CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Investigation of Jute Fiber Reinforced Concrete Having GFRP Rebars in Slabs Under Impact Loading

by

Muhammad Bilal

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Initially I would like to acknowledge Immense Allah who offered me a chance to commence this innovatory and then I would like to pledgee entirely of this tough toil to my loving household, who assist me through each hurdle and concern of my lifespan and forfeited all the eases of their survives for my upcoming accomplishments. I would like to prompt my genuine appreciation to my supervisor for his unceasing provision, endurance, inspiration and enormous knowledge. His precious remarks and recommendations during the research work have backed to the triumph of this study.

CERTIFICATE OF APPROVAL

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Abstract

Glass Fiber Reinforced Polymer Rebars (GFRP) are evolving substitute of steel rebars for civil works, due to its advanced characteristics like lightweight, rusts confrontation and tensile power. Jute is an economical natural fiber obtained from the bast or peel of the vegetables stem, having extraordinary tensile strength and is richly available in tropical regions. Jute fibers are utilized to increase the sturdiness, durability, shrinkage and crack proliferation in concrete. The inclusive determination of the study is to substitute steel rebars with GFRP rebars in Jute Fiber Reinforced Concrete (JFRC) slab to increase its strength under impact loading. In this research work, an exploration has been conceded to determine the behaviour of JFRC slabs having GFRP main rebars under impact loading. The distribution GFRP rebars also diverse to integrate the confining influence.

The mix design fraction 1:2:3:0.70 (Cement: Sand: Aggregate: w/c) of plain concrete (PC) and jute fiber reinforced concrete (JFRC) is used with the addition of 5% jute fibers by weight of cement, having 50 mm fiber length. The characteristics like splitting tensile strengths (STS), energies toughness indicies (ETI), compressive strengths (CS) and Flexural strengths (FS) are examined as per ASTM standards. The dynamic properties of the PC and JFRC samples are correspondingly examined. A total of twenty prototype specimens of PC and JFRC (reinforced with GFRP) ten each with a width of 225 mm, height of 75 mm and length of 450 mm are cast and tested under the impact loading.

The testing shown the substantial enhance in resistance under impact loading due to addition of jute fibers. The slump value of JFRC samples is 35% less than that of PC with similar mix design proportion. Density of JFRC samples is less than PC due to addition of low density jute fibers. PC and JFRC samples are tested in a servo-hydraulic testing machine (STM). Addition of jute fibers showed better resistance against crack propagation in concrete with GFRP rebars. In conclusion GFRP slabs having jute fibers showed better impact resistance than PC slab having no jute fibers. A comprehensive research program is required

to examine other features of jute fiber reinforced concrete such as toughness for marketable application in construction industry.

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Abbreviations

C.Em	Compressive Energy Absorption upto Maximum Load
Cr.E	Compressive Cracked Energy Absorption after Maximum Load
CTI	Compressive Toughness Index
FS	Flexural Strength
FEm	Flexural Energy Absorption upto Maximum Load
Feu	Flexural Energy Absoprtion from Maximum Load to Ultimate Load
FE	Flexural Total Energy Absorption
FTI	Flexure Toughness Index
$\mathbf{f}_l$	Longitudinal Frequency
$\mathbf{f}_t$	Transverse Frequency
$\mathbf{f}_r$	Torsional Frequency
GFRP	Glass Fiber Reinforced Polymer
Hz	Hertz
JF	Jute Fiber
JFRC	Jute Fiber Reinforced Concrete
kN	Kilo Newton
kJ	kilo-Joule
MPa	Mega Pascal
PC	Plain Concrete
s	Second
SEm	Split Energy Absorption upto Maximum Load
SEu	Split Energy Absoprtion from Maximum Load to Ultimate Load
STI	Split Toughness Index
STS	Splitting Tensile Strength

w/c Water-Cement

Symbols

Δf	Deflection under Flexure
Δi	Deflection under Impact
Δi70	Deflection under Impact Height of 70 cm
Δi100	Deflection under Impact Height of 100 cm
ξ	Damping ratio
δ	Strain

Chapter 1

Introduction

1.1 Background

The demand for the safety of structures against impact loading is a serious concern. The performance of slab under impact load is a part of exploration that was unstated so far; however, effort in this part remains to be encouraged by a comprehensive sort of applications. The concrete buildings considered to fight back fortuitous loading situations such as dropping rock effect; automobile or ship accidents with structures, bridges; and buildings that are utilized in extraordinary risk applications [1]. Failure of slab due to accidently drop of cellular tower installed on high rise buildings and sudden drop of partition walls is core area of alarm. Strength of buildings mainly depends on impact resistance of slab on which cellular tower are installed and partition walls are constructed. Falling of sliding rocks in hilly areas and wreckage movements are some common typical examples of impact loading which are often challenged by different constructions. Enriched IR and supreme energy absorption are the preferred stuffs in concrete. Altered approaches has stated by ACI to discover impact resistance of concrete and concrete grounded compounds in lab observing in vision of the significance of impact resistance. Between all the approaches, drop mass trial is the easy trial and can be utilized to produce impact load in lab to catch IR. Energy absorb to breach a sample, quantity of blows and extent of destruction are related to impact resistance. Act of concrete against impact loading can be computed in terms of thickness and propagation of cracks, degree of spalling, strain rate and deflections. Quantity of blows in drop load trial can also be utilized for comparative evaluation of impact resistance of samples [2]. To construct an intense consideration of the behaviour of the slabs under such loadings, it is vital to explore the outcome of energy dissipation. Throughout such a sudden load, structural safety relies primarily on its impact resistance. Impact resistance means concrete's ability to repel sudden load without cracking[3]. Natural fibers have been good to the environment (biodegradable). Jute fiber (being natural fiber) grown worldwide without any chemical (pesticides and chemical fertilizers not necessary) [4].The utilization of fiber in concrete had improved rapidly in the last decade because of their outstanding rust confrontation, high tensile strength, and virtuous properties. Illustrating fibber reinforced polymer in concrete creep and the quantity of cracks, and cracks width compare to steel models was supplementary important [5]. Dynamic loading is sometimes connected to the load of impact. Structures normally face extreme impact complex loading. For instance the effect and shock and explosion effects of car collisions, missiles or aircraft [6]. This is why impact efficiency and dynamic loads are important to find. The steel rebars have extraordinary density and weathering problems, thus, causing in a deprivation of concrete constructions. The fiber reinforced polymer rebar was prepared of extraordinary strength, vinyl ester resin strengthened fiber. In order to reduce corrosion problems, fiber reinforced polymer rebars as an alternate for steel bars have become genuine and reasonable. In current study, the behaviour of sample plain concrete (PC) and glass fiber reinforced polymer rebars (GFRP) slabs will be compared with the main and transverse reinforcement configuration. The fiber usage has increased quickly in the last few years in concrete structures 10 years because of their excellent resistance to corrosion, great tensile strength and outstanding non-magnetization. The analysis and number of cracks compared with steel samples was much more significant in the case of fiber refurbishment of reinforced polymer [7]. Scholars are utilizing fibers in mixtures due to their propensity of behaviour noteworthy stress and involvement in preserving concrete strength. To the finest of writers information, on the base of inadequate literature revision no study has been accompanied on GFRP having jute fiber in slab under impact loading.

1.2 Research Motivation and Problem Statement

The demand for building safety against heavy load (e.g. impact) is increasing with passage of time. This arises need of extra ordinary performance ingredients having greater mechanical stuffs. But frugality of constructions should not be bargained. Fibers that enrich the mechanical materials and affect strength of the concrete are used to achieve an economic efficiency without compromising the strength specifications. Fiber reinforced polymers (FRP) rebars have established one of the most likely and reasonable resolution to the rust complications of steel reinforcement in buildings. Fibers along with GFRP rebars are being utilized for enhancing the concretes confrontation to impact loading. Thus, to attain appropriate strength for the slab having GFRP rebar is to be examined in present study.
Thus, the problem statement is as follows:

"Structures having better resistance to severe dynamic/impact loading are of great concern. Concrete is main material used for construction but it is very weak in tension. Tension of concrete is controlled by providing steel reinforcements but it become little expensive. At the same time jute fibers are used to enhance the resistance against impact loading on concrete and convert crushing failure to bridging failure. Jute fiber reinforced concrete has enough load carrying capacity, compressive strength, flexural strength and splitting tensile strength. To obtain sufficient strength GFRP rebars can be an option to perform better resistance against severe dynamic/impact loading. Thus, to obtain sufficient strength of concrete slab surrounded GFRP rebars with JFRC is to be investigated in present study. And the overall behaviour of the slab is to be explored in depth."

1.2.1 Research Questions

- How mechanical behaviour of JFRC show better performance than PC?
- How dynamic properties of JFRC specimens have better performance than PC?
- How much impact resistance is improved when JFRC with GFRP rebars is used?
- How JFRC improved resistance to crack propagation and toughness?

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

The ultimate objective of the research is to replace steel rebars with FRP rebars with additional use of natural fibers for durability and performance in concrete structures.
However, the specific aim of this research is:

"*To replace steel reinforcement with GFRP rebars in slabs using Jute Fiber Reinforced Concrete under impact loading.*"

1.4 Scope of Work and Study Limitation

In this study work, an exploration has been studied to examine the behaviour of sample concrete members having variable number of GFRP rebars having jute fiber in slab application under impact loading. The horizontal confining steel reinforcement will also be changed to include the confining outcome. Three specimens were casted to find the mechanical properties of plain and jute fiber concrete, whereas the average values of two specimens for the behaviour of prototype as stated by Zia and Ali [8] and ASTM C39 [9].To examine the experimental behaviour of jute fibers having GFRP rebars in concrete slabs under impact loading. Compressive strength, flexural strength, energy absorption, toughness index and impact resistance are the intended properties to be determined. Prototype slab panel of size 450 mm x 225 mm x 75 mm will be tested for flexural strength and impact resistance.

This study focuses on relative comparison. This Ms study has an influence only the evaluation (fundamental frequency and damping ratios) of the basic dynamic characteristics, impact testing and fibre-breaking mechanism. Other aspects of this research work do not include co-relationship of impact mass and prototype mass, study of concrete cavities following casting, toughness of reinforced concrete. Bond strength investigation is outside the scope of this Ms thesis.

1.4.1 Rationale Behind Variable Selection

Due to high tensile strength, flexural strength and toughness jute fiber is used. To avoid segregation and to ensure appropriate mixing of concrete ingredients 0.7 W/C is used. By studying satisfying results explored by different researchers, the 1:2:3 and 5% of fiber by mass of cement is used in this research work. Rebars are used due to its corrosion resistance, high tensile strength, light weight and low maintenance cast.

1.5 Research Novelty, Research Significance and Practical Implementation

To the best of authors knowledge and on the basis of limited study, no research has been carried out by using of GFRP rebars with jute fiber in concrete slab to examine impact resistance yet.

To increase the impact resistance, to reduce crack propagation and to convert brittle to ductile behaviour of concrete.

There is a great concern in now-a-days to increase impact resistance due to falling of cellular towers on roof slab and land sliding in hilly areas.

There is a great concern in now-a-days to increase impact resistance due to falling of cellular towers on roof slab, land sliding in hilly areas, striking of missile on air craft shelter, falling of huge vertically cranes at construction site on slab and vehicle collision to traffic barrier.

1.6 Brief Methodology

In this experimental study, the mechanical properties of PC and JFRC is found in lab. The mix design ratio for plain concrete is 1:2:3:0.7 (cement: sand: aggregate: water). Jute fibers having length of 5 cm, with a fiber content of 5% by mass of cement are used for preparing JFRC. The mix design for JFRC is same as that of the PC. The standard specimens are cast and tested for determining the compressive, flexural and split tensile strength. Prototype slab panels of size 450 mm x 225 mm x 75 mm are cast and tested for flexural strength, energy absorption and impact resistance of PC and JFRC with GFRP rebars. Resonance frequencies of all cast samples are also be found separately.

1.7 Thesis Outline

There are five sections in this research work, which are defined as follows:

Chapter 1: thoroughly explained the introduction. It contains background, research motivation and problem statement, research questions, overall objective and specific aim of this MS thesis, scope of work and study limitations, rational behind variable selection, research novelty, research significance and practical application, brief methodology and thesis outline.

Chapter 2: describe the literature review. It contains background, Failure in slab, use of natural fibers in concrete (Jute Fiber), use of GFRP rebars with PC and JFRC (for horizontal members), testing technique and brief summary.

Chapter 3: explain the experimental technique. It consists of background, assortment of mix design for the recent study, raw materials, mix design, and casting procedure, specimens, mechanical properties, testing procedures, and summary.

Chapter 4: contains outcomes and exploration. It consists of background, impact resistance results frequencies and damping ratio, the behaviour of prototype slab specimens, bridging of jute fiber and summary.

Chapter 5: consist of a conclusion and future work.

After chapter 5, the bibliography is presented.

