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Case study

Suitability of locally manufactured galvanized iron (GI) wire fiber as reinforcing fiber in brick chip concrete

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ABSTRACT

A case study has been conducted in order to improve concrete quality in Bangladesh, using fiber reinforcing techniques with locally available low-cost Galvanized Iron (GI) wire fibers. GI wire is in fact mild steel wire with a thin coating of zinc. In order to assess the suitability of GI wire fibers as an alternative to steel fibers, various properties of GI wire fibers i.e. tensile strength, bending capacity etc. have been investigated and compared with the properties of steel fibers in light of relevant ACI and ASTM guidelines. Various tests were conducted on GI wire fibers as well as plain concrete reinforced with GI wire fibers. The experimental results show that GI wire fiber has compatible properties with steel fibers. Moreover, compressive strength, flexural strength, toughness indices and residual strength factors of GI wire fiber reinforced concrete (GFRC) have shown significant improvement compared to normal concrete. A comparison with Steel Fiber Reinforced Concrete (SFRC) revealed that performance of GFRC is quite similar to that of SFRC. It was observed that fiber content of 2.5-3.5% by weight produces relatively better results for the particular mix design used in the study. Furthermore, a cost analysis reveals that SFRC is about 19% more expensive than GFRC in Bangladesh; for 1 cubic meter of concrete work when fiber dosage is 2.5% by weight. Therefore, the study finds that GFRC has shown some promising results to be a low-cost alternative to steel fiber reinforced concrete from Bangladesh's perspective.

1. Introduction

Bangladesh is one of fastest developing countries in the world and construction industry in the country is booming. But due to negligence and lack of proper knowledge, there have been a number of incidents that have prompted civil engineers in the country to improve the quality of concrete. One such tragic incident is the infamous Rana Plaza collapse in April 2013 at Savar where the death count reads more than a thousand. After the accident, various aspects of concrete strength such as tensile strength, toughness, ductility etc. were considered for improvement. With this end in view, a case study was conducted in order to improve properties of general concreting work by adopting Fiber Reinforced Concrete (FRC) concept and the prime focus of the study was to find a relatively low-cost solution.

Numerous researches have been going on to explore the effectiveness of different types fibers ranging from micro to nano for improving mechanical properties of concrete [1–6]. However, among all fibers, steel fiber is the most popular and widely used. This is due to the fact that performance of steel fiber to augment mechanical properties of concrete such as tensile strength, ductility, toughness, fatigue life, impact resistance etc. has already been established over the past few years [7–16]. But additional cost for such fibers, steel in particular, has always been an issue to address; especially in countries like Bangladesh since steel fiber for use in FRC is

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not available in local market and importing is quite expensive, even from the most economical source. In this situation, fibers prepared from GI (Galvanized Iron) wire can provide a viable low cost substitute for steel fibers. GI wires are mild steel wires with a thin coating of zinc which are locally produced and are available at a relatively low price. Hence, a research has been carried out to investigate the properties of GI wire fiber so that a proper comparison can be established between the properties of steel fiber and GI wire fiber. It is also investigated whether GI wire fiber conforms to the ACI and ASTM standards for steel fibers of Steel Fiber Reinforced Concrete (SFRC). Also, compressive strength of GI Fiber Reinforced Concrete (GFRC) with variable GI fiber percentage is tested so that an initial comparison can be made between GI wire fiber in GFRC and steel fiber in SFRC. In addition to this, toughness indices and residual strength factors were determined according to ASTM A 1018 in order to understand post cracking behavior of GFRC.

Most of the previous works on FRC have been conducted with normal weight concrete. However, there are some studies on fiber reinforcing of Light Weight Aggregate Concrete

(LWAC) having oil palm shell, pumice, expanded clay etc. utilized as coarse aggregate [15,17–22]. But there is no significant research on FRC with brick chip aggregate as Light Weight Aggregate (LWA); despite the fact that, brick chips are often used in concrete works for wide availability and low cost in Bangladesh and nearby regions. Therefore, improvement of concrete with brick chips needs to be given appropriate attention since use of brick chips as coarse aggregate is very popular particularly for construction of beams and slabs. Only recently, there have been some works with brick chip light-weight aggregate and reinforcing with GI wire fiber [23,24]. Flexural performance of GFRC beams with conventional main reinforcement was also studied by Emon & Manzur [25] and performance of GI wire as reinforcing fiber was found quite satisfactory. But standard test for SFRC is generally based on specimens without main reinforcement. Thereby, in this work, suitable fiber size and length were determined based on the strength and aspect ratios specified by ACI 544.3R [26] and ASTM-A 820/A 820 M [27]. Fiber diameter and length was selected by testing a number of GI wire samples ranging from 0.5 to 1.0 mm in diameter. Then flexural performance of GFRC beams without main reinforcements was investigated and compared with SFRC with respect to load deflection behavior, toughness indices and residual strength factors etc.

