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Performance Analysis of Fiber Reinforced Concrete using Different Fiber Proportions

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Abstract – Concrete structures experience physical and chemical changes when they interact with the natural environment under service load conditions which results in cracking. Cracking is a critical problem which lowers the long-term service life, strength, as well as the durability of the concrete structures. Furthermore, if preventive measures are not taken on time, then these cracks will lead to the failure of structures. Fibers in different proportions when added into the concrete showed satisfactory performance in enhancing its mechanical properties. Both carbon and steel fibers are introduced in concrete and behaviors of both the Plain Cement Concrete (PCC) and Fiber Reinforced Concrete (FRC) is evaluated based on the mechanical testing. Numerious mechanical characteristics including compressive, tensile, and flexural or modulus of rupture (MOR) strength of both steel and carbon fiber reinforced concrete have been compared with PCC. When slump values of PCC and FRC are compared, it is found that the slump of steel and carbon fiber reinforced concrete is reduced due to water thin film in comparison to that of PCC. In the study, stress strain behaviors of PCC and FRC is also compared. The optimum content of carbon as well as steel fiber of 0.3% and 5% by weight of cement is added which after 28 days moist curing is subjected to mechanical testing. The improvement observed in mechanical properties of FRC indicated that fiber content is effective in strength as well as durability regarding the prevention of cracks in the concrete.

Keywords – Fiber Reinforced Concrete, Concrete Cracking, Flexural Strength, Plain Cement Concrete, Compressive Strength

I. INTRODUCTION

Concrete is the second most used construction material on earth, and it is a composite that is composed of coarse aggregates, fine aggregates, cement, and water. It is used extensively because it is readily available, simple to mold into any desired shape, and inexpensive when compared to other building materials. Over time, many materials have been added to concrete, improving, or altering its mechanical characteristics [1].

Concrete is a popular construction material due to its strength and durability, which make it well-suited for buildings, bridges, and other infrastructure. In addition, concrete has high fire resistance and requires little maintenance, reducing long-term costs. Concrete's versatility allows it to be molded into different shapes and sizes, making it suitable for various construction projects.

However, concrete has several problems that need to be addressed. The production of concrete requires large amounts of energy and emits significant amounts of carbon dioxide, contributing to climate change. Additionally, concrete is a heavy material that can be difficult to transport and can increase the load on foundations and supports [2]. Concrete can also crack over time due to changes in temperature, moisture levels, and other factors, which can compromise its strength and durability. The cost of production and installation can also be relatively high, particularly when compared to other building materials. Finally, concrete cancer, a condition where the steel reinforcement within the concrete rusts and expands, can cause cracks and spalling on the surface, significantly compromising the structural integrity of the concrete [3].

The idea of enhancing the properties of construction materials with fibers is a very old one. Early examples include adding straw to mud bricks, reinforcing plaster with horsehair, and reinforcing ceramics with asbestos. Although continuous reinforcement increases strength and ductility, it also demands skilled labour and careful application [4].

Concrete behaviour is dependent on the nature of the stresses such as under compressive stresses concrete is brittle in nature and bears significant strength but under tensile stresses it offers little tensile strength. Due to this weakness of concrete flexural cracks appear in tension zone. The ultimate cause of the flexural cracks is evaporation of water from the plastic concrete. The evaporation phenomenon causes the early cracking in the concrete structures. With the structure age, moisture ingression takes place through these flexural cracks causing the corrosion of rebars ultimately reducing the designed strength of the section. Heavy concrete section undergo shrinkage due to evaporation of water used during mixing of concrete which results in shrinkage cracks [5].

By introducing different types of fiber in concrete these shrinkage cracks are controlled. As an alternative, adding discrete fibres to PCC or RCC may offer a workable solution. Beginning in 1960s, fibres reinforced concrete (FRC) experienced modern development in construction industry. Concrete becomes homogeneous and isotropic when fibres are added, changing it from brittle to ductile. When concrete starts cracking, the randomly oriented and Well-mixed fibres begin to work, limiting the development and spreading of the cracks, and so contribute to enhancing the strength, service life and ductility of the concrete. The bond failure in between the fibres and matrix and material failures respectively are the two failure modes of fibres reinforced concrete (FRC) [6].

