O 126. ENGINEERING PROPERTIES OF HYBRID FIBER REINFORCED CEMENTITIOUS COMPOSITES FOR SUSTAINABLE STRUCTURES

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ABSTRACT*:* An experimental investigation was carried out on hybrid fiber reinforced cement mortars through the use of polymeric (1% by volume) and steel fibers (1% by volume). In order to compare results specimens were also produced with single fiber incorporation together with plain specimens as reference. The incorporation of single fibers was totally kept at 2% by volume of each mixture. A total of 4 mixtures were produced and specimens were tested to assess their compressive strength and flexural strength. Improvement of basic engineering properties was further elaborated via microstructural characterization including scanning electron microscopy and video microscope recorder. Results suggest steel fiber incorporated cement mortars by volume of 2% were promising to exhibit increased bending resistance while hybrid and single polymeric fiber reinforced specimens were comparable.

Keywords: Sustainability, polymeric fibers, steel fibers, mechanical properties.

1.INTRODUCTION

Different types of fibers are widely used to improve the flexural strength of cement-based composites (Balaguru et al. 1992; Nawy, 2001). The role of fibers is generally ascribed to bridging cracks to delay the propagation so that additional force is necessary to break the bond strength between fibers and matrix (Johnston, 2001). Also, fibers provide controlling shrinkage, improving fracture toughness and impact resistance for plain concrete mixtures (Sorelli et al., 2006). However, fiber inclusion may cause air-entrapped voids in cement paste and interface that worsen the mechanical properties. Delaying of crack growth can be possible when several processes take place in the concrete due to fiber pull-out, rupture or yielding of fibers. At the final stage, an increased number of cracks tend to link each other to create wider cracks that result in a fracture. Several studies suggest that the performance of the fibers in concrete mixtures is mainly related to their dispersion (Mobasber et al., 1990) and ratio (Betterman et al., 1995). So far, different types, sizes and ratios of fibers have been investigated to precisely understand their reinforcement contribution in concrete (Lawler et al., 2003; Sahmaran et al., 2005). Micro or/and macro fibers reinforcements sustain a random of crack arresting in cement-based materials composites, nevertheless, the fibers act solely at their specific properties. To date, studies have proved that utilization of at least two different types of fibers, i.e. hybrid fibers, can improve the engineering properties of cementitious composites. (Sahmaran et al., 2007). Hybrid reinforcement system in cementitious composites possesses a behavior of a higher chance of defect mitigation compared to specimens that do not contain fibers or contain single fiber type. In addition to that, not all fibers provide higher ductility due to their characteristic mechanical properties and brittleness (Lawler et al., 2003).

In this study, fiber hybridization system of cement-based materials has been developed by the incorporation of different fibers into the cementitious system. The compressive and flexural strength of cement mortars reinforced by microscale (steel and polymeric) fibers have been investigated. Furthermore, microstructural analysis has been performed to confirm the findings of abovementioned properties by SEM and microscope analysis. The contribution of fibers in the crack development mechanism was aimed to be outlined throughout the study.

2.EXPERIMENTAL DETAILS

2.1. Materials

Portland cement (PC) Type I CEM-42.5/R, similar to ASTM Type I, was used as a hydraulic binder in the production of mixtures. Specific gravity and Blaine fineness of Portland cement were 3.1 and 325 m^2/kg, respectively. Physical properties and chemical composition of PC was given in Table 1. Standard silica sand (max. aggregate size of 2 mm) was used in mixtures with the conformity of CEN (CEN 196-1, 2009). The particle size distribution of the silica sand was presented in Table 2. For each mixture, polycarboxylic ether-based high-range water reducing admixture (HRWRA) was added to obtain similar flow.

Table 1. Physical and chemical properties of PC

Chemical composition, %	PC
CaO	61.12
SiO_2	21.63
Al_2O_3	5.12
Fe_2O_3	3.45
MgO	2.41
SO_3	2.39
K_2O	0.69
Na_2O	0.22
SiO_2+Al_2O_3+Fe_2O_3	30.2
Specific gravity	3.10
Blaine fineness (cm^2 g^{-1})	3250

Table 2. Particle size distribution of the silica sand in mortars

Particle size (mm)	Cumulative retained sand (%)
2.00	0
1.60	7 ± 5
1.00	33 ± 5
0.50	67 ± 5
0.16	87 ± 5
0.08	99 ± 1

Hooked-end steel fibers with lengths of 30 mm, diameters of 0.56 mm, specific gravity of 7.85, and tensile strength of 1500 MPa were used in the mixtures. Polymer type synthetic fibers with lengths of 6 mm, diameters of 27 μ, specific gravity 1.14, and tensile strength of 962 MPa was used to the reinforce cementitious system. Polymeric fibers (PF) and steel fibers (SF) used in the study were given in Figure 1.

