

# Effect of Glass Fibers on The Mechanical Behavior As Well As Energy Absorption Capacity and Toughness Indices of Concrete Bridge Decks.

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## Research Article

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# Abstract

In this study, the incorporation of glass fibers in concrete bridge decks has been studied for improving its mechanical properties as well as energy absorption capacity and toughness indices. The mix proportion of 1:3:2 (cement:sand:aggregate) was selected having water-cement ratio of 0.71. For the manufacturing of glass fiber reinforced concrete (GFRC), the glass fibers (2-inch) were incorporated at a percentage level of 1%, 2%, 3% and 4% by weight of cement in concrete mixes. The findings reveal that the split-tensile and flexural strength of GFRC increases at all the percentage levels, however, the compressive strength of the blended mixes get reduced by increasing the dosage of glass fibers in the concrete. Besides, the energy absorption and toughness indices are also studied for different types of loadings (i.e. compressive, splitting-tensile and flexural loadings) up to a percentage level of 4%. The findings reveal that the split-tensile and flexural energy absorption was increased with the increase in the dosage of glass fibers in comparison with the conventional concrete mixes, however, the compressive energy absorption of the blended mixes get reduced by increasing the dosage of glass fibers in the concrete. Whereas, the toughness indices for compressive, split-tensile and flexure was increased while increasing the percentage of glass fibers as compared to the conventional concrete. Among the different percentages of glass fibers, its 4% addition gives better results as compared to 1%, 2% and 3%. Hence, the 4% of GF can be suggested to be the optimum percentage of the fibers for the selected mix-design in controlling the resistance of concrete in the bridge decks. Although, the energy absorption of GFRC is lesser in comparison with the toughness indices, GFRC are appropriate for enhancing ductility and resistance against loadings in concrete bridge decks.

## 1. Introduction

Concrete is a commonly utilized material for buildings, however, it is facing numerous deficiencies in the industry of engineering. These deficiencies are higher brittle behavior, low ductility, insufficient impact toughness and lower tensile strain and tensile strength [1–5]. Employing the principle of reinforcing bars at micro level, i.e. addition of different non-continuous fragmented fibers in concrete, such intrinsic shortcomings of concrete might be significantly avoided [6]. At commercial level, a lot of different kinds of fibers are available i.e. glass, steel, naturally produced fibers and synthetically produced fibers [1,7–14]. Amongst them, glass fiber (GF) is predominant micro-reinforcing material that is prevalently employed for the purpose of enhancing the concrete performance. Hence, predicting the characteristics of concrete reinforced with fibers is a crucial parameter for the secure and reliable construction.

Various investigations with regards to the incorporation of GF in concrete mixtures are performed to improve its mechanical behavior. Addition of GF might tie-up the micro cracks that occurs in the concrete mix by redistributing the stresses and preventing it from diffusing to the edges of the cracks [6,15–17]. Consequently, an enhanced prohibitory influence occurs at the initial and propagating phase of the crack in the matrix that may enhance the related bearing capacity after the ultimate loading [18]. Along with these, achieving a mode of failure in which cracks occurs without breaking [19–21], as a result improve the mechanical behavior of concrete such as, flexure-and tensile strength, ductility, toughness, energy

absorption and modulus of rupture [16,17,19,20,22–37] that results in changing the behaviour to a ductile material [29,31,32]. Most of the mentioned investigations are related to the impacts of fibers on the mechanical and durability characteristics of concrete where a constant water-to-binder proportion was used obtaining an optimum amount of fibers [24,31,32,38–40], without taking into account its influence that is a significant factor while preparing composite cementitious materials. Furthermore, the fibers dispersed in the random pattern might efficiently prevent the crack from widening and propagating in the concrete matrix that improve the post-cracking ductile behavior of concrete when subjected to static as well as impact loadings. The efficiency of fibers in improving the post-cracking behavior is dependent upon the performance of bond that is influenced by various parameters i.e. the amount of fibers in a unit area, shape of fibers, orientation of fibers, aspect ratio and strength of the matrix etc. By the developmental progress in the field of civil engineering, consideration has also been given to the concrete's durability. The incorporation of GF in the concrete may influence its durability. GF might efficiently regulate the cracking potential of plastic shrinkage [41,42], strain at drying shrinkage [14,21,25,27] and improve resistance of freezing and thawing [14,43–45].

The static and dynamic properties of concrete can be enhanced by the utilization of small distinct and homogeneously distributed natural fibers, which act as a crack arrestor [46]. In the early 1940s, glass fiber reinforced concrete (GFRC) was first recognized by the Russians and then the development was followed by the USA, England, and Canada [47]. The GFRC is a combination of cement, sand, aggregate, and glass fibers [48]. The improvement in the durability of concrete is reported by using glass fibers in concrete [49–55]. A parametric investigation was carried out by Shirish on GFRC to improve its durability and plummet cracking [46]. Before the application of load, the micro-cracks were developed. These micro-cracks opened up and propagated with the application of load which ultimately resulting in macro cracks. The different mix design ratios were used for the casting of cylinders and beams to assess the compressive and flexural strength. The 1:3.24:5.1 mixed design ratio was used for the control sample with w/c ratio of 0.50. The 0.025% of glass fiber was added by the total volume of concrete. The compressive and flexural strength was increased by 10% and 8% respectively as compared to that of control samples [56]. Globally the glass fiber is mostly produced by the USA, Europe, Latin America, and the Middle East and Africa. [57].