2. GI wire fiber and steel fiber

2.1. Specifications for suitable fibers in FRC

According to ACI 544.3R, the length of the steel fiber to be used in FRC generally varies between 12.7 mm (0.5 in.) to 63.5 mm (2.5 in.) and the most common fiber diameters are in the range of 0.45 mm (0.017 in.) to 1.0 mm (0.04 in.). In addition, the code stipulates that the aspect ratio should be between 30 and 100 with aspect ratio(λ) being the ratio of length(l) to diameter(d) or equivalent diameter(d_e). The specifications for aforementioned parameters of steel fibers in ASTM-A 820/A 820 M conforms to the specifications of ACI 544.3R. Moreover, the standard steel fiber must have a minimum ultimate tensile strength of 345 MPa (50,000 psi) but fibers are available with strengths up to 2068 MPa (300,000 psi) [26]. Furthermore, standard fiber must satisfy bending requirements which provide a general indication of fiber ductility, as may be important in resisting breakage during handling and mixing operations, in accordance with ASTM-A 820/A 820 M.

Five general types of steel fibers are identified in ASTM-A 820/A 820 M based upon the product or process used as a source of the steel fiber material: Type I, cold-drawn wire; Type II, cut sheet; Type III, melt-extracted; Type IV, mill cut; Type V, modified cold-drawn wire. Fiber from GI (Galvanized Iron) wire falls in the category of Type V, modified cold-drawn wire. Therefore, for GI wire fiber, ASTM specifications for Type V will be followed hereafter.

2.2. Test setup for GI wire

Tests were performed on GI wire with three different diameters: 0.50 mm, 0.70 mm and 1.00 mm as per ASTM A370 [28]. Three specimens of each diameter were tested for both tensile and bending requirements.

Universal Testing Machine (UTM) was used for testing GI wire samples. These tests were conducted to identify suitable wire diameter, which can meet the specifications for tensile strength of standard steel fibers. The length of the wire was kept same i.e. 91 mm for varied wire diameter as specified by ASTM A370 [28]. Another test setup was prepared in accordance with ASTM-A 820/A 820 M for testing the bending capacity of GI wire. The specification requires the fibers to withstand being bent around a 3.2 mm (0.125 in.) diameter pin to an angle of 90° without breaking at temperatures not less than 16 °C (60 °F). A pin with the specified diameter was made and inserted in a small wooden platform normal to the plane of the platform. This small device was good enough to perform the test.

2.3. Results, analysis and competence

All the GI wire fibers showed similar behavior during tests under tensile stress. From the various test results, it was found that all the GI wire fiber samples have produced stress-strain curves which are similar to those typically produced by steel in tension as found by Holt [29]. Fig. 1 shows typical stress-strain curves produced by the samples. The results from tension and bending tests and comparison with ASTM-A820/A820 M specifications are summarized in Table 1.

All the samples satisfied the required mechanical properties, namely tensile and bending requirements, of steel fibers in FRC. However, the sample with 0.70 mm diameter showed considerably higher tensile strength compared to the other samples as clearly

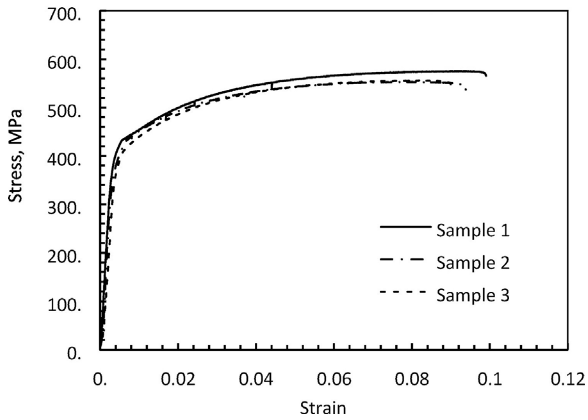

Fig. 1. Stress-strain curve for GI wire samples.

Table 1
Summary of mechanical properties analysis of different GI wire specimens.

Test Specimen		Yield Strength f_y, MPa	Avg. f_y, MPa	Ultimate Strength fu, MPa	Avg. Fu, MPa	Strain at Ultimate Stress (%)	Avg. Strain (%)	Required fu, MPa	Remarks on Tensile strength	Remarks on bending capacity
0.50 mm GI Wire	1	409	411	556	557	20.2	19.14	> 345	excellent	excellent
	2	403		554		18.72			excellent	excellent
	3	421		561		18.5			excellent	excellent
0.70 mm GI Wire	1	440	455	607	621	21.3	23.90	> 345	excellent	excellent
	2	469		633		24.8			excellent	excellent
	3	456		624		25.6			excellent	excellent
1.00 mm GI Wire	1	407	419	557	568	38.75	40.03	> 345	excellent	excellent
	2	428		573		41.3			excellent	excellent
	3	423		574		40.03			excellent	excellent

indicated in Table 1. As a result, for further research, 0.70 mm diameter GI wire fiber was selected due to its higher tensile strength.

Suitable length for the GI wire fibers was taken as 37.5 mm (1.5 in.). The resulting aspect ratio of 53.57 falls within the limit of 30 to 100 as specified in ACI 544.3R or ASTMA820/A820 M. Therefore, 0.70 mm diameter GI wire was cut into 37.5 mm pieces to produce GI wire fiber which was used to prepare GFRC with an aim at comparing with SFRC. Fig. 2 shows GI wire fiber ready-to-use as fiber reinforcement in GFRC.

