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# Improving mechanical properties of concrete by using fibrous materials

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**A B S T R A C T**

Concrete is the most significant source of construction in the construction industry of the world. However, concrete causes excessive production of cement, which is one of the key contributors of carbon dioxide emissions to the environment. To minimize the use of cement in concrete, various innovative materials are being added in concrete to make it sustainable. In this study, a comparative study between three fibers Carbon Fiber, Glass Fiber, and steel fibers was done to determine which one is the most suitable fiber. For this purpose, testing on specimens was done for tensile and compressive strength at 0.5% addition of each fiber. Testing was done after 3, 7, 14, and 28 days of curing. The results spelled out that the highest compressive strength of 37.53 MPa of cube specimens was found in carbon fiber after 28 days, and Glass fibers exhibited the lowest gain in strength at about 32.335 MPa. Carbon Fiber gained 28% more strength than the control mix. On the other hand, tensile strength was also found highest in carbon fibers i.e. for the cubes the maximum difference between different fibers inducted concrete samples is 28% approximately, and for cylinders it is 27%, respectively. On the other hand, the highest tensile strength of concrete was also gained with the carbon fiber at about 3.61 MPa. The same was found lowest in glass fiber at 3.12 MPa. Carbon fiber got about 44 % improvements in tensile strength.



## 1. Introduction

Concrete is a popularly used common construction material in the construction field of the world. Concrete is used in a variety of civil engineering structures varying from building, road, and hydraulic structures. It is extremely popular due to its higher load-carrying response and capacity, fire resistance, impermeability, and ease of being molded into any shape. Meanwhile, it has some deficiencies which include lower tensile strength, brittleness, limited fatigue life, low ductility and low deformations, post cracking capacity when they are subjected to large flexural forces. It is also a well-known fact that due to its brittle failure, concrete is considered extremely vulnerable to cracking induced from flexural loading. As a brittle material concrete exhibits a strong response against compression, but, when the cracks are initiated in it due to flexural loadings, the concrete loses all its loading capacity at once without any prior intimation. Although steel reinforcement is added to concrete to deal with its tensile failure, on the other hand, mild steel makes concrete heavier than plain concrete. Thus, in a new trend of research, to control and improve the flexural resistance of concrete, different kinds of fibers are being preferred to be used as an extra ingredient to improve the loading capacity of concrete once the load has been acted on it. It has also been studied that improvement in the durability, and other most important properties such as compressive resistance and tensile or splitting strength of the concrete can be made better by using suitable changes in concrete manufacturing ingredients such as cementitious materials, introducing different kinds of sustainable aggregates, and adding some special kind of admixtures into it. Hence, the use of sustainable and safe concrete has a vital role in the construction field.

