Construction and Building Materials 185 (2018) 648–660

Contents lists available at ScienceDirect

Construction and Building Materials

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

Interface bond performance of steel fibre embedded in magnesium phosphate cementitious composite

Hu Feng [a], M. Neaz Sheikh [b,*], Muhammad N.S. Hadi [b], Lu Feng [a], Danying Gao [a], Jun Zhao [a]

[a] School of Civil Engineering, Zhengzhou University, Henan 450001, China
[b] School of Civil, Mining and Environmental Engineering, University of Wollongong, NSW 2522, Australia

HIGHLIGHTS

- Interface bond between steel fibre and MPC based matrix was investigated.
- Bond properties were influenced significantly by the compressive strength of matrix.
- End-hooks of the steel fibre improved significantly the bond properties.
- Bond properties improved by the incorporation of silica fume up to 10% by mass.
- Effect of different types of cement on the bond properties was also investigated.

ARTICLE INFO

Article history:
Received 10 May 2018
Received in revised form 10 July 2018
Accepted 13 July 2018
Available online 20 July 2018

Keywords:
Pullout
Steel fibre
Magnesium phosphate cement
Physicochemical bond
Mechanical bond

ABSTRACT

A series of pullout tests were carried out to characterize the interface bond between steel fibre and magnesium phosphate cement (MPC) based matrix. The effect of the mixture proportions, curing time and end-hook of fibre on the interface bond properties between the steel fibre and the MPC-based matrix was investigated. The mixture proportions investigated include the mole ratio of magnesium oxide to potassium dihydrogen phosphate, mass ratio of sand to cement, mass ratio of water to cement and dosage of silica fume. The effect of different types of cement on the interface bond properties was also investigated.

1. Introduction

Magnesium phosphate cement (MPC) is a new type of binder in which the chemical bond is formed by acid-base reactions between magnesia and phosphate. Compared to the ordinary Portland cement, the MPC possesses many excellent properties including very rapid setting, high early strength, ability to set and harden at temperatures as low as −20 °C, low shrinkage, high bond strength, high abrasion resistance and high durability. Therefore, the study and applications of MPC as a repair and quick-construction material have received significant attention in recent years [1–7].

The MPC-based composites have excellent engineering properties; however, they are typically brittle in nature and have inherent weaknesses in resisting tension. Moreover, they are more brittle than the ordinary Portland cement (OPC) and sulphoaluminate cement (SAC) based matrix because of the high volume of cementitious compounds [8]. It has been recognized that the behaviour of such materials can be significantly improved by the addition of discontinuous fibres [9]. The results of some studies indicated that the addition of the proper type and amount of fibres into MPC-based matrix led to composites with an elastic-plastic or deflection hardening behaviour under bending [10]. The steel fibre is one of the most widely used fibres for improving the strength, ductility and toughness of brittle cementitious composites due to the ease of application together with its high efficiency. The chemical bond strength between the steel fibre and the MPC-based matrix was higher than chemical bond strength between the steel fibre and the sulphoaluminate cement (SAC)-based matrix [11,12]. The addition of steel fibre improved significantly the compressive strength, flexural strength, flexural toughness and flexural ductility of MPC-based composites [13]. The improvement in composite properties is largely attributed to the bond between the steel fibre and the matrix. The steel fibre-matrix interface bond strongly influences the ability of fibres to stabilize crack propagation in the matrix.

* Corresponding author.
E-mail address: msheikh@uow.edu.au (M.N. Sheikh).

https://doi.org/10.1016/j.conbuildmat.2018.07.107
0950-0618/

The interface bond between the steel fibre and the cementitious matrix can be separated into physicochemical and mechanical contribution. The physicochemical bond contribution is predominantly influenced by the cementitious matrix packing density and the properties of the fibre surface (i.e., smooth, etched, or roughened). The mechanical bond contribution is influenced by the geometric deformation of the fibre and the transverse tensile stress resistance of the matrix [14]. The packing density and transverse tensile stress resistance of the matrix are related to the mixture proportions of the matrix and curing time. While some studies provided preliminary results on the bond properties between steel fibre and MPC-based matrix, a large number of variables are yet to be investigated. The interface bond between the steel fibre and the MPC-based matrix has not yet been fully characterized. The test of pullout fibre embedded in the cementitious matrix is generally used to characterize the fibre-matrix interface bond [9]. The known parameters that govern the mechanical properties of fibre reinforced cementitious composites include fibre type, fibre dimensions [15,16], fibre geometry [17,18], volume fraction [19], strength of the fibre-matrix interface [20], surface texture of the fibres [21,22], fibre combination [23,24] and fibre distribution [25]. The effects of these parameters on the mechanical properties of fibre reinforced cementitious composites can be investigated by the pullout test.

