the first crack to the maximum load, flexural energy-absorption and flexural toughness index are more in loading rate L1. Similarly these values are slightly less in loading rate L2 when compared to that of loading rate L1. Similarly number of cracks, cracks length and cracks width are smaller in loading rate L1 when compare to that of loading rate L2. In short the behavior of specimens are changing with changing loading rate.

Hence, on the basis of this research, it is concluded that the JFRC with flexural GFRP rebars and shear steel reinforcement is better for casting in concrete bridge girders.

5.2 Recommendation

Recommendations for future are:

- To study the material properties of JFRC with admixture.
- To investigate the numerical behavior of JFRC with flexural and shear reinforcement using ABAQUS or ANSYS.

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