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Studies have revealed that the presence and development of micro-cracks in the concrete structures is always a matter of grave concern because these cracks are responsible for the weakness of the concrete particularly in tension and this vulnerability does not only make concrete structures unsafe but also leads to economic losses as well. On the other hand, such a failure of structures raises questions on material quality and design of structures as well. Although concrete is not sound enough in tension this deficiency in concrete can be easily removed by the induction of the fibers in the concrete mix (Golewski 2023). These fibers can be in the form of glass fibers, carbon fibers, steel fibers, and other similar fibers made from industrial waste or natural products such as coconut fiber. The use of fibers in concrete helps to improve its toughness and enhances its ability to prevent further growth of cracks in concrete structures. Moreover, these fibers are also responsible for forces being uniformly spread at the internal micro cracks; and make concrete lighter in weight as compared to conventional concrete. This is due to the fact that fibrous concrete is gaining more popularity among research scholars. Accordingly, there are several published papers and attempts to utilize different types of fibers or additives made from natural waste materials or industrial materials such as recycled crumb rubber, waste tire granules and silica fume (Fakhri et al., 2021, Karimi et al.2023), macro-synthetic, forta-aramid fiber (Aziz et al., 2023; Daneshfar et al., 2023; Rooholamini et al., 2018), recycled PET buttles (Rahmani et al., 2013; Asdollah-Tabar et al., 2021), steel fibers (Krishna & Rao, 2015; Domski et al., 2017; Su et al., 2019; Murali et al., 2021; Hoseini et al., 2022,2023, Mousavi et al., 2024), jute fiber (Bheel et al., 2021, Aliha et al., 2017; Ahmad et al., 2022, Ali et al., 2020a,b), agricultural waste fibers (Torkaman et al., 2014, He et al., 2020, Souza et al., 2021, Sugito et al., 2022), polypropylene fiber (Prasad & Murali, 2021; Mohammadhosseini et al., 2014,2017), carbon fiber (Singh et al., 2022, Reza et al., 2021), glass fibers (Reza et al., 2021; Algburi et al., 2019; Chandramouli et al.,2010; Khan et al., 2020; Islam et al., 2022; Grzymski et al., 2019; Özkılıç et al., 2022), Steel and copper slag recycled aggregates (Khanzadi & Behnood, 2009; Wang et al., 2013; Shaker et al., 2023), recycled aggregate from construction wastes (Patra et al., 2022; Pacheco et al., 2019; Zheng et al., 2018; Bai et al., 2020; Al-Azzawi 2016) and many other reinforcing particles and additives ( Amran et al., 2021; Singh et al., 2017; Firda et al., 2023; Zhang et al., 2018; Najjar et al., 2020; Meddah et al., 2009, Bakde et al., 2023, Ahmed et al., 2021). Different mechanical properties including fracture toughness and fracture energy or compressive strength and flexural strength of concrete materials have been investigated in the available published research articles. Concrete has fibers as another ingredient other than cement, and aggregates such as concrete with fibers are named reinforced fiber concrete or fiber reinforced Concrete. Thus, it is a composite material that is formed by a mixture of fibers and reinforced concrete. Fibers are preferred to be added in concrete so that concrete should gain improvement in its mechanical properties. All types of fibers have a good impact on both fresh and hardened properties of concrete. That is the reason that extensive research is being made to produce sustainable concrete with the addition of fibers (Thyavihalli Girijappa et al., 2019).

The application of fibers in concrete can be made in the form of an aggregate having extreme variation in its shape, size, and smoothness. Fibers like other ingredients of concrete possess proper shape, size, and texture. Not all the fibers in the world are applicable for concrete use. However, the use of fibers in concrete has many advantages including environmental and economic benefits. Fibers get interlocked and entangled around aggregate particles that is why all types of fibers reduce the workability of the concrete whereas concrete mix becomes extremely cohesive than conventional concrete and less pronounced to the segregation. Furthermore, the fibers are added into a concrete mix with the random capacity hence it improves the concrete in all parameters and directions. Although it depends upon the type of fiber it is found that the use of fibers helps the concrete to get higher ultimate ductility performance, pre-cracks improvement in splitting strength, and impact load resistance of the concrete emphatic strength of the concrete (Mahadik et al., 2014; Rooholamini et al., 2018; Daneshfar et al., 2023).

In addition, the presence of fibers in a concrete act as a crack controller resisting the expansion of cracks in the concrete mixture, cement concrete having extremely low tensile capacity and low impact resistance gets into a strong improved composite which during periods of crack resistance improves its ductility and the post cracking behavior which is beneficial for the concrete strength. Hence the use of the study allows us to understand the importance of different types of fibers which are used to improve the compressive strength of the concrete as well as the tensile strength of the concrete (Iucolano et al., 2013).

Fibers have also gained popularity because work is being done to minimize the use of cement in concrete. After all, cement production is one of the major causes of carbon dioxide emissions to the environment. According to Statista's research department, the production of cement has skyrocketed in many countries since 1992. The data shows that cement use has increased by 194% since 1995. Cement production was about 1.39 billion tons in 1995; however, it has touched the quantity of 4.1 billion tons in 2023. This excess in the production of cement has become a matter of utter concern for the whole world. Therefore, this study was carried out to know the best possible way to make strong and sustainable concrete.