Chapter 2

Literature Review

2.1 Background

Durability and stability of concrete slab also depends upon the impact resistance of slab. The failure in slab can be reduced by improving the mechanical characteristics of concrete. The strength of concrete can be enhanced by accumulation of fibers in concrete. Dynamic and static loading of concrete can be enhanced by using natural fiber. Natural fibers are also inexpensive and atmosphere pleasant. Among other natural fibers, jute fiber is cultured profusely in South Asian countries. The utilization of JFRC with flexural and shear GFRP rebars gives virtuous outcomes in dropping disaster in concrete slabs. This section contains brief description on failure of concrete slabs, concrete having jute fibers with flexural and shear GFRP rebars, testing technique and brief summary.

2.2 Impact Resistance of Concrete

Because of the importance of impact resistance in concrete under impact loading researchers are exploring many methods to improve impact resistance of concrete. The load carrying capabilities had been severely reduced when subjected to such immense impact loading on slabs. It may be noted that a load that changes with respect to time in magnitude, direction and location is called dynamic load. The response to a dynamic loader will also vary with time. An impact load is a short-lasting dynamic load, such as dropping a rock onto a floor, resulting in potentially high acceleration depending on the rigidity. Altered techniques were approached by many researchers to measure the impact resistance of concrete because there are no formal manners for experimentally assessing the impact resistance of concrete. Two experimental technique to measure impact resistance of concrete. Firstly, dynamic testing is used in which load is functional at a rate of 70 mm/s. This extraordinary loading rate will entertain just like impact load. Secondly, drop-weight test is used. A weight of 9.5 kg is released on samples and quantity of blows were calculated untill damages occurs in samples. Reinforced concrete with steel fiber were observed by using both technique and enhancement in the impact resistance is establish as paralleled to PC [10]. Natural fibers performance under impact loading in concrete. The behavior of dynamic and impact loadings of jute fiber-reinforced connects (JFRC) are also studied. Flexible strength and impact-resistance is tested in plain concrete (PC) and JFRC slab panels with and without steel reinforcements. The impact resistance in the laboratory is tested with a simple drop weight test. For different specimens, the elastic dynamic modulation, resonance frequencies and damping ratios according to ASTM C215 are found. In comparison with the plain concrete, JFRC effect resistance is increased up to 6 times. Both, 68% and 100 percent respectively increase the dynamic elastic modulus and damping ratio. It is found that about 28% steel reinforcement in slabs can be decreased by utilization jute fibers [11].

Samples of CFRC under drops in impact load are the output of the coconut fiber reinforced concrete. Using the drop weight configuration, single and repeated impact experiments were carried out. The regular cylinder size 200 mm x 100 mm was evaluated on both PC and CFRC concrete cylinders. Numerous energy impacts were used to monitor the dropping height of the samples. The past impact power, the shift in the module of Young and the CFRC dynamic increment factor (DIF) have been analyzed. There was a similar fault model between PC and CFRC. The effects of the impact height on the supreme stress and the failure outline were analyzed during repeated impact tests. [12]. This impacts on the high zirconium alkaline resistant glass fiber reinforced full-scale concrete slabs with the dynamics outlook of the falling hammer check and macro-polypropylene and stainless-steel material. The effect of fiber form and fibre-mass parts on the impact resistance of concrete labs, the acceleration of the concrete slab and the time history of the assisted reaction force time curve were investigated and the dynamic test results and the way samples are studied. The complete investigation indicated that it has benefits in the utilization of the rusty situation [13]. Takes account of the effect on the dynamic performance of rebar material, the quantity and patterns of reinforcements, the strength of concrete and the thickness of the layer, using laboratory experiments and statistical modelling. The conduct of fifteen 1000 X 1000 mm concrete slabs with two 75 mm heavy single slabs , five 75 mm heavy steel reinforced concrete slabs, six 75 mm heavy reinforced concrete slabs with GFRP and two 100 mm heavy reinforced concrete sheets with fallen masses has been experimentally examined. Their use of heavy steel was examined. [14]. Bast fiber, Glass fiber, and Poly propylene fiber were applied to cement each at once for purposes of evaluating the effect of new, cured, auto compacting fiber reinforced concrete (SCFRC), in volume fractions of 0.15 percent, 0.20 percent, 0.25 percent and 0.30%. Tests were performed on disc, disks and notched prism samples for experimental study. In addition, on the hardened samples, properties such as compressive and bending strength, impact resistance, hardness, and energy fractures were examined. Results showed that the addition of Bast fiber, Glass fiber and Poly propylene all improved bending power, impact resistance and fracturing capacity [15].

Tests of waste aluminium from gassy drink waste can as fibers in concrete were investigated on their efficacy. The strengths, load-deflection behaviour with bending load, and lower-speed impact resistance have been studied. Two fiber longitudes have been tested for 40 mm and 20 mm with 0 % , 0.5%, 0.75% and 1%. The findings have shown that the compressive strength of the concrete with aluminium fibers in particular with 0.75% and 4-mm fiber was substantially enhanced by adding fiber while separating power, rupture modules and impact resistance. In determining splitting power and rupture modulus, the ACI equation depends on the compressive force. Yet fibers marginally affected compressive strength in contrast to tensile one, while the fiber reactive dividing and bending strengths were underestimated by the ACI equation. Load beam deflection with fibers showed a more ductility when the bending load was unsuitable. Bonds strength has been improved and aluminium fibers have been applied to the failure. Beams with aluminium fibers that were exposed to impact loads showed greater resistance, higher absorption of energy and less failure crack duration. In both fiber lengths, 0.75% fibers were the best number. The 40 mm fiber eventually boosted concrete resistance more effectively than 20 mm fiber duration [16]. The resistance to abrasion and effect of a variety of self-containing and vibrating concretes in the presence of salt scaling was tested before and after exposure to freezing or thawing periods. The research investigated the impact of additional cement content (Fly Ash (FA), SL, Silica Fume (SF) and MK, binders (250 kg / m3 and 500 kg / m3), gross scale (10 mm and 20 mm) and coarse to fine ratio (0.7 and 2) of the aggregates. In samples exposed to abrasion before freezing and thawing in comparison with non-abstracted specimens exposed to freezing and breaking, an average additional scaling damage of approximately 32.5 percent was reported The findings showed that the resistance of concrete to frosting and thawing and impact loading was decreased with the higher C / F aggregation ratio while the coarse aggregate size had not been modified [17]. Figure 2.1 shows the failures in slab due to impact loading.

Figure 2.1: Collapse of tower on slab.

2.3 Utilization of Natural Fibers in Concrete

The influence of many fibers for decreasing the cracks in canal lining. For shrinkage and flexure split tension, output was observed in reinforced concrete (JFRC), reinforced concrete in nylon fiber (NFRC) and reinforced concrete in polypropylene (PPFRC). Standard size specimens have been examined. Significant changes in the strength and energy absorption of reinforced jute fiber concrete are observed in comparison to plain concrete. Additionally, water absorption of JFRC was also enhanced by 8%. It was determined that cracks could be expressively decreased [8]. In hollow concrete, wallets and walls, sisal fiber is used. The ductility of the blocks increased by the fiber bridged the opening cracks and further discontinuity of the material was observed. Because of the low elastic modulus, which results in an effective absorption of energy after the concrete is broken, wallets can withstand an increase in load even after cracking[18].By adding of jute fiber up to 0.5% in concrete exposed contrary effect on characteristics of concrete. But additions of jute fiber up to 0.25% in concrete can impact positively on concrete strengthen characteristics. Using of jute fiber in concrete up to 0.5% show supreme enhance in flexural strength. Although slightest enhance in flexural strength was observed when 0.25% of jute fiber was utilized in concrete. When jute fiber was supplemented up to 1.00% there was decreased in flexural strength of concrete [19].

The possibility of sheep wool fibers (SWF) and modified sheep wool fibers (MSWF) in the production of fiber-reinforced concrete was investigated by assessing the mechanical and microstructural properties. Furthermore, four concrete mixes were made with 01.5 per cent modified wool sheep fibers with the same length. However, the addition of sheep wool fibers subsequently improved concrete's tensile and flexural strength values, thus improving concrete ductility with increased energy absorption capacity [20]. Mechanical properties including energy absorption and toughness indices of silica-fume plain concrete (S-PC) and silica-fume coconut fiber reinforced concrete (S-CFRC) are considered with the addition of different silica-fume content, i.e. 5 %, 10%, 15 % and 20%, cement mass. It is found that S-CFRC has generally improved mechanical properties with 15 percent SF content, than that of their respective S-PC [21]. The Dendrocalamus asper species bamboo was used to produce the fiber ratio, and the fiber to volume ratio was set at 2:5. The composite plate was manufactured using a hand lay-up method by binding bamboo fibers with epoxy. The BFCP's flexural and tensile strength was measured and all beams under a four-point bending test were tested to failure [22].

Explored the behaviour of jute fibers for concrete consolidation. Two diverse mix design 1:2:4 and 1:1.5:3 with the volumetric changes of jute fibers having variable length 10 - 25 mm were utilized. It was determined that the compressive strength, splitting tensile strength and flexural strength was improved expressively [23].Explored the mechanical characteristics of jute fiber reinforced cements based ingredients. Two sets are utilized to classify the jute fiber characteristics. The percentage of fibers was constant whereas fibers length was altered steadily 10-50mm length in the first group and in the second one the fibers length was constant whereas the proportion of fibers was altered steadily 0.5-0.6 kg-m- 3. It was determined that the fraction enhance of the compressive strength of several grade of jute fiber concrete is 20.44% and the fraction enhance of flexural strength is 53.47% [24]. The resistance of jute fiber reinforced concrete was investigated. For the preparation of jute-fibe with a length of 20 mm with different percentages of 0 %, 1%, 3 % and 5% by weight of mixture is incorporated. Conclusions showed that the resistance to fractures of reinforced jute fiber concrete improved by 45% relative to specimens of plain concrete. In addition, the fiber ratios were improved, but no substantial change in the fiber fibers ratio was shown at 5 % level. Factors such as flexure, strain, stress and fracture strength of the reinforced concrete jute fibers were higher than that of the plain concrete specimen [25]. To investigate the fatigue behaviour of the jute fiber reinforced concrete based on repeated load tests carried out on beams in four-point beam bending mode. A two-stage experimental programme was designed to achieve these objects in which three jute quantities are utilized percent, 0.1 percent, 0.25 percent and 0.45 percent to recognize the impact of fiber content on different parameters. All the fiber content improved

the efficiency of the concrete mixes by increasing the strength and crack resistance capacity of the concrete mixes. In particular, there were no fatigue cracks in the 0.25 percent strengthened specimens and the overall tensile strains were decreased by 30 percent during this period [26].
The check matrix composed of 5 mm jute fibers weighing 1% cement. It's been found that the bending strength and stiffness improved by 49% and 166

Table 2.1: Mechanical properties of JF by researchers

Fiber Content	**Mix Design Proportion**	**Length of Fibers** (mm)	**CS**	**STS**	**FS**	**Reference**
PC	-	-	100	100	100	-
JFC						[24]
0.6 kg/m^3	1:1.74:3.24	30	119	-	154	[24]
0.25%[a]	1:1.5:3	15	105	105	119	[23]
0.50%[a]	1:1.5:3	15	98	78	90	[23]
0.25%[a]	1:2:4	15	102	101	111	[23]
0.50%[a]	1:2:4	15	88	113	101	[23]

Note: [a]fiber content by volume fraction of concrete

In Table 2.1 experiments performed with different design ratios of 1:2:4 on mechanical properties of jute fibers with a 1:1.5:3 (cement: sand chips: sands) of different lengths of 10 mm and 15 20 mm and 25 mm 25 mm of jute fiber of different doses, respectively 0.1, 0.25, 0.50 and 0.75 percent by volume. Brief findings review revealed that the quality and size of the fiber had a major impact on specific effectiveness. For fiber length 15 mm with fiber content 0.10% and a design ratio of 1:2:4 is excellently compressive strength of concrete achieved. Compared to plain concrete, the peak compressive stress was 10 percent, with the same fiber length and 1:2:4 mixing material. For 15 mm of fiber length, flexure strength was increased by 22 percent, with a fiber content of 0.10 percent and a design ratio of 1:1.5:3, and for 1:2:4 the design ratio was improved to 14 percent for the same fiber fiber length [23].

2.4 Utilization of Fiber Reinforced Polymer Rebars in Concrete

FRP rebars as a substitute for steel rebars have appeared as a genuine and inexpensive resolution to overwhelm the corrosion problems. The fiber reinforced polymer has plentiful favourites over conservative steel bars, counting a density of one quarter to one fifth that of steel, superior tensile strength than steel rebars, and no corrosion in harsh circumstances. The GFRP rebars are a comparatively new developing technique to enhance the flexural capacities of existing RC elements. Flexural strengthening of reinforced concrete girder by using GFRP is effective [28]. The glass fiber reinforced polymers (GFRP) rebars have developed one of the most likely and inexpensive solution to the corrosion problems of steel reinforcement in structural concrete [29]. The GFRP reinforced concrete beams failure either by concrete devastating at the thick region or divided of the GFRP reinforcement. The decisive load carrying ability of concrete beam can be enhanced by utilization GFRP reinforcement. GFRP rebar are non-rusty in nature and worthy substitute of steel rebars. plenty of cracks were greater in beam strengthened with GFRP rebars when related with conservative beam. Also cracks arrangement in beam reinforced with GFRP rebars were bigger when related to the control beam [30].