Figure 1. Polymeric and steel fibers

2.2. Preparation of Mixtures

A standard cement mortar fabrication was followed in conformity with the Turkish Standard (TS EN 197-1, 2009). Apart from standard mortar preparation, different amount of fibers were used for both steel and polymeric fiber reinforced cement mortars. To start with, water was put into mortar mixer together with the cement and mixing started for 30 seconds in 62 round per minute (rpm). Then, silica sand was gradually added into the mixer in 30 seconds and mixing continued for another 90 seconds in 125 rpm. SFs or/and PFs were gradually added into the mixer tank during 60 seconds for relevant mixtures. Together with fiber addition, chemical admixture was used to provide similar consistency (flow diameter 20±1) for each mixture. Specimens were molded to prismatic specimens with the dimension of 40*40*160 cm. Three specimens were fabricated for each type of mixture (Figure 2).

Figure 2. Specimens produced from four mixtures

After 24 hours, mortars were taken from molds and kept in thermostat controlled curing tank for 27 days in lime-saturated water at 20±2 C.

Figure 3. Thermostat controlled curing of specimens at 20±2 C

Ingredients of the total 12 specimens and their mixture identities were given in Table 3 in order to be easily followed in the study

Table 3. Ingredients of the mixtures by weight (gr)

Mix ID	Cement	Fly ash	Water	w/b ratio	Sand	PFs (by volume of total mixture)	SFs (by volume of total mixture)
1. M/Ref.	450	-	225	0.5	1350	-	-
3. M/PF	450		225	0.5	1350	1%	
4. M/SF	450	-	225	0.5	1350	-	1%
6. M/SF-PF	450	-	225	0.5	1350	0.5%	0.5%

2.3. Experiments

2.3.1. Mechanical Properties

Flexural and compressive strength of each mixture was evaluated in accordance with TS-EN 1015-11 (TS-EN 1015-11, 2000). Compressive strength was determined on each half of 160 x 40 x 40 mm prism specimen by uniaxial loading at 2400 N/second. The flexural strength of mortars was determined by three-point loading of a 160 x 40 x 40 mm prism specimen (Figure 4). The loading rate was applied at 50 N/second. Specimens were placed on supports of the testing machine as details were given in Figure 4. Both mechanical tests were carried out for 28 days-old specimens.

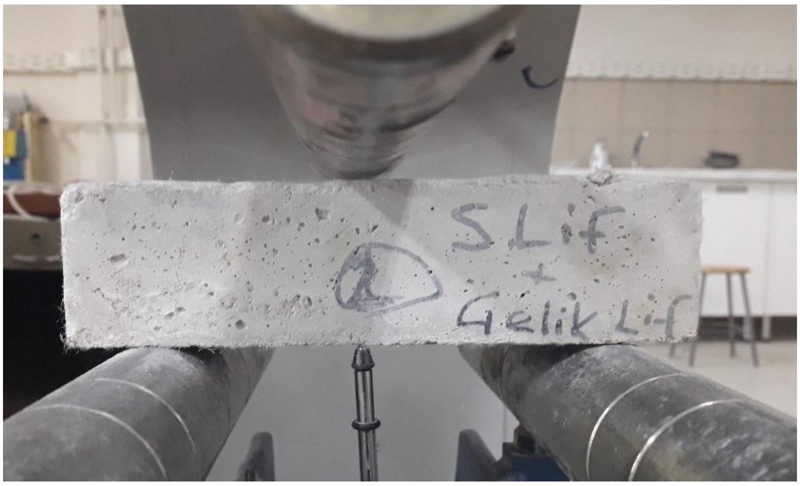

Figure 4. 3-point bending tests of hybrid fiber reinforced cement mortars

2.3.1. Microstructural analysis

Microstructural analysis was performed to confirm the physical structure of cement mortars at 28 days as a validation of mechanical results. To this end, microstructural properties of cement mortars were assessed with the use of SEM images. The surface of fibers and fiber-matrix interfaces were investigated under a scanning electron microscope. To that end, samples were sliced into 1*1*1 cm pieces for each mixture

3. RESULTS and DISCUSSIONS

3.1. Compression Tests

Mechanical properties of four different cement mortars were determined. The results of the experimental in compressive strength were given in Figure 5.

