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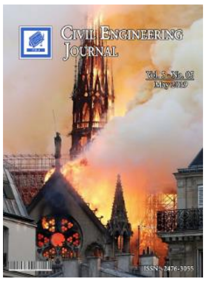

Influence of Glass Fibers on Mechanical Properties of Concrete with Recycled Coarse Aggregates

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Abstract

Despite plain cement concrete presenting inferior performance in tension and adverse environmental impacts, it is the most widely used construction material in the world. Consumption of fibers and recycled coarse aggregates (RCA) can add ductility and sustainability to concrete. In this research, two mix series (100%NCA, and 100%RCA) were prepared using four different dosages of GF (0%GF, 0.25%GF, 0.5%GF, and 0.75%GF by volume fraction). Mechanical properties namely compressive strength, splitting tensile strength, and flexural strength of each concrete mixture was evaluated at the age of 28 days. The results of testing indicated that the addition of GF was very useful in enhancing the split tensile and flexural strength of both RCA and NCA concrete. Compressive strength was not highly sensitive to the addition of GF. The loss in strength that occurred due to the incorporation of RCA was reduced to a large extent upon the inclusion of GF. GF caused significant improvements in the split tensile and flexural strength of RCA concrete. Optimum dosage of GF was determined to be 0.25% for NCA, and 0.5% for RCA concrete respectively, based on the results of combined mechanical performance (MP).

Keywords: Fiber Reinforced Concrete; Recycled Coarse Aggregates; Glass Fibers; Mechanical Properties; Tensile Strength; Flexural Strength.

1. Introduction

Concrete is used more than any other manmade material in the world due to its unique advantages. Formability, high strength (in compression), durability, and the cost-effectiveness of OPC concrete make it more adaptable material than any other conventional material such as wood, steel, bricks, stones, etc. Though concrete has a high compressive strength, but it is brittle and fragile in both tension and bending. Its tensile strength in most of the cases is less than 10% of its compressive strength and typically its tensile strength is neglected in the design of concrete structures [1]. Improving tensile and flexural/bending strength of concrete and minimizing its natural aggregate content can help to add more value to stature of concrete.

To address the lower performance of concrete in tension, different fibers has been used as reinforcement. Fibers of various kinds have been reported to decrease the crack proliferation not only in terms of width but also in numbers when compared to plain concrete. Fibers affect properties of concrete in both fresh and hardened states. Fibers affect workability, strength, ductility, and durability of concrete. But fibers are mainly used to enhance the structural performance of concrete. Fibers have been reported to decrease workability [2], therefore, to maintain workability higher dosages of plasticizers are employed. Various studies have shown that inclusion of fibers improves tensile strength,

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flexural strength, toughness, impact resistance, fatigue resistance, the abrasion resistance of concrete [3-5]. Positive effects of fibers on compressive strength have been reported in the studies as about 10% net increase in compressive strength of fiber reinforced concrete was noticed [6-8]. Recommended dosages of most of the fibers vary from 0.5% to 1% in volume fractions [2, 6, 9-12] The reason for the lower volume fractions of fibers being used for the optimal efficiency in increasing the strength properties of concrete is because higher dosages of fibers may result in loss of workability and poor dispersion of fibers. The most common types of fibers which have been used to reinforce concrete and mortars are steel fibers, basalt fibers, glass fibers, polypropylene fibers. Among all steel fibers are the extensively research fibers. Glass fiber (GF) has not been researched to that level, and variances occur in reported results in various studies concerning various parameters of glass fiber reinforced concrete (GFRC). Simes et al. have reported that different kind of fibers may affect the density and porosity of cement mortars differently [13]. They have also reported that polypropylene (PP) fibers decrease the porosity of FRC because their flexibility under compaction cause them to fill voids efficiently. On contrary, GF increase porosity for their rigidness cause them to create voids during the compaction process.

Exploitation of stone quarries for construction aggregates brings a huge negative impact on the environment. Also, natural sources of aggregates are exhausting as demands for them in construction section are growing day by day for new public infrastructure in a developing country like Pakistan. Using recycled aggregates instead of crushed stone aggregates can not only save natural reserves for aggregates but also can save human from issues of waste management pertaining to dumping of construction and demolition wastes. Akhtar et al. [14] reported that the use of recycled aggregates in concrete is eco-efficient and economical than other practices i.e. backfilling, disposal, landfilling, etc.

Use of RCA in concrete as coarse aggregates at very high percentages can affect the strength and durability characteristics of product concrete negatively [14-19]. Coarse aggregates are a major constituent of concrete. Most of the properties of concrete depend on quality of coarse aggregates. RCA usually possess poorer quality than its natural counterpart, due to the presence of low density adhered mortar. Kurda et al. reported in two of their studies that compared to conventional aggregates use of RCA cause insignificant reductions in compressive strength of concrete [15]. They have reported a 10% decrease in compressive strength of concrete when RCA is used as coarse aggregate instead of NCA. Kurad et al. [15] also reported that reductions in global warming potential of concrete are possible if RCA is used in concrete instead of NCA.