Fig. 2. GI wire fiber.

Table 2
Slump values of standard and GFRC Sample Cylinder.

Concrete	Control	1.5% GFRC	2% GFRC	2.5% GFRC	3.5% GFRC	5% GFRC
Slump (mm)	48	25	18	10	0	0

3. GFRC and SFRC

The influence of steel fibers on flexural strength and ductility of concrete is more significant than that of on direct tension and compression. Fibers are primarily added to concrete not to improve the strength, but to improve the toughness, or energy absorption capacity. To evaluate flexural strength, ductility and toughness of GI wire fiber reinforced concrete (GFRC) and compare with SFRC, a testing scheme was implemented along with determination of compressive strength.

3.1. Concrete

Conventional volumetric concrete mix ratio of 1:1.5:3 for cement, fine aggregate and coarse aggregate respectively, was employed for mixing the concrete. This mixing method was chosen since majority of the concreting work here in Bangladesh is performed by manual mixing using this ratio. Coarse aggregate was 12.5 mm (0.5 in.) downgraded crushed burnt clay bricks, also known as brick chips. Improving brick chip concrete with GI fiber was of principal interest particularly for two reasons; firstly, brick chips is used massively in this region and secondly, brick chips is considered as light weight aggregate and light weight aggregate concrete (LWAC) is relatively brittle than normal weight concrete [23]. Fine aggregate was locally available Sylhet sand (Fineness Modulus = 2.42). Water-cement ratio of 0.45, was adopted without any use of water reducing admixtures. Use of admixtures may be necessitated if concrete loses workability which is generally observed with FRC [30,31]. But for simplicity in mixing process and keeping in consideration the lack of proper knowledge and expertise of workers in this region, admixture was not used and a low volume of fiber content was chosen for the study. GI wire fiber contents of 1.5%, 2.0%, 2.5%, 3.5% and 5% by weight (0.44% to 1.45% by volume) of concrete were used. Slump tests were also carried out to determine the workability and consistency of fresh concrete according to ASTM C143 [32]. Slump test results are tabulated in Table 2. It is evident from the table that with increasing fiber content, slump value reduced considerably. One of the reasons for this reduction in slump value is the formation of a three-dimensional scaffolding inside the concrete matrix by the intertwined array of fibers. At lower fiber contents, the scaffolding is not so strong; but at higher fiber contents, it is strong enough to contribute to a zero slump value. Therefore, for using high fiber content, adding admixtures may become necessary. As a result, a moderately high water-cement ratio was used so that the concrete remains workable enough for compaction. Fig. 3 shows GFRC with almost zero slump value whereas control sample had about 48 mm slump.

3.2. Testing methodology

Cylindrical specimens of 100 mm (4 in.) diameter and 200 mm (8 in.) height were prepared with both normal concrete (without any GI wire fiber) and GFRC for compressive strength test. Three samples were made, cured and tested according to ASTM C 39/C39 M [33] for each concrete mix.

To determine flexural strength of fiber reinforced concrete, two flexural strength parameters are commonly reported i.e. first-crack flexural strength and ultimate flexural strength or modulus of rupture. The first-crack flexural strength corresponds to the load at which the load-deformation curve departs from linearity (Point A on Fig. 4) and the ultimate flexural strength or modulus of

Fig. 3. Zero slump value for GFRC.

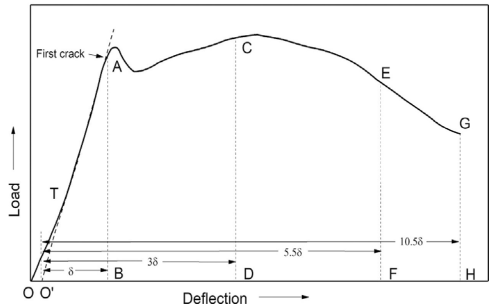

Fig. 4. Important characteristics of the load-deflection curve (redrawn) [35].

rupture corresponds to the maximum load achieved (Point C on Fig. 4). Procedures for determining first-crack and ultimate flexural strengths, as published in ACI 544.2R [34] and ASTM C 1018 [35], are based on testing 100 mm x 100 mm x 350 mm (4in. x 4in. x 14 in.) beams under third-point loading. Details of beam and test setup are shown in Fig. 5. A total of eleven sample beams were prepared with GFRC with brick chips as coarse aggregate; two each for control, 1.5%, 2%. 2.5% and 3.5% GFRC and one for 5% GFRC mix.

