Construction and Building Materials 188 (2018) 729–736

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental research on magnesium phosphate cement mortar reinforced by glass fiber

Yuan Fang [a], Bing Chen [a,b,*], Sajjad Yousefi Oderji [a]

[a] Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
[b] State Key Laboratory of Ocean Engineering (Shanghai Jiao Tong University), Shanghai 200240 China

HIGHLIGHTS

- Effects of glass fiber on mechanical properties of MPC were studied.
- The addition of glass fiber improved the water resistance of MPCs.
- The flexibility and deformation behavior of MPC can be improved by using glass fiber.
- The mechanism of glass fiber improving water resistance of MPC was analyzed.

ARTICLE INFO

Article history:
Received 17 July 2017
Received in revised form 12 July 2018
Accepted 23 August 2018

Keywords:
Magnesium phosphate cement
Glass fiber
Fiber-reinforced
Strength
Water resistance

ABSTRACT

This paper describes an experimental investigation into the compressive strength, the flexural strength and the water resistance of magnesium phosphate cement (MPC) mortar reinforced by glass fiber. Fiber volume fractions of 1.5%, 2.5%, 3%, 3.5% and binder/aggregate ratios of 1:1, 1:1.2 and 1:1.5 were designed for the experiments. The microstructural, mechanical and water resistance properties of fiber-reinforced MPCs were evaluated with respects to the variance in the fiber volume fraction, the ratio of binder/aggregate. The results showed that the glass fibers have more pronounced effects on the flexural strength compared to compressive strength. The optimum volume fraction of glass fiber is reported at 2.5%. Furthermore, the effect of glass fiber on the water resistance of MPC is discussed, and a "reserving" method to resist the strength loss by water has been proposed. In addition, the paper provides a possible explanation of the fiber reinforcement mechanism which is in agreement with the experimental results.

1. Introduction

Magnesium phosphate cement (MPC) is a new type of green cementitious material formed by mixing dead burnt magnesium oxide with phosphate and a retarder in certain proportions. The development of strength in MPC is due to the chemical bond formation by the acid-base reaction, similar to that of ceramics [1,2]. Comparing magnesium phosphate cement with traditional Portland cement, MPC exhibits a combination of performance properties including high early age strength, fast setting and hardening, high heat of hydration, good volume compatibility and excellent bonding to old concrete structures [3]. Due to the preponderance of MPC, it has potential applications in various fields, such as in fast mending of roads and bridges, in repair of human teeth and bones, and in plastering mortars [4]. However, there are still limitations to the application of MPC, some of which include high heat of hydration, a short setting time, poor water resistance and brittleness [5].

For enhancing strength, a great deal of controlling methodologies has been developed and applied widely [6–11]. The methods could be summarized into two types: First, optimization of the mix ratio design in order to enhance crystallization, leading to a denser microstructure. For example, it takes place by controlling Mg/P ratio to adjust the resultant and the rate of the reaction, which reported by Mathieu Le Rouzic et al. [6]. Moreover, the water-to-binder ratio and the molar ratio of magnesium-to-phosphate have been known to cause an effect on strength development [7]. Second, adding substances, such as mineral admixtures [8], fly ash [9] and slag [10], to improve the strength of MPCs.

For improving water resistance, in the 1990s, Sarkar et al. found that the strength of MPCs decreased by almost 20%, when they were immersed in water [11]. Water resistance can be improved

* Corresponding author at: Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China.
E-mail address: hntchen@sjtu.edu.cn (B. Chen).

https://doi.org/10.1016/j.conbuildmat.2018.08.153
0950-0618/

by two methods, improving the production of hydration products of struvite, and decreasing the porosity [12,13]. However, these are not suitable for external structures, so a suitable economical method for construction is urgently required.

Addition of fibers to these composites is a method for improving their ductility. Steel fiber was first used as a toughening medium fiber in cement concrete. Wang et al. [14] found that the incorporation of steel fiber can greatly improve the strength and wear resistance of MPC, while reducing its shrinkage. Chemical fiber, like polyvinyl alcohol fiber (PVA fiber), polypropylene fiber, carbon fiber, which have high strength, elastic modulus and corrosion resistance are commonly used in reinforced MPC. Chen et al. [15] study that the addition of PVA can significantly improve the toughness of MPC. Plant fiber reinforced MPC has been used in the field of thermal insulation materials. Chen et al. [16] studied that the addition of rape straw can reduce the apparent density and compressive strength of MPC, but at the same time it can also reduce its thermal conductivity.

Glass fiber reinforced cement (GFRC) is a cement mortar with glass fiber based composite material, which has been widely used for 50 years. Due to its easy moldability, good mechanical properties and good fire resistance, GFRC has been applied mainly as cladding panels [17]. However, the durability of glass fiber in an alkaline environment has been a main limitation of GFRC. Although alkaline resistant (AR) glass fibers have been widely utilized in GFRC, the durability problems still have not been solved completely [18]. The neutrality conditions of MPC may provide promising results, meanwhile, the effect of fiber on the water resistance of MPC has not been researched completely.