Consumption of both fibers (like GF) and RCA may add tensile strength and sustainability to concrete. Impact of GF reinforcement especially on mechanical properties of recycled aggregate concrete has not been studied widely. Rao et al. [20] investigated the behavior of GF reinforced concrete made with 50% RCA using very low fractions of GF. They reported that mechanical performance and ductility of RCA concrete is enhanced at 0.03% GF. But studies pertaining to use of GF with 100% RCA are very scarce. So, the aim of this study was to investigate the mechanical properties of GF reinforced concrete having 100% RCA as coarse aggregates. In this research, three different volume fractions of GF varying from 0.25-0.75% were used in both 100% NCA and 100% RCA concrete mixtures and their strength parameters namely compressive strength, split tensile strength and flexural strength were evaluated and compared.

2. Materials and Methods

2.1. Materials

General purpose (Bestway 43 grade) Portland cement was utilized as binder in this research. This cement follows the specifications for general purpose cement of type II adhering to ASTM C150 [21]. General properties of cement are given in Table 1. Less than 5% weight is retained on 100-micron sieve for this cement.

Natural sand of Lawrence Pur quarry was used as fine aggregate throughout this experimental study. NCA used in this study was crushed limestone obtained from a crushing plant in Margalla Hills, Taxila, Pakistan. RCA was obtained from manual crushing of tested specimen of concrete laboratory of Department of Civil Engineering, University of Engineering and Technology, Taxila, Pakistan. Compressive strength of parent concrete specimens was averaging 30 MPa at 28-days. General properties of both fine and coarse aggregates are listed in Table 2. All the aggregates meet the ASTM C33 requirements of aggregates for concrete [22]. Gradation curves of aggregates are shown in Figure 1, whereas, overview of coarse aggregates (RCA and NCA) is shown in Figure 2.

High range water reducing admixture Sikament 512 was utilized to achieve desired range of workability for all concrete mixes. The triethanolamine and sodium thiocyanate-based plasticizer had the specific weight of 1.12 g/cm^3. Admixture meets the requirements of ASTM type F [23]. Potable water was used throughout the research for mixing of concrete.

CEM-Fil 62 chopped strands type of GF has been used in this research it has general properties listed in Table 3. Overview of glass fibers is shown in Figure 3.

Table 1. Chemical and physical properties of cement

Chemical properties	
Calcium Oxide (CaO)	61.72%
Silica (SiO_2)	21.02%
Alumina (Al_2O_3)	5.04%
Iron Oxide (Fe_2O_3)	3.24%
Magnesium Oxide (MgO)	2.56%
Sulphur Trioxide (SO_3)	1.51%
Loss on ignition (LOI)	1.83%
Insoluble residue (IR)	0.54%
Free lime	0.98%
Physical properties	
Specific gravity	3.12
Specific surface (cm^2/g)	3720
Setting time (mins) (Initial)	102
Setting time (mins) (Final)	608
Strength at 28 days (MPa)	41.45

Table 2. Properties of aggregates

Property	Sand	NCA	RCA
Max. nominal size (mm)	4.75	12.50	12.50
Min. nominal size (mm)	0.075	4.75	4.75
Particle density (g/cm^3)	2.68	2.71	2.39
Saturated Surface dry (SSD) water absorption (%)	0.89	1.45	8.65
10% fine value (kN)	-	157	125
Dry rodded density (kg/m^3)	1624	1547	1271