Toughness is another significant characteristic that gives an impression of ductility. Under static loading, flexural toughness may be defined as the area under the load-deflection curve in flexure, which is the total energy absorbed prior to complete separation of the specimen [7]. Flexural toughness indices may be calculated as the ratio of the area under the load-deflection curve for the steel fiber concrete to a specified endpoint, to the area up to first-crack, as shown in Fig. 4 as per ASTM C 1018 [35], or to the area obtained for the matrix without fibers. There are some Index values i.e. I_5, I_{10}, I_{20}, I_{30} etc. that can be determined for indicating flexural strength as well as ductility of the material. These indices, defined in ASTM C 1018 [35], are obtained by dividing the area under the load-deflection curve, determined at a deflection that is a multiple of the first-crack deflection, by the area under the curve up to the first crack. I_5 is determined at a deflection 3 times the first-crack deflection, I_{10} is determined at 5.5, I_{20} and I_{30} at 10.5 and 15.5 times the first-crack deflection, respectively. Another parameter, residual strength factor, $R_{5,10} = 20\ (I_{10}–I_5)$ is computed to provide an impression of amount of strength retained after the first-crack.

3.3. Test results and discussion

All the specimens for compressive strength test were prepared, cured and tested according to ASTM C39/C39 M [33]. Six specimens were prepared for each concrete mix; three were tested after 7 days of curing and the rest after 28 days. Results from the compression tests are presented in Fig. 6. The GFRC samples showed variable increment of compressive strength as compared to normal concrete samples. Fibers do not have any direct influence on static compressive strength of concrete but they do enhance post-cracking ductility or energy absorption of concrete. Yet, due to their confining effect, observed increase in compressive strength was essentially from nil to 50 percent for SFRC [9,36]. From Fig. 6, it is found that increase in compressive strength for GFRC varies from

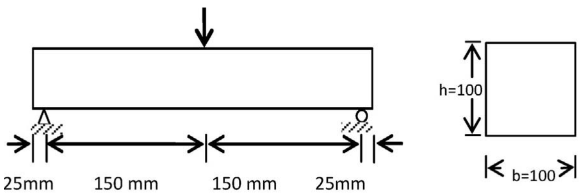

Fig. 5. Beam dimensions and test setup.

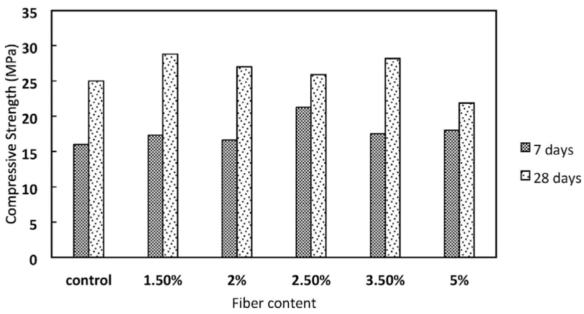

Fig. 6. Compressive strengths for various GFRC and control samples.

4 to 33% after 7 curing days and 4–15% for 28 days curing which clearly indicates that GI wire fibers has a similar effect as steel fibers on compressive strength of concrete. A slight decrease was observed for 28 day compressive strength of 5% GFRC. This can be due to the fact that this concrete mix lacked adequate workability and compaction. With fiber content as high as 5% by weight (1.45% by volume), addition of plasticizing admixture was necessary; but, as simplicity in construction was one of the goals of the study, no admixture was used in the current study, as mentioned earlier.

The most striking difference between control samples and GFRC samples under flexure was the failure characteristic. Controls samples demonstrated a brittle failure at ultimate load and almost instantly snapped into two pieces. Whereas, the GFRC samples continues to bear load with the help of fibers resisting tensile stress even after concrete fracture at ultimate load. Fig. 7 shows typical failure of a GFRC beam and also fibers bridging across the crack. Load deflection curves for various concrete mixes are presented in Figs. 8 and 9 . Control concrete specimens, without any fiber reinforcement, ruptured typically like any brittle material (Fig. 8) which is demonstrated by the sudden drop in load. After reaching ultimate failure load, these specimens retain no strength at all. For 1.5% and 2% fiber contents in GFRC (Fig. 9), the failure is also brittle in nature, but the difference with control samples is that these samples showed some resistance after a sudden fall in capacity and continues to absorb energy. 2.5% and 3.5% GFRC samples showed relatively ductile load deflection curves (Fig. 9). The sudden drop in capacity is minimized due to fiber addition and the specimens can take considerable amount of load with increasing deflection. Load-deflection curve for 5% GFRC (Fig. 9) sample also shows significantly ductile behavior but overall performance is relatively inferior to those of 2.5% and 3.5% GFRC. This is due to the fact that 5% GFRC did not have sufficient workability for ideal compaction. Without proper compaction, 5% GFRC with had some voids formed within the matrix which was therefore weaker compared to other samples. Fig. 10 presents load-deflection curves for all six mixes for comparative perspective. It is evident that control specimen can sustain a mid-span deflection up to 3 mm whereas GFRC samples resisted up to 10 mm deflection before breakage. The curves also demonstrate that GFRC with 2%, 2.5% and 3.5% can resist more load after cracking and continue to do so for a considerable deflection at mid-span. Consequently, areas under the curves of GFRC are higher compared to that of control concrete. This means GFRC is tougher and has the capacity to absorb more energy.