Steel fibres can be added to concrete to increase its crushing, tensile, as well as flexural strengths as well as its post-cracking ductility. Steel fiber utilization may also improve fatigue resistance, impact resistance, and the ability of ductile material to withstand flexure, compression, and torsion. Carbon fibres can be utilized to lessen or totally eradicate shrinkage and cracking shrinking because of its low density, strong heat conductivity, superior chemical durability, and exceptional resistance to abrasion [7].

Synthetic fibres improve some structural qualities such as impact strength, flexural toughness, flexural and tensile strengths. Additionally, carbon fibres improve the concrete's resistance to freeze-thaw cycles and dry shrinkage [8]. Carbon fibres are inert, suitable for use in medical procedures, and stronger than steel fibres, which tend to corrode. The behaviour of fibres reinforced concrete is examined in detail, and the author's testing on several FRC samples are presented [9].

The combination of fibers and concrete can offer several significant advantages in the serviceability. One of the most notable benefits is that fibers can help to improve the concrete tensile strength. Since concrete is sturdy in compression but weak in tension, fibers can bridge the cracks that develop in concrete under tensile loads, which ultimately enhances its tensile strength [10].

Fibers in various proportions also stimulate the concrete durability by reducing the likelihood of cracking. This is particularly important since cracks can lead to the ingress of water, chemicals, and other harmful substances that can weaken the structure over time. Thus, the use of fibers can help to extend the service life of concrete structures [11].

Similarly, blending of fibers in definite proportions in concrete results in increasing of concrete toughness, making it more resistant to impact and abrasion. This can be particularly useful in applications where the concrete is exposed to high traffic or heavy loads, such as airport runways or industrial floors. Fibers can also boost the ductility of concrete, enabling it to deform without fracturing under extreme loads. Ultimately improved concrete structure performance is observed in earthquake-prone regions, where ductility is crucial [12].

Certain types of fibers, such as steel or glass fibers, can also enhance concrete resistance against fire exposure by minimizing its tendency to spall or crack under high temperatures.

Overall, the mixing of fiber content in concrete can provide a range of essential benefits that can enhance both durability as well as performance of concrete structures.

The selection of the type and proportion of fibers added in the concrete, depend on the corresponding application and performance requirements of the concrete [13].

II. Experimental Program

A. *Materials and Methods*

In this research study, Ordinary Portland cement (OPC) from Best Way Cement factory is employed for all concrete mixes. Figure 1 indicates the chemical composition of OPC utilized in this study. Table 1 lists the cement's chemical and physical properties. In this study, natural sand from Lawrencepur with pass of 4.75 mm sieve is used and crushed stones from Margalla Hills are used as coarse aggregate in this research work.

The steel fibres added in the research are hooked end, with length as well as diameter of 38 mm and 0.55 mm respectively. The tensile strength and density of steel fibers used is 1200 MPa and 7.8 g/cm3 respectively. The characteristics of steel fibers are shown below in Table 2.

The plastic concrete is supplemented with shredded carbon fibres having length of 12 mm and tensile strength, tensile modulus and specific gravity of 4.6 GPa, 243 GPa, 1.8 respectively. The characteristics of carbon fibers are given in Table 3.