A finite element modelling approach was used to study the strengthening of RC columns with the combined use of NSM rebars and FRP jackets. Following validation of the numerical models with the existing experimental data, a comprehensive parametric study was carried out to determine the effect of axial load, implement FRP confinement around the base or over the entire height of the column [31]. Reviews current research on retrofitted concrete members of the NSM FRP system and exposed to monotonous and fatigue loading. It provides an outline of FRP composites and the fatigue behaviour of concrete materials, steel, and FRP. The review also focuses on the bonding characteristics between NSM FRP, adhesive and concrete substrate, and the flexure behaviour of NSM FRP-enhanced and repaired substrate [32]. Preparation of concrete samples (unreinforced concrete, smooth GFRP reinforced concrete, sand-coated GFRP reinforced concrete and reinforced steel concrete) with a fixed ingredient ratio (1:1.5:3) and 0.5 W / C at two healing ages (7 and 28) days in ambient conditions [33].

The flexural performance of partly steel fiber reinforced concrete with fiber reinforced polymer rebars. A entire of twelve beam samples are experienced under four point bending load. Various fractions of steel fibers were utilized in the tension zone of the beam. It was stated that the steel fibers have been effectively extended in the tension zone and have reserved care of overwhelming great bending and separating width FRP rebar reinforced beams. Ductility reduced with the enhancing depth of layer FRHSC and partition of the steel fiber capacity in FRHSC bars imposed in part with FRP bars. Including steel fibers in the complete deepness of the constructions with extraordinary ductility necessities is crucial [34]. The flexural strength and serviceability behaviour of geo polymer concrete beams having glass fiber reinforced polymer (GFRP) rebars under four-point bending test. It was determined that, grounded on experimental consequences, the performance of a beam was enhanced when the reinforcement ratio of glass fiber augmented [35]. The application of fiber reinforced polymer rebars in reinforced concrete member enhance deterioration conflict when we compare it to the common steel reinforcement bars [36].Beam was tested only with longitudinal reinforcements under drop-weight load. It was observed that SFRC beams failed due to flexural as compared to PC beams which failed due to shear [37].

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 properties of FRP product [38]. The use of JFRC with steel rebars to check reduction in reinforcement under impact loading [11]. The dynamic behaviour of concrete reinforced with carbon nanotubes (CNT). The results indicated that less damaged areas were generated in the CNT-reinforced concrete model [39]. Explore the performance of reinforced concrete columns reinforced with fibers reinforced polymer with diverse reinforcement kinds and proportions. An overall of 20 concrete samples having width of 350mm, length of 350 mm and a height of 1400mm were cast and tested under axial load. Glass fiber reinforced polymer rebars, Carbon fiber reinforced polymer rebars and Steel rebars are utilized as a longitudinal and transverse reinforcement. The consequences exposed that fiber reinforced polymer rebars subsidize to the concrete columns exposed to axial load as a longitudinal reinforcement and that the mixture of fiber reinforced polymer cross-reinforcement and longitudinal steel bars delivers sufficient forte and serviceability of the concrete [40]. The mechanical properties of GFRP rebar by different researchers are given in table 2.2.

Table 2.2: Mechanical properties of GFRP rebars by researchers

Reference	Diameter (mm)	Length (mm)	^{f}uT (MPa)	^{E}ft (GPa)	^{F}uC /^{f}uT	^{E}fc/^{E}ft
[41]	19.1	-	729	44	0.38	0.91
[42]	16	32	629	38.7	1.24	1.06
[43]	10	6.25	1103	92.4	0.62	0.65

f_{ut} = Maximum tensile strength of GFRP rebars,
E_{ft} = Elastic modulus of GFRP rebars,
F_{uC} /f_{Ut} = compressive strength to tensile-strength ratio of GFRP rebars,
E_{fc}/E_{ft} = compressive elastic modulus to tensile elastic modulus ratio of GFRP rebar.

Significant research fields in the field of FRP materials and FRP structural components that are important for better understanding of their behaviour. The paper describes the types of composite materials produced from the FRP and the most useful manner in the use of civil engineering composites. The material has excellent mechanical and essential service properties that are used to enhance stability, strength, reliability, life-cycle cost benefits and the effect on the environment when combined with other materials. The paper ends with the summary of main findings of the advanced civil infrastructure polymer composite. The more common use of FRP bars as substitution of steel bars is their low cost, such as the GFRP rebars. GFRP rebars in harsh conditions are not corrosive, environmentally friendly and non-hazardous [45].

2.5 Impact Loading Techniques

The analysis shows that natural fibers can be used to increase the resistance to impacts of concrete. Many of the investigators did a lot of work with artificial fibers. Artificial fibers are usually costly as related to natural fibers. Natural fibers are atmospheric sociable. For all natural fibers, the impact resistance was based on only fibers for coconut in concrete and jute fibers in mortar. There is still an inquiry into the efficiency of jute fibers in concrete under impact load. The construction of steel rebars was not suggested so far by taking into account impact load and the tension zone FRC. Impact actions and complex loads are important for determination The steel rebars have extraordinary density and erosion problems, thus, causing in a deprivation of concrete constructions. In order to reduce erosion problems, FRP rebar as an alternate for steel bars have become genuine and reasonable. In order to accurately determine the impact resistance of structures, failure analyzes of reinforced concrete slabs at impact load are essential; in addition, these studies help to objectively design and build engineering structures. In this text, we propose the latest three-dimensional (3D) method of simulating projectile penetration in reinforced concrete plates, coupled with Eulerian and Lagrangian methods. The entire computational field is covered by Eulerian cells in this process. In order to prevent numerical oscillation, the arming bar is often filled with Lagrangian particles. Through their topological relationships, the physical quantities of the Eulerian and the Lagrangian particles are mapped Compared with the corresponding experior data and the previous numerical tests, numerical simulations of the projectile penetration in the concrete slab test the impact of the combined Eulerio-Lagrangian process. Therefore, the history of the deflecting bar and the effect on the penetration efficiency are determined by the initial penetration speed, strengthening bar and the uniaxial compression strength and thickness of the concrete. Numeric tests indicate that the 3D Eulerian-Lagrangian process simulates projectile penetration in the reinforced concrete plate effectively [45].

Preparation of concrete samples (unreinforced concrete, smooth GFRP reinforced concrete, sand-coated GFRP reinforced concrete and reinforced steel concrete) with a fixed ingredient ratio (1:1.5:3) and 0.5 W / C at two healing ages (7 and 28) days in ambient conditions [40]. Molds used to manufacture the composite cores were made using a polylactic acid (PLA) 3D printing technique. Experiments were conducted on the basis of Taguchi design (L9) to determine the effect of each factor on the ultimate compression stress, deformation and absorption energy. The volume of compressive stress varied between 25.32 and 36.38 MPa.[46]. Impact resisting of structures, particularly in the mountainous areas because of the significant risk of falling rocks, has become an important part of construction projects. Such environmental changes, including deforestation and land life modifications, increased the danger to civilian structures and posed a grave threat to infrastructure and human life. Many researchers have studied the effect of the impact of falling rocks on reinforced concrete (RC) plates, although very few studies the effect of impact loading on pre-stressed structures. The aim of this analysis is therefore to investigate the actions of PT slabs under impact charges. A comparison with a conventional (RC) plate with the same capability at this time was made. The RC sheets were a flat sheet, 320 mm thick, while the two other sheets were PT and 250 mm thick. There was an effect of 605 Kg fell from 20 m free of charge at the plates. The load for the RC and PT1 plates was decreased in the center of gravity. On the other side, the load dropped on the second post-tensioning plate PT2 at a middle of the free edge. The tests showed the conduct of the PT plate under dynamic impact load because of its free drop block and its different action compared to the RC plate with the changes, impact strength, cracks and damage type [47]. Walls are typically found in residential buildings with reinforced concrete walls. It is important to investigate the effect of energy

dissipation on the equivalent impact force, medium-term destructive duration and damage pattern to gain a detailed understanding of the structural behavior of the slabs under such load. This research takes account of a sample reinforced concrete plate measuring 500 x 1000 x 100 mm. The goal of this paper is to find out how these variables differ as energy is increased as the drop load equivalent to real rock dropping drops between 0.6 m and 1 m in different heights freely [48]. Impact loading techniques and their results are shown in Table 2.3.

Table 2.3: Properties of different impact loads used by different researchers

Setup Type	**Impact Height**	**Impact Weight**	**Samples Size (mm)**	**Results**	**Reference**
Instrumented Drop-weight	10cm	9.5 kg	700x300x50	Strength (blows)	[10]
Instrumented Drop-weight	1.75 m	200 kg	125x250x2000 (Beam)	Strength (kN) and energy absorption (kN.m)	[37]
Instrumented Drop-weight	40cm	40 kg	200x100 mm (Cylinder)	Force (kN) and strain	[12]
Instrumented Drop-weight	3.26 m	150-300 kg	1800x130x130 (Slab)	Displacement (mm) and reaction(kN)	[1]

2.6 Summary

From the study of literature review, it is obvious that the natural fiber specifically jute fiber can be utilized to enhance the mechanical characteristics and impact resistance of concrete. Jute fibers have countless properties like enhance tensile strength, inexpensive, and abundantly found in delta areas. Jute fibers have optimistic influences to strengthen the properties of concrete. Glass fiber reinforced polymer rebars are more fruitful as compared to steel reinforcement with a substance to their characteristics like small density, greater tensile strength than conventional steel rebars, and no corrosion even in severe weathering conditions.

To the best of author knowledge on the root of partial reviews of the literature, no research has been showed on JFRCs fitness with GFRP rebars for utilization in slab under impact loading so far. In this research, twenty prototype slab having various longitudinal and transvers GFRP rebars, with different arrangement were casted and trailed.

Chapter 3

Experimental Program

3.1 Background

Utilization of natural fibers for enhancing the impact resistance under impact loading and mechanical characteristics of jute fiber concrete with glass fiber reinforced polymer rebars increasing now-a-days. Enhancement in mechanical characteristics, impact resistance, and energy absorption are the chief takings of fiber reinforced concrete. Behaviour of jute fiber for increasing the resistance with GFRP rebars is revealed in this research work. This chapter exhibits the variety of mix design, raw ingredients, casting methods samples and testing techniques.

3.2 Raw Material

The ingredients utilized in this study for arranging of PC and JFRC are ordinary cement, sand, coarse aggregate, water, jute fibers and GFRP rebars. The cement is ordinary Portland cement which is accessible nearby, well-intentioned class of sand is utilized as fine aggregate which is obtained from Lawerence-pur (Attock). Crushed stone is gathered from the Margallah hills and drinking water is obtained from university. The same material is used in the preparation of JFRC by adding Jute Fibers (JF).50 mm long jute fiber of 0.5 mm diameter is used. JF are cut by hand to achieve the wanted length of 50 mm.The jute fiber stayed privileged water tank for around twelve hours. After twelve hours the jute fiber is bring out of water and air dried in room temperature. The jute fiber for making PC and JFRC are shown below in Figure 3.1.

Table 3.1: Mechanical properties of GFRP rebar

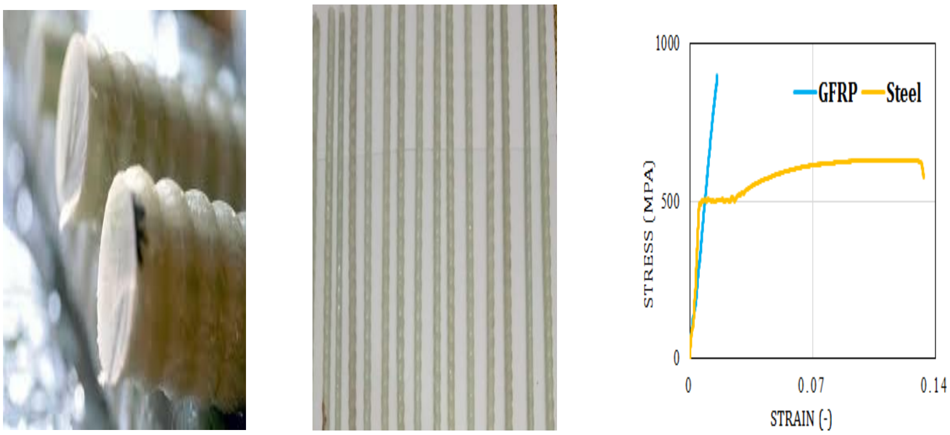
Properties	**Values**
Diameter	6 mm
Cross Section Area	28.27 mm
Density	2200 kg/m^3
Weight	0.051 kg/m
Ultimate Tensile Load	28.34 kN
Tensile Strength	>600MPa
Ultimate Shear Strength	>110MPa
Elastic Modulus E	>46GPa
Ultimate Tensile Strain ε	>1.9%

(a) (b)

Figure 3.1: Jute Fiber a) Raw jute fiber b) Prepared jute fiber

GFRP rebars are comparatively new developing method to increase the flexural abilities of current structural components. Flexural strength of reinforced concrete girder was increased by utilizing GFRP is beneficial [49]. Corrosion is the predominant issue related to steel reinforcement rebars in humid environments these days. To avoid this issue, in humid conditions, GFRP rebars are a good replacement of steel rebars in concrete structures as these are corrosion-free and display great strength. Likewise, concrete toughness can be strengthened by adding jute fibres.