Furthermore, the expansion of corroded steel is responsible to develop cracks and spall in the concrete bridge decks that result in significant cost of rehabilitation and interruption of the traffic [58]. Issues regarding the expansion of corrosion might be solved to protect steel reinforcement from agents that causes corrosion or to use non-corrosive materials for the production of steel. Fiber reinforced polymer (FRP) reinforcement for composite is an alternate choice which is being effectively utilized in various construction applications and are presently employed as a reinforcement in concrete for bridge decks and various other building components [59-62]. In practical terms, various concrete bridge decks are constructed in recent times in North America using GFRP composite reinforcement [63-64]. While facing shortage of funds, the government or the owners of bridge are nowadays seeking for finding alternate materials to be utilized for bridge rehabilitation, replacement and repair. After successfully completion of various FRP bridge deck schemes [65], for example, the Bentley Creek scheme in New York [66], polymer composites nowadays are getting popularity in the applications of civil engineering. Particularly, polymer

composite demonstrate several benefits over conventional reinforced concrete steel decks that includes resistance to corrosion, easiness in erection, continuous construction and higher ratio of strength to weight. Such features enable composites an option that is extremely desirable.

Concrete bridge decks constructed using GFRP are principally prominent because such types of bridges have satisfactorily replaced traditional concrete steel decks in numerous bridges. In comparison with the steel and concrete decks, GFRP composite decks have considerable benefits because such bridge decks have higher ductility as well as free of corrosion. Besides, GFRP bridge decks probably have lower cost for repairing and have extended service life as compared to traditional concrete decks. GFRP concrete decks possess light weight due to which the self-weight is almost reduced to 80% in comparison with the traditional concrete decks. And owing to the light weight of the GFRP composite decks, considerably smarter structure of the bridges can be constructed. Moreover, the capacity of the bridge decks when subjected live loadings might be enhanced without enhancing the capacity of the sub-structure when GFRP composite deck is utilized for the purpose of re-decking. As GFRP composite decks are constructed comfortably and rapidly, the constructing period decreases remarkably and at the same time the volume of interruption to traffic decreases. By means of this the savings of urban society will be remarkably enhanced with regards to direct or indirect cost.

The necessities of usage of GF in construction applications are increasing day by day. According to the authors, the findings related to different percentages of GF in the development of GFRC are limited. GF is significantly advantageous for improving the flexure and tensile strength of concrete [67–69]. Concrete reinforced with GF has been utilized in several construction purposes practically and acquired the compressive strength up to 40–60 MPa [70]. Concrete reinforced with GF have been widely used for the construction of sewer lines, formworks, roof finishing and head-walls of the mass structures [71]. Considering all of the above mentioned benefits of GF, efforts have been made in this study to conclude findings related to the utilization of different percentages of GF for concrete bridge decks.

## **2. Significance Of The Study**

A significant amount of studies has been carried out on the utilization of different fibers for the modification of concrete in order to enhance the mechanical and durability performance of concrete [37,72]. Past research studies revealed that GFRC shows better resistant against the aggressive environment and also improve compressive strength of the concrete at 1.5% dosage [37] and 1.2% dosage [73] of GF. But on the other hand, some research studies revealed that at 0.5%, 1% and 2% dosage [56] and 5% dosage [57] of GF, the compressive strength of the concrete decreases. Therefore, it is very essential to study the trend and effect at different percentage levels of glass fiber (i.e. 1%, 2%, 3% and 4%) on the mechanical and durability properties of concrete. In this study an attempt was made to develop blended mixes of GFRC and to evaluate the effect of different percentages of glass fiber on mechanical properties and their corresponding toughness indices, pre-cracked energy absorption and total energy absorption in order to obtain optimum value of glass fiber dosage.

### 3. Materials And Methods

#### 3.1 Materials

In this research, the locally available ordinary Portland cement, Fine aggregate of Lawrencepur (local name) quarry, the coarse aggregate of Margala (local name) quarry, tap water, and glass fibers having 2" length and diameter of 0.0063" were used for the production of control samples (CS), as well as for the glass fiber reinforced concrete (GFRC) to assess the effect of GF on the mechanical properties of concrete and their corresponding toughness indices, pre-cracked energy absorption and total energy absorption. The properties of glass fibers used in this study are shown in Table 1 while glass fiber used in this study is shown in the Figure 1. The maximum size of coarse aggregate was 0.75" in this study.

**Table 1:** Mechanical and thermal properties of glass fiber

Density (lbs/ft <sup>3</sup> )	Tensile strength (MPa)	Tensile modulus (GPa)	Linear coefficient of thermal (10 <sup>-6</sup> /K)	Elongation at break %
1.62937×10 <sup>-4</sup>	1595.6	72.66	5.56	3.78

#### 3.2 Mix proportioning and preparation of specimens

In this study, the mix design of concrete was prepared for the target strength of 2500 psi in accordance with ACI 211. A total of 135 specimens were casted, 27 for each batch which means 45 specimens for compressive, 45 specimens for Flexural, and 45 specimens for split tensile strength. In order to obtain the average result of each strength, 3 specimens were tested at each curing age. The different batch quantities of the control specimen and GFRC at 1%, 2%, 3%, and 4% mixes were calculated accordingly, which is shown in Table 2. For the preparation of different specimens for the compressive, flexural and splitting tensile strength, the molds were oiled and concrete with different percentages of GF were mixed according to the mix design given in Table 2. Then concrete was poured in the molds and stored for 24± 8 hours at room temperature. Before the immersion of the specimen in water, specimens were stored in an open environment for 30 minutes and then the specimens were kept in a water tank at 25 °C and consequently tested at the age of 7, 14, and 28 days. The coefficient of variation (COV) has also been found out for all the test results of 28 days strength as it is an important indicator of the dispersion of dataset.