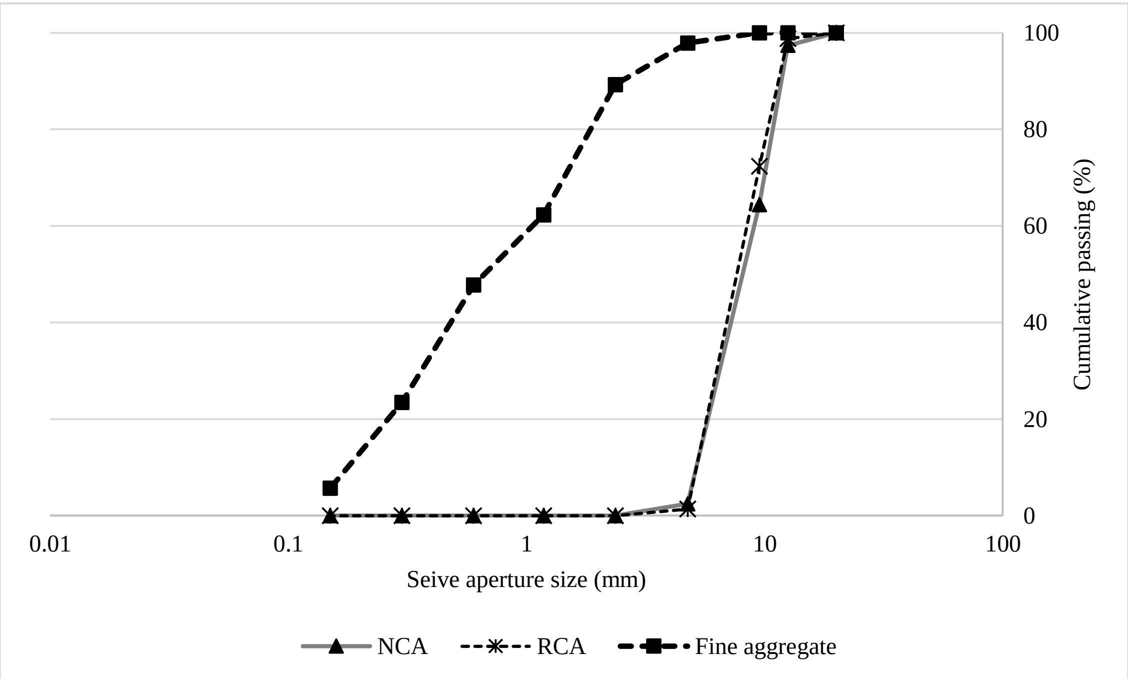


Figure 1. Gradation curves of all aggregates

Figure 2. Overview of (a) RCA and (b) NCA

Table 3. Properties of GF

Type of material	Alkali resistant glass
Fiber length	6-18 mm
Filament diameter	14 microns
Texture	82 gram/km
Loss on ignition	1.16%
Moisture	0.5%
Electrical conductivity	Very low
Chemical resistance	Very high
Modulus of elasticity	72 GPa
Tensile strength	1000-1700 MPa
Specific gravity	2.60 g/cm^3
Softening point	850^{o}C

Figure 3. Overview of GF

2.2. Composition of Concrete Mixtures

Two series of concrete mixes were prepared. All concrete mixtures were designed for cylindrical compressive strength of 30 MPa following ACI guidelines. The first series was prepared using NCA as coarse aggregates and the second series had RCA as coarse aggregate. Both series had a total of four-member mixtures. The first mixture in each series aid as a control for other member mixtures which are fiber reinforced with GF. Fiber reinforced mixtures has three different dosages of GF namely 0.25%, 0.5% and 0.75% by volume fractions. Details of each mix are shown in Table 4. As loss in workability of FRC mixes compared to the plain concrete mix is inevitable, thus dosage of plasticizer was varied to achieve a slump in the range of 80-100 mm.

Table 4. Mix proportions in unit cubic meter of each concrete mixture

Mix Series	Type of Coarse aggregate	GF by volume (%)	Cement (kg/m^3)	Medium sand (kg/m^3)	NCA (kg/m^3)	RCA (kg/m^3)	GF (kg/m^3)	Admixture (kg/m^3)	Water (kg/m^3)	Additional water (kg/m^3)
I	NCA	0	390	845	880	0	0	0	215	6.38
		0.25	390	845	880	0	6.5	0.45	215	6.38
		0.5	390	845	880	0	13	0.98	215	6.38
		0.75	390	845	880	0	19.5	2.13	215	6.38
II	RCA	0	390	845	0	725	0	0.24	215	56.44
		0.25	390	845	0	725	6.5	0.78	215	56.44
		0.5	390	845	0	725	13	1.45	215	56.44
		0.75	390	845	0	725	19.5	2.68	215	56.44

2.3. Preparation and Testing of Specimens

Mixing of all concrete mixtures was done in a mechanical mixer of 0.15 m3 capacity. First aggregates were mixed with 2/3 of water for about 6 mins, to allow aggregates sufficient time to absorb water up to their 80% capacity [24], then cement and GF (in case of fiber reinforced mixes) were added with remaining 1/3 of water and mixing continued for about 4 mins. Required dosage (already determined in trials) of plasticizer was also added along with 1/3 of water in case of the mixtures which required plasticizer to achieve the desired range of workability (80-100 mm slump).

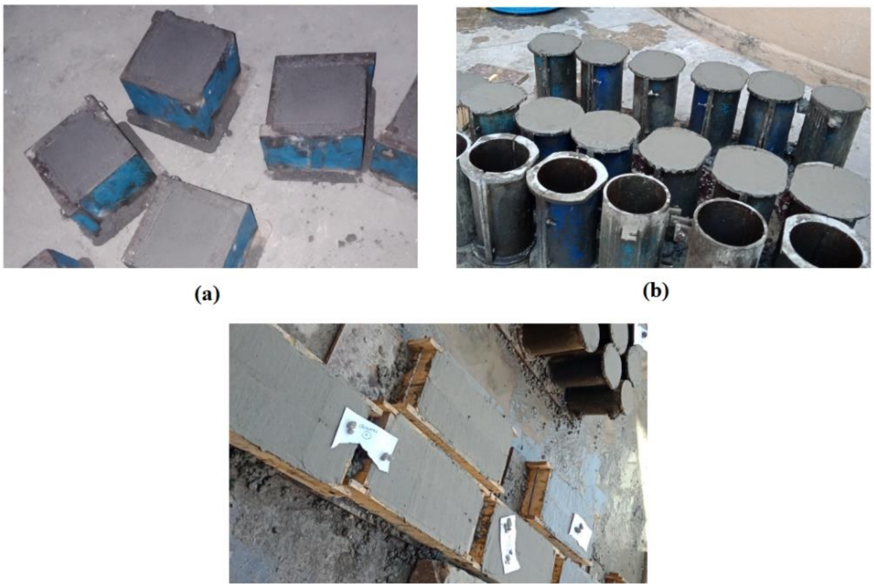
Slump test was used to determine the workability of fresh concrete according to ASTM C143 [25]. 100 mm cubes were cast to measure compressive strength of concrete mixtures following BS: EN 12390-3 [26]. Splitting tensile strength test was conducted on cylindrical specimens of 150 mm diameter x 300 mm height to estimate indirect tensile strength of concrete specimen according to ASTM C496 [27]. Three-point bending test on prisms of dimensions 100 mm x 100 mm x 500 mm was conducted to estimate flexural strength of each mixture according to ASTM C78 [28]. All specimens after casting were kept for setting in molds for about 24 hours. After demolding all specimens were cured in a water tank for the age of 28 days. To determine each strength parameter pertaining to a particular mix three replicate specimens were tested and their average was reported in this research paper. Moreover, the schedule of testing is shown in Table 5. Overview of casting and experimental test setups are shown in Figures 4 and 5 respectively.

