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Research Article

Assessment of Galvanized Iron Fiber and Waste Tire Composite Concrete

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Abstract

The traditional method of disposing of tire debris is now a huge worldwide problem and presents serious environmental risks. Because of this, using waste tires in concrete not only lowers its density but also guarantees an economical and environmentally responsible alternative for the building sector. However, because of their superior ductility and tensile strength, galvanized iron (GI) wire fibers are now more frequently used in plain concrete. Different amounts of waste tire fiber (WTF) with different coarse aggregate replacement ratios (0, 3, 6, and 9%) and different percentages of GI fiber (GIF) (0, 1, 3, and 5%) of concrete volume were examined in this study under axial compression in concrete grades M25, M30, and M35 respectively. According to the test results, GI fiber and waste tire composite concrete demonstrated ductile failure behavior in comparison to control concrete, in addition to delaying the propagation of cracks. On the other hand, the workability of concrete decreased as the percentage of mixed fiber increased. In addition, higher-strength concrete's ductility and compressive strength considerably improved as fiber percentages rose in comparison to lower-grade concrete. The specimen that contained 1% GIF and 3% WTF performed the best under peak load conditions for higher-strength concrete, according to the data.

Keywords

Waste Tire Fiber, Galvanized Iron Fiber, Workability, Compressive Strength, Ductility

1. Introduction

Waste tires produce massive volumes of carbon black powder when they are disposed of, which has made them a global environmental concern. Due to soil, water, and air pollution, piled tires also provide a number of economical, environmental, and health risks [1]. One potential remedy for these environmental issues is the use of scrap tires in concrete in place of natural aggregates. Several studies have shown that adding discarded tires to concrete improves its strain capacity, compression toughness, ductility, impact resistance, and freeze-thaw resistance while also providing the construction industry with an economical and environmentally beneficial alternative [2, 3]. However, because of its inadequate bond strength, rubberized concrete has been found to have inferior compressive, flexural, and tensile strengths [4, 5]. Concrete frequently contains waste or industrial steel fibers to improve these mechanical qualities. The properties of steel fiber in rubberized concrete, where positive synergy has been found, has not been extensively studied by researchers. Steel fiber was used in a study by to assess the impact on rubberized concrete under compression [6]. The researchers discovered

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that the fiber increases toughness, durability, and bond strength. Moreover, it was documented that steel fiber in rubberized mortar not only increased the flexural strength but also delayed the shrinkage cracking [7]. Relevant study revealed that adding steel belt wires to waste tire-modified concrete, which used rubber fibers of three different lengths to partially substitute coarse aggregate by 15% volume, significantly increased the concrete's strength and stiffness [8].

Steel fibers' exceptional strength properties have led to their widespread use in numerous construction projects [9]. The addition of steel fiber to concrete, represented in volume fractions, improves both strength and ductility but decreases workability. These fibers are produced at a far higher cost than the others. Nevertheless, Galvanized iron (GI) wire, which is inexpensive steel wire coated with zinc, can be utilized as a replacement to traditional steel fiber in order to get around this. Research has demonstrated that GI fiber (GIF) not only improves the strength characteristics of concrete but also performs comparably to steel fiber [9]. As a result, such type of fiber can be used in RCC structural elements [10]. The combination of GIF and WTF (Waste tire fiber) in concrete is quite uncommon, according to the literature study. So, in this study, a number of tests have been carried out to examine the performance of GIF and WTF composite concrete.

2. Materials and Methodology

In this study, twelve cubes with dimensions of 150 mm × 150 mm × 150 mm were prepared and tested under axial compression using a 1000 KN loading capacity universal testing machine (UTM). Three different GI fiber percentages, i.e., 1, 3, and 5% of concrete volume, were considered, maintaining the diameter and length were about 0.70 mm and 35 mm, respectively [Step 1]. Additionally, scrap tires having dimensions of 25 mm × 5 mm × 5 mm were used in the concrete cubes, with varying replacement ratios of coarse aggregate, i.e., 3, 6, and 9%, respectively [Step 2]. For reference specimens, three cubes were made without using GI fiber and waste tires (i.e., 0%).