**Table 2:** Mix design for mechanical properties evaluation

Materials	Batch Weights (lbs./ft <sup>3</sup> )				
	CS	MS <sub>1</sub>	MS <sub>2</sub>	MS <sub>3</sub>	MS <sub>4</sub>
Cement	165.3	165.3	165.3	165.3	165.3
Coarse aggregate	330.6	330.6	330.6	330.6	330.6
Fine aggregate	495.9	495.9	495.9	495.9	495.9
Water	115.7	115.7	115.7	115.7	115.7
Glass fibers	0	1.7	3.3	5	6.6

## 4. Experimental Program

### 4.1 Fresh properties

For the assessment of the workability of both modified concrete and control sample, slump cone tests were carried out according to the provision of ASTM C143M-15a [74] and the influence of glass fiber (GF) on the workability of concrete with a different fraction of glass fiber are determined. The density of control sample and modified sample were measured according to ASTM C138/C138M-16 [75]. From the workability, it can be predicted that with how much ease a concrete can be placed. The value of slump more than 5" indicates more workable concrete and less than 1" tells about the stiffness of concrete. Because of the retention and confinement effect of glass fiber, the workability of GFRC gets reduced by increasing the percentage of glass fiber. A similar trend of workability was reported by previous researches [2, 56]. The corresponding results are listed in Table 3.

**Table 3:** W/C ratio, Mix design ratio, Slump and density of CS and GFRC

Samples	W/C ratio	Mix design ratio	Slump(in.)	Density (lbs. /cft.)	Drop in Density (%)
CS	0.71	1:3:2	2.23	142	0
MS <sub>1</sub>	0.71	1:3:2	1.97	140	1.4
MS <sub>2</sub>	0.71	1:3:2	1.63	137	3.5
MS <sub>3</sub>	0.71	1:3:2	1.3	135	4.9
MS <sub>4</sub>	0.71	1:3:2	1	131	7.7

### 4.2 Hardened properties

For the assessment of hardened state mechanical properties compressive strength, flexural strength, splitting tensile strength and their corresponding pre-crack energy absorption, post-crack energy

absorption, total energy absorption and toughness index were carried out on both the control specimens as well as on glass fiber modified specimens.

#### 4.2.1 Compressive strength test

To assess the influence of GF on the compressive strength of concrete, ASTM C39/C39M-15a [76] standard method was followed and cylindrical specimens of 12" height and 6" diameter were used. The molds were oiled, and concrete with different percentages of GF was poured in cylinders and stored for  $24 \pm 8$  hours at room temperature. Before the immersion of the specimen in water, specimens were stored in an open environment for 30 minutes, and then the specimens were kept in a water bath at 25 °C for 7, 14, and 28 days, then the specimens were tested by using the universal testing machine (UTM). In order to obtain the average result of strength, 3 specimens were tested at each curing age.

#### 4.2.2 Flexural strength test

Flexural test was performed according to ASTM C78/C78M-15b [77] provision. Specimens of 4" × 4" × 20" beam were prepared for each mix of concrete and for the casting of samples, the same procedure was followed as for compressive strength. The beam specimens were tested according to ASTM C 78 provision using a third point load by UTM. After the failure of specimens, interpretations of the concrete matrix were made. The specimen's tensile strength was determined according to the given formula.

$$\text{Strength of flexural test (psi)} = \frac{PL}{BD^2}$$

Where,

P = Applied load

L = span length

B = Width in inches

D = failure point depth in inches

#### 4.2.3 Tensile strength test

Split tensile tests were performed according to C496/C496M-11 [78] provisions. Specimens of 6" × 12" cylinder were prepared for each Mix of concrete and for the casting of samples, the same procedure was followed as for compressive strength. The specimens were kept in a water tank for curing of 7, 14, and 28 days. The specimen's tensile strength was determined according to the given formula.

$$\text{Strength of split tensile test (psi)} = \frac{2P}{\pi LD}$$

Where,

P=applied load

L=length

D=diameter

#### 4.2.4 Energy absorption and toughness indices

The pre-crack energy absorption, post-crack energy absorption, total energy absorption and toughness index for Compression, splitting tensile and flexural are calculated in accordance with the past studies as described in the Table 4. The pre-crack energy absorption of compressive, flexural and splitting tensile strength (CPE, FPE, SPE) was taken as the load applied up to the first crack development. Similarly, the compressive, flexural and splitting tensile cracked energy absorption (CCE, FCE, SCE) was taken as the load from the first crack up to the maximum load taken by the sample in compression, flexural and splitting tensile. The stresses from zero to maximum absorbed by the sample in compression, flexural and splitting tensile were taken as total energy absorption (CE: P-Maximum), FE (P-Maximum), SE (P-Maximum) respectively. Whereas, the compression, flexural and splitting tensile toughness indices (CTI, FTI, STI) were taken as the ratio between the maximum energy absorbed during the Compression, flexural and splitting tensile tests to the energy absorbed before compression, flexural and splitting tensile pre-cracking energy (i.e. CE (Maximum-P)/CPE), FE (Maximum-P)/FPE, SE (P-Maximum)/SPE), under the load deflection curve, respectively [57,77,79,80,81,82].

**Table 4:** The parameters examined in accordance with the testing standards and past studies

Tests performed	Reference	Examined parameters
Compressive properties	[57,76,79]	Compressive strength, CPE, CCE, CE (P-maximum), CTI
Flexure properties	[77,83,84]	Flexure strength, FPE, FCE, FE (P-maximum), FTI
Split-tensile properties	[57,78,79, 85]	Split-tensile strength, SPE, SCE, SE (P-maximum), STI

## 5. Results And Discussion

### 5.1 Compressive strength, energy absorption and toughness indices

The utilization of low percentage of fiber to binding material is important in order to make a workable concrete mix and to get a homogenous distribution of fibers content within the plain cement composites [86]. Table 5 shows that even though the modified sample found to be workable, the compressive strength of the GFRC is significantly dependent on the percentage fibers in concrete.