Table 5. Schedule of testing

Mix Series	Type of coarse aggregate	GF(%)	Compression testing BS: EN 12390-3 [26] No. of specimens tested	Split tensile testing ASTM C496 [27] No. of specimens tested	Flexural testing ASTM C78 [28] No. of specimens tested
I	NCA	0	3	3	3
		0.25	3	3	3
		0.5	3	3	3
		0.75	3	3	3
II	RCA	0	3	3	3
		0.25	3	3	3
		0.5	3	3	3
		0.75	3	3	3

To optimize the concrete mixes based on their mechanical performance various weights were assigned to each of the strength parameters according to its importance in the design of concrete. Highest weight (of 4) was considered for compressive strength followed by flexural strength (of 2) and split tensile strength (of 1). Mechanical performance of each mixture was evaluated by using Equation 1. In Equation 1, the term ‘f’ refers to strength, ‘MIX’ refers to a particular mix whose mechanical performance (MP) is being evaluated, and ‘CON’ refers to plain NCA mix having 0%GF.

$$MP(\%) = \frac{4\times\frac{f_{compressive\_MIX}}{f_{compressive\_CON}}+2\times\frac{f_{flexural\_MIX}}{f_{flexural\_CON}}+1\times\frac{f_{split\_MIX}}{f_{split\_CON}}}{7} \times 100 \quad (1)$$



(a) (b) (c)

Figure 4. Casting of (a) cubes for compression testing (b) cylinders for split tensile strength and (c) prisms for flexural strength

(a) (b) (c)

Figure 5. Casting of (a) cubes for compression testing (b) cylinders for split tensile strength and (c) prisms for flexural strength

3. Results and Discussions

3.1. Compressive Strength

Results of compression testing are shown in Figure 4. Relative analysis of compressive strength results is also presented in Table 5. General trend shows that inclusion of RCA was detrimental to the compressive strength of concrete. GF inclusion improved the compressive strength of concrete by trivial margins compared to the plain concrete mixes. Compared to NCA mix compressive strength reduced by about 12% when RCA was used as coarse aggregate. As RCA contain some adhered mortar inherited from their parent concrete cause the increase in global porosity of concrete which subsequently reduces compressive strength of concrete [15]. Another factor which may contribute to reductions in compressive strength is that RCA mixes require more water than NCA mixes.

The inclusion of GF caused a trivial increase in compressive strength of NCA concrete. At 0.25% dosage of GF net increase in compressive strength of about 9.7% was observed, see Table 5. Compressive strength did not significantly improve compared to plain NCA mix on further incorporation of GF beyond 0.25%. Although GF had higher specific weight than cement matrix under compaction, their movements can generate voids in concrete due to their rigidity, which may increase the porosity [13]. This can be blamed to decrease compressive strength at dosages higher than 0.25%. Although compressive strength of mixes with GF higher than 0.25% showed a decreasing trend but outperformed plain NCA mix at all dosages. High et al. [9] reported a small increase in compressive strength upon the inclusion of basalt fibers, similarly, Kizilkanat et al. [29] and Song et al. [6] reported an insignificant increase in compressive strength concrete mixes at the age of 28 days upon the inclusion of different types of fibers compared to the control plain concrete mixes.