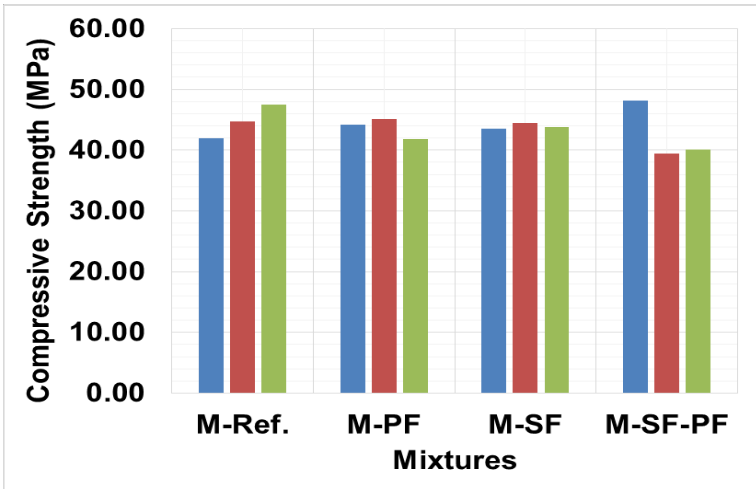

Figure 5. Compressive strength of different mixtures at 28 days

As given in Figure 5, the average compressive strength of mixtures were 44.8 MPa, 43.7 MPa, 43.9 MPa and 42.6 MPa for M-Ref, M-PF, M-SF and M-SF-PF specimens, respectively. The negligible reduction in the average compressive strength of M-SF-PF mixture compared to the reference mixture can be attributed to entrapped air due to the inclusion of fibers into mixtures. Also, it can be stated that variation in compressive strength of hybrid fiber reinforced mortars was higher than the other three mixtures. However, the average compressive strength of mixtures at 28 days was comparable and no significant reduction was obtained. Although fibers may have led to entrapping of air into the cement matrix, the capability of flaw-bridging effects of fibers at the microscale could have mitigated this detrimental effect.

3.1. Flexural Tests

Flexural strength of different mixtures under 3-point bending experiments was presented in Figure 6.

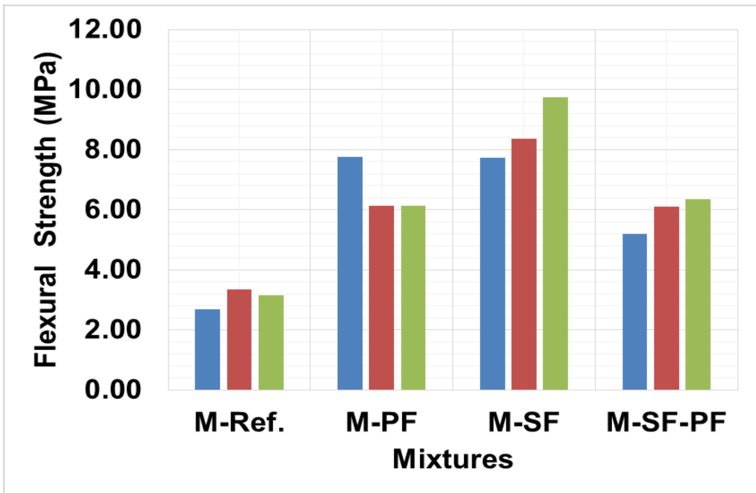

Figure 5. Flexural strength of different mixtures at 28 days

As can be clearly inferred from Figure 6, the average flexural strength of all fiber reinforced cement mortars was higher than control specimens. For example, the average flexural strength of PF based mixtures was 118% higher than the reference mixture. These increment rates were recorded at 182.6% and 92.7% for M-SF and M-SF-PF mixtures, respectively. Compared to compressive strength, the inclusion of fibers enhanced the properties of M-PF under flexural loadings, as expected. However, the dispersion of steel fibers into cement-based materials was more promising in terms of flexural strength. This result can be ascribed to higher rigidity of steel fibers contributing to higher resistance under flexural loadings. Since the tensile strength of steel fibers (1500 MPa) is higher than polymeric fibers (962 MPa), the increment of flexural strength in M-SF was more pronounced compared to M-PF. The average of flexural strength of M-PF specimens was 6.68 MPa while it was 8.62 MPa and 5.88 MPa for M-SF and M-SF-PF specimens, respectively. Although higher rigidity of steel fibers contributed higher flexural strength, it was observed that the crack width of M-SF specimens was larger than M-PF and M-SF-PF specimens. This suggests that fracture toughness is higher in M-SF specimens and it may indicate that lesser energy absorption capacity can be possible although this requires further study. Figure 6 presents the larger crack width of M-SF specimens and tight crack width of specimens.

Steel fiber reinforced cement mortars after flexural tests

Hybrid fiber reinforced cement mortars after flexural tests

Figure 6. Different cracks widths of specimens after tests

3.1. Microstructural Tests

Microstructural analysis confirms that larger crack widths of M-SF specimens are due to pull out of steel fibers under a high level of flexural loadings. Lesser ductile behavior of M-SF specimens compared to polymeric fiber incorporated specimens (M-PF and M-SF-PF) is due to sudden failure of M-SF specimens. On the other hand, tight crack width of polymeric fiber incorporated specimens can be related to reduced toughness of specimens so that higher chance of increased strain under bending loadings is possible. Figure 7 illustrates the dense hydration products and crack width of M-SF specimen.