## 2. Review of previous related works

At present, there are a number of different laboratory examinations that have been done on these fiber-reinforced concrete samples to measure their effectiveness and strength values. One of the detailed review studies was carried out by Weli et al., (2020) that they investigated the mechanical properties of the concrete using different fibers and concluded that there were good results when steel fibers were used in comparison with other fibers. In this study, it was observed that the resistance against compressive forces on concrete increased from 7 to 19% whereas the split tensile strength increased from 19 to 48%. However, the flexural strength increased by more than half which was around 25% but after the usage it moved up to 65% and at last the modulus of elasticity improved from 7% to 25% respectively (Weli et al., 2020). Another research on the use of fibers was conducted by Singh et al., (2022) who induced concrete with 0.33%, 0.65%, and 1% of GFRP (Glass Fiber Reinforced Polymers) and CFRP (Carbon Fiber Reinforced Polymers). These two types of fibers are most common now both make concrete strong in tensile strength and carbon Fiber polymers are gaining popularity in the making of light concrete as well. In this research, it was found that due to this addition of GFRP and CCFRP in concrete, the mechanical and hydrological properties of the matrix were affected. Since it was a comparative study, it revealed that the permeability and porosity of the composite concrete mixtures with GFRP were higher than the CFRP. The overall increase in the compressive strength of fibrous concrete was observed and it was recommended that the concrete became eco-friendlier and more cost-effective by using the wasted CFRP and GFRP (Singh et al., 2022)

Detailed research on fibers was also conducted on concrete samples by Aksar et al., (2023). In this experimental work, a total of 120 pieces of elements were cast which included 48 cubes, 24 beams, and 48 cylinders for split tensile strength test. The cylinders specimen had a diameter of 15 cm and the height of the cylinder was 30 cm, the concrete cubes were cast into 15 × 15 × 15 cm where the beam work hosted into 15 by 15 cm and the length of the beam was 56 cm and their testing was done by the single point loading technique and all standards were strictly followed for determining the true results. For normal strength 1:1.5: 2.5 was taken as normal strength proportion (NLSP) while for low strength 1:2.6:4.2 was taken as low strength proportion (LSP) for mix. All the samples were brought under testing after 7 days of curing and 28 days of curing age and their densities were recorded properly before being tested with the help of standard machines. Overall, the result exhibited that the addition of only 0.25% of chopped Carbon fiber reinforced polymer (CCFRP) onto concrete increased the resistance the resistance of low-strength concrete against compressive forces from 9.5 N/mm$^2$ to 11.2 N/mm$^2$, the overall increment of strength was about 10% in total whereas the 5% increment was there for the normal strength concrete. Meanwhile, the use of 0.25% of CCFRP exhibited a positive response for the flexural strength of concrete. It revealed that at this percentage both LSP and NSP represented an increase in the cylinder based tensile strength of concrete from 2.5 N/$mm^2$ to 3.6 N/$mm^2$, which was about a 44% increment in normal strength proportion (NSP) whereas 16.6% for low strength proportion (LSP) concrete mix. Similarly, the same scenario was with the flexural strength of the concrete which improved from 4.5 N/$mm^2$ to 5.4 N/$mm^2$. Therefore, it was recommended that 0.25% was the ideal percentage to be added to concrete to get better results in terms of strength of concrete (Askar et al., 2023)

Moreover, another research was conducted in which fly ash was added to concrete with the ground granulated blast furnace slag incorporated in place of cement with varying percentages. The concrete was modified in order to find the compressive and tensile strength, and durability of the concrete mixture. The proportion was mixed in different percentages which was 0.1%, 0.2%, 0.3%, and 0.4% whereas the glass fiber length was around 6 mm and 13 mm. It is also important to underline that the strength and effectiveness of fibers depend upon their length; therefore, the size of fibers is selected with proper care. Hence, experiments were made after taking the length of fibers between 6 mm to 13 mm. The results indicated that the addition of the glass fibers caused improvement in the overall flexural strength of the concrete and also resulted in enhancement of the split tensile strength of the concrete as well. The use of 13 mm glass fiber was more effective than the one which was around 6 mm as the main reason for this was that with 13 mm large fibers it gets more area contacted with concrete so the overall result was better in terms of greatest strength and durability performance of the concrete structure (Midhun et al., 2018).