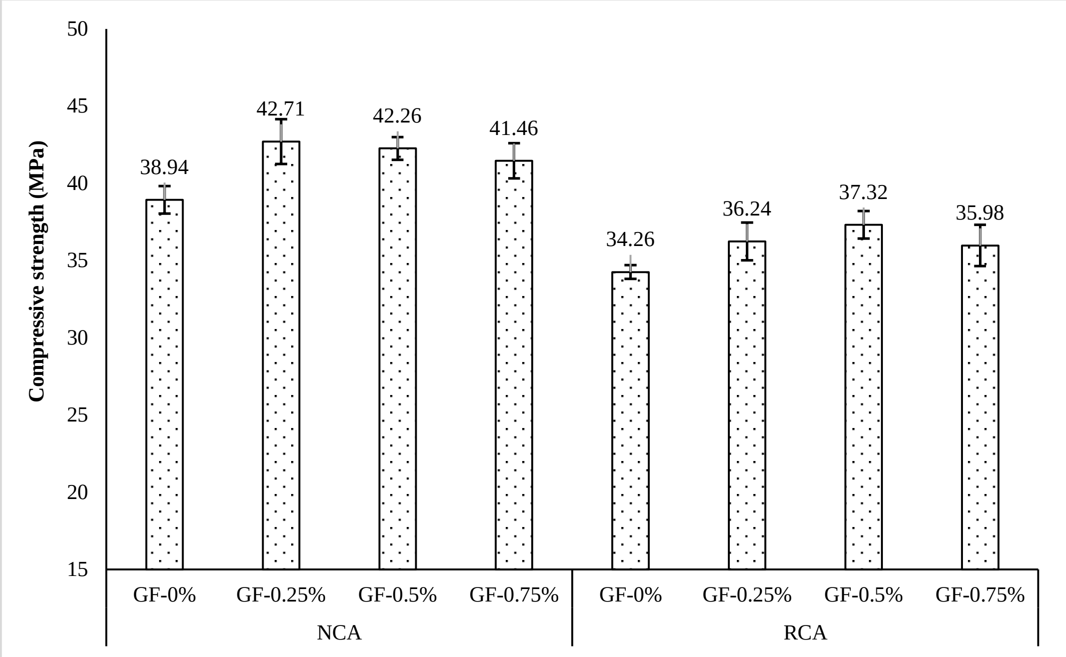


Figure 4. Results of compressive strength

GF addition in RCA mixes also showed ordinary improvements in compressive strength. A small increase of about 8.9% was noticed at 0.5% GF when compared to the plain RCA mix. Upon further inclusion of GF did not show any improvements in compressive strength. The inclusion of GF sufficiently compensates the loss in strength of RCA mixes compared to plain NCA mixes, see Table 6. RCA mix with 0.5% GF performs almost up to the 96% potential of plain NCA mix. It can be said the GF inclusion can help in recovering the drop in compressive strength of concrete with RCA as coarse aggregates.

Table 6. Relative analysis of results of compressive strength

Dosage of GF	NCA mixes	RCA mix	
	Relative compressive strength w.r.t plain NCA mix	Relative compressive strength w.r.t plain RCA mix	Relative compressive strength w.r.t plain NCA mix
0.00%	100.0%	100.0%	88.0%
0.25%	109.7%	105.8%	93.1%
0.50%	108.5%	108.9%	95.8%
0.75%	106.5%	105.0%	92.4%

3.2. Split Tensile Strength

Split tensile strength does not represent the true tensile strength of concrete, but it is a better estimation of the tensile strength and ductility of concrete, as the specimen is allowed to fail under loads that almost split a sample into halves. A brittle specimen would fail suddenly under splitting action of loads after the appearance of the first crack, but a ductile specimen undergoes a failure gradually after the first crack (with enough warning). So, split tensile test gives a good idea about the ductility of a specimen.

Results of splitting tensile strength of all concrete mixes are shown in Figure 7. Whereas, relative analysis of results of split tensile strength are presented in Table 7. While testing it was observed that fiber-reinforced specimens did take sufficient load after the appearance of the first crack, whereas, plain concrete specimens went under failure quickly after the appearance of cracks. RCA inclusion affects the split tensile strength as badly as it did compressive strength. The split tensile strength of plain RCA mix reduced about 11% when compared to that of the plain NCA mix. It can be seen in Figure 7 that effect of GF inclusion was more useful on the split tensile strength of concrete. At the dosage of 0.5%GF, both RCA and NCA mixes showed maximum tensile strengths compared to their corresponding plain concrete mixes.

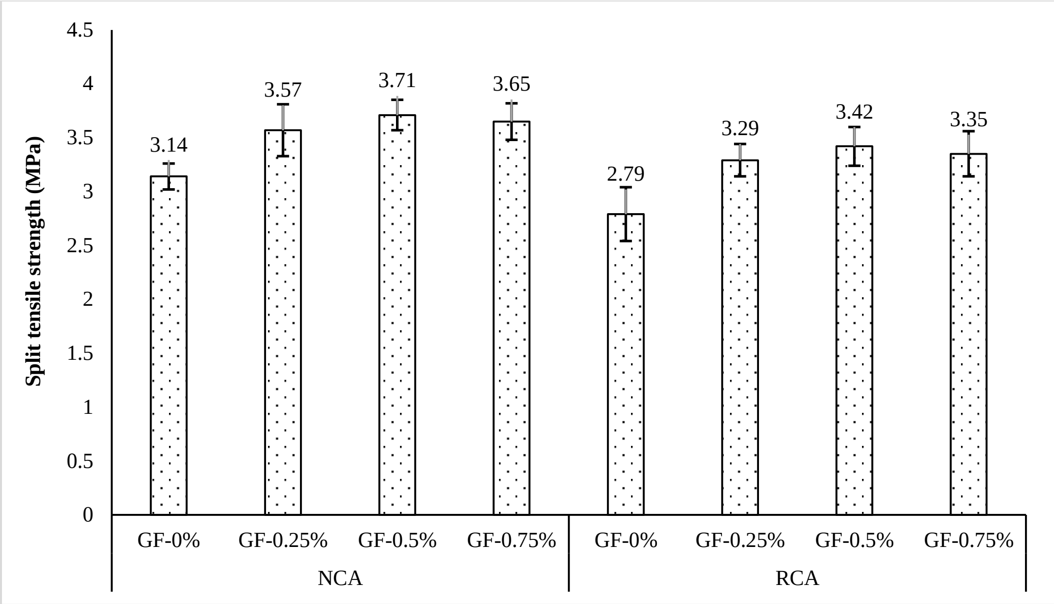


Figure 7. Results of splitting tensile strength testing

The tensile strength of NCA mixes increased by about 13%, 18% and 16% at 0.25%, 0.5% and 0.75% volume fractions of GF respectively when compared with plain NCA mix. Similarly, split tensile strength of RCA mixes increased by about 18%, 22%, and 20% at 0.25%, 0.50%, and 0.75% dosages of GF respectively. As GF have higher tensile strength about 1700 MPa, they increase the stiffness of cement matrix of concrete against tensile forces. Under splitting action of loads, both cohesion of cement matrix and glass fibers offer higher resistance to cracks. In plain concrete mixes where tensile strength only depends on the cement matrix show lesser strength than fiber-reinforced concrete. At dosage higher than 0.5% split tensile strength did not improve which may be ascribed to difficulty in the dispersion of fibers as noted by researchers [29]. Jiang et al [3] reported that inclusion of basalt fiber at optimum dosage increased split tensile strength by about 20%.

