



Effects of fiber–matrix interaction on multiple cracking performance of polymeric fiber reinforced cementitious composites



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ABSTRACT

The effects of polymeric fiber addition on the multiple cracking performance of composites have been investigated. For this purpose, cement-based matrices incorporating fly ash and a latex emulsion have been designed. Prismatic samples have been prepared and subjected to four-point bending load. The load-midpoint deflection curves and crack patterns have been determined. Meanwhile, flexural strength and relative toughness values have been calculated. Finally, the number of visible cracks formed throughout the testing period has been analyzed.

Test results showed that the toughening improvement mechanisms of PP and PVA fibers in a cement-based matrix are extremely different and matrix modifications significantly change the multiple cracking performance. The addition of a latex emulsion in a weak matrix decreased the multiple cracking tendency of PP fiber reinforced composites. However, the same modification attempt improved the multiple cracking capacity of weak matrix in case of PVA fiber reinforcement. The possible causes of this performance improvement have been discussed with the aid of microstructure investigations.

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1. Introduction

Strain hardening cementitious composite incorporating polymeric fibers is accepted as one of the future candidates to maintain the sustainability of construction infrastructure [1,2]. Polymeric fibers may significantly change the tensile and flexural performance of cement-based composites and multiple cracking behavior depending on fibers' dosage, bulk physical and mechanical properties and surface structure [3,4]. Multiple cracking performance and pseudo-strain hardening behavior of a fiber reinforced composite may be improved by optimizing the interaction between fiber and cement matrix [5,6].

It is possible to achieve this improvement by changing the fibers' surface structure. In case of polyolefin fibers (PP, PE) insufficient bonding is a problem and extreme slippage from matrix occurs at the stage of loading [7]. The bonding capacity of these fibers may be improved by using physical and chemical surface processing methods [7–9]. On the other hand, comparatively reactive nylon and polyvinyl alcohol (PVA) based fibers are susceptible to high bonding with matrix due to water affinity of fiber surface. As a result of this situation premature fiber rupture occurs rather than slippage at the stage of loading [10–12]. In this case, high bonding capacity of PVA fibers may be decreased by pre-processing the fibers' surface with oiling or lubricating agents [13,14]. How-

ever, the degree of pre-processing should be optimized since excessive surface lubrication may reduce composite performance rather than an improvement [15,16]. The concept of fiber–matrix interface tailoring by pre-processing of PVA fibers with an oiling agent was first introduced by Li and coworkers in 2001 [12,13]. Previously, Li and coworkers designed Engineered Cementitious Composites (ECCs) based on the micromechanics of crack initiation, fiber bridging and steady-state crack propagation in a brittle matrix reinforced with randomly distributed short PE fibers [17,18]. ECC can be characterized by its high tensile strain capacity due to multiple cracking behavior at both tensile and bending load [19,20].

Modification of matrix composition (fly ash, silica fume, blast furnace slag addition, changing W/C ratio, aggregate size, etc.) is another way of optimization of fiber–matrix bond to obtain or improve the multiple cracking behavior [10,21–26]. Li et al. [16] recommend combined use of fly ash and an oiling agent in order to sustain multiple cracking performance of composites incorporating PVA fibers. However, it is important to mention that any matrix modification may not change the composite performance in a similar way if fibers' from different origins are used. The strength of matrix may change the pull out behavior of polyolefin and other reactive fibers made from PVA and polyester in extremely different ways.

The effect of matrix modification (fly ash substitution and latex emulsion addition) on the multiple cracking performance of fiber reinforced composites incorporating fibers with extremely

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different load carrying mechanisms (PP and PVA) have been investigated with a three phase experimental study.

2. Experimental study

2.1. Materials

An ordinary Portland cement (CEM I 42.5R) conforming TS EN 197 [27] standard and a type C fly ash conforming ASTM C618 [28] standard have been used. The specific gravity and Blaine fineness of cement and fly ash were 3.1, 336 kg/m² and 2.2, 290 kg/m² respectively. Fine ground limestone powder (<100 μm) with a specific gravity of 2.67 was used as micro-aggregate phase of composites. In order to achieve appropriate workability a polycarboxylate-based superplasticizer is also employed in matrix compositions. The pH, specific gravity and solid content values of this admixture were 6.5, 1.18–1.20 and 35.7%, respectively.