A range of load-deflection curves obtained in the test of steel fiber reinforced concrete by Johnston [37] is shown in Fig. 11. It is evident that, load-deflection curves of 1.5% and 2% GFRC resemble curve 4 of Fig. 11. Curves of 2.5%, 3.5% and 5% GFRC are somewhere between curve 3 and 2. To compare moment-deflection behavior of SFRC and GFRC with brick chip aggregates, bending stress vs deflection curves from van Zijl et al. [38] with 1% and 1.5% fiber volume content have been presented in Fig. 12 As the cross sections for the two studies are not the same, stress-deflection curves are presented in place of moment-deflection curves. Slope of all the curves seem to be same for initial portion of loading; but GFRC samples have steeper slopes after deflection of about 1–2 mm. Again, GFRC samples had a sudden drop in stress after the cracking whereas SFRC did not show sudden decrease of stress. It can be due to the properties of GI fiber i.e. low strength, softness etc. as opposed to high strength and stiffness of steel fibers. However, ductility of GFRC samples is found to be satisfactory when compared to SFRC.

Fig. 7. Typical GFRC beam failure and GI wire fibers bridging the crack.

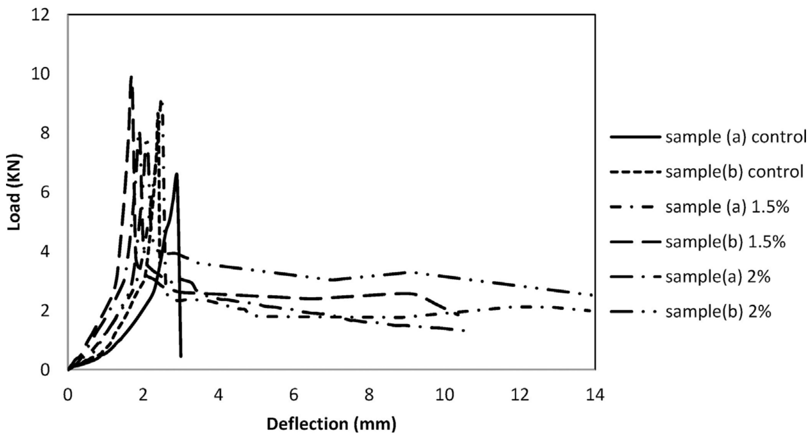

Fig. 8. Load vs deflection curves for control samples, 1.5% & 2% GFRC samples.

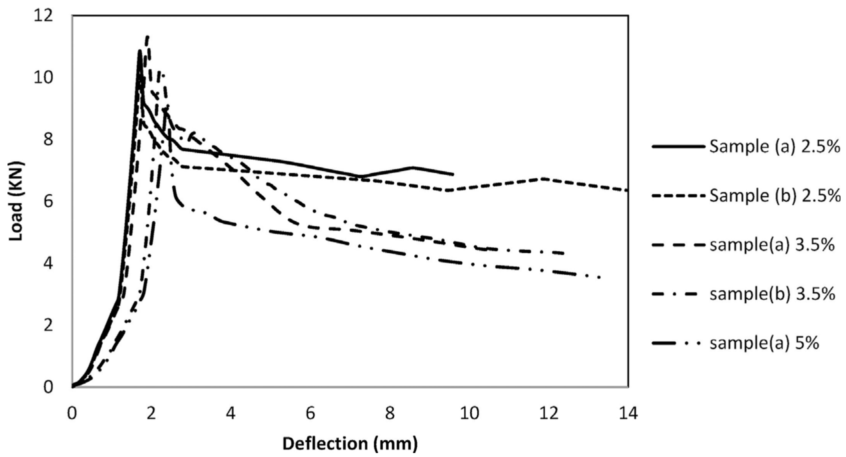

Fig. 9. Load vs deflection curves for 2.5%, 1.5% & 5% GFRC samples.

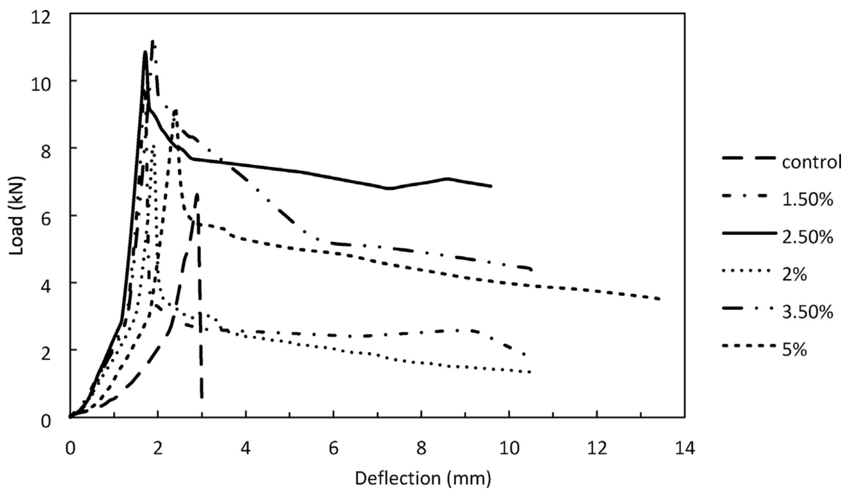

Fig. 10. Average load vs deflection curves for all concrete mixes.