**Table 5:** Compressive strength, COV, CPE, CCE, CE (Maximum-P), CTI of CS and GFRC for 28 days strength

Parametric Values	Different concrete samples				
	CS	MS <sub>1</sub>	MS <sub>2</sub>	MS <sub>3</sub>	MS <sub>4</sub>
Compressive strength (psi)	2887	2764	2747	2713	2650
COV (%)	3.1	2.5	1.8	1.3	1.1
CPE (kN.s)	1381.43	1305.63	1230.24	1195.50	1159.75
CCE (kN.s)	935.12	920.30	901.56	883.66	864.80
CE (Maximum-P) (kN.s)	2316.55	2225.93	2131.80	2079.16	2024.55
CTI (-)	1.68	1.70	1.73	1.74	1.75

Figures 2 and 3 shows the change in behaviour of compressive strength of concrete with the increase in percentage of GF. It can be clearly observed that as the percentage of GF increases, the compressive strength of concrete decreases and the maximum drop in strength percentage occurred was 10.2% at the age of 14 days in MS<sub>4</sub>. This is Because of entanglement of some GF which might probably produce pores and cause a reduction in the compressive strength. Another reason could be the heterogeneity of GF, besides, more binding material are required to coat the surface of the fiber when higher percentage of fibers are used and heterogeneity of GF with concrete. Similar trend and observation were made by the previous research studies on the compressive strength of fiber reinforced concrete [57,86].

Compressive strength for 28 days is calculated from the maximum load of the Compressive test results [76]. The coefficient of variance, compressive strength, CPE, CCE, CE (Maximum-P) and CTI of CS and modified specimens are illustrated in Table 6 and Figure 4. The compressive strength of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 2887 psi, 2764 psi, 2747 psi, 2713 psi, and 2650 psi, respectively. The compressive strength of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> has decreased by 4.3%, 4.8%, 6.0% and 8.2%, respectively, in comparison with the CS. The CPE of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 1381.43 kN.s, 1305.63 kN.s, 1230.24 kN.s, 1195.5 kN.s and 1159.75 kN.s, respectively. The CPE of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> reduced by 5.8%, 12.28%, 15.5%, and 19.1%, respectively in comparison with the CS. The CCE of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 935.12 kN.s, 920.30 kN.s, 901.56 kN.s, 883.66 kN.s and 864.80 kN.s, respectively. The CE (Maximum-P) of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 2316.55 kN.s, 2225.93 kN.s, 2131.80 kN.s, 2079.16 kN.s and 2024.55 kN.s, respectively. The CE (Maximum-P) of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were decreased by 3.92%, 7.98%, 10.25%, and 12.61%, respectively. The reason of the decrease in CPE, CCE and CE (Maximum-P) in the modified samples could be the same as for compressive strength i.e. because of pores development, due to the entanglement, heterogeneity of GF, higher percentage of the fibers [57,86]. The CTI of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 1.68, 1.70, 1.73, 1.74, and 1.74, respectively. Comparatively the CTI of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were increased by 1.19%, 2.97%, 3.57% and 4.16% in comparison with the CS, respectively. The CTI is increased due to the resistance provided by the glass fiber against the cracking phenomenon in concrete because GF provides significant resistance against

stresses after development of cracks. Similar results and observation were made by the previous research studies on the fiber reinforced concrete compressive Strength, pre-crack energy absorption and toughness index [57,86].

## 5.2 Flexural strength, energy absorption and toughness indices

The tests for Flexural strength were carried out at the age of 7, 14, and 28 days. Figures 5 and 6 show the change in behavior of the concrete with the increment in the percentage of GF. The results and data related to flexural strength revealed that, the flexural strength continuously increasing by increasing the percentage of fiber in the concrete mix. A maximum increase in the flexural strength of 21.5% was observed at the age of 28 days as compared to the control sample with the addition of 4% GF in the concrete mix. This is because of the efficiency of GF in controlling the cracks by delaying its first crack load [87,88]. Another reason could be the high elastic modulus and tensile strength of the GF which ultimately improves the flexural load carrying capacity of GFRC [89]. Similar trend and behavior of flexural strength was also reported by previous research studies by using glass fiber, steel fiber and carbon fiber etc. [57,90,91].

**Table 6:** MOR, COV, FPE, FCE, FE (Maximum-P), FTI of CS and GFRC for 28 days strength

Parametric Values	Different concrete samples				
	CS	MS <sub>1</sub>	MS <sub>2</sub>	MS <sub>3</sub>	MS <sub>4</sub>
MOR (psi)	567	584	605	656	689
COV (%)	1.2	2.3	1.6	1.4	1.3
FPE (kN.s)	75.35	72.26	69.48	67.35	65.73
FCE (kN.s)	0	5.66	9.96	13.22	15.05
FE (Maximum-P) (kN.s)	75.35	77.92	79.44	80.57	80.78
FTI (-)	1	1.07	1.14	1.19	1.22

Modulus of rupture (MOR) for 28 days is calculated from the maximum load of the flexural load test [77]. The coefficient of variance, MOR, FPE, FCE, FE (Maximum-P) and FTI of CS, and modified samples are illustrated in Table 6 and Figure 7. The MOR of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 567 psi, 584 psi, 605 psi, 656 psi, and 689 psi respectively. The MOR of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> has enhanced by 3.0%, 6.7%, 15.7%, and 21.5% respectively, in comparison with the CS.