Relative analysis of RCA mixes with respect to plain NCA mix presented in Table 7. It shows that RCA mixes with GF outperform plain NCA mix with significant margin. Unlike the results of compressive strength, RCA mixes with GF perform better than plain NCA concrete under tensile load. It is worth mentioning here that increasing the dosage of GF beyond 0.25% split tensile strength of both NCA and RCA concrete mixes does not undergo a marginal increase.

Table 7. Relative analysis of results of split tensile strength

Dosage of GF	NCA mixes	RCA mixes	
	Relative split tensile strength w.r.t plain NCA mix	Relative split tensile strength w.r.t plain RCA mix	Relative split tensile strength w.r.t plain NCA mix
0%	100.0%	100.0%	88.9%
0.25%	113.7%	117.9%	104.8%
0.50%	118.2%	122.6%	108.9%
0.75%	116.2%	120.1%	106.7%

3.3. Flexural Strength

Flexural strength of concrete shows its ability to resist bending loads. In plain concrete flexural strength mainly depends on the strength of the bond between constituents of concrete. It is very well known that harshness and grading of aggregates play a major role in defining flexural strength of plain. Well graded and harsh aggregates offer better flexural strength properties owing to better aggregate interlock and increased internal-friction. In the fiber-reinforced matrix, fibers by virtue of their higher tensile strength increase rigidity of the cement matrix of concrete hence higher flexural strength can be anticipated in fiber-reinforced concrete than that of the plain concrete.

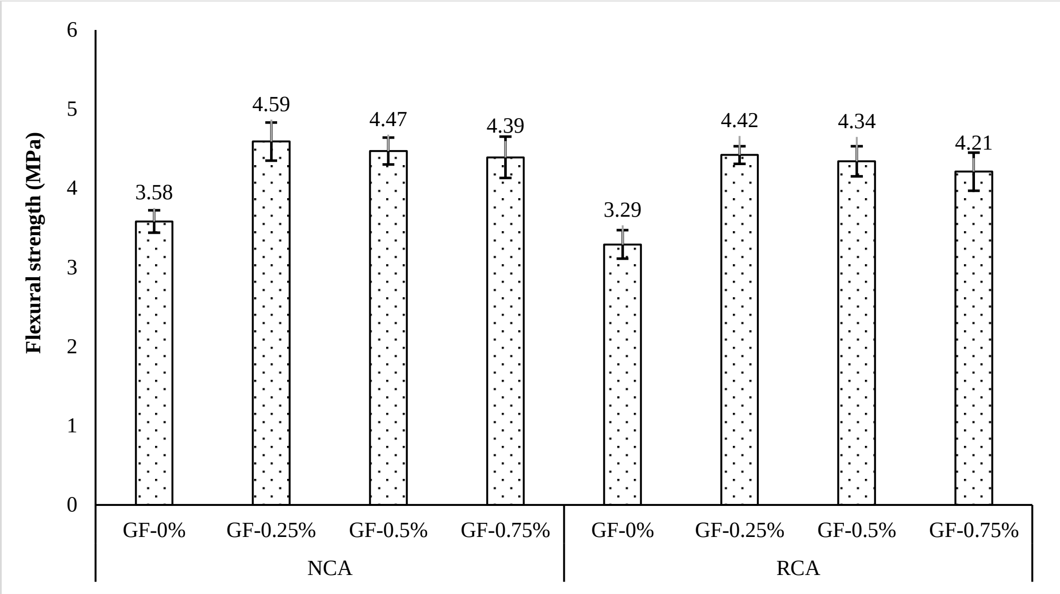


Figure 8. Results of flexural strength

Results of flexural testing are shown in Figure 8, whereas relative analysis of results of flexural strength is presented in Table 8. While testing prismatic specimens under three-point loading, it was observed that fiber reinforced specimens did take load after the appearance of crack at the bottom of prisms and failure was gradual, whereas, in case of plain concrete specimens' failure was sudden. It can be seen from Figure 8 that for both NCA and RCA mixes optimum dosage of GF is 0.25%, increasing GF beyond this dosage does not improve the flexural strength of concrete.

NCA mixes experienced a useful boost in flexural strength compared to the corresponding plain concrete mix. Flexural strength increased by about 28%, 24%, 22% at 0.25%, 0.5% and 0.75% dosages of GF respectively. The results are in accordance with studies of [6, 29, 30]. Jiang et al. [3] also reported a drop in flexural strength when GF dosage increased beyond 0.25%, maximum flexural strength was mentioned at 0.3% dosage of GF. They mentioned that higher dosages of GF were ineffective compared its lower dosages due to dispersion issues.