None of the specimens show deflection-hardening behavior and first-crack load and ultimate load was almost the same in every case and therefore these two parameters are considered the same in this paper. Ultimate flexural loads (or, first-crack loads) and corresponding mid-span deflections and toughness of the specimens are tabulated in Table 3 and also shown in Fig. 13. From the bar chart in Fig. 13, it is apparent that fiber content from 2.5% to 3.5% by weight has the best effect on flexural ultimate strength for this

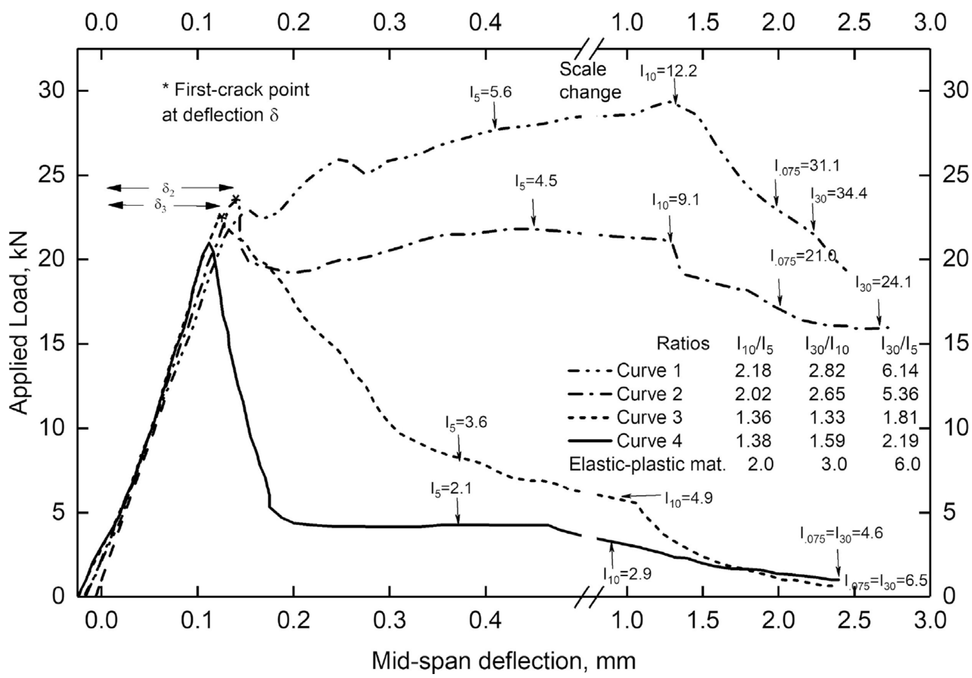

Fig. 11. A range of load deflection curves obtained in the testing of steel fiber reinforced concrete (redrawn) [37].

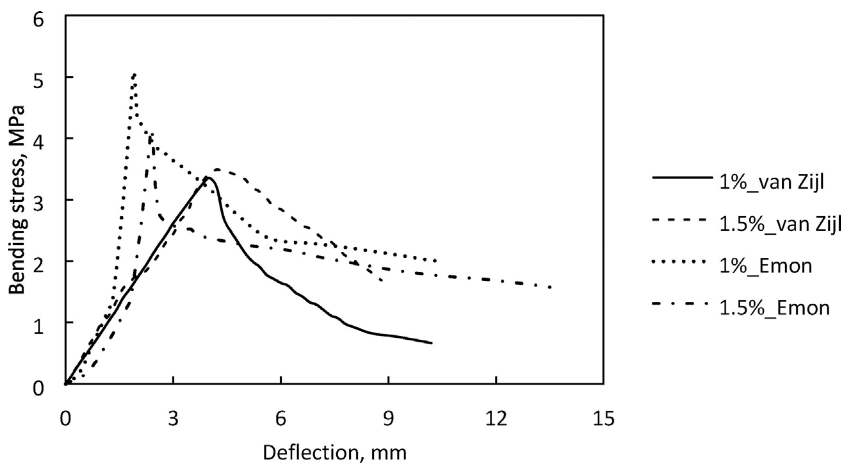

Fig. 12. Bending stress based on un-cracked section vs deflection from van Zijl [38] and present experiment.

Table 3
First-crack loads from experiment and prediction by analytical model by Singh [39].

Concrete Sample	Sample ID	First-crack deflection, mm	First-crack load, kN	Predicted first-crack load by Singh [39], kN	First-crack toughness, Nm
Control	a	2.9	6.53	6.44	5.26
	b	2.4	8.54	6.44	4.39
1.5% GFRC	a	1.7	9.77	7.84	6.57
	b	2.5	9.07	7.84	4.48
2.0% GFRC	a	1.9	8.04	10.16	4.98
	b	2.1	7.84	10.16	4.05
2.5% GFRC	a	1.71	10.85	12.36	5.83
	b	1.70	10.06	12.36	6.16
3.5% GFRC	a	1.9	11.31	16.41	5.69
	b	2.2	10.25	16.41	6.05
5.0% GFRC	a	2.4	9.19	21.75	10.02

