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The mechanical and durability properties of concrete containing hybrid synthetic fibers

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HIGHLIGHTS

- Slump value and flowing time of mixtures showed a nonlinear correlation between them.
- The tensile strength was estimated by fibers content and compressive strength of plain concrete.
- The inclusion of PO fibers increased the toughness of concrete.
- Inclusion of PP fibers enhanced durability performance of PO fibrous mixtures.
- The hybridization of PP with PO fibers improved the structural performance of RC beams in corrosive environment.

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ABSTRACT

In this study, the fresh and hardened properties of concrete including hybridization of polyolefin (PO) and polypropylene (PP) fibers were investigated. The twelve mixtures consisting of different dosages of PO and PP fibers were considered. Mixtures consisted of PO fibers at the volume fractions of 0.5, 1 and 1.5% that some part of those replaced with PP fibers at volume fractions of 0.1% and 0.2%. The properties of mixtures were evaluated using slump and Inverted slump cone tests in fresh state, and using compressive, splitting, and flexural tests in hardened state. In addition, the durability properties were investigated using water absorption, electrical resistivity and chloride penetration tests. The reinforced concrete beams including fibers were made and tested under accelerated corrosion. The influence of fibers on structural performance of sound and corroded beams were assessed by four-point loading test.

The results indicated that hybridization of PO with PP fibers can improve the compressive and splitting tensile strength of mixtures up to 7.5% and 23% compared to those of control mixture, respectively. However, the hybridization of these fibers did not show a positive effect on post-cracking behavior at the flexural test. From durability viewpoint, replacement of some part of PO fibers with PP fibers can control the negative effect of using PO macro fibers. However, at the high volume fraction of fibers, the hybridization of PO with PP fibers showed the negative effect. Based on an overall view of results, hybridization of PO and PP fibers at the volume fraction of 0.9% and 0.1%, respectively, can be recommended for practical usage. This combination of fibers decreased the corrosion of steel in RC beams and improved the key parameters of structural behavior such as yield and ultimate loading, and stiffness of beams.

1. Introduction

One successful strategy for mitigating concerns regarding concrete brittleness is to use short randomly distributed fibers in the concrete mix [1]. The key factors affecting the characteristics of fiber reinforced concrete (FRC) are fiber type, geometry, content, distribution and its orientation as well as matrix properties. Fibers, depending on their geometry, can be classified into two major types: micro- and macro-fibers. The micro-fibers are defined as short fibers having a diameter of 100 µm or less with a specific surface area exceeding 500 cm^2/g. In contrast, the macro-fibers are referred to bigger fibers in diameter and length in comparison with those of micro-fibers with a specific surface area of roughly 10 cm^2/g [2]. According to ACI 544.1R, the fibers used in concrete, with regard to their materials, are divided into four basic groups: steel, glass, synthetic and natural fibers [3]. The studies confirmed that addition of steel fibers into concrete can significantly improve

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the splitting tensile strength and modulus of rupture [4], the load-carrying capacity, ductility, and energy absorption capability [5,6], and impact resistance of concrete [7]. Also, it was reported that steel fibers can positively affect the compressive strength and modulus of elasticity of concrete [4].

Despite the benefits of using steel fiber in concrete, there are some issues, such as high volumetric density, corrosion, and effect on electric and magnetic fields, which limit its usage [8]. Taking into account these disadvantages, the synthetic fibers can be considered as a practical alternative. Among various types of synthetic fibers, polymer-based fibers are more famous than the others. Polypropylene and polyolefin fibers are two main members of the polymer-based fibers used in concrete. These polymeric fibers, owing to their hydrophobicity and excellent chemical stability, can exhibit long-term durability in an aggressive environment [9,10]. Over the last decade, many researchers studied the characteristics of concretes including polypropylene or polyolefin fibers.

Review of the past studies indicated that polyolefin fibers can positively influence the tensile strength, fracture energy [11], and restrained shrinkage cracking of concrete [12] in comparison with plain concrete, although conflicting results were reported about their effects on compressive strength [11,13,14]. According to available literature, utilization of micro-size polypropylene fibers in concrete mixtures can improve the splitting tensile strength, flexural strength, sorptivity coefficient, chloride ion penetration [15], water permeability [9,15,16], electrical resistivity [9], and shrinkage [9,16] in comparison with plain concrete. Furthermore, it was reported that the presence of polypropylene fiber in the concrete mixture can decrease the quantity and size of micro voids, and it also reduces porosity at the interfacial transition zone around the aggregates [16].