The FPE of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 75.35 kN.s, 72.26 kN.s, 69.48 kN.s, 67.35 kN.s and 65.73 kN.s, respectively. The FPE of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were reduced by 4.2%, 8.4%, 11.8%, and 14.63%

respectively in comparison with the CS. The reason for the increased FPE of CS is that the first crack in CS appears at the maximum load and then it goes through brittle failure phenomena [57]. The FCE of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 0 kN.s, 5.66 kN.s, 9.96 kN.s, 13.22 kN.s and 15.05 kN.s, respectively. The FE (Maximum-P) of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 75.35 kN.s, 77.92 kN.s, 79.44 kN.s, 80.57 kN.s and 80.78 kN.s, respectively. An incremental trend has been observed while increasing the percentage of glass fiber in the concrete which was 3.41%, 5.42%, 6.92%, and 7.2%. The FTI of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 1, 1.07, 1.14, 1.19, and 1.22 respectively. Comparatively, the FTI of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were increased by 7%, 14%, 19%, and 22% respectively, in comparison with the CS. The increase in the FCE, FE (Maximum-P) and FTI could be the same as in flexural strength i.e. efficiency of GF of controlling the cracks, by delaying its first crack development [87,88]. Another reason could be the high elastic modulus and tensile strength of the GF, which ultimately provide the bridging effect and improves the FCE, FE (Maximum-P) and FTI of the modified specimens [89]. Similar incremental trend and behavior of flexural strength, toughness indices and energy absorption were reported by previous research studies by using glass fiber, steel fiber and carbon fiber etc. [57,90,91].

### 5.3 Split tensile strength, energy absorption and toughness indices

The tests for splitting tensile strength were carried out at the age of 7, 14, and 28 days. Figures 8 and 9 show the change in behavior of the concrete with the increment in the percentage of GF. The test results and data related to splitting tensile strength revealed that, the splitting tensile strength continuously increasing by increasing the percentage of fiber in the concrete mix. A maximum increase in splitting tensile strength of 31.2% was observed at the age of 28 days as compared to the control sample with the addition of 4% of GF in the concrete mix. This is because of the utilization of the maximum tensile strength capacity and bridging effect of GF under the splitting tensile load [57,90]. Similar trend and behavior of splitting tensile strength was also reported by previous research studies by using glass fiber, steel fiber and carbon fiber etc. [90,91,92].

**Table 7:** STS, COV, SPE, SCE, SE (Maximum-P), STI of CS and GFRC for 28 days strength

Parametric Values	Different concrete samples				
	CS	MS1	MS2	MS3	MS4
STS (psi)	391	432	456	487	513
COV (%)	1.4	1.7	1.9	1.8	1.1
SPE (kN.s)	662.38	647.82	635.65	619.30	609.8
SCE (kN.s)	0	80.44	115.35	140.50	164.95
SE (Maximum-P) (kN.s)	662.38	728.26	751.00	759.8	774.75
STI (-)	1	1.12	1.18	1.22	1.27

The splitting tensile strength (STS) for 28 days was calculated from the maximum load taken by the specimen during the splitting tensile strength test [78]. The coefficient of variance, STS, SPE, SCE, SE (Maximum-P) and STI of CS, and modified are illustrated in Table 7 and Figure 10. The STS of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 391 psi, 432 psi, 456 psi, 487 psi and 513 psi respectively. The STS of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were increased by 41 psi, 65 psi, 96 psi and 122 psi, respectively in comparison with the CS. The maximum value of STS was obtained for MS<sub>4</sub> which was 513 psi. The SPE of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 662.38 kN.s, 647.82 kN.s, 635.65 kN.s, 619.30 kN.s and 609.8 kN.s, respectively. The SPE of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were reduced by 2.2%, 4.2%, 6.9%, and 8.6% respectively in comparison with the CS.

The reason for the increased in SPE of CS is that the first crack in CS appears at the maximum load and then it goes through brittle failure phenomena [57]. The SCE of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 0 kN.s, 80.44 kN.s, 115.35 kN.s, 140.50 and 164.95 kN.s, respectively. The SE (Maximum-P) of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 662.38 kN.s, 728.26 kN.s, 751.00 kN.s, 759.8 kN.s and 774.75 kN.s, respectively. An incremental trend has been observed while increasing the percentage of glass fiber in the concrete which was 9.9%, 13.37%, 16.21% and 16.9%. The STI of CS, MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> were 1, 1.12, 1.18, 1.22, and 1.27 respectively. Comparatively the STI of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> was increased by 12% 18%, 22%, and 27% in comparison with the CS, respectively. The increase in the SCE, SE (Maximum-P) and STI could be the same as in splitting tensile strength i.e. utilization of maximum tensile capacity of GF, and bridging effect of GF [57,88,89]. Similar fashion of increasing trend and behavior of splitting tensile strength, toughness indices and energy absorption were reported by previous research studies by using glass fiber, steel fiber and carbon fiber etc. [57,90,93].

#### 5.4 Discussion on optimization of glass fiber in concrete bridge decks

The optimization of glass fiber content for control sample and modified sample are shown in Table 5–7. A study [94] was conducted on the mechanical and durability properties of glass and polypropylene fiber reinforced concrete and according to the authors, owing to the positive effect of bonding force between fibers and cement paste, the compressive and flexural strength of fiber reinforced concrete showed an obviously higher value than the control specimen. Another effective research [95] was carried out in which the authors reported that the maximum compressive strength was obtained at 1.2% percentage of fiber and achieved 13.14% increase over the control mix without using fibers. On the other hand, another study [57] was carried out in which the authors reported in their study that the compressive strength of GFRC will decrease with the addition of glass fibers. A similar result was reported in another study [96], that reduction in compressive strength will occur with the addition of fibers in concrete. A comparison of the past studies and current study are tabulated in Table 8.