Table 8. Relative analysis of results of flexural strength

Dosage of GF	NCA mixes	RCA mixes	
	Relative flexural strength w.r.t plain NCA mix	Relative flexural strength w.r.t plain RCA mix	Relative flexural strength w.r.t plain NCA mix
0%	100.0%	100.0%	91.9%
0.25%	128.2%	134.3%	123.5%
0.50%	124.9%	131.9%	121.2%
0.75%	122.6%	128.0%	117.6%

Fiber reinforced RCA mixes undergone a significant increase in flexural strength compared to the corresponding plain mix. At an optimum dosage of GF (0.25%) flexural strength of RCA concrete compared to the plain RCA was increased by more than 34%. This increase was dropped to 28% at 0.75% GF. All RCA mixes with GF showed higher strengths than the corresponding plain RCA mix. Compared to the plain NCA mix flexural strength of RCA concrete was about 23% higher at an optimum dosage of GF.

Strength parameters of fiber-reinforced mixes confirm that addition of GF has been more useful to flexural strength than both splits tensile and compressive strength. Addition of GF on RCA helped in recovering loss in flexural strength to a great degree.

3.4. Mechanical Performance (MP)

MP (%) of each mix using Equation 1 was calculated by incorporating results of compressive, split tensile, and flexural strength. MP of each mix is shown in Figure 9. It can be observed that all mixes with GF outperform plain NCA mix (CON) in MP. For fiber-reinforced NCA concrete mixes, maximum MP is at the dosage of 0.25%, whereas for fiber-reinforced RCA mixes maximum MP is at the dosage of 0.5%. This is due to the fact that RCA mixes showed higher values of compressive and split tensile strength at the dosage of 0.5%. Considering MP (%) RCA mix with 0.5% GF at the optimum dosage outperforms conventional plain NCA mix by more than 5%.

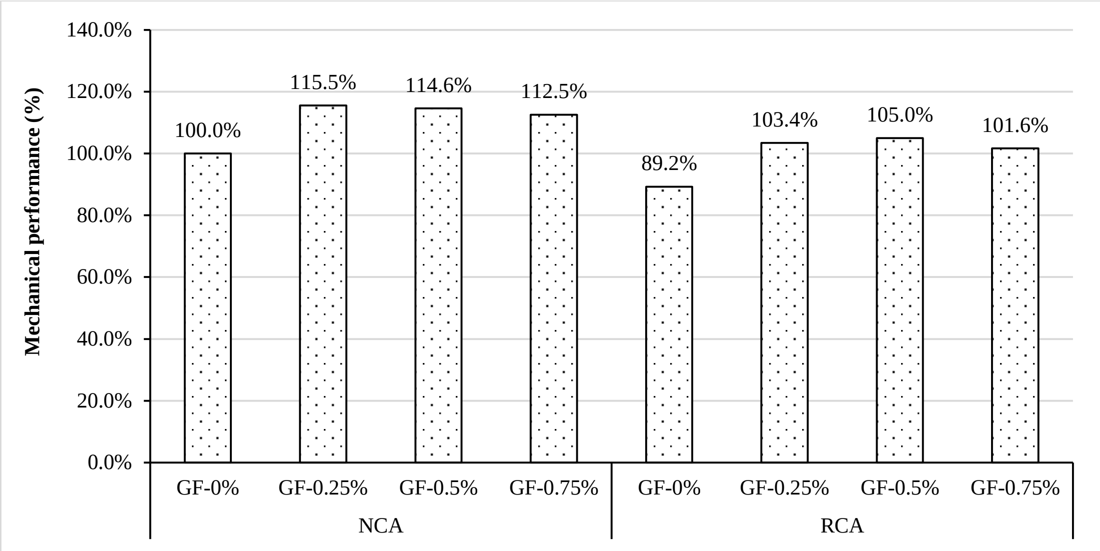


Figure 9. Mechanical performance of each mixture with respect to plain NCA mix (0% RCA and 0% GF)

RCA mixes achieve sufficient MP at 0.25% of GF compared to their plain mix, increasing the dosage of GF to 0.5% cause a further increase of 2% in MP, therefore, 0.25% dosage of GF can also be considered for optimum both NCA and RCA mix from an economic point of view. Increasing the dosage of GF from 0.25% to 0.5% would increase the quantity of GF in 1 m3 of concrete from 6.5 kg to 13 kg. Out of all ingredients, GF is the most expensive (nearly its market price is 7 USD/kg). So, 0.25% dosage of GF can be considered optimum. Also, a higher dosage of GF would increase the dosage of plasticizer which is also considered very expensive (nearly its market price is 1 USD/kg).

GF inclusion in concrete is more useful to tensile strength properties of concrete i.e. split tensile and flexural strength, it can be seen in Figure 10, that ratio of split tensile strength and compressive strength is higher for the fiber reinforced mixtures than that of the plain mixes (having 0%GF). For example, for fiber-reinforced concrete mixes split tensile strength is approximately 9% of the compressive strength, whereas, for plain concrete mixes split tensile strength is approximately 8% of that of the compressive strength. Similarly, the ratio of flexural strength and compressive strength as shown in Figure 11, is higher for the fiber-reinforced concrete mixes. For example, for fiber-reinforced concrete mixes, flexural strength is approximately 12% of the compressive strength, whereas, for plain concrete mixes flexural strength is approximately 9.5% of that of the compressive strength. It can be concluded that addition fiber addition increases the ratio of tensile-to-compressive strength of concrete.