For this reason, in this research, jute fibres with GFRP rebars in slab are used to boost the overall structural efficiency, Better corrosion resistance, enhanced durability and increased resistance against crack propagation The GFRP rebars utilized in this study work are imported from China. The length of longitudinal reinforcement GFRP rebars used in PC and JFRC slabs is 400 mm and diameter are 6 mm. GFRP have numerous mechanical characteristics such as high tensile strength, corrosion proof and light in weight. It can be noted that Figure 3.2(c) that the curve of GFRP rebar do not show yielding stress point which shows its brittle behaviour. Mechanical properties of GFRP rebars are given below in Table 3.1.



(a) (b) (c)

FIGURE 3.2: GFRP a) Cross section b) Prepared rebars c) Stress Strain relationship b/w GFRP and Steel rebar

3.3 Preparation of Concrete

3.3.1 Mix Design Ratio

Different researchers had used different mix design i.e., Khan and Ali [57] used 1:1.33:3.67 , Zia and Ali [8] used 1:3:1.5 , Hussain and Ali [11] used 1:3:2 and Ejaz and Ali [50] used 1:2:3.Among these mix design of 1:2:3 was better in terms of mechanical properties ,impact resistance and dynamic properties. Therefore, in current study, for these aspects, mix design of 1:2:3 is used. For both PC and

JFRC the same mix design is used with 0.7 W/C. All the dry ingredients are placed into the concrete drum mixer to prepare PC mix and water is added at the end. The mixer was revolved for seven minutes continuously. Firstly, JF are kept in water for one day. After that JF are placed in open air for half hour before placing it in drum mixer. Coarse aggregate and fine aggregate are placed in the concrete drum mixer coating by coating to avoid from balling effect. 33.3 percentage of coarse aggregate and fine aggregate are placed into the drum mixer. For making of JFRC 5% of JF by weight of cement is also used.

3.3.2 Casting Methodology

When all the ingredients are distributed into the mixer, the same cycle was repeated. Almost a third of the water is put on all products after a thorough spread of the ingredients into the drum mixer. Drum mixer rotates and water spreads indefinitely. Over seven minutes the drum mixer is switched to also generate concrete. The jute fiber reinforced concrete at this point is Very difficult to be utilized. After that again the drum mixer is rotated for few times to obtain improved and consistent combination. At this stage movement from jute fiber reinforced concrete can occur as consequence of adding of additional water. Before casting of specimens, the PC and JFRC slump are collected. Compared to JFRC, the device has a higher slump due to the increased JF water absorption ability. Jute fibers consume relatively less water because of the soaking. Compared to PC, JFRC 's downward decline is reduced by 48%. Slump amount for plain concrete is 65 mm while for Jute fiber reinforced concrete is 44 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. Moulds are filled with three layers of concrete and tapped per coat twenty-five times with tapping rod. Similar method is to manufacture flat concrete fiber and jute fiber reinforced concrete. After 48 hours samples were remoulded and positioned into water chamber at least for 28 days to obtain maximum strength. Earlier to testing, densities of plain concrete and jute fiber reinforced concrete are obtained by dividing the masses of samples by their respective volumes. A reduction in the JFRCs density is witnessed.

3.3.3 Slump and Density of Specimens

The slump and density of plain concrete and jute fiber reinforced concrete are shown in table 3.2. The slump of JFRC is less that of plain concrete due to addition of 5%of fibers. Because jute fibers have ability to absorb more water. The slump of PC is 19 mm more than JFRC having w/c 0.7 for both .The density of PC is 2517 kg/m3 and for JFRC is 2444 kg/m3.The reduction percentage in JFRC density is 3%.

(a) (b)

FIGURE 3.3: Slump test a) For PC b) For JFRC.

TABLE 3.2: Slump, Density and W/C ratio of PC and JFRC

Description	W/C ratio	Slump (mm)	Density (kg/m^3)
Plain Concrete	0.7	65	2517
Jute Fiber Reinforced Concrete	0.7	44	2444

3.3.4 Properties of JFRC and PC

Stress-strain curves and compressive strength are deliberated for each plain concrete and jute fiber reinforced concrete samples are given in Figure 3.5(a). In Figure 3.5(a) compressive performance of plain concrete and jute fiber reinforced samples at left direction while crack pattern of samples is given in the right direction. The cracking propagation was illustrated at three separate stage of loading. The cracks established on the external faces at the three separate level of loading were relatively supplementary noticeable in situation of plain concrete samples as paralleled to jute fiber reinforced concrete samples. This illustrates the efficiency of accumulating jute fibers to govern and bound the expansion and circulation of cracking occurrence in concrete. Compressive strength is taken as the great stress from the stress-strain curve. The energy absorption capability, explicitly the energy absorption per unit volume of concrete stuff, was explained by the area below the stress strain curve and specified in units of MJ/m3 as stated by [51, 52]. Energy absorption in compression is found by the area under the stress-strain curve up to the extreme load. The area under the stress-strain curve from extreme load to the ultimate load is occupied as the cracking energy absorption in compression. Overall energy absorption in compression (TE) is found by the area under the stress-strain curve from early to final stress. Toughness index in compression (TI) is the proportion of whole energy absorbs in compression to the energy absorbs in compression up to peak stress (TE / Em). Table 3.3 shows the compressive strength, the energy consumed by compression, the total energy absorption in compression and the toughness index of plain concrete and jute fiber reinforced concrete with a mixing design ratio of 1:2:3:0.7. The samples are formerly verified in STM machine to examine compressive, splitting tensile and flexural strengths as per ASTM standards C39 [8], C496 [53], C78 [54] utilizing the typical of ranges specified for loading rates.

The Splitting tensile load-time curves for plain concrete and jute fiber reinforced concrete are given in Figure 3.5 (b). Figure 3.5 (b) shows the performance of samples and growths of flaws throughout the test. At completion of the extreme load of plain concrete, initial crack is established and samples are split into dual parts within no time. Though, in situation of jute fiber reinforced concrete, initial crack is observed at 90% at the peak loading. Cracking is minute in width and length in jute fiber reinforced concrete, and the samples have never been broken. Crack quantity and size increase for reinforced concrete at peak loading. Now the length of the crack reaches 70 mm. At high loading, however, tests of reinforced concrete with jute fiber only increased in cracks, but remained uninterrupted. The crack length is now as much as 85 mm. Since jute fiber is bound together, the superior action of jute fiber reinforced concrete is significant. Jute fiber reinforced concrete samples are purposely cracked to identify the fibers propagation. The breakup and stretching of the fiber is 75:35 propagation. During their further separation, the little tensile force of the jute fibers, but further binding strength stopped them from being pulled. Table 3.3 indicates the splitting strength of the tensile (f), the absorption potential for energy and the strength of plain cement and reinforced jute fibre. The high splitting tensile strength associated with PC is observed for JFRC samples JFRC samples have 0.35 MPa higher splitting tensile strength than PC. This is due to the bounding influence of jute fiber. Stiffness of jute fiber reinforced is enhanced up to 0.3 only as related to PC.

Evaluation of splitting tensile strength, energy immersion, and stiffnesss of plain concrete and jute fiber reinforced concrete is given in Figure 3.4 (b). The splitting tensile strength, Em, Cr. E, TE, and TI of JFC specimen are increased by 0.35 MPa, 7.5 J, 28.1 J, 30.6 J and 0.77 respectively as related to PC specimen. Comparison of mechanical properties is shown in Figure 3.5 (b). In which all properties of PC and JFRC specimens are compared in percentage. Load-displacement curves, flexural strength are measured for entirely PC and JFRC samples which are given in Figure 3.5(c). In Figure 3.5(c) flexural performance of PC and JFRC samples at left direction while crack pattern of samples is seen at the right direction. The cracking configuration was renowned at three separate stages of load. In situation of PC samples the cracks were witnessed to progress at first level of loading. Though, the JFRC samples revealed minute cracking at first stage of loading. As the loading was enhanced to greater stages, the crack pattern was prominent in situation of PC samples when related to crack configuration established on the external layer of JFRC samples. This illustrates the influence of accumulation of jute fibers to govern and bound the expansion and pattern of cracking occurrence in concrete. Flexural strength is measured as the great load from the load-displacement curve. Energy absorption in flexure (Em) is calculated as the portion under the load-displacement curve up to the extreme load. The region under the load-displacement curve from extreme load to the critical load is considered as the cracked energy absorption in flexure (Cr.E). Total energy absorption in flexure (TE) is calculated as the region under the load-displacement curve from first to ultimate load. Toughness index in flexure (TI) is the proportion of whole energy absorption in flexure to the energy absorption in flexural to peak load (i.e. TE / Em The flexural strength, Em, Cr. E, TE, and TI of JFRC

Table 3.3: Compressive, flexural and splitting-tensile properties of PC and JFRC specimens with MD ratio of 1:2:3:0.7

Intended Properties	**Compressive**		**Splitting-tensile**		**Flexural**	
	PC	**JFRC**	**PC**	**JFRC**	**PC**	**JFRC**
P (kN))	170	145	77	84	7.87	8.35
Strength	22	19.21	2.15	2.50	5.20	5.80
Em	0.10	0.13	22.80	30.1	4.31	4.90
Cr E	0.09	0.28	0	28.1	0	9.32
TE	0.16	0.29	22.80	53.4	4.31	12.97
TTI	1.6	2.23	1	1.77	1	2.64

Note: 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.

samples are enhanced by 0.6 MPa, 0.59 J, 9.32 J, 8.66 J and 1.64 correspondingly as linked to PC sample. Evaluation of mechanical characteristics is given in Figure

3.5 (c). All characteristics of PC and JFRC samples are related in percentage. The flexure strength of JFRC is enhanced by 11% as linked to the PC. In assessment with PC, the supreme energy at extreme load and whole energy absorption of the JFRC sample is enhanced by 13% and 200% correspondingly. The total index of stiffness has also been enhanced up to 164% as linked to PC. Unlike the outcomes of compressive test, the flexural test revealed an enhance in all the numerous characteristics including strength, energy absorption capability and total stiffness index of JFRC sample when related with PC samples). The flexural strength, Em, Cr.E, TE, and TI of PC and JFC with mix design ratio of 1:2:3 are given in Table 3.3.

