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Resistance to sulfate attack and underwater abrasion of fiber reinforced cement mortar

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HIGHLIGHTS

- The addition of fibers effectively increases erosion resistance to mortar.
- The increase depends on fiber types and dosages.
- Polypropylene fiber is superior to steel and micro polypropylene fiber.
- Submersion in 5% w/w sodium sulfate decreases erosion resistance of mortar.
- Fibers cannot reduce the adverse effect of sulfate attack on mortar.

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ABSTRACT

This research was conducted to study the combined effect of sulfate attack and underwater abrasion on fiber reinforced cement mortar. Compared to plain mortar mix, cement mortars reinforced with three types of fiber, i.e. steel fibers, polypropylene fibers, and micro polypropylene fibers were investigated. Each fibers was used individually and the micro polypropylene was additionally hybridized with steel and polypropylene fibers. Test specimens were prepared as per ASTM C1138. Their abrasion resistance were examined after submersed in 5% sodium sulfate (Na_2SO_4) solution for 4 and 8 months. The experimental results showed that the Na_2SO_4 solution increased the weight loss of all specimens. The longer the period of submersion, the higher the weight loss. In the specimens reinforced with fibers, the abrasion resistance was enhanced. The highest resistance was found in the mortar mixed with the polypropylene fiber at 1% volume fraction. Moreover, in abrasion resistance point of view, the addition of micro polypropylene fiber had little or no benefit.

1. Introduction

In construction industries, fiber reinforced cementitious composite has become a versatile material widely implemented due to its various advantages [1]. These include, but are not limited to, bridging and confining cracks, gaining toughness and tensile strain capacity, lessening the need for steel reinforcement and laborers, repairing concrete structures and offering a durable and lasting solution [2–4]. Owing to those benefits, fibers hinder the deterioration of cementitious matrices.

Various deleterious mechanisms degrade concrete performance. Depending on what types of aggressive environments concrete is encountered, its damage occurs by means of physical, chemical, and mechanical actions [5]. When two or more actions concurrently take place, concrete is disintegrated more rapidly and severely. Some examples of such circumstance having sulfate attack in common are reported in literatures [6–12]. It is noted that, in two of those reports in which sulfate combined with frost attack, steel fibers play a prominent role on mitigation of concrete degradation.

Another example is a concrete chute in a wastewater treatment system of sulfate-involved industries. While sulfate-laden wastewater flows through the chute, sulfate ions and waterborne sediments in the wastewater together degrade concrete because of

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sulfate attack and abrasion, respectively. To maintain its service life, a thin fiber reinforced cement mortar overlaid on concrete surface is one of feasible repair materials. Fiber is introduced as research studies have showed its achievement on concrete resistance either to sulfate [11–15] or to abrasion [16–18]. However, there is no (or limited, if any) experimental study that investigates fiber performance under the combination of both effects by which the surface erosion may be exacerbated.

Hence, this research was conducted to study the combined effect of sulfate attack and underwater abrasion on fiber reinforced cement mortar as a repair material. A plain mortar is presented as a control mix. Subsequently, cement mortars reinforced with three types of fiber, i.e. steel fibers, polypropylene fibers, and micro polypropylene fibers were prepared. Each fibers was used individually and then the micro polypropylene was additionally hybridized with steel and polypropylene fibers. Test specimens were prepared as per ASTM C1138. After submersed in 5% sodium sulfate (Na_2SO_4) solution for four and eight months, their abrasion resistance were examined.

2. Experimental program

2.1. Materials and mix proportions

A control mix made of plain mortar having a sand to cement ratio of 1:3 and a water to cement ratio of 0.3 by weight was used for a comparison with fiber reinforced cement mortars. Locally available ordinary Portland cement (ASTM Type I) was used in the study. The fine aggregate was river sand having a bulk specific gravity of 2.60. A SNF (Sulfonate Naphthalene Formaldehyde) based superplasticizer was used to manage a workability. The solid content and specific gravity of the superplasticizer were 30% and 1.25, respectively.

Three types of fibers used to reinforce cement mortar in this research were steel fibers (SF), polypropylene fibers (PP), and micro polypropylene fibers (MPP). Their appearances were illustrated in Fig. 1 and their physical properties were listed in Table 1. Initially, each fiber was investigated at two fiber volume fractions – steel fibers and polypropylene fibers at 0.5% and 1% whereas micro polypropylene fibers at 0.15% and 0.3%. After that, steel and polypropylene fiber at the dosage of 0.5% were hybridized with micro polypropylene fiber at 0.3%. Hence, including the plain mortar mix aforementioned, there were nine mixes in total as shown in Table 2.