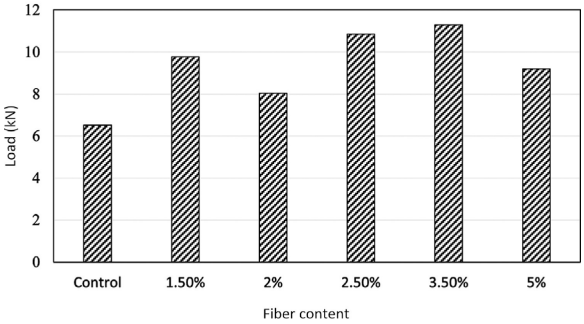

Fig. 13. Ultimate load vs fiber content chart.

particular concrete mix design with brick chip aggregate. Predicted ultimate loads of the specimens using flexural model of SFRC proposed by Singh [39] are also given in Table 3. Loads calculated using the model do not quite match with experimental results. For low fiber contents (below 2.5% by wt.), experimental results are within ± 25% of the predicted results. For 3.5% and 5% GFRC, experimental loads are less than the predicted loads by 31% and 58%, respectively. As for 5% GFRC, the result could be closer to the predicted value if water reducing admixture could be used to ensure sufficient compaction of concrete. Now, for most GFRC mixes (except 1.5% fiber content), predicted loads from the proposed model are higher than those from the experiment. There can be several reasons for these deviations. Firstly, the model was developed for concrete with stone chip aggregates as opposed to brick chips. Secondly, the model assumes fiber-fracture failure mode for the fibers considering material properties used in the study; but from observation of the specimens after failure, it was manifested that all the fibers bridging the crack were not fractured; rather, some of them were pulled out. Thirdly, GI wire fiber is relatively softer, weaker and more ductile than high-strength steel fibers and its pull-out behavior is unknown. Therefore, in order to predict flexural capacity of GFRC with brick chip aggregate, the analytical model should be modified for certain factors as described above. An attempt was also made to compare predicted first-crack toughness according to method described by Al-Ghamdy et al. [40]; but experimental results do not match with the predicted results. Therefore, a new model, perhaps, needs to be developed for applying to GFRC.

The most significant benefit that fiber addition to concrete can provide is the post-cracking resistance and energy absorption capacity which means that FRC shows improved ductility and toughness over conventional concrete. GFRC samples also showed increased ductility and toughness as fibers within the matrix bridge across the cracks to add to the strength and also helps carry a significant stress over a large strain even during the post-cracking phase. In order to quantify the enhancement of energy absorption and post-cracking capacity of GFRC due to GI fiber addition, first-crack toughness, toughness indices and residual strength factors were determined from the load-deflection curves produced from third-point loading of beams in accordance with ASTM C 1018 [35]. Toughness was calculated using trapezoidal rule of numerical integration from the continuous load-deflection data from the tests. Relevant toughness indices (I_5, I_{10}) and residual strength factor ($R_{5,10}$) of various GFRC mixes and control concrete are provided in Table 4. All GFRC samples have better toughness when compared to control samples. 2.5% and 3.5% GFRC specimens demonstrated the best indices when compared with other GFRC specimens. Indices found by Al-Ghamdy et al. [40] are also given to compare GFRC with SFRC. It is found that GFRC and SFRC have comparable I_5 and I_{10} which means GI wire fibers can perform well as reinforcing fibers as far as post-cracking energy absorption is concerned. Average results are presented together in Fig. 14 for comparison. From Fig. 14, it is observed that first-crack toughness of most GFRC samples (except 2% GFRC) is more than that of control sample. This indicates that GFRC samples can absorb more energy than normal concrete even before the onset of cracking. The exception of 2% GFRC can be due to localized defects in the specimens, lack of favorable fiber orientation or any other reason; which can, perhaps, be ascertained through further investigation. A maximum increment of 24% was observed with respect to control concrete for 2.5% GFRC for first-crack toughness value. Toughness indices characterize energy absorption after the cracking of section up to certain

Table 4
Toughness and Residual strength Indices relevant to ASTM 1018[35].

Concrete Sample	Sample ID	I_5	Avg. I_5	I_5, as per Al- Ghamdy [40]	I_{10}	Avg. I_{10}	I_{10} as per Al- Ghamdy [40]	R5,10	Avg. R5,10
Control	a	1	1	–	1	1	–	0	0
	b	1			1			0	
1.5% GFRC	a	2.6	2.95	–	4.5	4.9	–	38	39
	b	3.3			5.3			40	
2.0% GFRC	a	4.3	3.95	–	7.5	6.5	–	64	51
	b	3.6			5.5			38	
2.5% GFRC	a	5.6	5.7	4.7	10.8	10.3	9.5	104	92
	b	5.8			9.8			80	
3.5% GFRC	a	5.9	5.9	–	9.9	10.1	–	80	84
	b	5.9			10.3			88	
5.0% GFRC	a	5.5	5.5	5.2	9.8	9.8	10.5	86	86