Additionally, Reis et al., (2023) conducted research using a glass fiber with fiber length of 6 to 25 mm long. It was reported that the application of fibers in conventional concrete mixes made the concrete more durable and strengthened. Moreover, the incorporation of these fibers boosted the flexural resistance of the concrete and improved the splitting properties of the concrete material. It was also investigated that the elasticity modulus of the glass-based fiber-reinforced concrete increased by 40% in comparison with the conventional concrete. The main purpose of the research was to understand the mechanical and flexural properties of the polymer concrete which was induced using the class fibers. Waste glass fibers were used to solve safe waste disposal and environmental issues simultaneously. Furthermore, in one of the research studies conducted in 2018, Pan and coworkers (2018) analyzed the Carbon fiber-reinforced polymer grade by taking into consideration the cyclic behavior in reinforcement ratio, aspect ratio, and reinforcement configuration. Moreover, for these analyses, two varying types of concrete specimens were used: one of them was 13 concrete sheare walls which were about 13 in quantity, and secondly 11 credit samples varying from 1.01 to 2.20 were examined under the inverted loadings. The results clearly witnessed that the reduction in aspect ratio would directly encourage the ductility of the concrete specimen from 13.8% to 36% with an increment of more than 100%. Secondly, the samples that were cast with carbon fiber-reinforced polymer showed an increment in the loading capacity for the concrete shear wall. In addition, Yoo et al., (2022) used carbon fiber-reinforced polymers as the main reinforcement in place of mild steel. The main purpose was to check elevation in temperature along with other properties. It checked the properties of carbon fiber reinforced polymers as reinforcement in compression members in carbon fiber reinforced concrete using the reinforced concrete columns. For this purpose, 24 short columns were used which were subjected to different temperatures (0, 150, 300, and 450 ºC). These columns were subjected to centric loading after the cooling process had been done. From this study the conclusion was made that as the temperature increases the compressive strength of the concrete samples which were short columns also increased, the increment was from 3 to 15% whereas for 300 ºC and 450 ºC, the increment was of about 50%. So, it was clear that in terms of increment of the temperature the compressive strength of the concrete increased as well (Yoo et al., 2022). Other researches were conducted by Madenci et al., (2023) and Aksoylu et al., (2022) in order to examine the elastic characteristic of the textile-based composite materials with carbon nano-tube (CNT) material in the concrete samples. The use of carbon nano-tube (CNT) enhances the axial tensile strength of the concrete as well as makes concrete strong against bending. It was also determined in this study that CNT raised the tensile modulus of the concrete by 9%.

Some detailed studies were done in order to examine how the wrapping of composite beams may have an effect on the resistance against the flexural forces of beams made from reinforced fibrous concrete and load-caused deflection. Nine beams were used in this study with three three-point loading force mechanisms and four-point loading mechanisms with variation in the shear span to depth ratio. As a result, the ductility and strength of the beam were enhanced significantly by using glass fiber reinforced polymers (GFRP) wraps (Ozkilic et al., 2022; Madenci et al., 2023a,b). Additionally, Arslan et al., (2022) and Gemi et al., (2021) investigated experimentally, numerically, and analytically the behavior of glass fiber reinforced polymer composite beams. The variables that were used in experiments included GFRP box profiles and steel bars, which were in conventional form, hybrid steel bars, and externally wrapped glass fiber reinforced polymer. As a result, it was evaluated that, reinforcement by fibers improved the overall strength of the concrete and it made the concrete more durable. Meanwhile, detailed research was also carried out by using a glass fiber in a concrete sample; the maximum dosage of the class fiber was found as 0.5% of the weight of the cement used. Five different Binder ratios were used which were in the range from 0.5 to 0.52. As a result, there was an average improvement in flexural strength and compressive strength of concrete was about 28% and 13% respectively. Along with that, the concrete with the presence of glass fiber represented a small resistance to carbonation attack as compared to the conventional concrete mix. The addition of fiber boosted extra post-cracking flexural strength to the concrete samples. An overall increment of 44% was observed in the flexible strength of the concrete as compared to the control concrete sample (Hussain & Yadav, 2023). Moreover, in another study, high-performance fiber-reinforced lightweight concrete was made up of by making use of polyvinyl alcohol fibers with suitable addition percentage, which exhibited an increment of the flexural strength along with the higher flexural strength ductility in the concrete and improved the toughness of the concrete as a result (Arisoy et al., 2008). With the addition of a small amount of polyvinyl alcoholic fiber into a concrete sample the mechanical characteristics of the concrete improved significantly as an outcome (Noushini et al., 2013). On the other hand, the addition of metal into concrete made from glass fibers caused the fibers to have chances to get easily pulled out comparatively more than the chances of being broken off the fibers. However, the induction of these kinds of chemicals into concrete did not provide reasonable results and neither improved much of its Mechanical properties (Enfedaque et al., 2010). Lastly, it is also found that the induction of the high-performance polypropylene fibers into the concrete samples improved all characteristics of concrete such as penetration of chloride in it, water absorption, and carbonation attacks on an ultrasonic pulse velocity of the concrete which makes the concrete more strengthened and durable as a result (Ramezanianpour et al., 2013). In one of the research works, the magnesium phosphate cement mortar was added to a glass fiber using the dosage of 1.5%, 2.5%, and 3.5%. The optimum of the ideal value of the glass fiber was 2.5% and consequently, this addition resulted in the flexural strength of concrete increasing dramatically for all of the concrete samples (Fang et al., 2018). When the resistance of concrete against the compressive forces and tension forces of the concrete were checked studies revealed that compressive strength and the split tensile strength of the concrete were improved by 9 to 13% and 22 to 50% respectively by the induction of the glass fibers into a concrete mix (Choi et al., 2005). With the addition of only 2% of the glass fibers into the lime-made mortar, the darkness of the concrete increases, and it improves the mechanical particularly compressive and tensile behavior and properties of the concrete mixture (Iucolano et al., 2013).