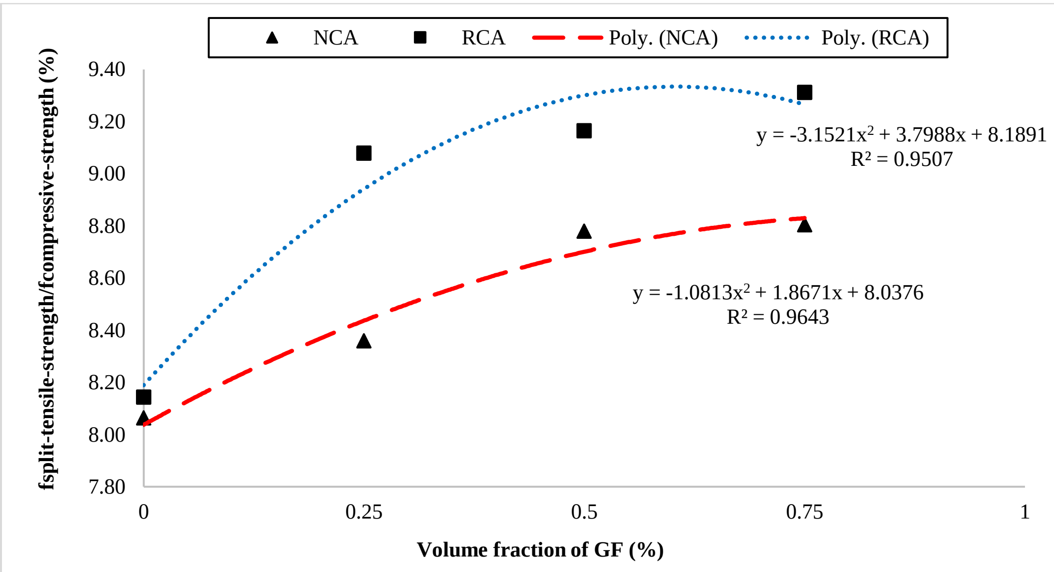


Figure 10. Split tensile strength-to-compressive strength ratio vs GF (%)

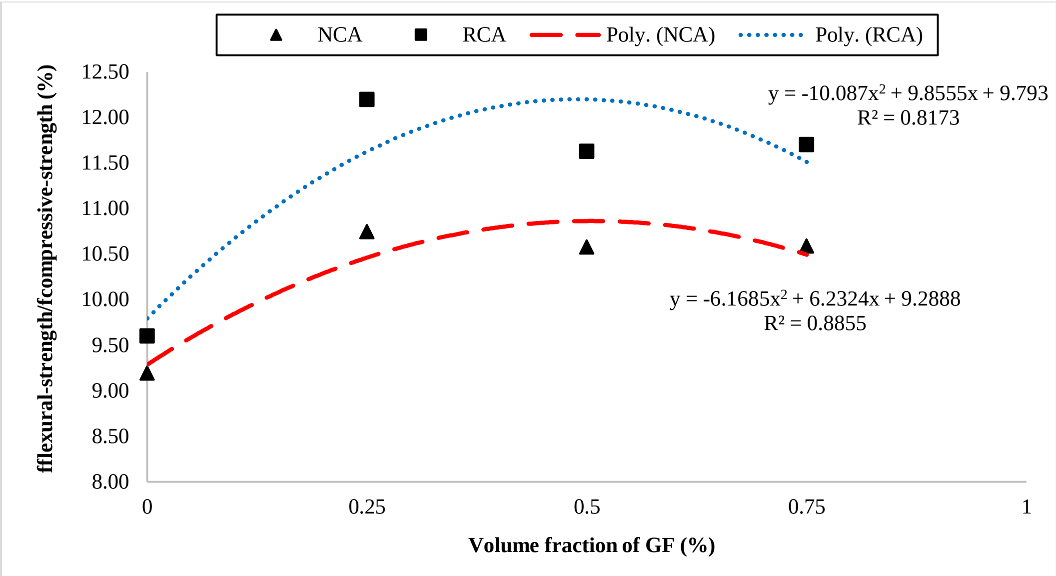


Figure 11. Flexural strength-to-compressive strength ratio vs GF (%)

4. Conclusions

Following conclusions can be drawn from this research paper:

- RCA and GF inclusion influence the workability of concrete badly and both increase the demand of plasticizer to achieve the desired range of slump.
- RCA influence the strength parameters of concrete badly. When RCA replaces NCA it reduces the compressive strength, split tensile strength, and flexural strength by about 12%, 11%, and 8% respectively.
- Influence of GF in both NCA and RCA mixes was more useful on flexural and split tensile strength of concrete than that of the compressive strength.
- Although GF improves the compressive strength of RCA concrete but it does not outperform plain NCA concrete at the optimum dosage (0.5% of GF). RCA concrete with 0.25-0.5% of GF outperforms plain NCA concrete in split tensile and flexural strength test.
- Combined MP indicate that RCA concrete with 0.25% GF can outperform plain NCA concrete by a fair difference mainly due to boost in split tensile and flexural strength.
- Optimum dosage of GF considering combined MP is 0.25% for NCA concrete and 0.50% for RCA concrete. But considering both economy and MP optimum dosage of GF may be taken as 0.25% for both NCA and RCA concrete mixes.

5. Conflicts of Interest

The authors declare no conflict of interest.

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