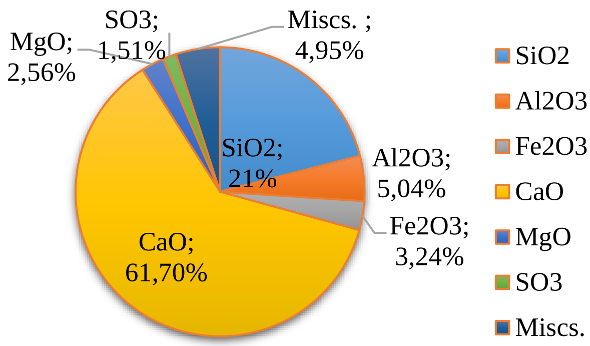

Fig. 1 Chemical Composition of OPC

Table 1. Properties of OPC

Chemical Parameters	**Best way Results**	**Standard Requirement ASTM C-150-07**
Physical Characteristics		
Fineness by Blaine cm2/g	Fineness by Blaine cm2/g	Fineness by Blaine cm2/g
Setting Time		
Initial Setting Time (minutes)	Initial Setting Time (minutes)	Initial Setting Time (minutes)
Final Setting Time (minutes)	Final Setting Time (minutes)	Final Setting Time (minutes)

Table 2. Properties of Seel Fibers

Parameters	
Length	12 mm
Specific Gravity	1.8
Tensile strength (GPa.)	4.6
Tensile Modulus (GPa.)	243

Table 3. Properties of Carbon Fibers

Parameters	
Length	10 mm
Density (g/cm³)	7.8
Tensile strength (MPa)	500-2600
Modulus of Elasticity (MPa)	210,000

B. *Mix Design and Casting Procedure*

The specimen size and number of specimens used in a variety of testing are given in the table VI. Specimen preparation and curing in the laboratory is made according to ASTM C192, C192M standard procedure [14].

The faces of the mold are thinly coated with oil so that de-molding later can be done easily. In the experimental work weight batching is done and each of the materials is taken in kgs according to the mix design ratio. The dimensions of various specimens and their quantities utilized in the study are presented in Table 4.

Table 4. Specimen Sizes and Quantity

Strength Test	Specimen Size	No. of Specimens
Compressive Strength Test (CS)	150 mm X 300 mm	2
Tensile Strength Test (TS)	150 mm X 300 mm	2
Flexural Strength Test (MOR)	100 mm X 100 mm X 500 mm	2

The faces of the mold are thinly coated with oil so that de-moulding later can be done easily. The casting of cylinders and prism beams is shown in figure 1

In the experimental work weight batching is done and each of the materials is taken in Kg according to the mix design ratio.

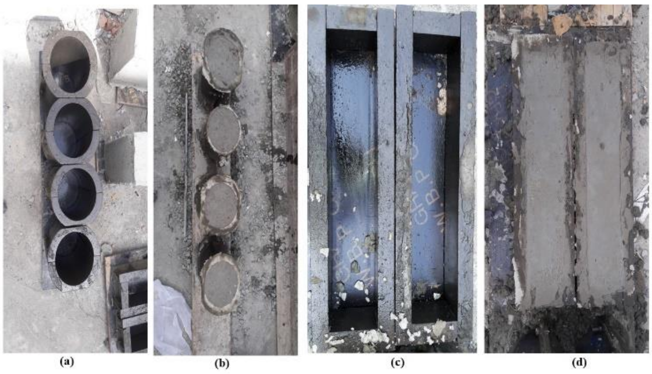

Fig. 2 : The Casting of (a and b) Cylinders and (c and d) Prism Beams

The carbon and steel fibers percentage by weight of cement taken in the study are presented in Table 5.

Table 5. Percentage of different fibers used in mix.

Specimen	Percent Fiber used by weight of Cement
PCC	0%
SFRC	0.5%
CFRC	0.3%

Machine mixing method is adopted for better workmanship and mixing quality using a non-tilting drum mixer. For mixer capacities of up to 1 m3 or less, the minimum time of mixing chosen is 1 minute +15 seconds for every additional m3. To test if fresh concrete is workable, the slump cone test method is adopted. Each of the specimens is packed in three layers, and a vibrator is used for compaction of each layer. Finally, the specimens are prepared for compression, split tensile, modulus of rupture test. Curing of the specimen is done for 28 days in a curing tank for the achievement of desired strength characteristics. Specimens are taken out from tank before 24 hours of testing and surface dried with piece of the cloth. After 28 days curing the corresponding tests are performed on each test specimen [15].

