Analyzing the Strength Behavior of Cement Composites with Waste Glass Fibers

Nikhil Kale, Mangesh Madurwar and Rahul Ralegaonkar

Abstract Cement composites fail due to tensile strains exceeding their limiting strain capacity. This results into development of cracks and gradual loss of strength. The controlling of cracks is vital for better fatigue performance of concrete construction. The paper presents a study of the suitability of waste glass fibers for utilization in cement mortar and concrete specimens in order to promote sustainable construction. These fibers were added to the composites by weight fraction, and relevant tests were performed on them. Test results indicate that cement mortar showed an increase in strength and a pseudo-ductile behavior due to addition of fibers. while concrete specimens showed loss in compressive and flexural strength.

Keywords Tensile strain · Fatigue · Waste glass · Sustainable
Pseudo-ductile

1 Introduction

Construction sector has been tried and tested extensively use of fibers over a long period of time. The use of fibers to reinforce brittle materials can be traced back to ancient times when straws were used for brick manufacturing. Fibers have been widely used in cement composites prominently to assess their strength behavior, crack resistance, energy absorption, permeability, and elongation properties. Due to sudden and at times heavy application of loads, premature cracking occurs in cement composites. Cement being a brittle material, development of cracks leads to

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gradual loss of its strength. Fibers help in controlling of cracks by accommodating into the very fine gaps of the microstructure. They impart additional energy absorbing capability, thus helping in transforming a brittle material into a pseudo-ductile one. They also serve as a crack arrestor creating a stage of slow crack propagation and gradual failure.

There is a considerable amount of research done on the use of glass fibers. Cahn et al. [1] studied a durability of Portland cement mortar having epoxy-phenol coatings with fiberglass protection. Their tests of the duration of two years on stress corrosion and aging showed that normal glass fiber requires a complete protection of pin hold coating to endure the alkali attacks over longer duration and a coating to give better bond strength, because the coating will emigrate into the mortar to give better bond strength. Choi et al. [2] used the glass fiber (GF) and carbon fiber (CF) to enhance the properties of non-ductileflexural concrete components. They determined a volume ratio of (CF/GF) to be approximately (8.8/1) to produce pronounced hybrid effects and pseudo-ductility. Ho and Woodhams [3] examined the compressive strength and flexural strength of fiber-reinforced sulfur concrete for a polyethylene terephthalate (PET) fiber and a glass fiber (alkali-resistant). The glass fibers increased maximum flexural load by a factor of 3.5 and the compressive strength by 50%, whereas the polyester fibers increased maximum flexural load marginally by a factor of 1.3 and compressive strength by 33% at the optimum fiber length of 4–5 cm. Shah and Naaman [4] studied the mechanical properties of steel and glass fiber-reinforced mortar. Compressive, flexural, and tensile tests were conducted on mortar samples reinforced with various volumes and lengths of glass and steel fiber. The flexural or tensile strength of the reinforced samples was 2–3 times that of control mortar, while the resultant deflection or strain was nearly 10 times that of mortar. Failed flexural sample surfaces were observed to have extensive micro-cracking; significant contribution of the matrix was observed even after the first cracking. Messan et al. [5] studied the early shrinkage of cement mortar due to the influence of cellular ether, ethylene-vinyl acetate (EVA), and glass fibers. Optical instrumentation system found the free plastic shrinkage. Active restrained system performed the restrained shrinkage tests. The residual stress and the overall shrinkage were decreased because of the use of EVA. The shrinkage was reduced by the glass fibers and the heterogeneity of the surface shrinkage. Khan et al. [6] studied the consequence of aging on the physico-chemical properties of glass fiber under the different environmental circumstances. Indoor and outdoor atmosphere, 95% humidity, low temperature, water soaking treatment, and the chemical environment were the conditions selected. The results showed that glass fiber is good in resisting corrosive atmosphere, sunlight, shady atmosphere, and low temperature, but the detrimental outcome on the glass fiber was caused because of the influence of prolonged time exposure to water. Nunes and Reis [7] used digital image correlation method to estimate crack extension and the crack-tip-opening displacement of glass fiber-reinforced polymer mortars to study their fracture behavior. The percentage blending of fiber in mortar mix was 0, 2, 5, 10% by the weight of aggregate. Curing of all the samples was done for 7 days at room temp. and the post-curing for 3 h at 800 °C. Study results showed that the fractured resistance of polymer mortar was increased because of glass fibers. Lva et al. [8]

studied that the glass fiber-reinforced concrete (GFRC) in flexure has the fatigue performance. The fatigue lives of GFRC at various stress levels were obtained by testing the beam specimens (size of 100 × 100 × 400 mm) under four-point flexural fatigue loading. 0.6, 0.8, and 1% volume fraction of glass fiber was incorporated into the samples. They obtained results for the coefficients of the fatigue equation corresponding to different survival probabilities so as to predict the flexural fatigue strength of GFRC for the desired level of survival probability.

