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Feasibility study of strain hardening magnesium oxychloride cement-based composites

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HIGHLIGHTS

- MOC based engineered cementitious composites (MOC-ECC) were developed.
- MOC-ECC exhibits saturated crack pattern and tight crack width control under tension.
- The tensile strain capacity of MOC-ECC ranged from 5% to 7% at the peak stress.
- The performance of MOC-ECC is originated from the crack bridging capacity of PE fibers.

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ABSTRACT

Magnesium oxychloride cement (MOC) has been studied as an alternative to the ordinary Portland cement. Although MOC based concrete has good strength, early hardening and high bond strength, the applications have been limited due to its disadvantageous chemical nature to steel reinforcement and the natural brittleness. In order to extend this material to wider applications, MOC based engineered cementitious composites (MOC-ECC) was developed. The present paper introduces the fabrication of MOC-ECC with 4 different mixture proportions and a series of tests on the mechanical properties. The tests indicated that the MOC-ECCs have the tensile strain capacity ranging from 5% to 7%, and the tensile strength about 5 MPa. Furthermore, tight crack width control and exceeding compressive ductility were experimentally demonstrated. The addition of fly ash is proved of significant effect on the mechanical properties, including compressive strength, tensile strength, tensile strain capacity, matrix fracture toughness and fiber bridge capacity. The fracture toughness and fiber bridge capacity were used to explain the influence of fly ash to the tensile strain capacity of MOC-ECC in a mesoscopic scale.

1. Introduction

Magnesium Oxychloride Cement (in short MOC, also known as Sorel cement) is a magnesia-based cementing material which has air-hardened and micro-expansive characteristics. With chemical reaction between light-burned magnesium oxide and magnesium chloride solution at ambient temperature, the MOC system is a typical ternary system with magnesium oxide, magnesium chloride and water [1–3], and the mechanical properties of MOC depend largely on the phases formation of its main reaction products, which are $5\,Mg(OH)_2{\cdot}MgCl_2{\cdot}8H_2O$ (phase 5) and $3\,Mg(OH)_2{\cdot}MgCl_2{\cdot}8H_2O$ (phase 3).

As compared with the ordinary Portland cement, MOC has many superior properties, such as high compressive strength, early setting and hardening, good resistance to abrasion and chemicals, as well as good bond strength to large amounts of different substances [4]. Mixed with various additives, such as fly ash, silica sand and reactive powder, MOC has been applied as wood packaging materials, road isolation facilities, grinding tools, interior walls and partition walls, etc. [5]. Furthermore, compared with the calcination temperature needed for producing Portland cement, the requirement of that for producing light burnt MgO is much lower. Therefore, MOC attracts the attention from construction industry because it is energy efficient and environment friendly.

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Table 1
Mixture proportion of MOC-ECC.

Mixtures	Binder			Water	HRWR	Fiber (volume%)
	MgO	$MgCl_2$	Fly ash			
FM20	0.58	0.22	0.20	0.2	0.0019	2
FM30	0.50	0.20	0.30	0.2	0.0019	2
FM40	0.43	0.17	0.40	0.2	0.0019	2
FM60	0.29	0.11	0.60	0.2	0.0019	2

Note: All numbers are mass ratios of binder weight except fiber contents (volume fraction).

Table 2
Chemical compositions of the raw powders.

Ingredients		MgO	Fly ash
Chemical composition (%)	Na_2O	–	0.58
	MgO	84.46	0.90
	Al_2O_3	0.07	23.90
	SiO_2	12.88	51.70
	P_2O_5	0.03	0.40
	SO_3	0.09	0.91
	K_2O	0.04	1.40
	CaO	1.78	7.65
	TiO_2	–	1.19
	MnO	0.04	0.07
	Fe_2O_3	0.60	5.22

Despite all those advantages, MOC has serious issues to be used as a structural material. First of all, MOC is not a suitable matrix for steel reinforcement. Owing to its chemical nature, MOC based concrete has lower alkalinity (pH of 10–11) but very higher content of free chloride ions (1.5%–6.0%). It is known that chloride ion is a kind of extremely strong depassivator. At low alkalinity condition, chloride concentration can result in a broken passivating film of steel and leads to serious corrosion [6,7]. It is suggested that "magnesium oxychloride cement must not be combined with steel reinforcement or put in contact with steel surfaces, as chloride ions present in the pore solution and the low pH of the latter promote steel corrosion" [8].