Figure 1. Preparation of concrete cube.

Table 1 shows the properties of GI fiber and waste tire, whereas Table 2 indicates the details of concrete mixes, where CA is coarse aggregate, FA is fine aggregate, GIF stands for galvanized iron fiber, and WIF stands for waste tire fiber. Three concrete mixes, i.e., M25, M30, and M35, were prepared by using locally available materials according to the provisions of ACI 211.1-91 [11]. After preparing the concrete mixes, slump tests were performed to assess the consistency and workability of fresh concrete according to ASTM C143 [12]. During casting, a relatively high water-to-cement ratio was used in order to maintain the flowable mixture.

Table 1. Properties of GI fiber.

Approximate Length, L (mm)	Approximate Diameter, D (mm)	Aspect Ratio (L/D)
35	0.70	50

Table 2. Details of concrete mix design.

Specimen Design	Mix design	Cement (Kg/m^3)	CA (Kg/m^3)	FA (Kg/m^3)	Water (Kg/m^3)	GIF%	WTF%	Density (Kg/m^3)
C1	M25	370	1023	771	185	0	0	2457
C2		370	993	771	185	1	3	2445
C3		370	962	771	185	3	6	2429
C4		370	931	771	185	5	9	2432
C5	M30	420	1018	745	184	0	0	2451
C6		420	988	745	184	1	3	2440
C7		420	957	745	184	3	6	2424
C8		420	927	745	184	5	9	2414
C9	M35	475	1007	700	185	0	0	2448
C10		475	978	700	185	1	3	2435
C11		475	947	700	185	3	6	2423
C12		475	918	700	185	5	9	2405

3. Results and Discussions

3.1. Workability of GI and Waste Tire Composite Concrete

Figure 2 demonstrates that the workability of concrete reduced for the addition of fiber [13]. The slump shown decreasing trend for M25 concrete ranging 62 mm to 9 mm. For M30 and M35 concrete, the slump value range was found 46 mm to 4 mm and 40 mm to 0 mm respectively. Such significant reduction in slump was observed with the increase of the percentages of both GI and waste tire, as shown in Figure 2. This is because of the formation of stronger 3D scaffolding inside the concrete by the intertwisted array of GI fibers. In addition, the higher water-absorbing nature of tire fibers can be considered another reason behind this reduction. Usually, tire fibers absorb water from the concrete mixture primarily through surface adsorption due to their rough texture and porosity, and to a lesser extent through capillary action in any internal pores. Their hydrophobic nature limits significant internal absorption. They can also contribute to water entrapment at the fiber-paste interface.

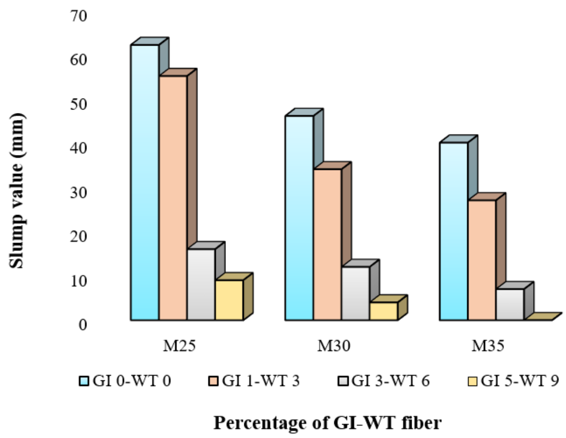


Figure 2. Fluctuation of slump based on GI-WT fiber content.

The water/cement (W/C) ratio is a critical factor influencing the workability and strength of concrete. A lower W/C ratio generally leads to higher strength and durability but reduces workability, making the concrete mix stiffer and harder to place and compact. Conversely, a higher W/C ratio increases workability but typically results in lower strength and increased porosity. Despite the reduction in workability caused by the fibers and waste tire materials, the target strength of the concrete still needs to be achieved. A slightly higher W/C ratio might be needed compared to plain concrete of the same strength grade to compensate for the reduced workability due to the fibers and waste materials. However, this increase must be carefully controlled to avoid compromising the final strength and durability. Furthermore, workability-enhancing admixtures, such as superplasticizers (high-range water reducers), are often essential in fiber-reinforced and composite concretes. These admixtures can significantly improve the workability of the mix at a given W/C ratio or allow for a lower W/C ratio while maintaining adequate workability, thus helping to achieve both strength and ease of placement.

