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Experimental investigation on flexural toughness of hybrid fiber reinforced concrete (HFRC) containing metakaolin and pumice

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HIGHLIGHTS

- The mechanical properties for hybrid fibers reinforced concrete.
- Investigation the effect of pumice and metakaolin on compressive strength and flexural toughness of concrete.
- Effect of pozzolans on load versus deflection diagram of hybrid fibers reinforced concrete.
- Modulus of rupture of hybrid fibers reinforced concrete containing pumice and metakaolin.

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ABSTRACT

Fiber reinforced concrete (FRC) has been widely used due to its advantages over plain concrete. It can be an appropriate material for the repair of structures in a variety of situations. However there is a weak zone between fibers and paste in fiber reinforced concretes and this weak zone is full of porosity, especially in hybrid fiber reinforced concretes. Therefore, using of pozzolanic materials is required to reduce the porosity.

Pumice and kaolin are two pozzolanic materials that have been found abundantly in some regions of the world. In this paper, the mechanical properties of concretes containing various amounts of the pozzolanic materials and steel and polypropylene fibers are investigated.

At the first step of this paper, the flexural and impact resistance tests were carried out to choose the optimum percentage of steel and polypropylene fibers. Results showed that hybrid fiber reinforced concrete with 0.75% steel fibers and 0.25% polypropylene fibers had higher toughness indexes, modulus of rupture and impact resistance than other hybrid mixtures. Afterward, compressive strength and flexural tests on hybrid fiber reinforced concretes containing pumice and metakaolin were carried. Results showed that, metakaolin with highest substitution of cement had the best performance of mechanical properties of concrete. Moreover, this pozzolan caused increasing in compressive strength in comparison with control mixture. However, replacing pumice into the specimens had negative effect on the mechanical properties results.

1. Introduction

Concrete is one of the most widely used construction materials, due to its good quality durability to cost ratio. However, it is a tension-weak building material, which is often reinforced with various fibers. The results of various experiments, show that the brittleness of concrete increases with increasing strength. This may be due to low tensile strength and lack of bonding in the transition zone of the cement matrix [1,2].

Fibers are commonly used to enhance the shrinkage cracking, toughness and impact resistance of concretes. Concrete reinforcement with a single type of fibers improves mentioned properties in a limited range [3–5]. However, in hybrid fiber reinforced concretes (HFRC) two or more different fibers suitably applied to provide superior properties. In a well-designed composite, there is a suitable interaction between the fibers so the resulting hybrid has a better performance than mono fiber composite [6–17]. According to Bentur and Mindess [3] the main advantage of a hybrid fibers system is that it provides a system in which one type of fiber, which is stronger and stiffer, improves the first crack stress and ultimate strength, whereas the second type of fiber, which is more flexible and ductile, leads to the improved toughness and

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strain capacity in the post-cracking zone. Moreover, Qian and Stroeven [16] show that the presence of the fiber can increase the strength and toughness retention after certain age while another type is to guarantee the short-term performance during transportation and installation of the composite elements.

However, despite the advantageous effect of fiber on the performance of concrete, a serious deficiency also exists in the transition zone of HFRC [18]. For instance, there is a thick transition zone with a lot of porosity much more than paste in monofilament fibers such as steel fiber [19]. Because of this weak zone between fibers and the paste in fiber reinforced concretes and especially in hybrid fiber reinforced concretes, it is necessary to apply materials that reduce porosity and consolidate this transition zone [20–27]. Therefore, substitution a portion of the cement by pozzolanic materials causes improvement in mechanical properties of concrete and hybrid fiber reinforced concretes and reduces porosity in transition zones [28–36].

Natural and artificial pozzolans, which are materials exhibiting cementitious properties when reacting with calcium hydroxide in the presence of water, have been widely used as partial replacement for Portland cement in blended cements and concrete [37–40]. Generally, substitution of ordinary Portland cement (OPC) by pozzolans in concrete can decrease porosity of concrete especially in long-term [41–45]. On the other hand, obvious economic considerations have directed scientific and industrial interests towards using natural products, such as kaolin, and pumice, [46–54].

As there are several natural pozzolan mines in all around the world and many researches are about the effect of artificial pozzolans on the mechanical properties of fiber reinforced concrete, in this research the effect of pumice and metakaolin on the mechanical properties of hybrid fiber reinforced concretes was investigated.