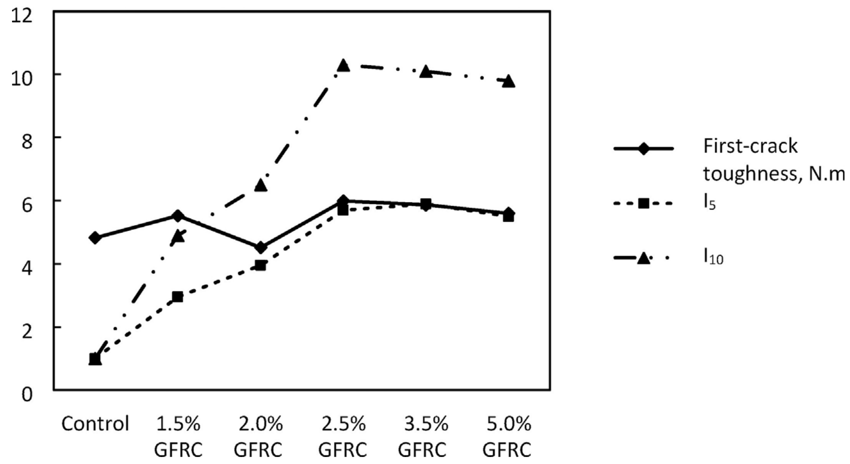

Fig. 14. Average First-crack toughness and Toughness indices I_5 and I_{10}.

deflection. Higher index value implies more energy absorbing capacity of the specimen after cracking. Conventional concrete have these indices equal to zero, elastic-plastic materials have index values close to 5 and 10 for I_5 and I_{10}, respectively. Observed range for I_5 and I_{10} for conventional steel fibrous concrete is 1–6 and 1–12, respectively [35]. Index values of GFRC falls within the range and 2.5-5% GFRC samples shows indices better than elasto-plastic materials. From Fig. 14, it is evident that 2.5-3.5% GFRC mixes produce relatively better results and there is substantial augmentation in toughness after first-crack of the specimens. Residual strength factor, $R_{5,10}$ is the percent of first-crack toughness that is retained between specific deflection of 3δ and 5.5δ; where δ is the first-crack deflection. $R_{5,10}$ factor for 2.5% GFRC shows the maximum value, as presented in Table 4. Therefore, considering overall un-cracked and post-cracking flexural behavior of GFRC with brick chip aggregate as LWA, it can be said that fiber content of 2.5-3.5% by weight produces relatively better results for this particular mix design.

3.4. Cost comparison

For bulk purchase, locally produced GI wire costs about US$ 950–1150 per ton in Bangladesh. Retail price for a kilogram in local market varies from US$ 1.00 to 1.25. Additional cost for processing of wire into fibers is about US$ 125 per ton. On the other hand, steel fiber for use in FRC is not produced in Bangladesh and importing fiber from nearby sources costs around US$ 1500–2500 per ton including shipment costs. Estimated cost analysis of materials for GFRC and SFRC with 2.5% fiber content (weight basis) for 1:1.5:3 concrete mix ratio reveals that about US$ 69 can be saved per cubic meter of concrete work; if GI fiber is used as a substitute of steel fiber. This indicates that SFRC costs about 19% more than GFRC, per cubic meter of concrete when fiber dosage is 2.5% on weight basis.

4. Conclusion

Incorporation of locally available GI wire as fiber in concrete is a relatively new technique in Bangladesh. Properties of both GI wire as fiber and GI wire fiber reinforced concrete as FRC have been studied. This paper has presented the outcome of the research with GI wire as a fiber to be used in concrete and a comparison is made between the performance of GI wire fiber and steel fiber from literature. The results from the first phase of the experiments show that GI wire fiber can be considered as a suitable substitute for steel fiber in FRC considering fiber specifications and requirements i.e. tensile strength, bending capacity, size and shape etc. The second phase of the research features use of GI wire as fiber in concrete and evaluation of certain mechanical properties such as compressive strength, flexural behavior, toughness etc. Experiments show that GI wire fiber reinforced concrete (GFRC) have shown significant improvement compared to normal concrete. Also, results from this phase reveal that GFRC can emulate SFRC as far as compressive strength and toughness are concerned i.e. increment in compressive strength was found to be 4–15% for 28 curing days. Load-deflection behavior and ductility of GFRC and SFRC were compared and found to be quite similar. About 39% higher first-crack load was noted for 2.5% GFRC than control concrete. Moreover, toughness indices and residual strength factors of GFRC are comparable with those of SFRC. I_5, I_{10} and $R_{5,10}$ values of GFRC (2.5-5% fiber content) were close to 5, 10 and 90, respectively. These values show significant improvement when compared to control concrete and are comparable with results of SFRC. This indicates that GI fiber can impart sufficient post cracking ductility and energy absorption capacity to concrete. These parameters are very significant in a sense that there is no authentic published record of such indices for GI wire fiber reinforced concrete with brick chips aggregate and therefore these indices/factors can be used for future reference. And, current study found that 2.5-3.5% fiber content by weight produce relatively better performance with the particular mix design that was followed in the experiments. Furthermore, cost analysis clearly depicts the financial advantage of using GI wire fiber instead of steel fiber from the perspectives of Bangladesh. And also, it could enhance the quality of overall concrete work. In fine, suffice it to say that GI wire fiber has shown great potential and promise as a viable low-cost alternative for steel fiber to be used in FRC.

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