III. EXPERIMENTAL RESULTS AND ANALYSIS

A. *Slump Test*

The workability of the fresh concrete is determined by slump test. The result of the slump test here provides the ultimate information about the water content, the aggregate size and distribution, and the consistency of the concrete. This information is critical for ensuring that the concrete meets the required specifications and will perform as expected in its intended use which is essential for ensuring the performance and durability of the finished product [16].

The standard procedure of ASTM C143 / C143M has been adopted to assess the slump of PCC and fiber reinforced concrete using standard cone having height 300 mm and diameter at bottom and top is 200 mm and 100 mm respectively [17]. The measurement of slump is shown in figure 3. The slump value for PCC, CFRC and SFRC are shown in Table 6.

Fig. 3 : Evaluation of Slump

Table 6. Slump values of PCC and FRC

Specimen	Slump (mm)
PCC	85
Concrete with Steel Fibers (SFRC)	24
Concrete with Carbon Fibers (CFRC)	41

It has been observed that in comparison to the plain cement concrete (PCC), slump value of CFRC and SFRC is reduced by 51.76 % and 71.76% respectively.

B. Concrete Compressive Strength Behaviour (CST)

Concrete compressive strength is a crucial factor that affects the durability and longevity of concrete structures. ASTM C39 has been followed for compressive strength test. Test is performed on cylindrical specimens moist cured for 28 days at Compression Testing Machine (CTM) after 28 days under loading rates of 0.01 MPa/s. The experimental setup for the determination of compressive strength of the cylindrical specimens is shown in figure 4.

Fig. 4 : Compressive strength test on cylindrical specimens

During testing, data is obtained from CTM, and graph is plotted for Load verses Time and is given in figure 5. Percentages difference in compressive strength along with the loading rate plotted in the form of bar chart in Figure 6. Simple PCC is taken as control and values of compressive strength of other mixes are compared with it [18]. The addition of fibers in FRC has significantly enhance the compressive strength of concrete. The fibers act as reinforcement and help to distribute the stress within the concrete matrix, reducing the likelihood of cracking and increasing the load-carrying capacity as identified in the analysis of the strength results.

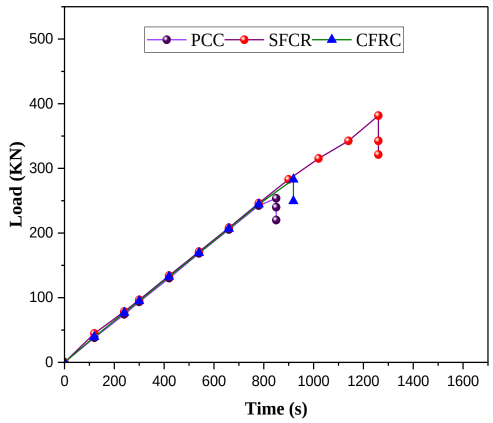

Fig. 5 : Compressive Load verses Time Curve for PCC, SFRC and CFRC.

The type, length, and volume fraction of fibers used in FRC are critical factors as they affect concrete compressive strength behaviour [19]. From the figure 4, maximum percentage difference of compressive strength is observed between P.C.C and concrete with 5% of steel fibre contents which is approximately 34% similarly the increase in compressive strength for carbon fiber reinforced concrete is 10% in comparison to PCC.

To determine the stress strain behaviour of cylindrical specimen in compression Linear Variable Differential Transformer (LVDT) is attached with specimen and strain is measured with the help of P3 box strain indicator. The stress strain curve of PCC and FRC is shown in figure 6, indicating maximum ductile behaviour for SFRC in comparison to PCC and CFRC.