At the first step of this paper, the flexural and impact resistance tests were carried out to choose the optimum percentage of steel and polypropylene fibers. Afterward, compressive strength tests on hybrid fiber reinforced concretes containing pumice and metakaolin were carried out.

2. Experimental program

2.1. Materials

ASTM C 150 type II Portland cement, for all the concrete mixtures produced by ABIEK Factory. For producing metakaolin, local kaolin was heated by the special furnace at 800 °C and 60 min burning time. The chemical Analysis of cement, pumice and metakaolin was done by measuring wavelength-dispersive X-ray fluorescence spectrometry (XRF). The chemical properties and composition of cement, pumice and metakaolin, used as supplementary cementitious material, are given in Table 1.

Table 1
Chemical characteristics of cement, metakaolin and pumice.

Chemical composition (%)	Cement	Metakaolin	Pumice
SiO_2	19.9	74.3	67.7
Al_2O_3	3.58	17.8	15.8
Fe_2O_3	3.94	0.82	3.39
CaO%	59.9	3.38	3.90
MgO%	3.08	0.22	0.99
SO_3%	5.00	–	0.33
Na_2O%	0.05	0	2.95
K_2O%	0.84	0.39	2.00
TiO_2%	0.35	–	0.33
MnO%	–	–	0.04
P_2O_5%	0.06	–	0.12
LOI%	2.51	2.56	2.30
C_3S	48.68	–	–
C_2S	20.33	–	–
C_3A	2.82	–	–
C_4AF	11.99	–	–

For all mix designs, coarse aggregates were crushed calcareous stone with a maximum size of 19 mm and fine aggregate was natural sand. The coarse aggregates have a specific gravity and a water absorption of 2510 kg/m^3 and 1.90%, respectively, and the fine aggregate has a water absorption of 2.75% and a specific gravity of 2570 kg/m^3. The grading of aggregates according to the ACI 506-R [55] and ACI 544-1R [56] Standards is presented in Table 2.

Used steel fibers were hooked ended fibers (Fig. 1). Physical and mechanical properties of steel fibers are given in Table 3. The type of used polypropylene fibers was staple with a length of 12 mm (Fig. 2). Physical and mechanical properties of polypropylene fibers are given in Table 4. Potable water was used for casting and curing of all concrete specimens. The polycarboxylic ether based superplasticizer was employed to achieve the desired workability.

2.2. Mixture proportion and mixing procedure

2.2.1. Steel–polypropylene hybrid fiber reinforced concrete specimens

The mixing procedure started with a dry mixing of coarse and fine aggregates with the steel fibers for 30 s. Then one third of the mixing water was added to the mixture and mixed for 30 s. After that cement and half part of polypropylene fibers were added to the mixture and mixed for 2 min. Finally the rest of water and polypropylene fibers were added to the mixture and mixed for another 1.5 min. The fresh concrete was placed in three100 * 100 * 500 mm prismatic molds and three 100 * 200 mm cylindrical molds. The former is for the test of flexural test and the second is for the impact resistance test.

After casting, the concrete specimens were covered with a wet towel for 36 h and cured under laboratory conditions. Then, they were demolded and cured in lime-saturated water at 23 ± 2 °C for 28 days to prevent possible leaching of $Ca(OH)_2$ from these specimens. Table 5 gives the detail of the mixture proportions for a cubic meter of concrete. As shown in Table 5, five mixtures were made. All the mixtures were prepared in pan mixer which has 0.06 m^3 capacity.

Table 2
Aggregate grading.

Sieve size	Percent by weight passing individual
3/4 in. (19 mm)	100
1/2 in. (12 mm)	100
3/8 in. (10 mm)	96
NO. 4 (4.75 mm)	75
NO. 8 (2.4 mm)	55
NO. 16 (1.2 mm)	37
NO. 30 (600 μm)	25
NO. 50 (300 μm)	11

Fig. 1. Steel fibers.

Table 3
Physical and mechanical properties of steel fibers.

Length (mm)	Diameter (mm)	*L/D*	Tensile strength (MPa)	Density (kg/m^3)
36	0.80	45	>1200	7850