Fibers are broadly classified as natural and synthetic. Use of natural fibers like coir, jute, sisal depends upon their regional availability. Synthetic fibers like steel, polypropylene, polyester, nylon-66 which incur costs are being effectively used in cement composites. In recent times, growth in industrialization has resulted into generation of more and more waste by-products. These materials are non-degradable, difficult to dispose off. Thus, it becomes equally important to consider alternative ways for their utilization in order to promote sustainability.

The main objective of this research paper is to study the strength behavior of cement mortar and concrete specimens with the use of glass fibers that are obtained as an industrial waste.

2 Materials and Methods

2.1 Materials

Portland Pozzolana Cement (fly ash based), conforming to IS 1489-1991, part 1 was used. Clean river sand, conforming to IS 650-1991, was used. The properties were determined as per IS 2116-1980. Aggregates confirming to IS 383-1970 were used. The properties of the materials used were as mentioned in Table 1.

A melamine resin-based superplasticizer (anionic) having specific gravity 1.23 and pH 7–8 was used, confirming to IS-9103:1999. Recommended dosage percentage (v/w of cement) is 0.5–1%. The glass fiber (Fig. 1) sample was collected from an industry which comes as a waste after specific processing. It is available in white color with non-uniform thread length varying from 10 to 50 mm and diameter of around 0.02 mm (20 microns). Water absorption was observed as 0%.

2.1.1 Characterization of Glass Fiber

For identification and quantification of crystalline phases and understanding the surface morphology of the fibers, X-ray diffraction (XRD, Fig. 2) and scanning electron microscope (SEM, Fig. 3) tests were conducted, respectively. The frequent occurrence of peaks (Fig. 2) shows that the glass fiber has a definite crystalline cell structure. The compounds in the fiber are quartz (SiO_2), calcium and aluminum oxide ($Ca_3Al_2O_6$, i.e., $3CaO \cdot Al_2O_3$), along with minute amounts of titanium oxide

Table 1 Properties of materials

Property / Material	Specific gravity	Standard consistency (*P* %)	28-days compressive strength (Mpa)	Sieve analysis	Water absorption (%)	Free surface moisture (%)	Shape, nominal size (mm)
Cement	3.00	32	47.45	–	–	–	–
Sand	2.61	–	–	Zone 3 (as per IRC 44: 2008, Table 2)	1.01	0	–
Aggregates	2.91	–	–	–	2	0	Angular,10 and 20

Fig. 1 Waste glass fibers

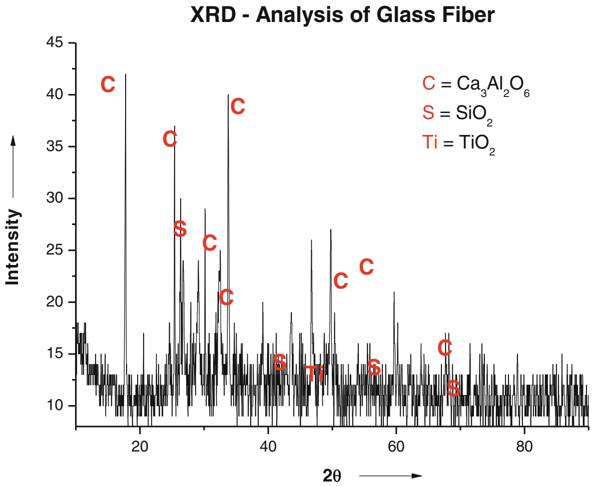

Fig. 2 XRD analysis of glass fiber

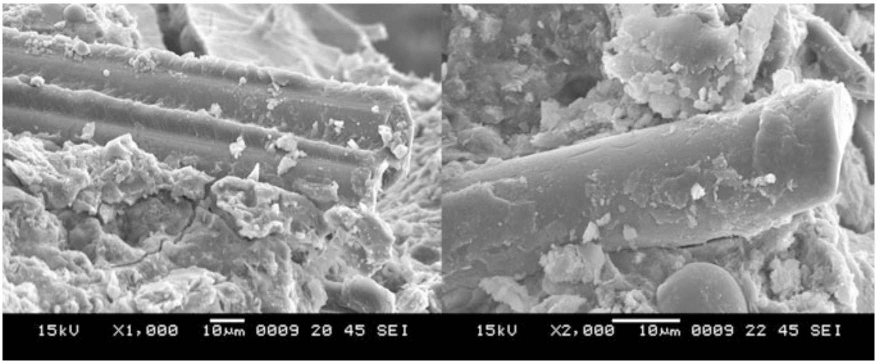

Fig. 3 SEM micrographs for glass fiber

(TiO_2). TiO_2 is mostly used as a white pigment and physical blocker to ultraviolet light. The surface texture (Fig. 3) of the fibers was found smooth.