## 3. Research Methodology

### *3.1 Materials Used*

Cement as a binding material, Fine aggregates (FA), Coarse aggregate (CA), water, waste glass, carbon fibers, and steel fibers were used as fibrous material in order to make the concrete samples. Suitable water available was used for the preparation of concrete as already studied by (Jamali et al., 2020, 2022; 2023; Ahmed et al., 2022).

*3.1.1 Cement:* The cement that was used for the mix was Ordinary Portland Cement (OPC) and Pak land cement was used because it was readily available in the study area. However, cement was manufactured following all standard guidelines. The OPC - Grade 43 having a specific gravity equal to 3.15 was picked for concrete. The initial setting and final setting time of the cement was determined as 20 minutes and 30 minutes, respectively.

*3.1.2 Fine Aggregate (F.A):* The sand used was Lawrencepur. Lawrencepur sand is coarse sand. According to ASTM, sand or fine aggregates that pass through sieve no. 4 and are retained on sieve no.200. The sand used for casting was passed through sieve no. 4 for larger particles to remove from it.

*3.1.3 Coarse Aggregate:* The aggregates used in the research were obtained from the field. In addition, normal aggregates of the Sargodha source were also used. The size of aggregates was a half inch down for normal aggregates and 10 mm down for field aggregates.

*3.1.4 Fibers:* The fibers that were used in the casting were of different kinds, steel fibers, carbon fibers, and glass fibers. Approximately the length of the fiber was 1 inch long and the quantity of the steel fibers was calculated as a certain mass per unit volume which was 0.5% of the defined weight of the concrete sample.

*3.1.5 Design Mix Ratio:* The mix ratio used is:- ACI 5200 psi target strength Based on the conditions of the materials, the quantities are different. In the saturated surface dry condition of the materials, the quantities are:

Cement quantity calculated = 420 kg/$m^3$; Sand Quantity = 840 kg/$m^3$

Coarse aggregates volume = 1680 kg/$m^3$; Water volume = 210 kg/$m^3$

The mix ratio becomes 1:2:4 with water to binder (w/b or w/c) ratio of 0.5.

If materials are in oven dry condition, the quantities are; Cement = 420 kg/m3

Sand = 632 kg/m3

Coarse aggregates = 1228 kg/m3 Water = 197 kg/m3

The mix ratio becomes 1:1.5:2.9 with a water to cement (w/c) ratio of 0.469.

**Table 1.** detail of Mix Proportion

| S No | Mix | Cement % | FA % | CA % | CF % | GF % | SF % | W/B ratio | Specimen |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Control Mix | 100 | 100 | 100 | 0 | 0 | 0 | 0.5 | 12 |
| 2 | Mix-I | 99.5 | 100 | 100 | 0.5 | 0 | 0 | 0.5 | 12 |
| 3 | Mix-II | 99.5 | 100 | 100 | 0 | 0.5 | 0 | 0.5 | 12 |
| 4 | Mix-III | 99.5 | 100 | 100 | 0 | 0 | 0.5 | 0.5 | 12 |

### *3.2 Experimental Procedure*

The following table presents the samples, which are to be casted. These include cubes of 150mm and cylinders of size as 200 mm in height and 100 mm diameter.