Consequently, in the present work, the effect of glass fiber on mechanical properties of MPCs was systematic studied. Besides, the improving of water resistance was presented in this paper and their mechanisms are analyzed.

2. Experimental details

2.1. Materials

The magnesium phosphate cement (MPC) was prepared from a mixture of dead burnt magnesium oxide, ammonium dihydrogen orthophosphate ($NH_4H_2PO_4$), fly ash (FA) and borax at various proportions and used in the same manner as Portland cement. The magnesium oxide powder with specific surface area (SSA) of 230 m^2/kg and average particle size of 1.05 μm was acquired from the Taishan Refractory Plant of Shanghai. Its calcination was undertaken at approximately 1500 °C for 6 h, which attained a purity of 91.5%. The ammonium dihydrogen orthophosphate and borax added in the current research were industrial grade. The chemical composition of magnesia and fly ash are shown in Table 1.

The glass fiber of 12 mm length with constant diameter of 9.4 μm was used in the present study. The physical properties of the glass fiber are provided in Table 2. In this study, the natural river sand was utilized as fine aggregates and its grading curve is shown in Fig. 1.

2.2. Sample preparation

For each sample, the weight ratio of water to solid (W/C) which includes of magnesium oxide, ammonium dihydrogen orthophosphate, fly ash, borax, sand and glass fiber was fixed at 0.16, and fiber volume fractions of 1.5%, 2.5%, 3%, 3.5% was design for the specimen. The samples were prepared using a fixed consists of borax (3.5% of the weight of metal oxide) with a sand/binder ratio of 1:1, 1:1.2 and 1:1.5. Table 3 summarizes these mixing parameters.

Table 2
The physical properties of glass fiber.

Property	Unit	Glass fiber
Dry density	g/cm^3	2.5
Linear density	dtex	1.53
Modulus of elasticity	GPa	29.5
Breaking strength	MPa	1510
Elongation at break	%	5.4

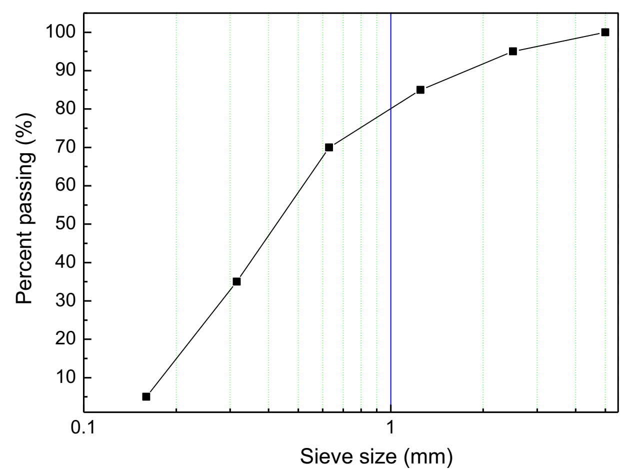

Fig. 1. The grading curve of natural river sand.

It is to point out that the water to solid ratio affect the strength of specimen while the existence of glass fiber increase water requirement. In order to have a balance of water-fiber, when the volume fraction of fiber is increasing or the cement/sand is smaller than 1:1, the adjustment of water reducer (Sodium Polyacrylate, PAAS) was due for maintaining the fluidity of mixture and the workability of specimen. Flowing table test (standard UNE-EN 1015-3) were tested to evaluate the workability of the mixed cement. The picture of experimental process was showed in Fig. 2. The mixing proportions and maximum diameter are listed in Table 3.

The samples of series Ⅰ were separated into two groups: half of the samples were cured in water and the other half were cured at a similar controlled condition (temperature 10 ± 2 °C, humidity of 50 ± 5%) as the samples of series Ⅱ. The samples of size 40 × 40 × 40 mm were casted for the compressive strength using MTS servo hydraulic testing machine at the speed of 500 N/s and size 40 × 40 × 160 mm were casted for the flexural strength by controlling the loading rate of flexural strength at 0.05 mm/min. Strength of specimens cured in controlled condition at ages of 1 h, 1d, 7d and 28d and cured in water at ages of 28d were tested. The samples cured in water were dried at 15 ± 2 °C for 2 h before testing the strength. Finally, the microstructure and morphology of samples were observed by scanning electron microscopy (SEM, NOVA Nano SEM 230).

3. Results and discussion

3.1. Effects of fiber volumes

3.1.1. Compressive strength

The effect of various volume fractions of glass fiber on the compressive strength of GFRC mortar at 1 h, 1d, 3d, 7d and 28d are illustrated in Fig. 3. The compressive strength of all specimens regardless of the curing time first increased with the volume fraction of glass fiber from 0% to 2.5%. A slight drop was observed when the quantity of glass fiber surpassed 2.5%. For example, the com-

Table 1
Chemical composition of magnesia and fly ash.

Material	Mass fraction of the sample (%)								
	MgO	Al_2O_3	Fe_2O_3	CaO	SiO_2	P_2O_3	SO_3	K_2O	Na_2O
Magnesia	89.51	2.35	1.16	1.44	4.91	0.11	–	–	–
fly ash	1.80	25.80	6.90	8.79	54.90	–	0.60	0.30	0.30