3 Experimental Procedure

3.1 Preparation of Cement Cortar Cubes

Cement and sand were mixed in 1:3 proportions. The fibers were chopped into length of 10 mm and added to the mixture in quantities of 0.2, 0.4, 0.8, 1, and 1.5% by weight of cement. The fibers were randomly oriented during dry mixing. Water of amount (P/4 + 3) % of combined weight of cement and sand was then continuously added to the mix while mixing to provide the homogeneous mix without twine or lump as per standard procedure. A total of six sets of specimens of size 70.6 × 70.6 × 70.6 mm were prepared using standard molds (Fig. 4). Demoulding was done after 24 h followed by curing for 28 days at constant temperature of 270 °C and relative humidity of 90%.

3.2 Preparation of Concrete Specimens

3.2.1 Mix Proportioning for M-40 Grade

For pavement quality concrete (PQC), mix design and proportioning were done as per IRC 44-2008 [9]. Target design strength was set as 48.25 MPa. Table 2 indicates the weight as well proportion of the ingredients.

Fig. 4 Set of 18 cubes casted

Table 2 Mix proportions for M40 grade per m^3 of concrete

Component	Weight (kg)	Proportion (%)
Cement	391.6	1
Sand	629.21	1.61
Coarse aggregate	1386.83	3.54
Water	148.8	0.38 (water/cement ratio)

3.2.2 Concrete Cube Specimens

A total casting of 18 cubes of size 150 × 150 × 150 mm was done using standard molds with fibers added in proportions of 0, 0.2, 0.4, 0.6, 0.8, and 1% by weight of concrete (Fig. 5). After 24 h, demoulding was done and curing for 28 days was carried out under controlled environment for studying the change in ultimate strength of concrete as per IS 516-1959 [10].

3.2.3 Preparation of Concrete Beam Specimens

Casting of 18 beams of size (500 × 100 × 100) mm was done for M-40 grade using standard molds with fibers added in 0, 0.2, 0.4, 0.6, 0.8, and 1% by weight of concrete (Fig. 6). After 24 h, demoulding was done and curing for 28 days was carried out under controlled environment for studying the change in flexural strength of concrete.

Fig. 5 Cubes after 28 days curing

Fig. 6 Specimen after filling and compaction

4 Test Results and Discussions

4.1 Test Results of Cement Mortar Specimens

The tests were carried out with compression testing machine at a fixed loading rate of 0.228 MPa/s (Fig. 7). Due to the smooth surface texture of fiber, bond slippage occurs between cement paste and fiber. At 0.2% fiber content, lower fiber concentration causes ineffective dissipation of stresses, so strength decreases. With the increase of fiber content, its density in the matrix increases leading to more number of fibers contributing in dissipation of stresses. Hence, strength goes on increasing till it reaches a maximum value of 57.02 MPa which is 20% more than strength

Fig. 7 Gradual failure under compression

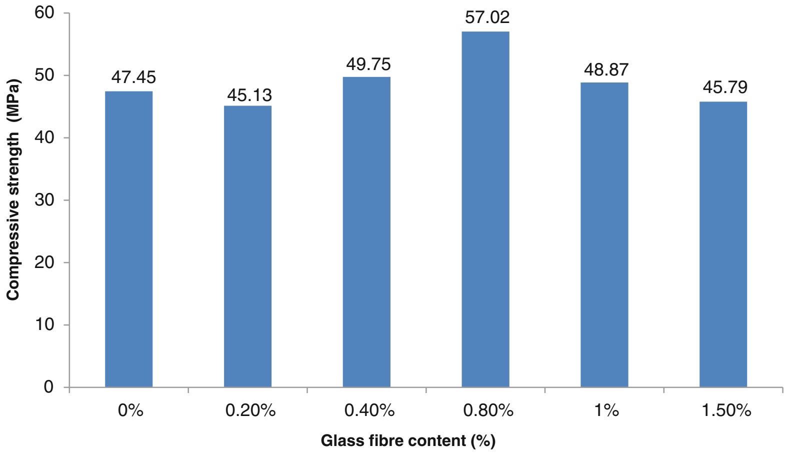

Fig. 8 Estimated compressive strength for mortar with varying glass fiber content

obtained at 0% fiber (Fig. 8). Beyond 0.8% fiber added, the mortar mix becomes stiff due to increased fiber content making it less workable. Hence, the strength achieved is less compared to value of 57.02 Mpa.