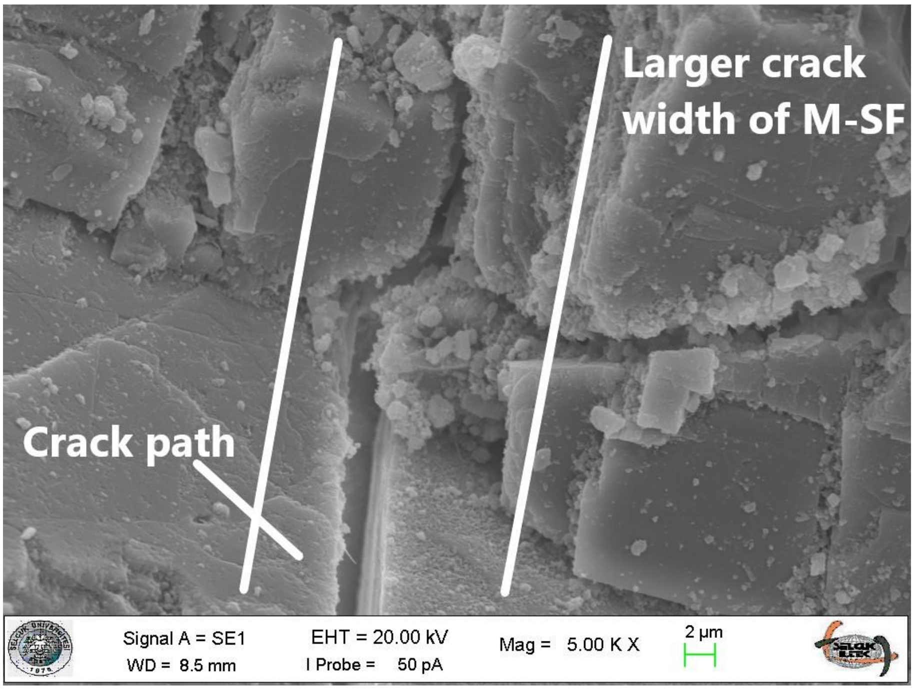

Figure 7. SEM image of steel fiber reinforced cement mortars

4. CONCLUSIONS

An experimental investigation was performed to determine the mechanical properties of single and hybrid fiber reinforced cement mortars. After evaluating the basic engineering properties, the microstructural analysis was performed on mortars. The following conclusions can be made below;

- The addition of polymeric fibers or/and steel fiber did not cause a considerable reduction in compressive strength although the variation of compressive strength values was higher in M-SF-PF mortars. These results suggest that more experimental investigation should be made on hybrid cementitious mortars. Possibly, the inclusion of fibers may have led to entrapped air whereas fibers may have also played a significant role in delaying of cracks under compressive loadings.
- Steel fiber based mortars were promising in flexural strength compared to M-SF-PF, M-PF, and M-Ref. specimens. The reason can be related to higher tensile strength and rigidity of steel fibers that triggers resistance at a higher level of flexural loadings at fracture stage.
- Microstructural analysis supports the abovementioned findings that steel fibers increased the flexural strength however larger crack width was obtained after experiments compared to polymeric fiber incorporated specimens. These results also support that steel fiber incorporated specimens were more fragile than other specimens although this finding necessitates further investigation.

REFERENCES

Balaguru P.N, Shah S.P., 1992, *Fiber Reinforced Cement Composites*. McGraw-Hill Inc. 37–84.

Betterman, L.R., Ouyang, C. and Shah, S.P., 1995., *Fiber-matrix interaction in microfiber-reinforced mortar*, Advanced Cement-Based Materials 2: 53-61.

Johnston C.D., 2001, *Fiber-reinforced cement and composites.* Gordon and Breach Science Publishers, 24–49.

Lawler JS, Wilhelm T, Zampini D, Shah SP., 2003., *Fracture process of hybrid fiber reinforced mortar.* Mater Struct; 36:197–208.

Mobasber, B., Stang, H. and Shah, S.P, 1990, *Microcracking in fiber reinforced concrete*, Cement and Concrete Research, 20: 665-76.

Nawy E.G., 2001., *Fundamentals of high-performance concrete*. 2nd ed. John Wiley & Sons, Inc. pp. 246–289.

Sahmaran M., Yurtseven A., Yaman I.O., 2005., *Workability of hybrid fiber reinforced self-compacting Concrete.* Building and Environment, 40-12:1672-1677.

Sorelli, L.G., Meda, A., Plizzari, G.A, 2006, *Steel fiber concrete slabs on ground: A Structural Matter*. ACI Struct. J. 103, 551–558.

TS EN 197-1 Cement-Part 1: Compositions and conformity criteria for common cements.