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Mechanical property and water stability of the novel CSA-MKPC blended system

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HIGHLIGHTS

- Novel CSA-MKPC blended system was proposed.
- The CSA-MKPC blended system had favorable strength and water stability.
- The mechanism of the effects of CSA on the system had been proposed.

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ABSTRACT

The mechanical property and water stability of the novel CSA-MKPC blended system were investigated. This system was made up of MKPC and 20, 30 and 40 wt.% CSA, cured in five schedules, including 25 °C-95% HR, 25 °C-50% HR, 10 °C-95% HR, 10 °C-50% HR, and −5 °C. The mechanisms were analyzed by porosity distribution, XRD and SEM-EDS. The results indicated that the novel CSA-MKPC blended system had better mechanical property and water stability than MKPC, and possessed advantageous temperature suitability. The presence of CSA not only enhanced the compact of the matrix by filling effect, but also generated amorphous materials to coat on the K-struvite surface. These effects were more obvious after immersing in water.

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1. Introduction

Magnesium phosphate cement (MPC) is new chemical bonding cement with advantages of rapid setting, high early strength, good volume stability, extensive temperature suitability and advantageous bonding strength [1–5]. Therefore, it has been regarded as a good candidate to replace the traditional repair cement for quick repair and reinforcement structure, and was widely researched in recent years [6–12]. Traditional MPC was constituted by dead burned magnesium (MgO), ammonium dihydrogen phosphate ($NH_4H_2PO_4$) and retarder (borax or boric acid), mainly generated struvite ($NH_4MgPO_4{\cdot}6H_2O$) by through-solution acid-base reaction [13–15,4,16–19]. Since the release of ammonia caused unpleasant environmental odor and container corrosion during processing and storage, the potassium dihydrogen phosphate (KH_2PO_4) has been regarded more appropriate for MPC preparation in recent years [20–23]. Cement prepared by MgO, KH_2PO_4 and retarder was named as magnesium potassium phosphate cement (MKPC). It can achieve the same excellent mechanical properties compared with MPC, because the main reaction product K-struvite ($KMgPO_4{\cdot}6H_2O$) had similar physical and chemical properties with $NH_4MgPO_4{\cdot}6H_2O$ [24,25].

At present, although MKPC has been attempted applying in practical civil engineering applications such as airport, runways, concrete pavements, industrial floors and bridge decks, the security and service life of the engineering were seriously affected by the poor water stability of the MPC or MKPC [13,26–29], which has been demonstrated by many researches. Sarkar et al. found that the strength of MPC cured in air environment at 28 days decreased almost 20% after immersing in water for 62 days [28]. Seehra et al. reported that the residual strength of MPC was only 83% after immersion in water [13]. Furthermore, Li et al. studied the MKPC prepared by different contents of KH_2PO_4. The results indicated that the MKPC samples would have significant strength loss after curing in water, and the strength loss increased from 12.0% to 65.3% as then (KH_2PO_4): n(MgO) decreased from 8:1 to 2:1 [29].

In order to solve the problem of the poor water stability, many researches focused on the modification of MKPC in last two decades [11,30–36]. Most methods were focused on enhancing the density of the matrix, such as adding fly ash, slag and silica fume

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[11,30–33]. They were almost inert and enhanced the water stability mainly by physical effect and little chemical effect. If the modified materials could hydrate with water, harden and generate strength quickly, the water instability of MKPC would be greatly improved. Calcium sulphoaluminate cement (CSA) is a kind of hydraulic rapid repair cement, probably was a nice modified material [37]. The composite of MKPC and hydraulic CSA may combine the advantages of both, had the high early strength and favorable water stability.

The reaction and strength development process of the CSA-MKPC blended cement was complex affected by the environment humidity and temperature, because that CSA needed wet environment to keep on hydrating, while that condition was adverse for the development of MKPC [29,38]. Furthermore, MKPC had widely temperature adaptability due to its special reaction properties, especially the negative temperature, while the hydration process of CSA was affected significantly [3,39].

Therefore, the compressive strength and water stability of the novel CSA-MKPC blended cement were studied with different contents of CSA, and five different curing conditions. For comparison, two single systems (MKPC and CSA) were also studied. Porosity structure of samples was tested by mercury intrusion porosimetry (MIP) to demonstrate the modification effect. In addition, the reaction products and microstructure were detected by X-ray diffraction (XRD) and scanning electron microscope-energy dispersive spectrometer (SEM-EDS) to investigate the complex reaction mechanisms of the novel CSA-MKPC blended cement.