The other two drawbacks of MOC concrete are the vulnerability under tension and the weak durability. MOC based concrete is a material with inherently brittleness. Under moist environment, it deteriorates significantly due to the leaching of magnesium chloride, resulting in strength loss and macroscopic cracking. In turn, the cracked matrix will significantly speed up the water penetration rate, thus accelerating the deterioration and form a vicious circle [9–11].

In recent years, significant efforts have been expended to improve the reaction mechanisms, chemistry and engineering properties of MOC. Chau et al. studied the effects of fly ash on the properties of Magnesium oxychloride cement. The experimental results indicated that the addition of fly ash changed the flow property, setting times, compressive strength development, water resistance, volume stability and microstructures of MOC. It is concluded that MOC containing a certain amount of fly ash has a potential to be utilized in the construction industry [12]. Li et al. conducted a parametric study to investigate the influences of the molar ratios of $MgO/MgCl_2$ and $H_2O/MgCl_2$ on the properties of magnesium oxychloride (MOC) cement [7]. Karimi et al. studied the influences of the mole changes of magnesium chloride on the compressive properties of MOC concrete. Magnesium oxychloride cements with fixed moles of magnesite/water and the varying moles of magnesium chloride (0.5–1.9) were test for nano SiC composite purposes [13]. Li et al. experimentally studied the effect of granite fragment and granite sludge on the compressive property of fly ash magnesium oxychloride cement [14]. Tan et al. added phosphoric acid (H_3PO_4) to improve the water resistance of MOC though its addition resulting in a reduction in compressive strength [15]. In particular, Anna Tatarczak et al. studied the influ-

Table 3
Properties of PE fiber.

Property	Diameter (μm)	Fiber aspect ratio	Strength (GPa)	Elastic modulus (GPa)	Rupture elongation (%)	Density (g/cm^3)
PE	25	480	2.9	116	2.42	0.97

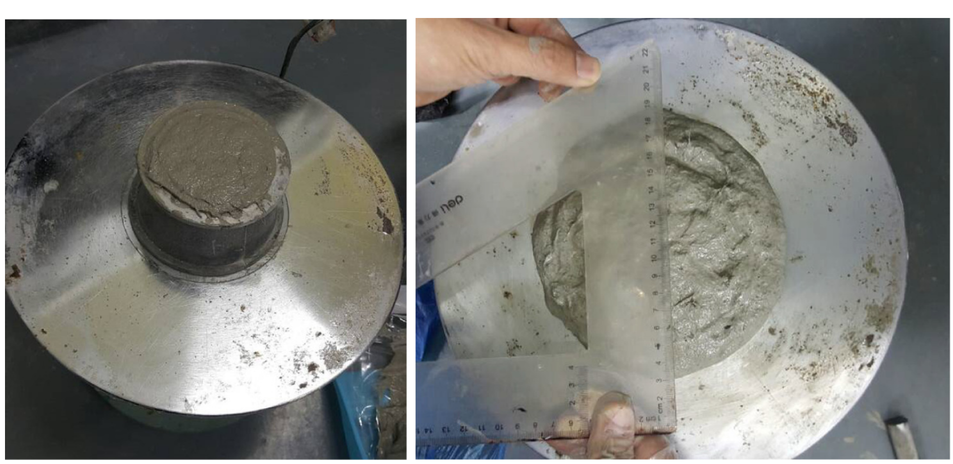

Fig. 1. Fluidity test of MOC-ECC.