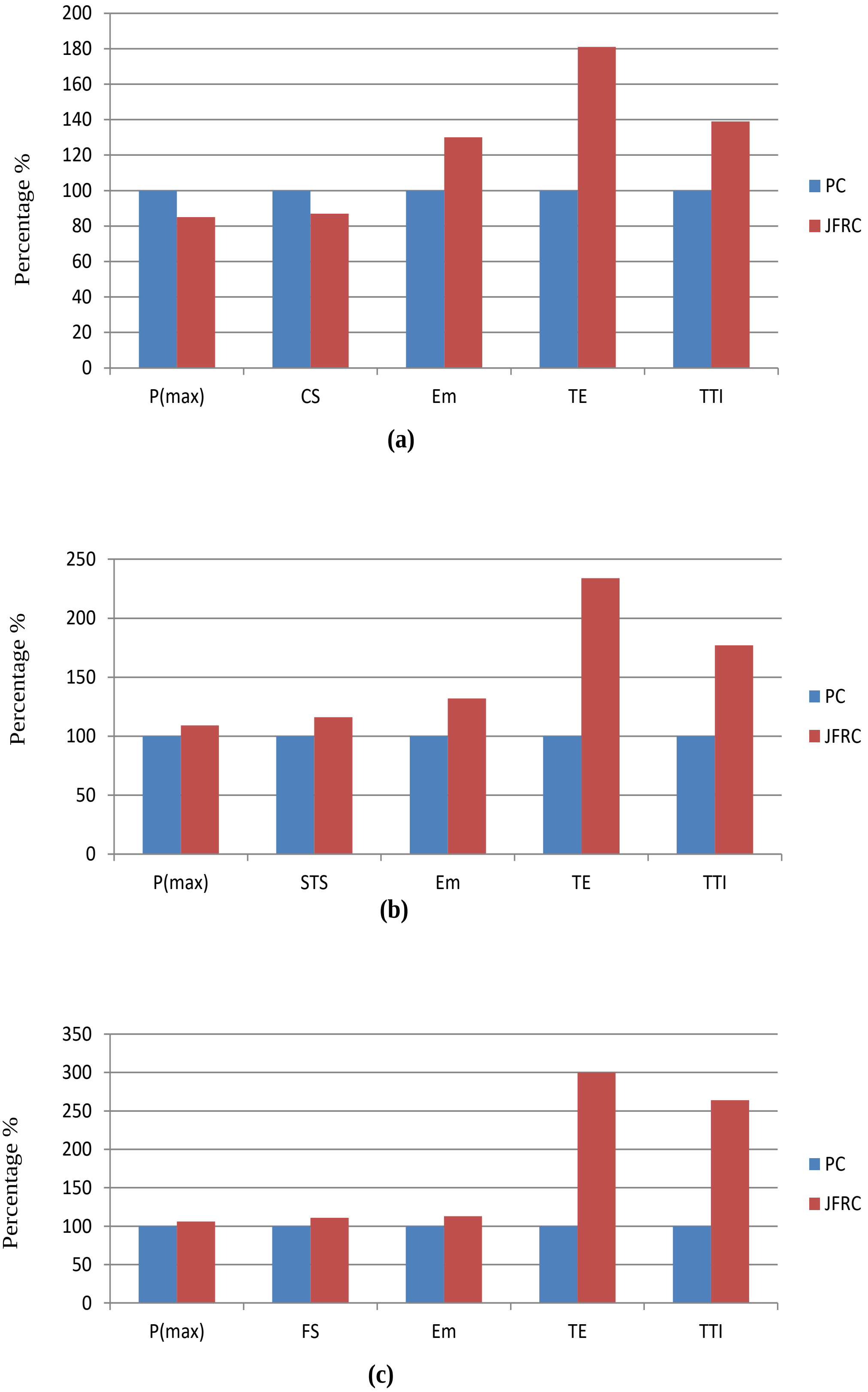


FIGURE 3.4: Comparison of mechanical properties of PC and JFRC a) Compressive Strength, b) Split-Tensile Strength, and c) Flexural Strength

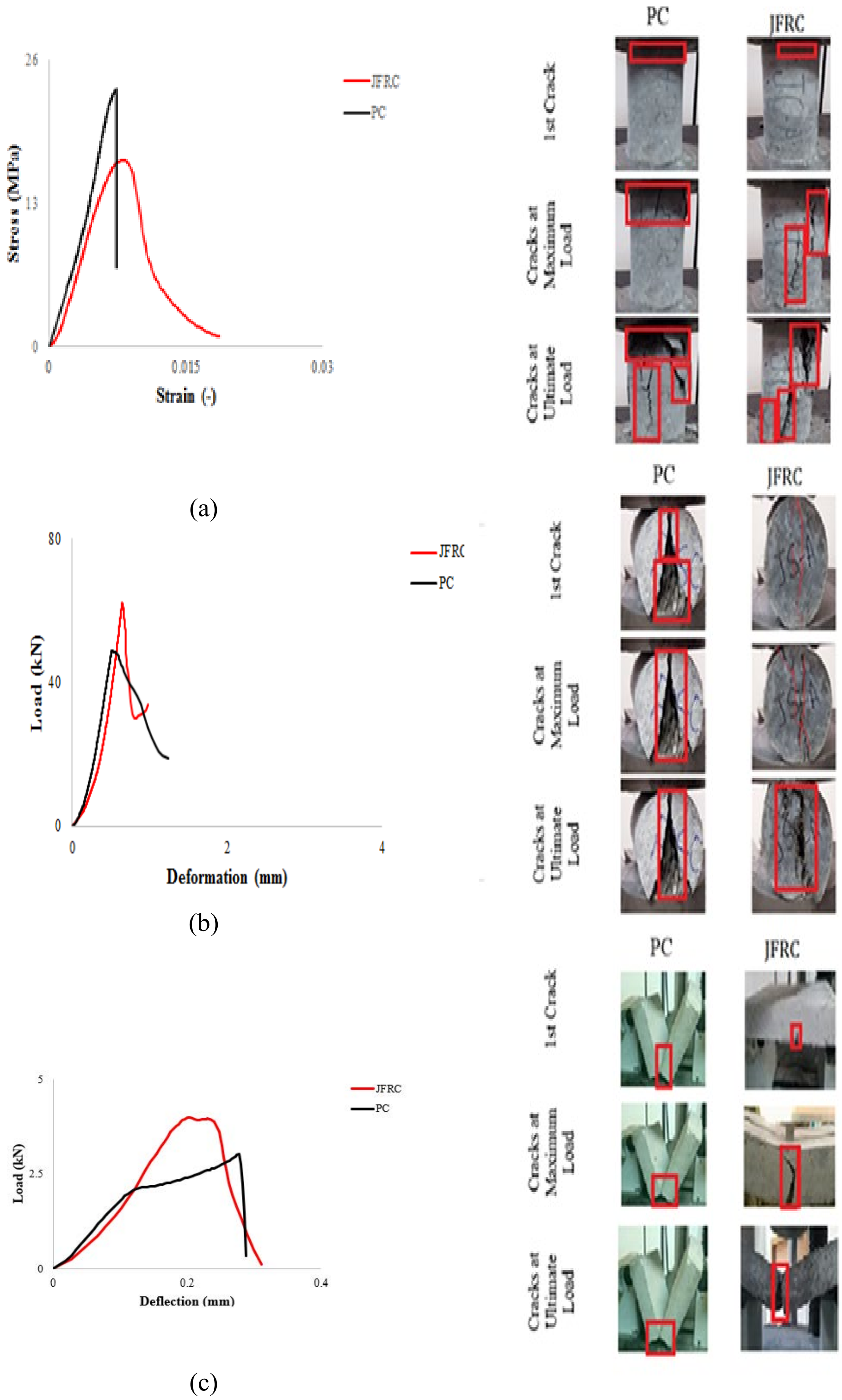


FIGURE 3.5: Mechanical behavior (left) and Crack propagation (right); a) Compressive Strength, b) Split-Tensile Strength, and c) Flexural Strength

3.4 Labelling Scheme of Specimens

The details of specimens are shown in Table 3.4.

Table 3.4: Detail of specimens prepared.

PC (1:2:3,w/c 0.70)		**JFRC** (1:2:3,w/c 0.70 ,50mm fiber length,5% of fiber by mass of cement		**Properties determined**
P1	**P2**	**J1**	**J2**	▪ Compressive strength and strain ▪ CE_m, CTE, CT
P3	**P4**	**J3**	**J4**	▪ Split tensile strength ▪ SE_m, STE, ST
PX	**PY**	**JX**	**JY**	▪ Flexure strength ▪ FE_m, FTE, FT ▪ Load–deflection curve
Impact height 70cm	Impact height 100cm	Impact height 70cm	Impact height 100cm	Behavior of prototype (450mm x 225mm x 75mm) ▪ Impact first crack strength ▪ Impact ultimate strength ▪ Deflection ▪ Cracking behavior
3P76X ø2-76mm 3-ø2	**3P76Y** ø2-76mm 3-ø2	**3J76X** ø2-76mm 3-ø2	**3J76Y** ø2-76mm 3-ø2	
3P64X ø2-64mm 3-ø2	**3P64Y** ø2-64mm 3-ø2	**3J64X** ø2-64mm 3-ø2	**3J64Y** ø2-64mm 3-ø2	
4P76X ø2-76mm 4-ø2	**4P76Y** ø2-76mm 4-ø2	**4J76X** ø2-76mm 4-ø2	**4J76Y** ø2-76mm 4-ø2	
4P64X ø2-64mm 4-ø2	**4P64Y** ø2-64mm 4-ø2	**4J64X** ø2-64mm 4-ø2	**4J64Y** ø2-64mm 4-ø2	

The 450 mm x 225 mm x 75 mm slab prototype is constructed from plain concrete and reinforced fiber concrete with GFRP rebars for flexure and impact assessment. For flexure strength checks, a group of four prototypes is built for the PC and JFRC community. Three versions out of four have plain cement and three others have reinforced jute fibre. Eight prototypes for each impact height of 70 and 100 cm, and PC and JFRC party, are likewise made for impact testing. The compressive and split tensile test from the group PC and JFRC involves four cylinders with a diameter of 10 cm and a height of 20 cm. A total of 20 slabs and 8 cylinders are prepared. In both plain concrete and jute fiber reinforced concrete, GFRP rebars are used instead of steel rebars as main and distribution rebars. The main specimens are PC with GFRP rebars and JFRC with GFRP rebars with different reinforcement configuration to study the behaviour of reinforced concrete. For PC and JFRC distribution reinforcement GFRP rebars of 2 having 64 mm and 76 mm spacing are used. For PC and JFRC main reinforcement, three and four GFRP rebars are used. Impact height of 70 cm and 100 cm are used for each prototype having different configuration. Notation X is used for impact height of 70 cm and Y is used for impact height of 100cm. Notion P is used for plain concrete, J is used for jute fiber reinforced concrete.. An average of two readings is used for chief mechanical characteristics (compression, flexure, and split-tension).

3.5 Testing Procedures

.Impact resistance, frequencies of resonance, dynamic Elastic module, damping ratio and fibres failure in tested slabs are found in this research program.

3.5.1 Impact Resistance Testing

Falling of cellular towers on slab, sudden drop of sliding rock on roof slab in hilly areas, striking of missile on air craft shelter and falling of huge vertically cranes at construction site are typical examples of impact loading. All these indicating a

particular impact at a particular point in a slab. This can be replicated in lab by using drop weight mechanism. Drop-weight can be used to generate impact load in laboratory to find impact resistance according to ACI 544.2R-89 [8]. In laboratory the drop weight mechanism is used to measure specimens impact resistance. A simple configuration is designed in the laboratory containing pulley system, a support for slab prototype and impact weight.
Schematic diagram and for test setup are shown in Figure 3.6.

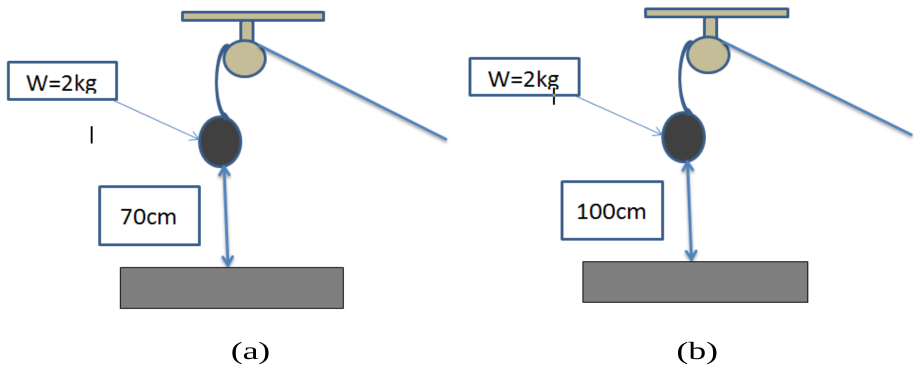


Figure 3.6: Schematic diagram a) Impact height of 70 cm b) Impact height of 100 cm for impact test setup

Hussain and Ali [11] used same concept with 1.5 kg drop weight to find impact resistance of prototype slabs under impact loading. JFRC was used with steel rebars to investigate the reduction of reinforcement in slab under impact loading. This Ms work is continuation of their research from their future recommendation was to increase drop weight. Therefore, 2 kg drop weight is used in this carried work to find the impact resistance in prototype slabs under the impact loading using JFRC with GFRP rebars. The weight of 2 kg of impact is released from different rates and pattern of cracks is seen. In this test setup 70 cm and 100 cm impact heights are used. Blow volume, release weight and damage are observed at first break. Sample failure is assessed when an entire crack is identified in the sample portion. Deflection is also discovered during damage.

3.5.2 Testing for Dynamic Properties

All cast samples have resonance frequencies as per ASTM standard C215 [55]. Until processing, resonance frequencies of all samples are sought. The resonance frequency is measured after examination of all unbroken samples. The system of impact resonance describes complex elastic modulus, damping ratio, longitudinal, transverse and rotating frequencies.

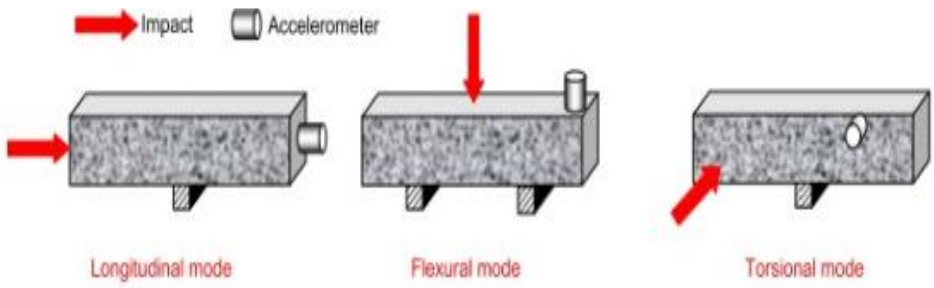


FIGURE 3.7: Schematic setup for dynamic properties

3.5.3 Fiber Failure in Tested Slab

The broken surface is further investigated at the micro level of the tested specimens using pictures to help. Pictures of tested specimens are taken JFRC slab tests effect. The goal is to recognize the mechanism for failure and the binding of concrete ingredients with fibres.