2. Experimental

2.1. Materials

The CSA-MKPC mortar was prepared as a mixture of magnesia (MgO or M), potassium dihydrogen phosphate (KH_2PO_4or P), borax ($Na_2B_4O_7 \cdot 10H_2O$ or B), calcium sulphoaluminate cement (CSA or A), water reducer and sand (S) in diverse proportions. The dead burned MgO powder with a specific surface of $230 \sim 250\ m^2/kg$ and purity of >98%, calcined at 1500 °C for 10 h, was used. KH_2PO_4 and $Na_2B_4O_7 \cdot 10H_2O$ were used, both the purity more than 99%. Commercial CSA with the specific surface of $350 \sim 400\ m^2/kg$ was used. And its chemical composition supplied with the manufacturer were listed in Table 1. Moreover, the setting time of CSA was recorded by using a modified Vicat needle according to the ASTM C187 standard, the compressive strength of CSA was tested by Chinese standard GB17671-1999 and the results were listed in Table 2.

For CSA-MKPC system, the selected CSA contents were 20, 30 and 40 wt.% taking place of MgO and the different CSA-MKPC mortars were prepared with the same weight ratio of P to M + A (1/4). Cement (C) was mostly made up with M, P, and A. The B content is 4% of the weight of C and the weight ratio of S to C was 1:1. Flowing table test (standard UNE-EN 1015-3) were test to evaluate the workability of MKPC mortar and the flow were keep as 250 mm. Compared to MKPC, CSA-MKPC needs much more water to maintain the same fluidity, because CSA has larger specific surface. Therefore, several different water to cement (w/c) ratios were used, such as 0.188, 0.202 and 0.216 when the CSA contents were 20, 30 and 40 wt.%, respectively. For the two single systems, MKPC was prepared with w/c of 0.160, and CSA was prepared with w/c of 0.300. The detailed mix proportions were listed in Table 3. After dry-mixing of the powders consisted of M, P, B and A for 1 min, water reducer and S were added to the mixture and then were further mixed for 2 min, finally, the mixed mortars were casted into the molds immediately and were demoded half of an hour.

Table 1
Chemical composition of CSA (wt.%).

CaO	Al_2O_3	SO_3	SiO_2	Fe_2O_3	MgO	Na_2O	K_2O	Loss
40.86	34.57	9.83	8.55	2.97	2.22	0.23	0.05	0.72

Table 2
Performance of CSA.

Index	W/C[a]	S/C[b]	Compressive strength (MPa)		Setting time (min)	
			7 d	28 d	Initial setting	Final setting
Value	0.45	3.0	65.75	79.63	28	40

[a] The weight ratio of water to cement.
[b] The weight ratio of sand to cement.

Table 3
Mix proportions of mortars.

System	A/M	P/(M + A)	B/C	W/C	S/C
MKPC	–/10	1/4	0.04	0.160	1:1
CSA20	2/8	1/4	0.04	0.188	1:1
CSA30	3/7	1/4	0.04	0.202	1:1
CSA40	4/6	1/4	0.04	0.216	1:1
CSA	10/–	1/4	0.04	0.300	1:1

2.2. Curing schedules

Samples were cured in a high-low temperature test chamber. Three kinds of temperature (25 °C, 10 °C and −5 °C) and two relative humidity (50% HR and 95% HR) were selected. The relative humidity could not be controlled at negative temperature, so there are five different curing schedules in total. Before mixing cement mortars or pastes, materials and modules were placed into the chamber to preheat or precool. After mixing and placing, samples were immediately placed into the chamber and cured to designate ages.

2.3. Testing methods

2.3.1. Compressive strength

A batch of six $20 \times 20 \times 20\ mm^3$ mortar specimens were made for compressive strength testing, and the compressive strength was test at the age of 1 h, 1 day and 7 days with the MTS servo hydraulic testing machine at a speed of 1 mm/min.

2.3.2. Water stability

Water stability was reflected by the compressive strength retention rate after immersing in water. The compressive strength of MKPC was almost stable after air curing 7 days [40], To short the test cycle, the compressive strength of samples at air curing 7 days was used as standard values. In this study, samples were cured at designed curing schedules for 7 days, and then immersed in water for 28 days. The strength retention rate was calculated by Eq. (1).

$$K = f/F \tag{1}$$

where K denotes the compressive strength retention rate of the sample, f denotes the compressive strength of the sample at 7 days + 28 days (MPa) and F denotes the compressive strength of the sample at 7 days (MPa).

2.3.3. Porosity structure

Mortars were prepared for testing the porosity structure. They were cured at designed curing schedules and were stopped hydration by ethanol at 7 days and 7 days + 28 days. Samples were

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