A literature search shows that polypropylene and polyolefin fibers were mostly used in micro and macro size, respectively. Hence, their impact area is different. According to an idea proposed by Rossi et al., the fibers based on their geometrical characteristics exhibit two different level of performance in the cracking process. At the material level, the strength and ductility of the concrete can be enhanced by incorporation of micro fibers. At the structural level, the load bearing capacity and ductility of structure can be improved by using of macro fibers [17]. To take the simultaneous advantages of various types of fibers, the idea of hybridization of fibers has been developed. In general, the hybrid fibers' systems are a combination of fibers different in material and/or geometry, which under optimal proportion can provide superior performance in comparison to conventional fiber reinforcement of concrete with a single type of fiber [18,19].

The studies on the combination of steel fibers of different length or diameter corroborated the beneficial influence of hybridization on the toughness of concrete [20,21]. One kind of hybridization, which have been studied by many researchers, is the combination of steel fiber with synthetic fibers. Based on the results of previous studies, combination of steel and polypropylene fibers can improve the compressive and flexural strength [22,23], load bearing capacity [19], impact resistance [24,25], electrical resistivity and water absorption [26] of concrete in comparison with the concrete produced only with steel fibers. Also, it was reported that an optimized hybrid steel-polypropylene fibers system with less content of fibers can produce similar significant improvement in mechanical properties of concrete in comparison with the system using mono fiber [27].

Alberti et al. examined the flexural strength of steel-polyolefin hybrid fiber concrete and reported the complementary performance of polyolefin fiber in improving the post-cracking strength and toughness of steel fiber reinforced concrete [28,29]. Dawood and Ramli studied the mechanical and durability performance of a flowable high strength concrete containing ternary steel-palm-barchip hybrid fiber [8].

Due to the attractiveness of the subject of using synthetic fibers in concrete, researchers have considered the hybridization of synthetic fibers in recent years. A study by Soroushian et al. showed that the combination of polyethylene fibers of two different sizes enhanced the impact and flexural strength and mitigated the negative effect of fibers on compressive strength compared to the cases where each type of fibers were used alone [30]. Hsie et al. found that the combined use of polypropylene fiber of different size, due to the complementary effect of fibers, leads to better mechanical performance of concrete than that of obtained from concrete with single type of fibers. Also, the results corroborated the positive effect of the hybridization of polypropylene fibers on reducing the drying shrinkage strain of concrete [31].

Abovementioned literature review reveals that the majority of published studies on the use of synthetic fibers in concrete have been restricted to the addition of a single type of them alone or in combination with steel fibers; however, a limited number of published research have focused on hybridization of synthetic fibers in concrete. Studying on a combination of different types of synthetic fibers to improve the properties of synthetic-fiber reinforced concrete is therefore of prime importance that can extend the knowledge of this type of concrete and help engineers design and utilize it practically.

In this paper, the influence of hybridization of macro-size polyolefin and micro-size polypropylene fibers, on the fresh and hardened properties of concrete has been investigated. To the authors' knowledge, no research has been performed using a combination of these two types of synthetic fibers in concrete. On the fresh state, the slump and inverted slump cone tests were performed to assess the workability of concrete. On the hardened state, the mechanical properties of concrete were evaluated through measurement of compressive strength, splitting tensile strength, flexural strength, and toughness. Moreover, to investigate the physical and durability properties, the drying shrinkage, initial (30 min) and final water absorption and the electrical resistivity were studied. Also, the resistance to penetration of chloride ions was investigated by measuring the depth of chloride penetration after exposure to NaCl solution for a period of 180 days. The reinforced concrete (RC) beams including fibers were made and evaluated under accelerated corrosion to assess their performance under corrosive environment. The four-point loading test was done to assess the influence of fibers on structural performance of sound and corroded beams.

2. Experimental work

2.1. Materials

A typical commercial Type I Portland cement conforming to the requirements specified in ASTM C150 was used for all mixes. A river sand with fineness modulus of 2.92 was used as fine aggregate. For coarse aggregate, a natural crushed gravel with a maximum size of 12.5 mm was used. A modified polycarboxylic-ether based high-range water-reducing admixture (HRWRA) was used to improve the workability of mixtures. Two different type of fibers including polyolefin fiber with continuously embossed surface texture, in macro size; and polypropylene fiber, in micro size, were used. The characteristics of fibers are given in Table 1.

Table 1
The properties of fibers.

Property	Polyolefin	Polypropylene
Length (mm)	48–50	12
Diameter (mm)	1–1.25	0.02
Density (gr/cm^3)	0.91	0.91
Tensile strength (MPa)	550	400
Elastic modulus (GPa)	>8	3.5