A latex emulsion based on styrene butadiene copolymer (Lipaton SB5813) was used at the third phase of experimental study. The pH, solid content, specific gravity and viscosity values of emulsion were 8, 48.5%, 1.01 and 30 mPa·s, respectively. Average polymer particle diameter is approximately 0.15 μm and emulsion is maintained by a mixture of anionic and non-ionic emulgators. The minimum film forming temperature is 3 °C. The tensile strength of the film and elongation at break were 6 N/mm² and 1000%, respectively.

The diameters of PP and PVA fibers are in the range of 18–20 μm and 30–40 μm, lengths were 12 and 8 mm, respectively. The selected fibers were extremely different from the view point of surface structure and bulk properties. Both fibers are circular in cross-section. Surface structures of PP fibers are smooth and PVA fibers are rough. According to the previously reported single fiber pull-out test results, embedded PP fibers tend to slip from cement–matrix when subjected to tensile loading, however, PVA fibers usually rupture before slipping [29]. The tensile strength and modulus of elasticity of PP fibers are 300 MPa, and 4 GPa, respectively. On the other hand, the same properties of comparatively high strength PVA fibers are 1600 MPa and 42 GPa, respec-

tively [30,31]. The elongation capacities of PP fibers before rupture (>30%) are quite higher than PVA fibers (6%).

2.2. Mix proportions and specimen preparation

As presented in Section 1, a three phase experimental study has been performed. At the first phase, a strong matrix with solely cement binder has been prepared and notated as MI. Secondly, matrices weakened by replacing 50% of cement with fly ash (MII), and finally, a latex emulsion has been added to this weakened matrix (MIII). PP and PVA fibers have been added to all composites at constant dosage (3% by volume).

A Hobart mixer with ~1500 cm³ capacity was used for mixture preparation. Standard ECC mixing procedure as described in [32] was used. Dry ingredients (cement, limestone powder and fly ash) initially mixed for 30 s., then water and superplasticizer were gradually added and mixing was continued for 2 min until a homogeneous cement slurry is obtained. In case of latex modification, liquid SBR emulsion was mixed with water before addition to the mixture. Fibers were finally incorporated into matrix and sample preparation sequence was finished after 2 min of high speed mixing.

The workability of fiber reinforced mixtures has been measured by using a flow-table conforming the ASTM C1437 [33] standard requirements. Flow diameters of fiber reinforced fresh mixtures arranged between 130 and 150 mm by using a polycarboxylate-based superplasticizers. These admixtures usually preferred to obtain required workability and deforming ability without causing any stability loss and segregation [34]. As can be seen in Fig. 1a, it is easy to deform fresh MI matrix despite the addition of 3% PP fibers. Latex addition into cement matrix (MIII) also promoted the deformation ability of PP fiber reinforced mixtures (Fig. 1b). The mix proportions and required superplasticizer dosages are presented in Table 1. The 28 days compressive strength values of plain matrices are also given in Table 1 for strength grade comparison purpose. Strength values have been determined according to ASTM C349 [35] standard. The compressive strength of high strength MI matrix is 66 MPa. Fly ash substitution (MII) and latex modification



Fig. 1. The spread diameter of PP fiber reinforced MI matrix (a) and deformability of PP fiber reinforced MIII matrix incorporating SBR latex emulsion (b).

Table 1
Mix proportions of matrices.

Matrix code	Cement (kg/m ³)	Water (kg/m ³)	Fly ash (kg/m ³)	Limestone powder (kg/m ³)	Latex emulsion (kg/m ³)	Superplasticizer (%wt of binder)	28 days compressive strength (MPa) ^a
MI	854	380	0	854	0	1.2	66
MII	378	399	378	757	0	2.5	43
MIII	380	266	380	760	133	1.5	38

^a Plain matrices have been casted into 40 * 40 * 160 mm molds, prismatic specimens demolded one day after casting and cured in water for 28 days before testing. Compressive strength values have been determined in accordance with ASTM C349 [35].

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