3.6 Summary

The mix design proportion of cement, sand and aggregate for plain concrete and jute fiber reinforced concrete are 1:2:3.The water cement ratio is kept 0.7 for PC and JFRC. 5% of jute fiber by weight of cement is supplementary to make JFRC specimens. The length of jute fiber utilized in this research is 50 mm. GFRP rebars having 6 mm are utilized in samples to make PC and JFRC slabs samples to investigate impact behaviour. A overall of 28 specimens are casted. As per ASTM principles, slump, thickness, compressive strength, splitting tensile strength and flexural are observed for both PC and JFRC. To check the behaviour of GFRP reinforced slab failure manner is observed under impact loading.

Chapter 4

Experimental Evaluation

4.1 Background

Mix design ratio of 1:2:3:0.7 (cement: sand: aggregate: w/c) are utilized for casting of Plain concrete. JFRC is prepared with a same mix design except for 50 mm length of jute fibers by adding of 5% weight of cement. Experimental outcomes of PC and JFRC samples to inspect the dynamic characteristics, mechanical characteristics and performance of prototype slabs being debated in this section.

4.2 Impact First Crack Strength and Impact Ultimate Crack Strength of Slabs

Figure 4.2 displays PC, JFRC, PC with GFRP and JFRC's computations of GFRP with impacts at 70 cm and 100 cm. It shows the picture of the failure of the samples at different stages, e.g. the initial crack and the damage. JFRC crack, PC with GFRP and JFRC with GFRP cracks in comparison to a plain concrete crack are minutes. Specimen failure is seen when the entire cross-section of the specimen is formed and visible to the naked eye. When a plain concrete experiment failed, the JFRC, PC with GFRP and JFRC with GFRP split in pieces but only noticed the rise in crack duration. flexure failure has been reported as cracks have been found in JFRC and JFRC with GFRP comparing to PC with GFRP transverse direction which showed shear crack in Figure 4.2. Recorded a shear failure when fibers of steel were checked under impact load. Shear failure was observed. At 100 cm, after 34% of total strikes, PC observed initial cracking. After 49%, PC with GFRP, JFRC and JFRC with GFRP saw first crack, respectively 42% and 55% of the overall strikes [1]. The PC with GFRP, JFRC, and JFRC with GFRP reveal very small cracks Figure 4.2. However, PC with GFRP, JFRC and JFRC with GFRP have seen the width of cracks rise. PC specimens are breaking in pieces in failure. JFRC and JFRC with GFRP and PC with GFRP scars indicate flexure failure. More JFRC and JFRC with GFRP absorbed blows are indicating a higher impact resistance compared to PC and PC with GFRP, respectively. In addition, JFRC and JFRC with GFRP performance is shown by flexure cracks.

Table 4.1 displays the effects of the impact assessment for different specimens when measured at various drop rates. The impact first strength (IFS) and IUS of PC, JFRC, PC with GFRP and JFRC with GFRP at 70 and 100 cm are shown maximum deflections. IFS and IUS are defined as regards the amount of specimens consumed by hits. For both IFS and IUs for relation to PCs, the PC with GFRP, JFRC and JFRC with GFRP changed substantially. The IFS of a PC is the first crack after the first strike is made, at impact height of 70 cm. IFS however amount to 7, 13 and 22 blows for both the JFRC, the PC with GFRP and the JFRC with GFRP. Ultimately, after 2-3 blows, the PC specimen divided into parts and has an average IUS of 2 blows. The average IUS is also 16 blows of JFRC, PC with GFRP and JFRC with GFRP, 25 blows and 34 blows respectively. With an impact height of 100 cm, the average IFS for the PC is 1, meaning that some specimens were broken up at first blow. JFRC, PC with GFRP and However On average, JFRC having GFRP has IFS of 4, 8 and 14. As regards the IUS, the IUS of the PC is 2 blows on average. Similarly, the average IUS for JFRC, PC with GFRP and JFRC with GFRP is 10, 16 and 25. The test results show clearly that JFRC with GFRP has maximum IFS and IUS at both impact levels. For JFRC, IFS and IUS are greater than PC but less PC with GFRP rebars. IFS70 and IUS70 also exceed IFS100 and IUS100 by around 35-50%. This shows that impact resistance is dependent upon the impact force height / distance (or speed). The PC detects a null deflection, divided in two parts, as opposed to experiments in terms of deflection. In comparison to the PC, at an impact height of 70 cm and an impact height of 100 cm JFRC deflected to 32 mm and 22 mm respectively. In terms of deflection, PC with GFRP are like PC, since shear crack is formed without any deflection.

TABLE 4.1: Impact test results

Intended Properties	Impact test			
	PC	JFRC	PC with GFRP	JFRC with GFRP
IFS (blows)	1	7 ±0.5	13 ±3.5	22 ±5.5
IUS (blows)	2±2.5	16±3.5	25±3.5	34±6
Di_{70}	0	32±4	0	43±5
IFS (blows)	1	4±1.5	8±2.5	14±2.5
IUS (blows)	2±0.5	10±4.5	16±2	25±3.5
Di_{100}	0	22±4	0	26±4

Note: 1. IFS = Impact first strength, IUS = Impact ultimate strength
2. An average of six readings is taken

PC that are similar to PC with GFRP behaviour are built without deflection as shear crack. However, JFRC with GFRP rebars are deflected 43 and 26 mm at impact height of 70 and 100 cm respectively. The indication of flexure failure is additional deflection.The results for PC, PC with GFRP, JFRC and JFRC with GFRP are compared to each other as shown in Figure 4.1. The PC value is taken as the reference unit. When compared to JFRC and PC, the impact resistance is significantly improved. When JFRC with GFRP is compared to PC with GFRP, the increase in impact resistance also is high which clearly shows the significance of jute fiber and GFRP rebars.

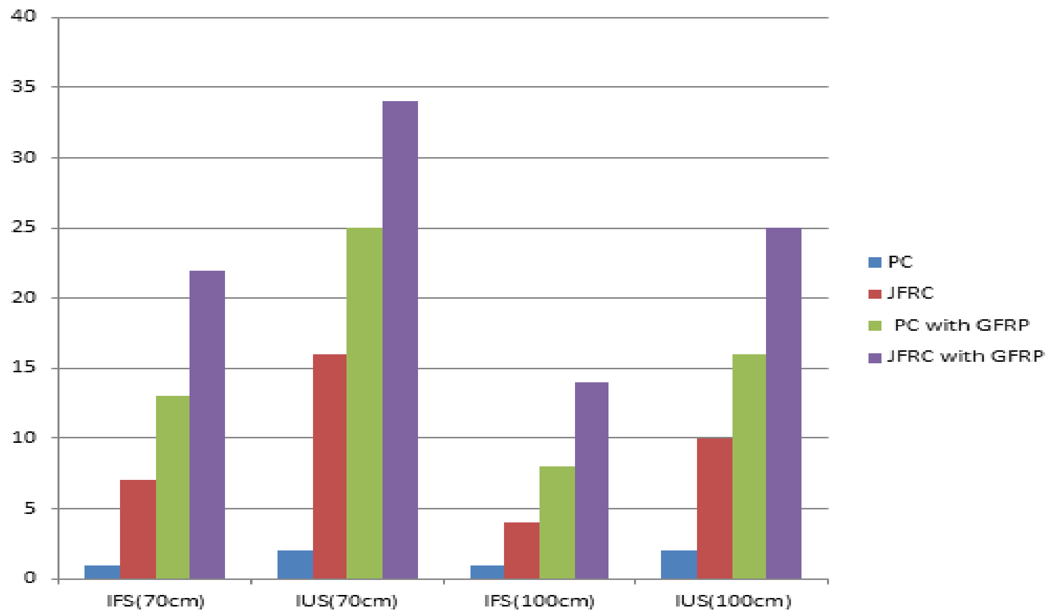


FIGURE 4.1: Comparison of impact test results

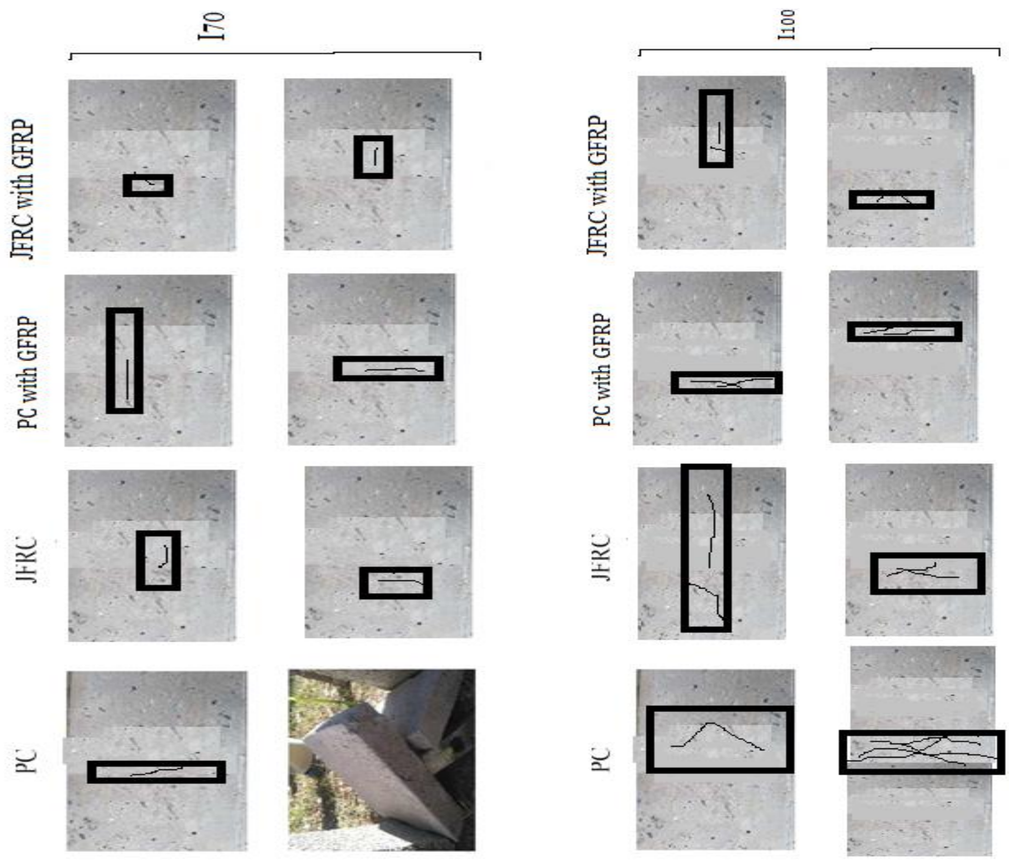


FIGURE 4.2: Behaviour of specimens under impact loading.

4.3 Dynamic Properties of PC and JFRC

Resonance frequencies, and damping ratios (ξ) of diverse samplesare given in Table 4.2. Longitudinal (fL), transverse (ft) and rotational (fr) frequencies are presented for flexure test and impact test. As PC samples are broken into two pieces therfore resonance testing is not possibe. Outcomes of samples afore to any test are related with the outcomes of similar sample after flexure test and impact test. It is observed that there is reduction in resonance frequencies but proliferation in damping proportions. In cylinder applications there is an average of six readings and an average of three for the slabs. In the absence of any separate criteria for fiber reinforced concrete (FRC) in codes, the method used for obtaining the JFRC and JFRC with GFRP frequencies and damping ratio was the same as for PC or PC with GFRP specimens. In the case of the JFRC cylinder length frequency, the transverse and rotational frequency is less than the PC. Test results presented in the Table 4.2.