3.2. Failure Modes of Concrete

In Figure 3, it was noticed that GI fiber has a significant effect on the failure pattern of the test specimens. Under compression, the control specimen (without fiber) displayed crushing failure, whereas the GI fiber-reinforced cube significantly delayed this failure by absorbing additional energy. In addition, noticeable ductile and narrower cracks were observed in the specimens with higher percentages of GI fiber due to the formation of fiber bridging across the crack. Similar type of cracking phenomenon was found in a study with steel fiber [13].

(a) Reference specimen failure (b) Fibrous specimen failure

Figure 3*. Failure of concrete specimens (reference vs fibrous).*

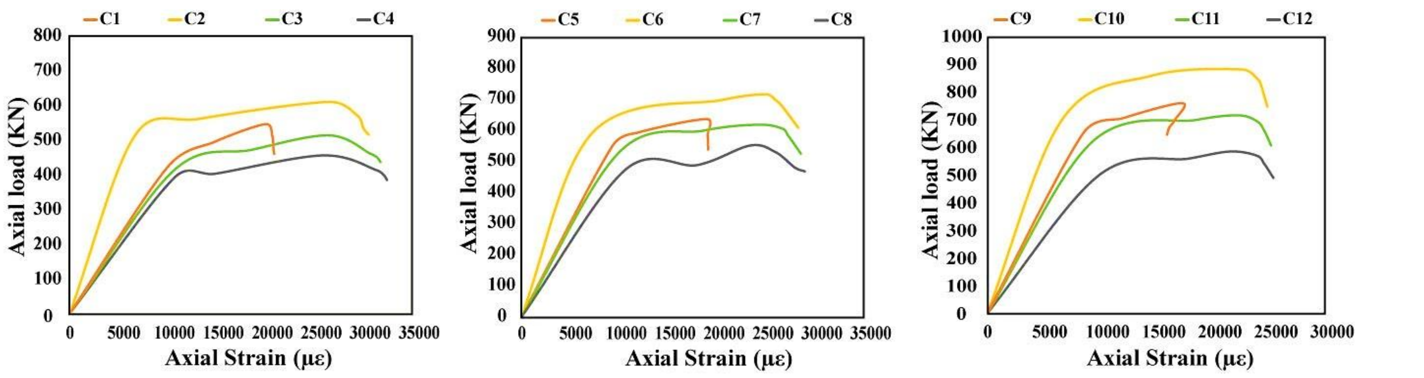
3.3. Axial Load Versus Axial Strain Curves

The axial loads (N) versus axial strain (ε) curves of the tested specimens are presented in Figure 4. Comparing M25, M30, and M35 concrete to the control specimen, it is evident from Figure 4 and Table 3 that the addition of 1% GI fiber and 3% tire fiber increased the initial stiffness and concrete's strength by 11.47%, 11.89%, and 21.41%, respectively. This is due to the fact that GI fiber could provide extra confinement and stiffness to the rubberized concrete, resulting in better bond strength.

Table 3*. Test data of specimens under axial compression.*

Specimen	Mix design	Peak Load (KN)	Compressive strength of concrete at 28-day, $f_c^/$ (MPa)	% variation of $f_c^/$	Strain at peak Load (με)	Ductility Index (D.I)
C1	M25	539.50	23.97	-	20000	1.05
C2		601.20	26.72	+11.47%	26560	1.15
C3		526.30	23.39	-2.42%	26524	1.19
C4		471.63	20.96	-12.56%	25880	1.25
C5	M30	622.37	27.66	-	19057	1.01
C6		696.45	30.95	+11.89%	24997	1.13
C7		631.15	28.05	+1.41%	24179	1.18

Specimen	Mix design	Peak Load (KN)	Compressive strength of concrete at 28-day, $f_c^{/}$ (MPa)	% variation of $f_c^{/}$	Strain at peak Load (με)	Ductility Index (D.I)
C8	M35	569.50	25.31	-8.49%	23445	1.23
C9		737.60	32.64	-	17369	0.90
C10		894.85	39.63	+21.41%	22597	1.09
C11		724.88	32.10	-1.65%	22330	1.13
C12		617.00	27.42	-15.99%	21654	1.17



(a) M25 (b) M30(c) (c) M35

Figure 4. Axial load vs axial strain curves of different concrete grades.

