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Polymer-modified mortar with a gradient polymer distribution: Preparation, permeability, and mechanical behaviour

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HIGHLIGHTS

- Magnetic Field Targeting Technology (MFTT) is introduced in polymer modified mortar.
- Gradient Polymer Distribution (GPD) in PMM is achieved by MFTT.
- GPD leads to lower chloride diffusion coefficient at the same polymer addition.
- PMM with GPD shows much different mechanical behaviour in terms of flexural strength.
- MFTT can potentially extend application of PMM with reduced material cost.

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ABSTRACT

A technology that produces a gradient polymer distribution in polymer-modified mortar (PMM) was developed to minimize the polymer addition in PMM without losing the improved properties. The mortar was modified using a magnetic responsive polymer latex and was subjected to a magnetic field during moulding. Driven by magnetic force, the added polymer particles were enriched in the superficial region of the PMM, and a dense protective layer with much higher polymer content was generated in the hardened mortar, which increased the impermeability of the material. The gradient polymer distribution was confirmed by thermogravimetric analysis and X-ray diffraction analysis. The chloride permeability test according to ASTM-C1202 and alternative current impedance spectroscopy measurement were carried out to compare the permeability of PMM with the gradient and homogenous polymer distributions with the same polymer addition. The results from the bending test revealed that the gradient polymer distribution led to a higher flexural strength when the polymer-rich side was placed downwards during the test.

1. Introduction

Polymer modified concrete (PMC) has already been used in various applications in the construction industry since the concept of polymer modification for cementitious materials was put forward in the 1920s [1,2]. Many effective polymer modification systems for mortar and concrete have been developed and intensively applied because of their improved properties compared with conventional cement mortar and concrete. Previous studies have shown that the incorporation of polymers into cement mortar or concrete often leads to an improved workability and mechanical properties, especially higher flexural strength and decreased elastic modulus [3–7], improved impermeability such as lower chloride diffusivity [8–10], higher frost resistance [11], reduced shrinkage rate [12], and eventually improves the durability [13–16] of the concrete structure. Various types of polymers such as poly vinyl acetate, styrene butadiene copolymer rubber, and acrylate polymer have been used. The mechanism of polymer modification is related to the influences of polymers on the microstructures of hardened cement mortar and concrete, cement hydration process, and pore size distribution [15–18]. Among these studies, the addition of polymers is a very effective way to improve the performance of cement mortar and concrete in terms of either mechanical property improvement or durability aspects. Shaker et al. [19] found that PMC with a polymer to cement mass (P/C) ratio of 15% has a superior water tightness, better steel protection against chloride, improved abrasion, and improved sulphate solution resistance compared with conventional concrete even after a very long experimental time of 12 months. Rossignolo and Agnesini [20] investigated the effects

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Table 1
Composition of Portland cement (wt%).

Chemical composition									Mineral composition			
SiO_2	Fe_2O_3	Al_2O_3	SO_3	MgO	CaO	Na_2O	K_2O	Loss	C_3S	C_2S	C_4AF	C_3A
23.47	2.97	7.41	2.39	1.97	60.28	0.14	0.62	2.8	49.58	28.04	8.57	7.28

Table 2
Properties of Portland cement.

Water content for standard consistence (%)	Initial setting time	Final setting time	Soundness	Flexural strength (MPa)			Compressive strength (MPa)		
				3 d	7 d	28 d	3 d	7 d	28 d
27.5	172 min	262 min	Satisfied	5.46	6.96	8.69	27.9	40.9	51.7

Testing according to Chinese Standards, GB/T17671-1999 and GB/T1346-2001.

Table 3
Properties of magnetic polymer latex.

Core	Shell	Solid content (%)	Magnet content (%)	pH	Particle size (nm)	Glass transition temperature (Tg) (°C)	Minimal film formation temperature (MFFT) (°C)
BA/St	Fe_3O_4	20	30	8.0	200	−6	<1

of styrene butadiene rubber latex with P/C ratios of 5% and 10% on the durability of lightweight concrete. The use of PMC led to lower water absorption and significantly improved resistance to chemical attacks and corrosion.

Different amounts of polymer addition are required to gain various improved properties of mortar or concrete. As far as mechanical properties or impermeability is concerned, a polymer addition of 3–20% is usually needed. With less than 3% of polymer addition, the mechanical properties or impermeability hardly changes. For example, impermeability can only be improved when the polymer forms a semi-continuous film in the matrix of hardened cement hydrates. Hence, a minimum polymer addition is required to ensure film formation, which is usually larger than 3% of P/C ratio. Such amount of polymer addition in concrete will notably increase the material cost of concrete because of the very high material cost of those polymers compared with cementitious materials. The high cost of these polymers is considered to be the key factor that limits the application of PMC or PMM despite their superior properties. In addition, a high P/C ratio also results in several negative effects to the PMC, such as retarded cement hydration and decreased compressive strength [12,21,22]. Therefore, a new technology must be developed to reduce polymer addition without losing the improved properties of PMC and ultimately extend the application of PMC.

On the other hand, the magnetic field targeting technology has been widely used in drug delivery and bio-engineering. This technology ensures that the drug is correctly positioned at the treatment location as much as possible [23–27]. In this paper, we proposed a method to generate a gradient polymer distribution in PMM based on the magnetic field targeting technology to improve the impermeability at significantly lower polymer additions because impermeability against water, attacking ions like Cl^-, are considered as the most important key factors that determine the durability of the cementitious structure. The polymer used was a type of acrylate polymer latex with a magnetic field responsive feature, which was synthesized in our lab. The fresh moulded mortar was subjected to a magnetic field during the setting period. This way, the polymer latex added into the fresh mortar migrates to-

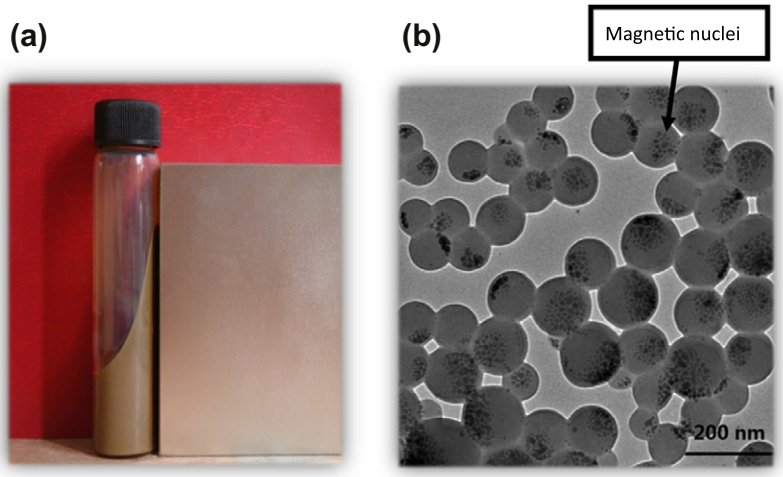

Fig. 1. Photograph and TEM image of the magnetic polymer latex (a) Photograph of the magnetic polymer latex; (b) TEM image of the magnetic polymer particles.