A series of pullout tests of steel fibres embedded in the MPC-based matrix were carried out in this study. The effect of the mixture proportions, curing time and end-hook of the fibre on the interface bond properties was experimentally investigated. The mixture proportions of the matrix investigated include the mole ratio of magnesium oxide (MgO) to potassium dihydrogen phosphate (KH_2PO_4), mass ratio of sand to cement, mass ratio of water to cement and dosage of silica fume. The fibres investigated include straight and hooked-end steel fibres. The effect of cement types (MPC, SAC and OPC) on the interface bond properties was also explored. The results obtained from this investigation are important for better understanding the role of steel fibres in improving the strength and toughness of MPC-based composites.

2. Experimental program

2.1. Materials

The Magnesium Phosphate Cement (MPC) was prepared from a mixture of magnesium oxide (MgO), potassium dihydrogen phosphate (KH_2PO_4) and multi-composite retarder. The multi-composite retarder consisted of borax ($Na_2B_4O_7{\cdot}10H_2O$), disodium hydrogen phosphate dodecahydrate ($Na_2HPO_4{\cdot}12H_2O$) and calcium chloride ($CaCl_2$). The MgO was sourced from Zhengyang Casting Material Company of Xinmi, Henan, China [26] in the form of magnesia powder with a specific surface area of 429 m^2/kg. The detailed chemical composition of MgO is provided in Table 1 [26]. The industrial-grade potassium dihydrogen phosphate (KH_2PO_4) with a purity of 98%, particle size of 180–385 μm and relative density of 2.338 was supplied by Weitong Chemical Co., Ltd of Wujiang, Jiangsu, China [27]. The industrial-grade borax ($Na_2B_4O_7{\cdot}10H_2O$) with a purity of 95% and particle size of 80–220 μm was provided by Banda Technology Co., Ltd. of Liaoning, China [28]. The disodium hydrogen phosphate dodecahydrate ($Na_2HPO_4{\cdot}12H_2O$) with a purity of 99% and calcium chloride ($CaCl_2$) with a purity of 96% were analytic grade chemical provided by Kermel Chemical Reagent Co., Ltd. of Tianjin, China [29]. The silica fume with a purity of 92% and a specific surface area of 200 m^2/kg was sourced from Nangong Ruiteng Alloy Material Co., Ltd of Hebei, China [30]. Tap water and natural river sand with fineness modulus of 2.06 were used in this study.

Table 1
Chemical composition of MgO [26].

Composition	MgO	Fe_2O_3	SiO_2	CaO	Others
Mass fraction of the sample (%)	92.53	0.87	3.1	1.6	1.9

The fibre-S and fibre-H were used to investigate the effect of the end hook of the steel fibre on interface bond properties in this study. Both the fibre-S and fibre-H have a smooth surface with a round section. The fibre-S (diameter of 0.75 mm and length of 30 mm length) was straight. The fibre-H (diameter of 0.54 mm and length of 35 mm) was hooked at the end. Table 2 summarizes the properties of steel fibre provided from manufacturers [31]. The sulphoaluminate cement (SAC) of Grade P.O 42.5R according to GB20472-2006 [32] and the ordinary Portland cement (OPC) of Grade P.O 42.5 according to GB175-2007 [33] used in this study were obtained from Anda Special Cement Co., Ltd. Group of Yicheng [34] and Mengdian Group Cement Co., Ltd of Henan, China [35], respectively.

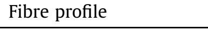
2.2. Mixture proportions

The proportions of the mixtures are shown in Table 3. As shown in Table 3, the "M" in the Series names represents the MPC. The "M/P", "S/C", "W/C" and "SF/C" in the series names represent the MgO-KH_2PO_4 mole ratio, sand-cement mass ratio, water-cement mass ratio and percentage of silica fume to cement by mass, respectively. The magnesium phosphate cement consists of the magnesium oxide (MgO) and potassium dihydrogen phosphate (KH_2PO_4). The default values of MgO-KH_2PO_4 mole ratio, sand-cement mass ratio, water-cement mass ratio and silica fume dosage for the MPC-based matrix are 4, 0.8, 0.14 and 0%, respectively. When one of the variables was changed in the experimental program, the other variables were kept fixed. The dosage of multi-composition retarder was 9.0% of MgO by mass for all MPC matrices. The mass ratio of borax ($Na_2B_4O_7{\cdot}10H_2O$), disodium hydrogen phosphate dodecahydrate ($Na_2HPO_4{\cdot}12H_2O$) and calcium chloride ($CaCl_2$) in the multi-composition retarder was 1:3:1.

2.3. Specimen preparation

The solid raw materials, included the cement (magnesium oxide and potassium dihydrogen phosphate), borax and sand were mixed evenly by a mixer at a low speed. Then the water was added into the mixer and mixed at a low speed for 30 s, followed by a high speed mixing for 60 s. The mixture was cast into the steel moulds, and the steel moulds were compacted on a vibration table. The specimens of MPC-based, SAC-based and OPC-based composites

Table 2
Properties of steel fibres [31].

Fibre profile	Fibre type	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Shape and Surface
	Fibre-S	30	0.75	≥1100	Straight/Smooth/Round
	Fibre-H	35	0.54	≥1200	Hooked-end/Smooth/Round