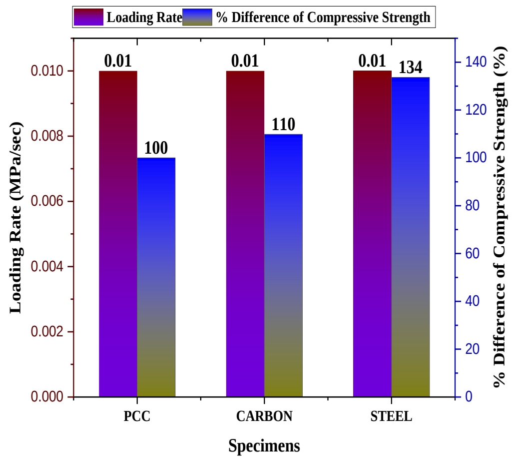

Fig. 6 : Compressive strength comparison for PCC, SFRC and CFRC under a constant loading rate of 0.01 MPa/sec.

C. *Concrete Behaviour in Split Tensile Strength (STS)*

The split tensile strength (STS) is a measure of the tensile strength of concrete, which is determined by splitting cylindrical or cubical specimens along their diameters. PCC, CFRC, and SFRC are different types of concrete mixtures with varying properties, including different levels of tensile strength. To demonstrate the differences in split tensile strength between these types of concrete, standard ASTM C496 procedure is followed for measuring the concrete split tensile strength.

Diametrical lines were drawn on each end of specimen, making sure that they are in same axial plan [20, 21]. The experimental assembly for spilt tensile strength of cylindrical specimens is shown in figure 7.

Fig. 7 : Compressive Load verses Time Curve for PCC, SFRC and CFRC.

In compression testing machine (CTM), each specimen was placed lengthwise. Percentage difference of split tensile strength for three types of specimens is also shown in Figure 8.

In comparison to PCC, the split tensile strength of concrete with 5% steel fibers and 0.3% for carbon fiber is observed which is 8% and 30% respectively. The presence of steel or carbon fibers in concrete provides additional tensile strength to resist cracking and splitting, resulting in higher split tensile strength compared to PCC.

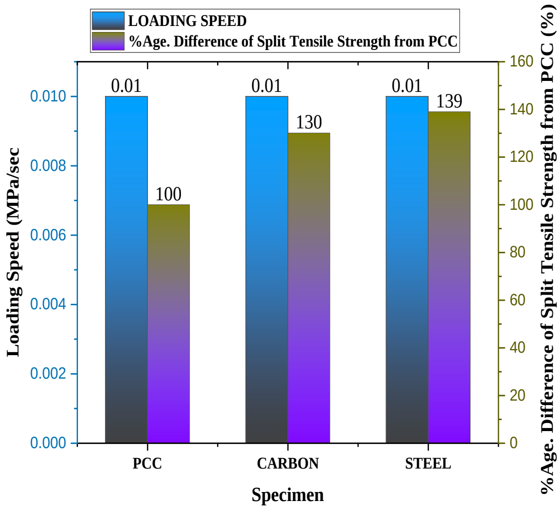

Fig. 8 : Splitting tensile strength comparison of PCC, SFRC and CFRC under a constant loading rate of 0.01 MPa/sec

D. *Concrete Behaviour in Modulus of Rupture Strength (MOR)*

The Modulus of Rupture (MOR) is a measure of a material's ability to resist bending or breaking under a load. The behaviour of concrete in terms of MOR varies depending on the type of concrete used. The standard ASTM C78-02 procedure has been adopted for MOR test. In this graphical comparison is made for modulus of rupture strength of prism beam specimens [22]. The experimental assemblage for the determination of modulus of rupture strength of prims beam specimens is shown in figure 9. The stress strain relation of beam prism is shown in Figure 10.

The modulus of rupture strength is measured separately for RCC, CFRC and SFRC specimens for comparative analysis.

Fig. 9: Determination of modulus of rupture strength

Similarly, statistical comparison of percentage difference of modulus of rupture strength for PCC and FRC is presented in Figure 11. It is clear from the figure that maximum difference of modulus of rupture strength between PCC and 5% steel fibers content obtained is 34%.