TABLE 4.2: Resonance frequencies and Damping Ratio

Type	**Specimen**	**No.**	**Resonance Frequency**			**Damping Ratio**
			$\mathbf{f}_l$ (Hz)	$\mathbf{f}_t$ (Hz)	$\mathbf{f}_r$ (Hz)	%
Cylinder	PC	4	7706 ± 175	4763 ± 390	4798 ± 450	2.2 ± 0.04
Cylinder	JFRC	4	6235 ± 220	3826 ± 225	6998 ± 500	3.6 ± 0.03
Slab	PC	2	4254 ± 240	3198 ± 300	3890 ± 600	2.6 ± 0.02
Slab	JFRC	2	2860 ± 200	2637 ± 400	2993 ± 600	4.6 ± 0.04
Slab	PC with GFRP	8	4398 ± 200	4719 ± 600	4690 ± 800	3.0 ± 0.04
Slab	JFRC with GFRP	8	3580 ± 275	4280 ± 380	3580 ± 100	4.1 ± 0.05

Note: f_l = Longitudinal frequency , f_t = Transverse frequency , f_r = Rotational/-torsional

Damping ration of PCs cylinders is 63.63% less than JFRCs cylinders. Damping ratio of PC slabs is 77% is less as compared to JFRC slab. PC with GFRP rebars slabs have damping ratio 37% less than JFRC with GFRP rebars slabs. Any change in damping due to the addition of jute fibers is the principal aim of deciding the dynamic characteristics of the material. Damping can reduce structural response and associated forces[56]. Following effect measurements relative to previous test conditions, the JFRC, PC with GFRP rebars and JFRC with GFRP rebars damping ratio is improved. JFRC with GFRP rebars has a higher damping ratio than PC with GFRP rebars when compared with each other in the post-impact test state. In addition, JFRC with GFRP rebars found the highest damping increase when tested in comparison with before test conditions. Thus, the dissipation of energy is more likely to occur in JFRC members than in PC members.Figure 4.3 shows the comparison of damping ratio for PC and JFRC specimens.

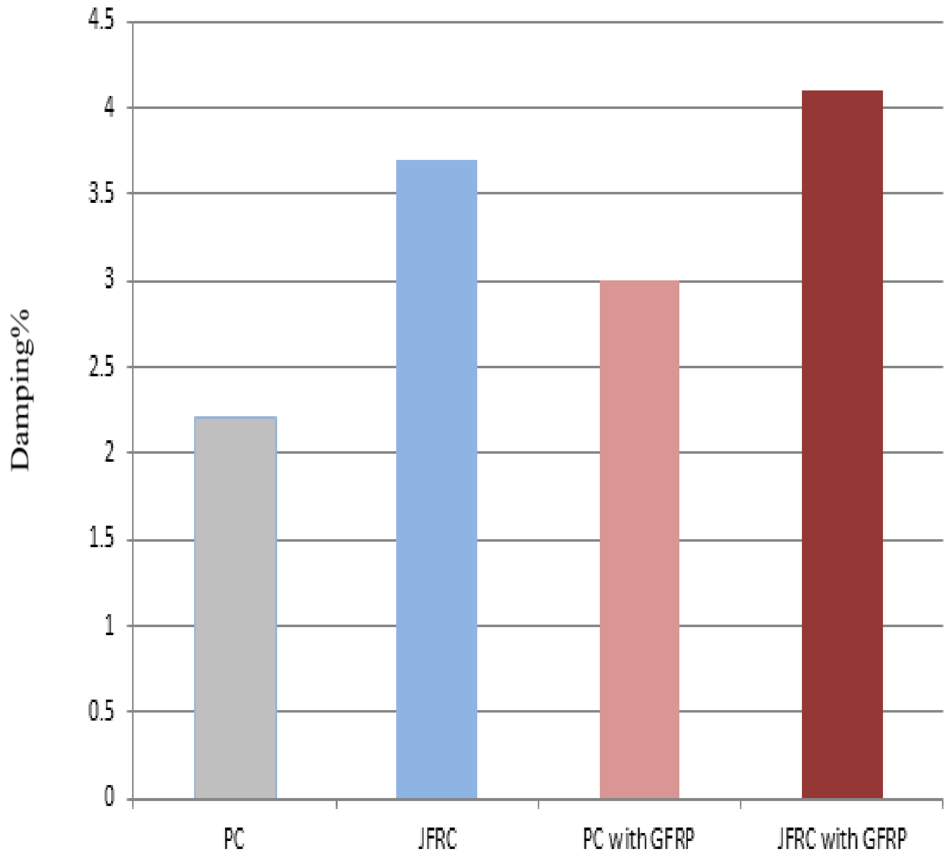


Figure 4.3: Comparison of damping ratios for specimens

4.4 Fiber Damage Mechanism

Binding of fibers and the matrix of concrete are studied in the images given below in Figure 4.4. Failure of JFRC surface images after mechanical testing and impact loading are shown in Figure 4.4. From these images the pull-out of concrete fibers is obvious. The fibers and the concrete component of these images are strongly linked. Such images also demonstrate the correct mixing of concrete. Very little voids and voids are very small and converted into small particles at ultimate load. From these images, it can be seen that broken particles of concrete are attached with each others due to fibers. It means that fibers with concrete composites are tightly bridged. There is no improvement in jute fibers relation to concrete composites at 1st crack. Thanks to jute fibers, broken concrete pieces of composites are bound to each other. The majority of fibers can be used as a pull-out from concrete, even after application of mechanical packing, instead of splitting in bits.

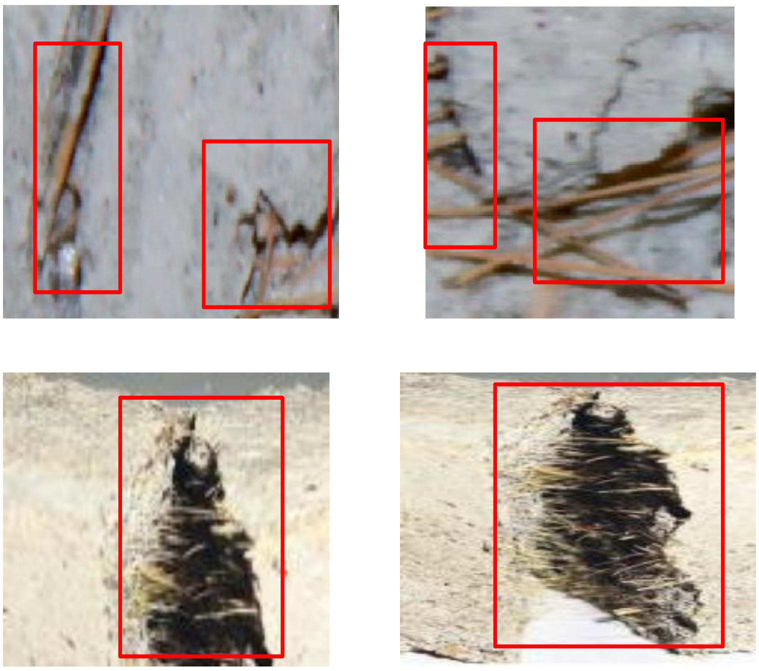


FIGURE 4.4: Bridging pattern of destructed JFRC specimens.

The length of the jet fibers after processing is 50 mm, which is equal to the length used during the JFRC planning. Fibers' voids are not more serious suggesting that fibers with concrete components are better mixed and bonded. It can be seen from the Figure 4.4 that, after application of mechanical loads and impact load fibers pulled out from JFRC test samples and cavities are formed. These images also indicate an adequate bonding of fibers and concrete. In addition, clear mixing is observed of concrete materials and fibres.

4.5 Summary

The material characteristics are analysed using a mix design ratio of 1:2:3:0.70. JFRC increases in slump and density compared to PC. Compared to their respective PC, JFRC's bending strength and splitting tensile strength is enhanced. The previous study [57] was also referred to that. Compared to the PC samples, the efficiency of JFRC with GPRP flexural bars, load-bearing capability including bending power, total absorption of energy and toughness indexes are improved. JFRC impact resistance is up to seven times higher, compared to the JFRC damping ratio of PC 37% higher. Therefore using JFRC having GFRP rebars is better solution to reducing failure in slabs under impact loading. Bridge pattern of jute fiber shows significant bonding between concrete and fibers.

Chapter 5

Conclusion and Future Works

5.1 Conclusion

Experimental studies to improve impacts and dynamic properties investigate the performance of jute fibers with GFRP rebars in concrete. Specimens of plain concrete (PC) are designed for a 1:2:3:0.7 mixing pattern. Jute fiber is used to prepare jute fiber reinforced concrete (JFRC) of the same mixture type, 5% by weight of cement. Specimens are also supplemented to prepare rebar reinforced concrete of PC with GFRP and rebar reinforced concrete JFRC with GFRP having 2@ 64 mm and 76 mm reinforcement. In the case of flexure and impact loading a total of 20 PC, PC with GFRP, JFRC and JFRC with GFRP slab panels are tested. For impact resistance with drop heights between 70 and 100 cm, a drop weight between 2 kg is used. The compressive and split tensile strengths are tested on eight cylinders. The frequencies of resonance and damping ratios are also checked for all specimens. The enhancement is finished by the JFRC stress zone and its reliability is verified by experimental results for the slab. The findings are as follows:

- The improvement in JFRC's properties enhance the resilience of concrete, which enhances its usefulness in slab for structural application.

- The compressive strength of JFRC samples reduced up to 13% and other properties namely energy maximum, cracked energy, total energy, and toughness index increased up to 30%, 211%, 81%, and 40%, respectively, w.r.t that of PC specimens.
- Due to low density of jute fiber, JFRCs strength under compressive loading is decreased as compared to PC. Similar trend is also observed in past researches [8,11,57]. But total energy absorption and total toughness index has increased for JFRC as compared to PC.
- The splitting tensile strength, energy maximum, cracked energy, total energy immersion, and toughness index of GF specimens are improved up to 16%, 32.01%, 28.1%, 134%, and 77%, respectively, as compared to that of PC samples.
- Flexural strength, energy maximum, cracked energy, total energy, and toughness index of GF specimens are increased up to 11%, 13%, 9.32%, 200% and 164%, respectively, as compared to PC samples
- The JFRC impact resistance has been significantly improved. Seven times the height of impact increments of 70 cm and four times the height of impact of 100 cm, as shown by the PC in different simple loading forms. Similarly, JFRC having GFRP has a greater impact resistance of nine times over 70 cm impact height and nine times over 100 cm impact height compared to PC having GFRP under impact loading.
- Dynamic ratio ξ of JFRC specimens enhanced up to 63% as compared to PC. The damping ratio for GFRP rebars enhanced up to 37% as compared to PC with GFRP rebars.
- Bridging pattern of jute fiber shows significant bonding between concrete matrix and fibers.

Accordingly, the JFRC with GFRP rebars can therefore be used to increase the reliability of structural members based on the findings above. The future optimization analysis of GFRP rebars should be carried out.

5.2 Future Work and Recommendation

The recommendations for future research are as follows:

- Impact test should also be performed with increased impact height and drop weight.
- Experimental results may be checked by carrying out empirical equation.

Bibliography

[1] Hrynyk, T. D., & Vecchio, F. J. (2014). "Behavior of steel fiber-reinforced concrete slabs under impact load, *ACI Structural Journal*, 111(5), 1213.

[2] 544.2R-89, Measurement of properties of fiber reinforced concrete, American Concrete Institute Std.

[3] Muda, Z. C., Usman, F., Syamsir, A., Yang, C. S., Mustapha, K. N., Beddu, S., & Itam,Z. (2016, March). "Effect of Thickness and Fibre Volume Fraction on Impact Resistance of Steel Fibre Reinforced Concrete (SFRC) , *In IOP Conference Series: Earth and Environmental Science*, 32 (1).

[4] D. Gon, K. Das, P. Paul, and S. Maity, "Jute Composites as Wood Substitute, *International Journal of Textile Science*, vol. 1, no. 6, pp. 8493, 2013.

[5] A. A. Ahmed, M. Hassan, H. Mohamed, A. Abouzied, and R. Masmoudi, "Axial behavior of circular CFFT long columns internally reinforced with steel or carbon and glass FRP longitudinal bars, *Engineering Structures*, vol. 155, pp. 267-278, 2018.

[6] Zineddin, M., and Krauthammer, T. (2007). "Dynamic response and behavior of reinforced concrete slabs under impact loading, *International Journal of Impact Engineering*, 34(9), 1517-1534.

[7] T. C. Triantallou and C. P. Antonopoulos, "Design of Concrete Flexural Members Strengthened in Shear with FRP, *Journal of Composites for Construction*, vol. 4, no. 4, pp. 198205, 2000.

[8] Zia, A., & Ali, M. (2017). "Behavior of fiber reinforced concrete for controlling the rate of cracking in canal-lining, *Construction and Building Materials*, 155, 726-739.

[9] C39/C39M, Standard test method for compressive strength of cylindrical concrete specimens, ASTM International Std., 2015

[10] Rehacek, S., Hunka, P., Kolisko, J., & Kratochvile, L. (2013). "Two Type of Impact Load Tests, Tested on Fiber Reinforced Concrete Specimens, *Procedia Engineering*, 65, 278-283.

[11] T. Hussai & M. Ali, "Improving the impact resistance and dynamic properties of jute fiber reinforced concrete for rebars design by considering tension zone of FRC. *Construction and Building Materials*, vol. 213, pp. 592607,2019.

[12] Wang, W., & Chouw, N. (2017). "The behaviour of coconut fibre reinforced concrete (CFRC) under impact loading, *Construction and Building Materials*, 134, 452-461.