**Table 8:** Comparison of modification with past research studies

Parameters	Compressive strength	Flexural, Splitting tensile, toughness indices, total energy absorption
Liu, J., Jia, Y., & Wang, J. (2019).	Increase at 1.5% GF	Increases
Mazen Hilles, M., & Ziara, M. M. (2018)	Increase at 1.2% GF	Increases
Khan, M., & Ali, M. (2016).	Decrease at 5% GF	Increases
Current study	Decreases at 1%, 2%, 3%, and 4% GF	Increases at all levels of percentages

In the current research study, the effect of glass fibers of various percentages (i.e. 1%, 2%, 3%, 4%) on the mechanical and durability properties of concrete were studied with w/c ratio of 0.71 and it was concluded that with the addition of glass fiber, the compressive strength was decreased which is exactly the coincident with past studies [57]. While the flexural, splitting tensile strength, pre-crack energy absorption, post-crack energy absorption, total energy absorption and toughness index were significantly increased. The similar results of improving the flexural, splitting tensile strength, pre-crack energy absorption, post-crack energy absorption, total energy absorption and toughness index were reported by the previous researchers in their studies. Based on the current study, it is concluded that the optimized glass fiber content for the modification of concrete is 4% by weight of cement, which can be used for the improvement of flexural strength, splitting tensile strength, toughness indices and total energy absorption. Moreover, the GFRC with optimized percentage of glass fiber can be used for the controlling of early age micro cracks in bridge deck and for durable concrete against aggressive environment as reported by the previous research studies [37,57,72,73].

## 6. Conclusion

The following conclusions are drawn from this study:

- i. The slump of GFRC specimens is reduced by increasing the dosages of glass fibers in comparison with the controlled specimens. For instance, it is reduced up to percentage level of 11.6%, 26.9%, 41.7% and 55.1% for MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> respectively. Similarly, the density of GFRC was reduced by 1.4%, 3.5%, 4.9% and 7.7% for MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> respectively.
- ii. The flexural and split-tensile strength of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> is increased by increasing the dosages of glass fibers in the concrete as compared to the conventional concrete. The highest

increment in the flexural and split tensile strength was 21.5% and 31.2% respectively, at 4% glass fiber content. Whereas, the compressive strength of MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> are reduced by increasing the content of glass fibers. The highest reduction of 8.2% for 28 days strength was observed when 4% of glass fiber was incorporated in concrete as compared with the conventional concrete.

- iii. Flexural energy absorption is increased by 3.41%, 5.42%, 6.92% and 7.2%, for MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> respectively as compared to that of the conventional concrete. Similarly, the splitting tensile energy absorption is increased by 9.9%, 13.37%, 16.21% and 16.9% for MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub>. On the other hand, the compressive energy absorption is decreased by 3.92%, 7.98%, 10.25% and 12.61% for MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub> respectively as compared to conventional concrete.
- iv. For MS<sub>1</sub>, MS<sub>2</sub>, MS<sub>3</sub>, and MS<sub>4</sub>, the toughness Indices of the compressive strength was increased by 1.19%, 2.97%, 3.57% and 4.16%, it was increased by 7%, 14%, 19% and 22% for flexure while for split tensile it was increased by 12%, 18%, 22% and 27%, as compared to that of the control specimen.
- v. Among the different percentages of glass fibers, its 4% addition gives better results as compared to 1%, 2% and 3%. Hence, the 4% of GF can be suggested to be the optimum percentage of the fibers for the selected mix-design in controlling the resistance of concrete in the bridge decks. However, the relevance of the findings by the authors encourages further study concerning the durability properties of concrete bridge decks incorporating glass fibers, besides; further study might be conducted for more mixture compositions of glass fibers (more than 4%) in order to clearly summarize it before its applications.

## Declarations

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### Authors Contributions

All authors whose names appear on the submission made substantial contributions to the conception, design of the work, acquisition, analysis, interpretation of data and writing/revision of the article

### Availability of data and material

The data used to support the findings of this study are included within the article.

### Conflict of interest

The authors declare that there is no conflict of interest.

## Consent to participate

Not applicable.

## Consent for publication

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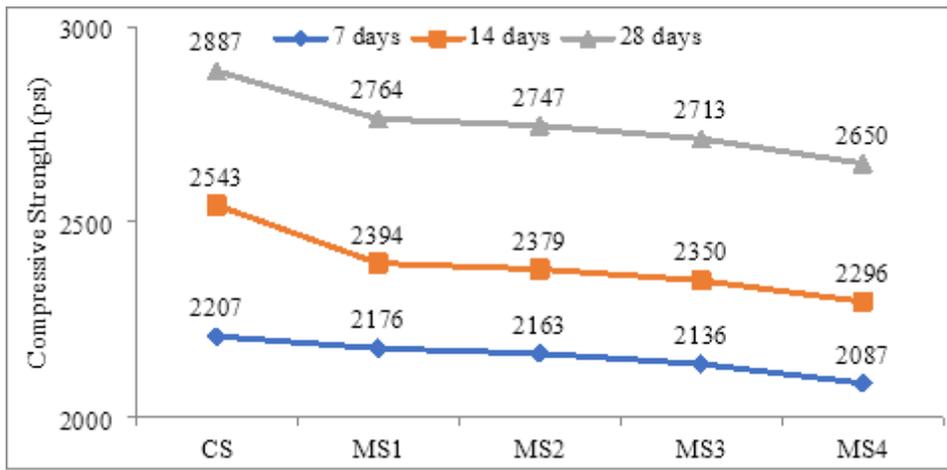
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## Figures