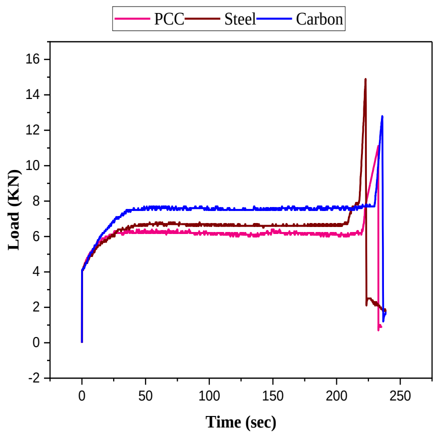

Fig. 10: Stress-Strain Comparison for MOR test on PCC, SFRC and CFRC.

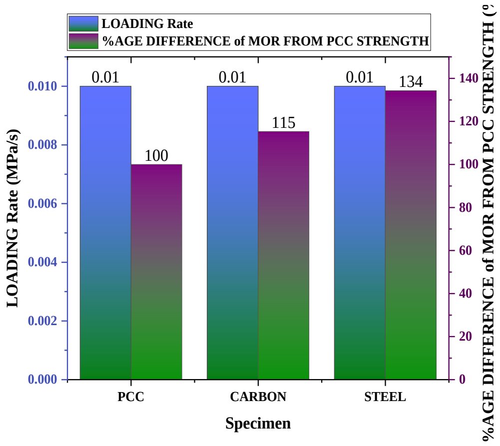

Fig. 11: MOR Strength Comparison of PCC, SFRC and CFRC under a constant loading rate of 0.01 MPa/sec

This is due to the fact that blending of reinforcing fibers significantly enhances the MOR strength of concrete. Since it can be seen from the figure that SFRC and CFRC have higher MOR compared to PCC due to the presence of steel and carbon fibers, respectively, which provide additional tensile strength to the material. Concrete and steel fiber composite imparted the highest MOR due to the superior properties of steel fibers [23].

IV. CONCLUSION

The research is conducted to evaluate the characteristics of steel and carbon fiber reinforced concrete (SFRC & CFRC) with varying percentages of fibers for controlling the concrete structures early cracking. The mechanical characteristics of both SFRC and CFRC have been measured in the laboratory. To evaluate the flexural performance, samples of prism beams have been manufactured.

During the further testing, it has been observed that for a constant w/c ration, slump value of Fiber Reinforced Concrete for both CFRC and SFRC have been reduced in comparison to plain cement concrete (PCC) by 51.76 % and 71.76% respectively. This reduction of workability is because of the development of thin film of water around the fibers. The reduction in slump value of CFRC and SFRC compared to PCC is mainly due to the addition of fibers in the concrete mix, that tend to hinder the flow of the particles of concrete and absorb some of the water in the mix. The extent of the reduction in slump value is dependent upon the nature and properties of the fibers imbedded in the mix.

The three types of experimental studies including compressive, split tensile and modulus of rupture is performed on specimens. The percentage difference of compressive strength resulted by addition of 5% steel fiber and 0.3% carbon fiber by weight are 28% and 6% in comparison with PCC. It is important to note that the percent growth in compressive strength resulting from the mixing of steel fibers (28%) is higher than that resulting from the addition of carbon fibers (6%). This is because steel fibers are more effective in preventing propagation of cracks and enhancing the overall concrete strength in comparison to carbon fibers.

Similarly, the split tensile strength of both steel and carbon fiber reinforced concrete (SFRC and CFRC) has been improved by 41% and 20% in comparison to PCC. The increased split tensile strength of steel fiber reinforced concrete, SFRC (41%) in comparison to carbon fiber reinforced concrete, CFRC (20%) may be because steel fibers are more effective in cracks prevention and propagation, ultimately enhance the strength of the concrete as compared to carbon fibers. Additionally, the higher percentage increase in split tensile strength of SFRC may also be attributed to the fact that the steel fibers used in

SFRC are typically longer and have a higher aspect ratio than the carbon fibers used in CFRC, which can lead to a more significant improvement in the tensile strength of the concrete.

Flexural or MOR strength has been observed to be enhanced by 34% for SFRC and 15% for CFRC in comparison to PCC. Concrete with 5% steel fiber contents gives the max value of strain 0.00221 mm/mm.

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