[13] Dong, Z., Deng, Z., & Yao, J. (2019). "Impact Mechanical Properties of Fiber Reinforced Concrete Slab with Alkali-Resistant Glass Fiber of High Zirconium, *KSCE Journal of Civil Engineering*, 23(6), 2657-2665.

[14] Sadraie, H., Khaloo, A., & Soltani, H. (2019). "Dynamic performance of concrete slabs reinforced with steel and GFRP bars under impact loading, *Engineering Structures*, 191, 62-81.

[15] Celik, Z., & Bingl, A. F. (2020). "Fracture properties and impact resistance of self-compacting fiber reinforced concrete (SCFRC) , *Materials and Structures*, 53, 1-16.

[16] Hama, S. M. (2020, April). "Strengths, Load-Deflection Behavior and Impact Resistance of Two-Way Slab for Concrete Incorporating Waste Aluminum Fibers, *In 3rd International Conference on Recent Innovations in Engineering.*

[17] Ismail, M. K., & Hassan, A. A. (2019). "Abrasion and impact resistance of concrete before and after exposure to freezing and thawing cycles, *Construction and Building Materials*, 215, 849-861.

[18] I. S. Izquierdo, O. S. Izquierdo, M. A. Ramalho, and A. Taliercio, "Sisal fiber reinforced hollow concrete blocks for structural applications: Testing and modeling, *Construction and Building Materials*, vol. 151, pp. 98-112, Oct. 2017.

[19] L. Mohammed, M. N. M. Ansari, G. Pua, M. Jawaid, and M. S. Islam, "A Re- view on Natural Fiber Reinforced Polymer Composite and Its Applications, *International Journal of Polymer Science*, vol. 2015, pp. 1(15), 2015

[20] Alyousef, R., Alabduljabbar, H., Mohammadhosseini, H., Mohamed, A. M., Siddika, A., Alrshoudi, F., & Alaskar, A. (2020). "Utilization of sheep wool as potential fibrous materials in the production of concrete composites, *Journal of Building Engineering*, 30, 101216.

[21] Khan, M., Rehman, A., & Ali, M. (2020). "Efficiency of silica-fume content in plain and natural fiber reinforced concrete for concrete road, *Construction and Building Materials*, 244, 118382.

[22] Chin, S. C., Moh, J. N. S., Doh, S. I., Mat Yahaya, F., & Gimbun, J. (2019). "Strengthening of Reinforced Concrete Beams Using Bamboo Fiber/Epoxy Composite Plates in Flexure, *In Key Engineering Materials* (Vol. 821, pp. 465-471). Trans Tech Publications Ltd.

[23] Zakaria, M., Ahmed, M., Hoque, M. M., & Islam, S. (2017). "Scope of using jute fiber for the reinforcement of concrete material, *Textiles and Clothing Sustainability*, 2(1), 11.

[24] B. Liu, L. Z. Zhang, Q. X. Liu, and T. Ji, "Study on behaviors of jute fiber reinforced cement based materials, *in Applied Mechanics and Materials*, pp. 508-511, 2013.

[25] A. Razmi and M.M. Mirsayar, "On the mixed mode I/II fracture properties of jute fiber reinforced concrete, *Construction and Building Materials*, vol. 148, no.4, pp. 512-520, 2017.

[26] Varma, K. R., & Saride, S. (2019). "Fatigue Behaviour of Jute fiber reinforced asphalt concrete, (Doctoral dissertation, Indian institute of technology Hyderabad).

[27] S.P. Kundu, S. Chakraborty, and S. Chakraborty, "Effectiveness of the surface modified jute fibre as fibre reinforcement in controlling the physical and mechanical properties of concrete paver blocks, *Construction and Building Materials*, vol. 19, no. 6, pp. 554-563, 2018.

[28] Hosen, M., Alengaram, U. J., Jumaat, M. Z., Sulong, N. H., & Darain, K. (2017). "Glass Fiber Reinforced Polymer (GFRP) bars for enhancing the flexural performance of RC beams using side-NSM technique, *Polymers*, 9(5), 180.

[29] A. Yazdanbakhsh, L.C. Bank, "The effect of shear strength on load capacity of FRP strengthened beams with recycled concrete aggregate concrete, *Construction and Building Materials*, vol. 102, no. 12, pp. 133-140, 2016

[30] Masmoudi, M. B. Ouezdou, and M. Haddar, "Mode of failure for reinforced concrete beams with GFRP bars, *Journal of Theoretical and Applied Mechanics*, vol. 54, no. 4, pp. 1137-1146, 2016.4

[31] Noroozieh, E., & Mansouri, A. (2019). " Lateral strength and ductility of reinforced concrete columns strengthened with NSM FRP rebars and FRP jacket, *International Journal of Advanced Structural Engineering*, 11(2), 195-209.

[32] Al-Saadi, N. T. K., Mohammed, A., Al-Mahaidi, R., & Sanjayan, J. (2019). " A state-of-the-art review: near-surface mounted FRP composites for reinforced concrete structures, *Construction and Building Materials*, 209, 748-769.

[33] Jabbar, S. A., & Farid, S. B. (2018). " Replacement of steel rebars by GFRP rebars in the concrete structures, *Karbala International Journal of Modern Science*, 4(2), 216-227.

[34] H. Zhu, S. Cheng, D. Gao, S. M. Neaz, and C. Li, "Flexural behaviour of partially fibre-reinforced high-strength concrete beams reinforced with FRP bars, *Construction and Building Materials*, vol. 161, no. 13, pp. 587-597, 2018.

[35] Maranan, G. B., Manalo, A. C., Benmokrane, B., Karunasena, W., & Mendis, P. (2015). "Evaluation of the flexural strength and serviceability of geopolymer concrete beams reinforced with glass-fibre-reinforced polymer (GFRP) bars. *Engineering Structures*, 101, 529-541.

[36] Ellis, D. S., Tabatabai, H., & Nabizadeh, A. (2018). "Residual tensile strength and bond properties of GFRP bars after exposure to elevated temperatures, *Materials*, 11(3), 346.

[37] Ulzurrun, G., & Zanuy, C. (2017). "Flexural response of SFRC under impact loading, *Construction and Building Materials*, 134, 397-411.

[38] Ou, Y., Zhu, D., Zhang, H., Huang, L., Yao, Y., Li, G., & Mobasher, B. (2016). "Mechanical characterization of the tensile properties of glass fiber and its reinforced polymer (GFRP) composite under varying strain rates and temperatures, *Polymers*, 8(5), 196.

[39] Eftekhari, M., & Mohammadi, S. (2016). "Multiscale dynamic fracture behavior of the carbon nanotube reinforced concrete under impact loading, *International Journal of Impact Engineering*, 87, 55-64.

[40] Tobbi, H., Farghaly, A. S., & Benmokrane, B. (2012). "Concrete Columns Reinforced Longitudinally and Transversally with Glass Fiber-Reinforced Polymer Bars, *ACI Structural Journal*, 109(4)

[41] N. S. Muhammad, F. Hadi, K. Hogr, and M. S. Neaz, "Experimental investigations on circular concrete columns reinforced with GFRP bars and helices under di erent loading conditions, *Composite Construction,* vol. 20, no. 41, pp. 55-65, 2016.

[42] K. Khorramian, and P. Sadeghian, "Experimental and analytical behavior of short concrete columns reinforced with GFRP bars under eccentric loading, *Engineering structures*, vol. 151, no. 4, pp. 761-773, 2017.

[43] M. N. Hadi, and J. Youssef, "Experimental investigation of GFRP-reinforced and GFRP-encased square concrete specimens under axial and eccentric load, and four-point bending test, *Composites for Construction*, vol. 5, no. 5, pp. 20-35, 2016

[44] L.C. Hollaway, "A review of the present and future utilization of FRP composites in the civil infrastructure with reference to their important in-service properties, *Construction and Building Material*, vol. 24, no. 12, pp. 2419-244, 2010.

[45] Ning, J., Meng, F., Ma, T., & Xu, X. (2020). "Failure analysis of reinforced concrete slab under impact loading using a novel numerical method, *International Journal of Impact Engineering*, 103647.

[46] Cherief, M., Belaadi, A., Bouakba, M., Bourchak, M., & Meddour, I. (2020). Behaviour of lignocellulosic fibre-reinforced cellular core under low-velocity impact loading: Taguchi method. INTERNATIONAL JOURNAL OF ADVANCED MANUFACTURING TECHNOLOGY.

[47] Al Rawi, Y., Temsah, Y., Baalbaki, O., Jahami, A., & Darwich, M. (2020). "Experimental investigation on the effect of impact loading on behavior of post-tensioned concrete slabs, *Journal of Building Engineering*, 101207.

[48] Jahami, A., Temsah, Y., Baalbaki, O., Darwiche, M., Al-Rawi, Y., Al-Ilani, M., & Chaaban, S. (2019). "Effect of Successive Impact Loads From a Drop Weight on a Reinforced Concrete Flat Slab, *In MATEC Web of Conferences* (Vol. 281, p. 02003). EDP Sciences.

[49] A. Ashour, "Flexural and shear capacities of concrete beams reinforced with GFRP bars, *Construction and Building Materials*, vol. 20, no. 10, pp. 10051015, 2006

[50] A. Ejaz and M. Ali, "Development of empirical relation for moment capacity of a concrete prototype bridge deck slab reinforced with GFRP rebars and jute fibers,, *in Proceedings of 2nd International Conference on Sustainable Development in Civil Engineering*, MUET, Jamshoro, Pakistan, December 05-07 2019, p. 218

[51] X.-h. Wang, S.-r. Zhang, C. Wang, R. Song, C. Shang, and K.-l. Cao, "Fragmentation-based dynamic size e ect of layered roller compacted concrete (RCC) under impact loadings, *Construction and Building Materials*, vol. 192, pp. 58-69, 2018.

[52] L. Zhang, S. Feih, S. Daynes, S. Chang, M. Y. Wang, J. Wei, et al., "Energy absorption characteristics of metallic triply periodic minimal surface sheet structures under compressive loading, *Additive Manufacturing*, vol. 23, pp. 505-515, 2018

[53] C496/C496M, Standard test method for splitting tensile strength of cylindrical concrete specimens, ASTM International Std., 2011.

[54] C78/C78M, Standard test method for flexural strength of concrete (using simple beam with third-point loading), ASTM International Std., 2016.

[55] C215-02, Standard test method for fundamental transverse, longitudinal, and torsional resonant frequencies of concrete specimens, ASTM International Std., 2014.

[56] A. K. Chopra, "Dynamics of Structures. Theory and Applications to, *Earthquake Engineering*, 2017.

[57] M. Khan and M. Ali, "Use of glass and nylon fibers in concrete for controlling early age micro cracking in bridge decks, *Construction and Building Materials*, vol. 125, pp. 800808, 2016.

Annexure A

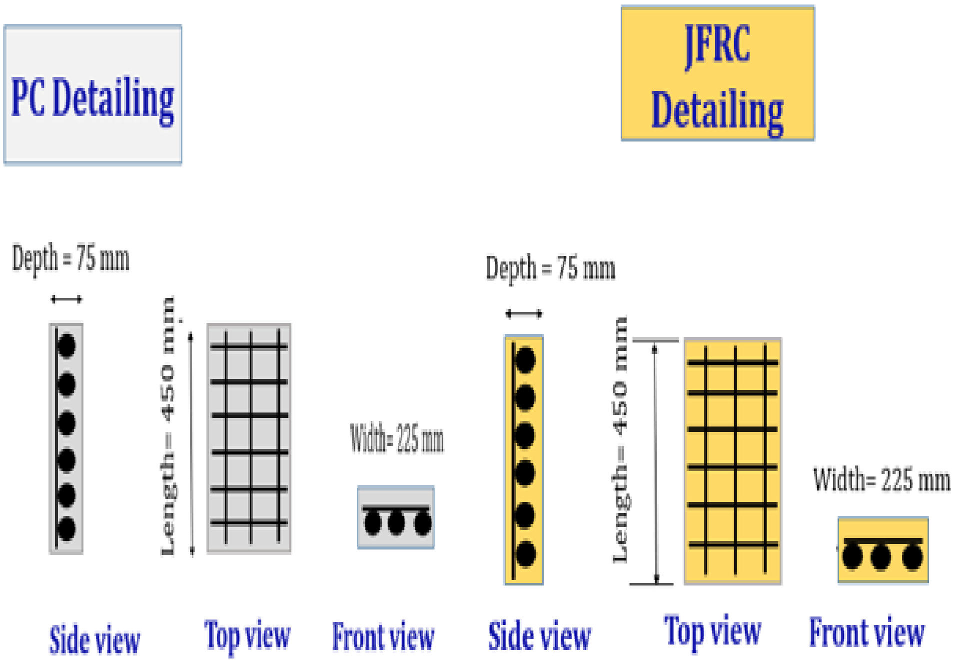


FIGURE A.1: Typical details of PC and JFRC prototype slabs for impact testing.