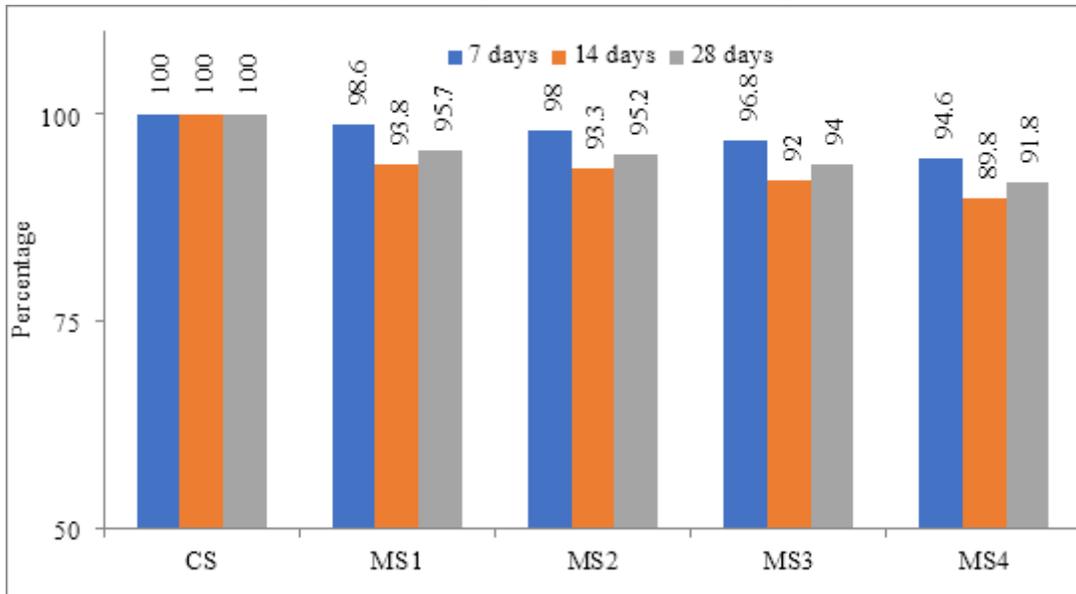
**Figure 1**

Image of the glass fibers used in this study



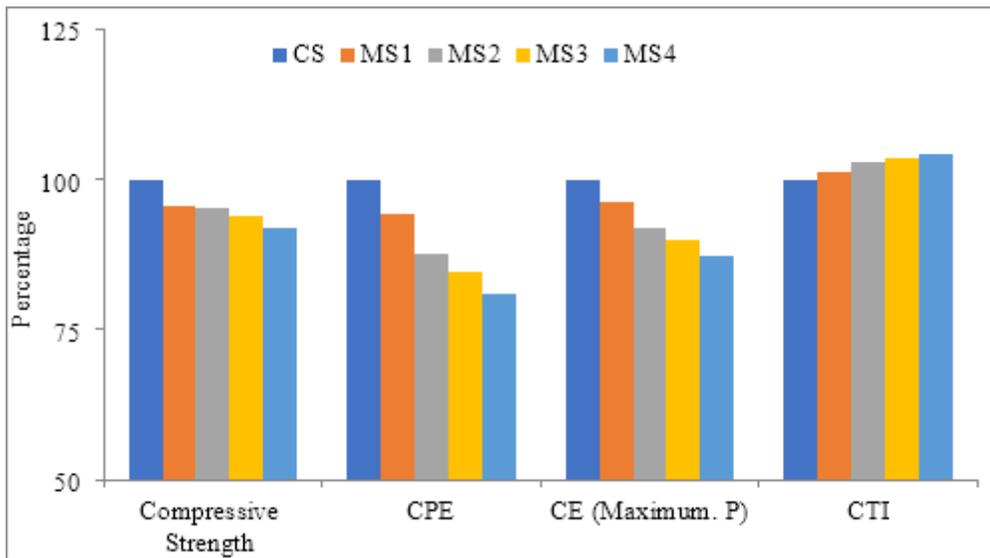
**Figure 2**

comparison of compressive strength at 7, 14 and 28 days



**Figure 3**

Drop in compressive strength (%age)



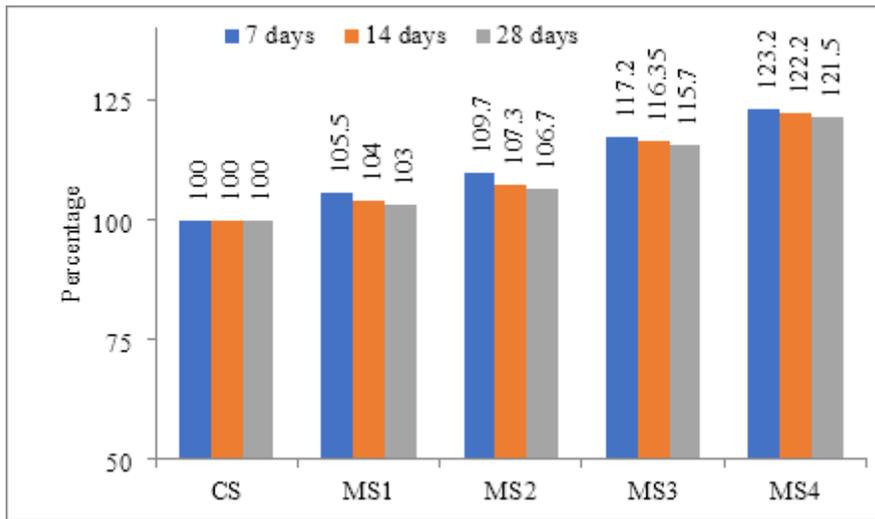
**Figure 4**

comparison of Compressive strength, CPE, CCE, CE (Maximum-P), CTI of CS and GFRC for 28 days strength.