The mortar mixes were prepared in a 40 L concrete mixer and were molded into two specimen types. One was a round panel with a diameter of 302 mm and thickness of 102 mm for an abrasion test. Another was a 100 × 100 × 350 mm beam for a flexural performance test. Both types of specimens of all mixes were made in three replicates. The specimens were demolded at 24 h after casting and then cured in water for 28 days at room temperature prior to testing. To examine how much sulfate ions can affect the abrasion resistance and flexural performance, they were subsequently submerged in 5% Na_2SO_4 (Sodium Sulfate) solution for 4 and 8 months. The solution was replaced weekly to maintain the concentration of sulfate solution.

2.2. Experimental method

Nine mortar mixes – one plain mortar mix (FRM1), six single type fiber reinforced mortar mixes (FRM2 – FRM7), and two hybrid fiber reinforced mortar mixes (FRM8 and FRM9) – were prepared in three sets of two specimen types. Each set was exposed to three different conditions – one was cured in water for 28 days and the other two were submerged in 5% sodium sulfate solution for 4 and 8 months after water cured for 28 days. After exposed to those conditions, they were examined in the underwater abrasion test as per ASTM C1138 and the flexural performance test as per ASTM C1609. The test methods were described briefly as follows.

2.2.1. Underwater abrasion resistance

To evaluate the underwater abrasion resistance of the mortar mixes, the ASTM C1138 test method was employed. It determines the abrasion resistance in term of weight loss of cementitious materials, which were submerged in water and eroded by flowing particles in the water. The abraded action was simulated on a 302 mm diameter and 102 mm thick round panel specimen by using a circulating tank filled with water and steel balls. At first, after the mortar specimen was removed from a curing bath and the excess water on its surface was wiped off, it was immediately weighed in air to determine its initial weight. Then it was placed into the bottom of the test tank as shown in Fig. 2. Seventy stainless steel balls (10–ϕ 25.4 mm, 35–ϕ 19mm, and 25–ϕ12.7 mm) were placed on top of the test specimen and the water was filled to 165 mm above the specimen's surface. The tank was covered with an electric motor operated paddle box. An agitation paddle was mounted 40 mm above the surface of specimen and was rotated constantly at 1450 rpm. The test was run for 72 h. At every 12 h, the weight of the specimen was measured to find a percentage weight loss with regard to the initial weight. This result was employed to evaluate the influence of sulfate attack and fiber addition on the abrasion resistance of mortar.

2.2.2. Flexural performance of fiber reinforced cement mortar

In addition to abrasion resistance, flexural performance of fiber reinforced cement mortar was evaluated after exposed to sodium sulfate solution for four and eight months. The ASTM C1609 standard test method was followed by using a beam specimen having dimension of 100 × 100 × 350 mm. The beam specimens were loaded with third point bending at the span length (L) of 300 mm by using a universal testing machine. While loading was performed, a net deflection was monitored by using two linear variable differential variable transducers (LVDTs). To eliminate the effect of seating or twisting of the specimen on its supports, a steel jig clamped at mid-depth of the specimen over the supports was installed as recommended in the test standard. Load and net deflection were then plotted. Subsequently, the first peak strength (f_1), the equivalent flexural strength ratio ($R^D_{T,150}$) and the toughness (T^D_{150}) at the net deflection of L/150 (i.e. 2 mm in this case) were analyzed.

3. Results and discussion

After exposed to three curing conditions – one was only moist cured in water for 28 days and the other two conditions were similar to the first plus a further submersion in 5% sodium sulfate solution for 4 and 8 months, the nine mortar mixes (FRM1 – FRM9)

Fig. 1. Photos of fibers used in this study: steel fibers (left), polypropylene fibers (middle), and micro polypropylene fibers (right).

Table 1
Properties of fibers evaluated in the research.

Fiber	Length (mm)	Diameter (mm)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Density (kg/m^3)
Steel Fiber (SF)	60	0.90	1160	210	7850
Polypropylene Fiber (PP)	58	0.9–0.95	450	~10	910
Micro Polypropylene Fiber (MPP)	20	~32 × 10^{-3}	250	3.5–3.9	905