4.2 Test Results on Concrete Cube Specimens

Initially with addition of 0.2% fibers, strength decreases by 17.65% as compared to conventional specimen at 0% fiber (Fig. 9). This happens due to the "bond slippage" between cement paste and fiber. The fiber's smooth surface ineffectively transfers the stress at the interface that leads to considerable loss instrength. With further gradual increase in fiber content, more fibers contribute to stress dissipation that results in increase of strength till it reached a value of 48.63 MPa. Further, increase in fibers causes decrease in workability of concrete leading to lesser efficient compaction and hence strength decreases.

4.3 Test Results on Concrete Beam Specimens

For the tested concrete beams, it was observed that flexural strength decreases with the addition of fibers (Fig. 10). This shows that these fibers are fragile and have poor tensile strength leading to loss in flexure strength.

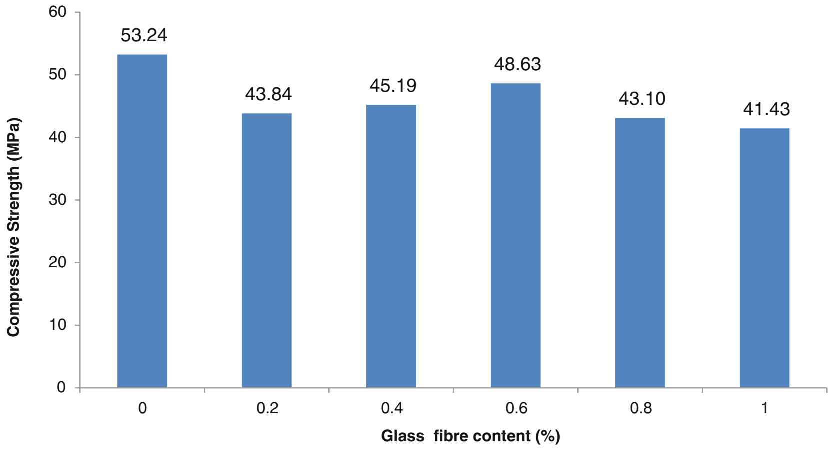

Fig. 9 Estimated compressive strength for concrete cube with varying glass fiber content

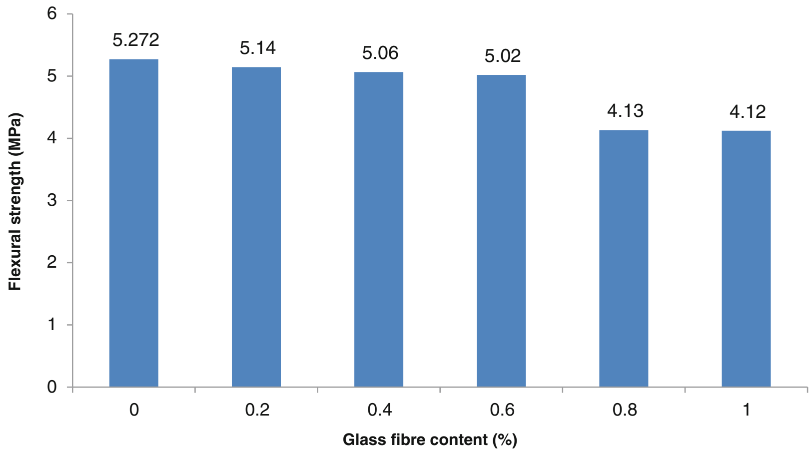

Fig. 10 Glass fiber content (%) versus flexure strength for concrete beam

5 Conclusion

Effective transfer of stresses from cementitious matrix to fibers is influenced by interfacial bonding and dissipation of stresses is influenced by fiber density matrix. Interfacial bonding is influenced by surface texture of fibers, whereas fiber density matrix depends upon the amount of fiber content available in the matrix.

In cement mortar, initially at 0.2% fiber content, ineffective stress transfer phenomenon is more pronounced and so strength decreases. At 0.8% fiber content, optimum fiber density helps in stress dissipation, and hence, higher strength is achieved. Also, addition of fibers causes gradual failure of specimens thus imparting them pseudo-ductility.

In concrete cubes, similar trend was observed. The strength achieved at 0.6% fiber content (i.e., 48.63 MPa) was slightly more than target design strength (i.e., 48.25 MPa) but less than 53.24 MPa at 0% fiber. This is because concrete is more heterogeneous material than cement mortar.

It is concluded that the waste fibers have been found fit for utilization in mortars.

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