**Table 2**
Concrete Cubes and Concrete Cylinder Specification

| Sr. No. | Shape of specimen | Size of specimen (mm) | No. of samples for testing | Volume ($m^3$) |
|---|---|---|---|---|
| 1 | Cube | 150 × 150 × 150 | 48 | $3.37\times10^{-3}$ |
| 2 | Cylinder | 100 × 200 | 48 | $1.57\times10^{-3}$ |

Standard procedure was used to pour ingredients in the mixer. The procedure is to pour the fine aggregates first, then cement and then coarse aggregates. Start mixing the mix and pour water.To add fibers in the mix, use a half inch sieve and pour the fibers using it. The fibers should fall vertical on the mix. **Fig. 1** is shown below.

(a) Mixing of Materials

(b) Concrete Mix

**Fig. 1.** Concrete mix design formation

The desired slump of the concrete was 20 mm for desired workable concrete. The following figure shows the slump test on the concrete. **Fig. 2** below shows the desired outcome in terms of slump.

**Fig. 2.** Slump test on concrete mix
Slump Test on Concrete

## 4. Results and Discussion

In this study, the workability of fresh concrete and mechanical properties of hardened concrete, specifically the compressive strength and split tensile strength of concrete were determined. It was a comparative study between various types of fibers such as Carbon Fiber, Glass Fiber, and steel fiber, which are being commonly used in concrete particularly for improving the flexural resistance of conventional concrete. In order to get a true idea about useful application fibers in concrete, during this study the compressive strength of concrete was tested under an ultimate compressive testing machine and values were noted down for each sample tested after curing of 3, 7, 14, and 28 days. In total 96 samples were cast out of which 48 were cubes for checking compressive strength of concrete and 48 were cylinders for testing split tensile strength of concrete. All samples were checked having fibers proportion equal to 0.5% for all fibers at once.

### *4.1 Workability of Concrete*

The result showed that the workability of concrete kept reducing for various types of fibers. In other words all types of fibers have a negative impact on the workability of concrete. Workability of concrete decreases because fibers increase the cohesiveness of concrete as well. The results as shown **Fig. 3** revealed that workability of concrete reduced from 22 mm for conventional concrete to 17 mm for carbon fiber. It is because fibers make concrete cohesive and reduce segregation and bleeding effect in concrete. Irrespective of fiber type, concrete experiences continuous declination in its workability as the proportion of fiber increases in concrete.

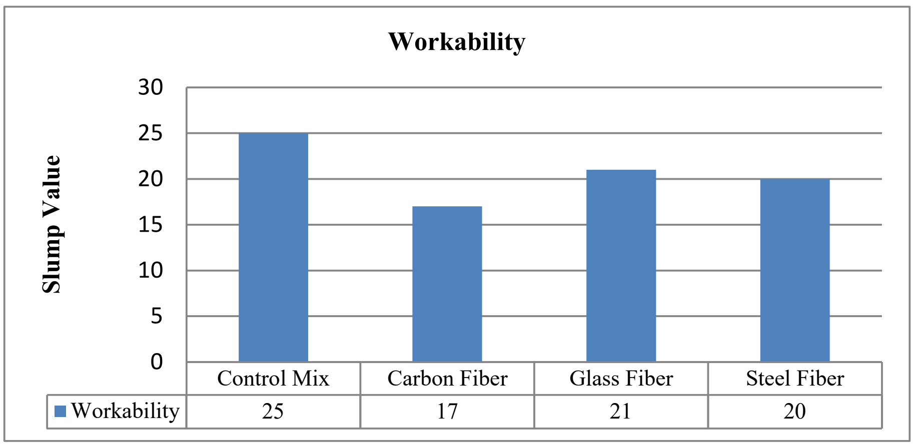


**Fig. 3.** Workability of fibrous concrete

### *4.1 Compression Resistance of Concrete*

One of the important mechanical properties of any type of concrete on which service life of structure depends is the resistance of concrete against compressive forces. Therefore, the compressive strength of concrete was checked at 0.5% addition of each fiber separately after 3, 7, 14, and 28 days of curing. The graph below shows the results of the testing, which was done for concrete casted samples.