For all concrete grades, initial stiffness and compressive strength also declined dramatically as fiber combinations increased. This is because concrete that has greater fiber doses forms heterogeneous mixes. The creation of excessive voids and incorrect orientation of both fibers may result in such a mixture, which could lead to moderate segregation in the concrete matrix. Thus, it is evident from the research above that the specimen with 1% GIF and 3% WTF performed best under peak load conditions for higher-strength concrete.

3.4. Ductility Index

In this experimental study, ductility index (DI) is employed to measure the ductility of test specimens. The ductility index has been considered as the ratio of the axial strain at 85% of the peak load (N_{ut}) during the descent stage to the corresponding strain at N_{ut}. According to Table 3, there is a noticeable decrease in DI while control concrete strength increases. This fact is caused by the brittle nature of higher-strength concrete.

For lower-grade M25 concrete, it is observed from Figure 5 that higher fiber percentages result in a significant increase in DI by 9.52%, 13.33%, and 19.04% respectively. As discussed earlier, GI fiber provides stiffness to the concrete, while rubber fiber improves the strain capacity after peak load, resulting in positive synergy to increase ductility under axial compression. For M30 concrete, increase in DI is found to be 11.88%, 16.83%, and 21.78% respectively. Furthermore, Figure 5 shows that DI significantly increased for higher grade M35 concrete by 21.11%, 25.55%, and 30.00% respectively, with the rate of increment being greater than that of the lower grade.

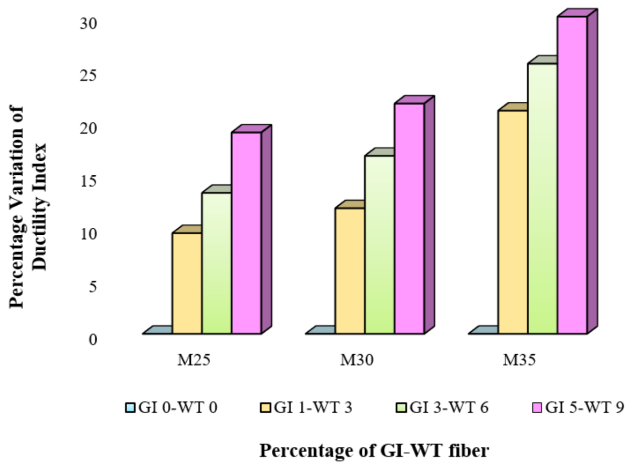


Figure 5. Variation of ductility index based on GI-WT fiber content.

4. Conclusions

Twelve cube specimens with different percentages of waste tire and GI fiber were put through axial compression testing in this study. We investigated how the concrete was affected by failure modes, concrete strength, and ductility utilizing the combination of these fiber materials. The following conclusions can be drawn based on the experimental findings:

1) Slump of concrete specimens decreased significantly due to addition of fibers.
2) Composite concrete demonstrated ductile failure behavior in comparison to control concrete, in addition to delaying the propagation of cracks.
3) For the higher-strength concrete, the specimen with 1% GIF and 3% WTF performed best under peak load.
4) The highest increase of Ductility Index for M25, M30 and M35 concrete was 19.04%, 21.78% and 30.00% respectively.

Abbreviations

GIF	Galvanized Iron Fiber
WTF	Waste Tire Fiber
DI	Ductility Index

Author Contributions

Md. Rejoan Chowdhury: Conceptualization, Formal Analysis, Methodology, Project administration, Supervision, Writing - original draft, Writing - review & editing

Md. Shahidul Islam: Data curation, Investigation, Resources, Validation

Arifa Akter Swarna: Data curation, Funding acquisition, Investigation, Visualization

Md. Saim Hossen Noman: Funding acquisition, Methodology, Software, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

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