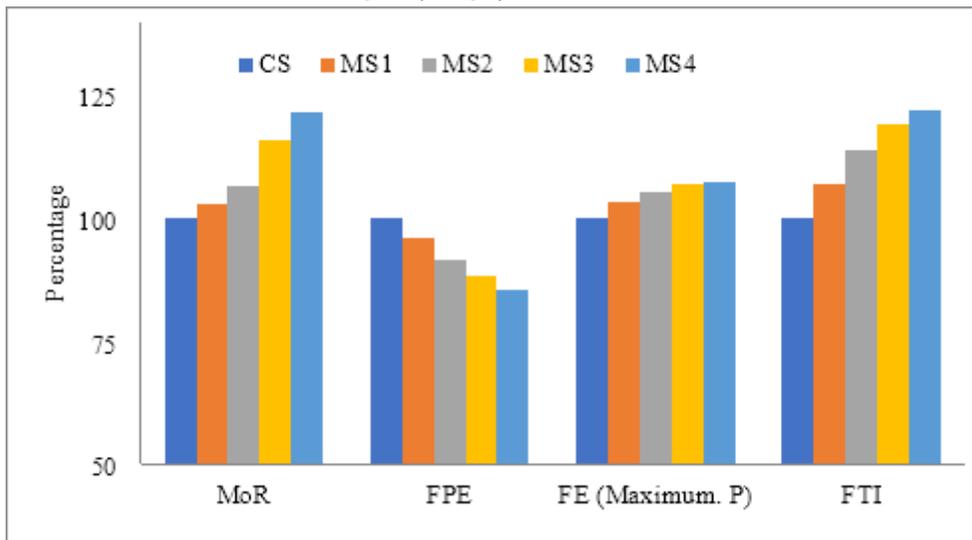
**Figure 5**

Comparison of Flexural strength at 7, 14, and 28 day



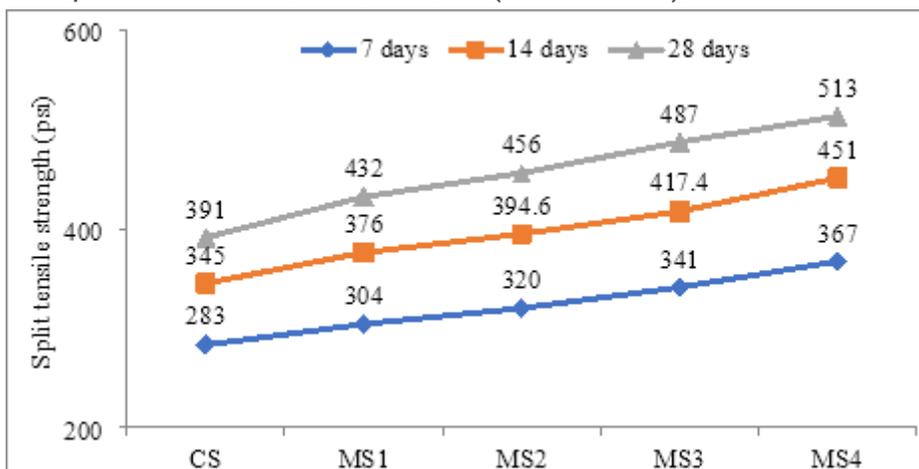
**Figure 6**

Increase in Flexural Strength (%age)



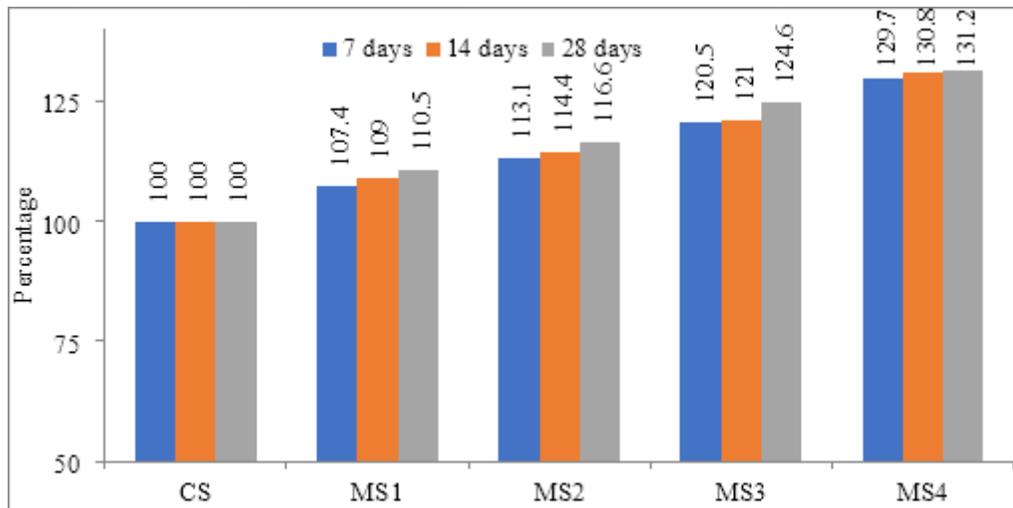
**Figure 7**

Comparison of MOR, FPE, FCE, FE (Maximum P), FTI of CS and GFRC for 28 days strength.



**Figure 8**

Comparison of split tensile strength at 7, 14, and 28 days



**Figure 9**

Increase in Split Tensile Strength (%)



**Figure 10**

Comparison of STS, SPE, SCE, SE (Maximum P), STI of CS and GFRC for 28 days strength.