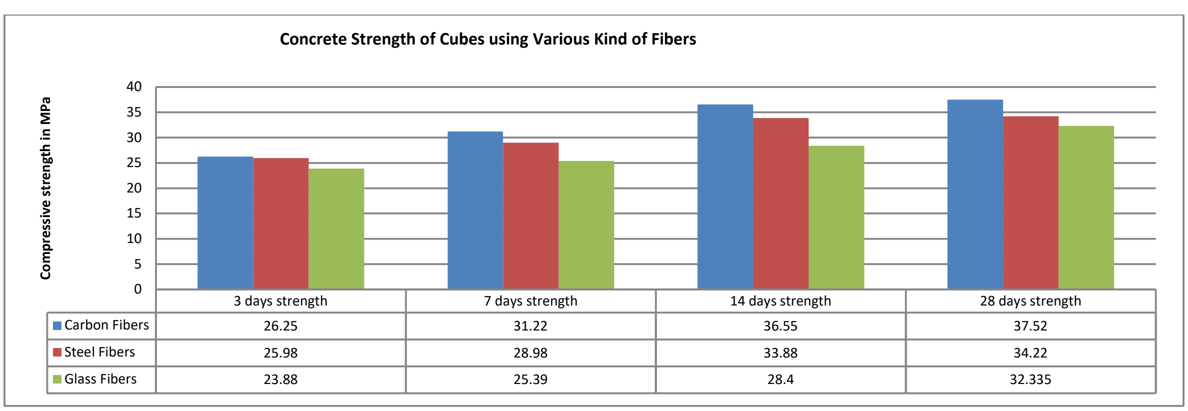


**Fig. 4.** Concrete Strength of Cubes using Various Kind of Fibers

The results as exhibited in **Fig. 3** revealed that the compressive strength of concrete is improved far better with the carbon fibers as compared to any other fiber, and glass fiber was found as a fiber which provides improvement in strength lower than the carbon and steel fiber from starting. The compressive strength of concrete after 3, 7, 14, and 28 days is witnessed in **Fig. 3.** It exhibits that the value of full Compressive strength of concrete after 28 days of curing was found as 37.53 N/, with the addition of steel fiber it investigated about 34. 2 N/, however, the lowest value 32.335 N/ was found due to addition of glass fiber in concrete. Carbon fiber gives high strength to concrete at the range between 0.5 to 0.6 % was also reported by Khan et al., 2023. Similarly, Ji et al., 2023 have also reported that the best results for carbon fiber can be gained at a range lower than 0.6, otherwise as the percentage of carbon fiber in concrete increases above 0.5% concrete experiences a drastic reduction in its compressive strength.

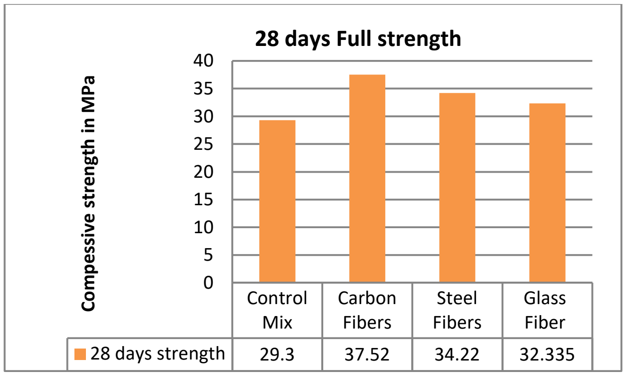


**Fig. 5.** Full Compressive strength of concrete after 28 days curing

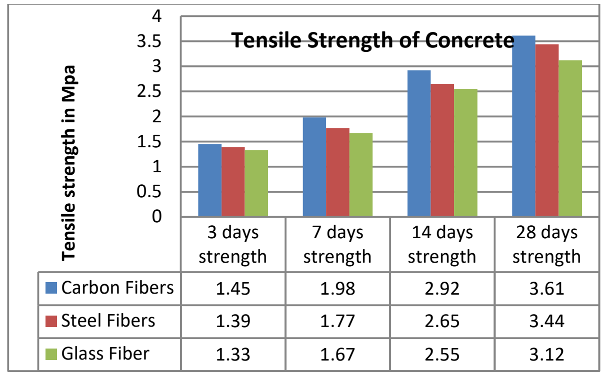


**Fig. 6.** Concrete Tensile Strength of Various Kinds of Fibers

*4.3 Tensile strength of Concrete*

Tensile or the split strength of concrete was checked for concrete specimens. The split tensile test method was followed. Cylinder specimens were prepared with proper care and guidelines to test the tensile strength of concrete. When testing was done the results elucidated that carbon fibers provided the highest improvement in the strength of concrete as compared to other fibers. It further disclosed that the carbon fiber is also lightest in weight in comparison with glass and steel, thus it makes concrete lighter and sustainable as compared to glass fiber concrete and steel fiber concrete. It was further found that after 28 days curing, the tensile strength of concrete with glass fiber was about 3.12 MPa; with steel fiber it gained strength of about 3.44 MPa; and concrete having carbon fibers as composite material boosted strength of concrete to 3.61 MPa that was the highest value of compressive strength at 0.5% addition. It is noted that the Khan et al., 2023 also reported that Carbon fibers provide higher tensile strength of concrete at 0.5 to 0.6 percent of addition. Bheel et al., 2021 also reported similar results for nylon fiber. **Fig. 5** illustrates the results of the study.

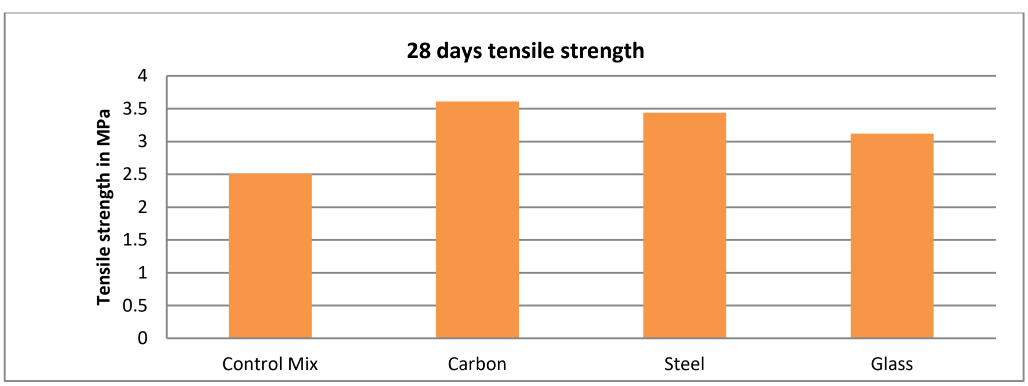


**Fig. 7.** Full Tensile strength of concrete after 28 days curing

## 5. Conclusions

Sustainable concrete is in high demand due to the environment being vulnerable to carbon dioxide emissions. Efforts are being made to use innovative industrial waste materials to make concrete stronger and sustainable. Thus, different fibers were added to concrete in order to enhance its mechanical properties and make it eco-friendly. Fibers such as Carbon, Glass, and steel were added to concrete and testing was done. The results spelled out that addition of fibers reduced workability of concrete by 30 to 32%, however, highest reduction among glass fiber, carbon fiber, and steel fiber, was found in carbon fiber about 32% reduction as compared to control mix concrete. Results also disclosed that the specimen which was cast with carbon fibers had a higher compressive strength as compared to the concrete mix which is formed by using steel and glass fibers for both concrete cubes and concrete cylinders. The main reason for the higher compressive strength of carbon fiber reinforced concrete should be because carbon is the toughest material in comparison to steel and glass. The use of carbon fibers in concrete can make the samples higher in load capacity and as a result, we can get more strength value. Overall, for cubes the percentage difference for 28th day concrete strength of carbon fibers was 28% approximately as compared to glass fiber reinforced concrete. Glass fiber improved the compressive strength of concrete by 10.3%, and steel fiber enhanced the full strength of concrete by 16.44%. On the other hand; the higher tensile strength of concrete was also gained with the addition of carbon fiber in concrete. It was determined that carbon fiber raised the tensile strength of concrete by 44%, while the tensile strength of steel and glass fiber was improved by 37% and 24% respectively. It shows how strong the concrete gets when it is induced with carbon fibers. However, the excess use of concrete with carbon fibers can make the concrete more brittle but at the same time the load-carrying capacity of the concrete sample increases.

It is further suggested that there is possibility to get more enhancement in the properties of concrete if the proportion of fibers is increased above 0.5%. There is a need to further study in this regard, however, it should also be kept in mind that as the proportion of fibers increases in concrete the workability of concrete decreases drastically. Therefore, it will be recommended to add admixture as well in order to make sound, sustainable, and workable concrete.

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