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The effect of slag on the properties of magnesium potassium phosphate cement

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HIGHLIGHTS

- The byproduct B-MgO is used to formulate MKPC.
- The effects of slag on the properties of the MKPC system are studied.
- The addition of slag can improve the water resistance and seawater resistance of MKPC.
- The hydration products of MKPC are analyzed by XRD using the Rietveld method and SEM.

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ABSTRACT

Magnesium potassium phosphate cement (MKPC) incorporated with slag was prepared from the byproduct boron-containing magnesium oxide (B-MgO) from the production of Li_2CO_3 from salt lakes. The influence of the slag content on the setting time, compressive strength, water resistance and seawater corrosion resistance of MKPC was investigated. The composition and microstructure of MKPC were also studied in detail. The results demonstrate that the setting time of MKPC increases with increasing slag content. The compressive strength at 3 h and 28 d of MKPC specimens with 20 wt% slag can reach approximately 35 MPa and 60 MPa, respectively. Moreover, slag significantly improves the water resistance and the seawater corrosion resistance of MKPC. The properties of MKPC incorporated with 20 wt% slag indicated that it met the requirements for rapid repairing materials.

1. Introduction

Magnesium phosphate cement (MPC) is a potential magnesia-based cementitious material that has become the focus of recent research due to the obvious advantages, such as rapid setting and hardening, high early strength, high bonding and compatibility with old Portland cement concrete, low shrinkage and good frost resistance. MPC is widely utilized in civil engineering applications, such as patching damaged airfield runways, pavement, bridges and highways [1–3]. Additionally, MPC is frequently used for the stabilization/solidification (S/S) of mixed wastes and low-level nuclear wastes [4–6] and as a type of bone-repair material [7–9].

The reaction mechanism of MPC has been studied by many researchers. However, a generally accepted opinion has not been established. Abdelrazig et al. considered that the MPC reaction is a through-solution process; the reaction occurs between large amounts of the dissolution phosphate (ADP) and part of the MgO [10]. Wagh and Jeong considered this process to form chemically bonded ceramic materials [11]. Sarkar proposed that an insoluble diffusion barrier coating consisting of polyphosphate units cross-linked with Mg^{2+} is formed around MgO particles at early time, and then this gel slowly crystallizes into struvite [12].

During decades of research, ammonium dihydrogen phosphate and potassium dihydrogen phosphate (KDP) have been used frequently as phosphate components. The former can be called magnesia ammonium phosphate cement (MAPC) and the latter can be called magnesium potassium phosphate cement (MKPC). Recent studies have shown that an unpleasant environmental odor (ammonium) is created during MAPC processing, and the reaction rate is too fast and inconvenient for engineering applications compared to the use of MKPC [13]. Thus, MKPC has been broadly

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Table 1
Chemical compositions of the B-MgO and slag.

Raw material	Mass fraction of the sample (%)									
	MgO	B_2O_3	CaO	SiO_2	Na_2O	Li_2O	K_2O	SO_3	Al_2O_3	Fe_2O_3	LOI*
B-MgO	82.63	4.63	0.14	0.031	1.24	0.77	0.27	0.76	–	–	9.53
Slag	10.59	–	36.35	33.48	1.27	–	0.56	0.66	12.31	1.40	0.36

* LOI: loss on ignition.

researched in recent years. To control the setting time of exothermic reactions and to allow a reasonable working time, dead-burned MgO is usually used to produce MKPC [14–16].

The dead-burned MgO, which has a moderate ionic potential and a relatively weak basicity [17] due to the highly crystallized structure resulting from calcining magnesite in the temperature range of 1500–1700 °C [18], was proved to work well with KDP, leading to slow hardening and high early strength. However, the reaction between dead-burned MgO and KDP is still fast, and the short setting time does not meet the requirements of field repair [19]. Therefore, to make MKPC materials applicable to engineering use, boric acid or borax are used as retarders to decrease the hydration rate of MKPC [20,21]. However, the high costs of dead-burned MgO calcined at high temperature and boric retarder make MKPC more expensive and limit its practical applications. Moreover, boric acid and borax decrease the early mechanical strength of hardened MKPC paste [20,22,23].

Recently, the development of new types of materials that are environmentally friendly, inexpensive and energy efficient, has become a major concern. Many works have been performed to obtain a low-cost and high-performance MPC, and there have been major achievements in this field. On the one hand, hard-burned low-grade MgO and the byproduct boron-containing MgO (B-MgO) were used instead of high-purity dead-burned MgO to produce MPC [24,25]. On the other hand, the addition of fly ash and slag to MPC reduced the dosage of high-purity dead-burned MgO, reducing the overall cost [26–28].

The B-MgO byproduct was obtained as a byproduct from the production of Li_2CO_3 in Qarhan Salt Lake in Qinghai Province, China [29]. The results of the authors' previous work indicated that the MKPC produced by calcined B-MgO (1000 °C) has good mechanical properties and a long setting time [25]. However, the durability and mechanical properties of MKPC made from B-MgO blended with supplementary cementitious material (SCM) were not investigated.

Fly ash and slag are important SCMs that have been widely used in Portland cement and concrete [30,31]. Hence, many studies focused on the durability and mechanical properties of MPC blended with fly ash [23,26,32], but few publications reported the durability and mechanical properties of MKPC modified with slag [33]. Thus, taking into account the abovementioned factors, this paper is dedicated to investigating the properties of MKPC incorporated with slag. The effects of slag on the setting time, compressive strength, water resistance and seawater corrosion resistance of MKPC made from B-MgO are studied in detail. Additionally, the results of the mineral composition and microstructure of MKPC specimens are discussed in the present work.

2. Experiments

2.1. Raw materials

The magnesium oxide used in the experiments was byproduct B-MgO after the production of Li_2CO_3 from the salt lakes by Qing-

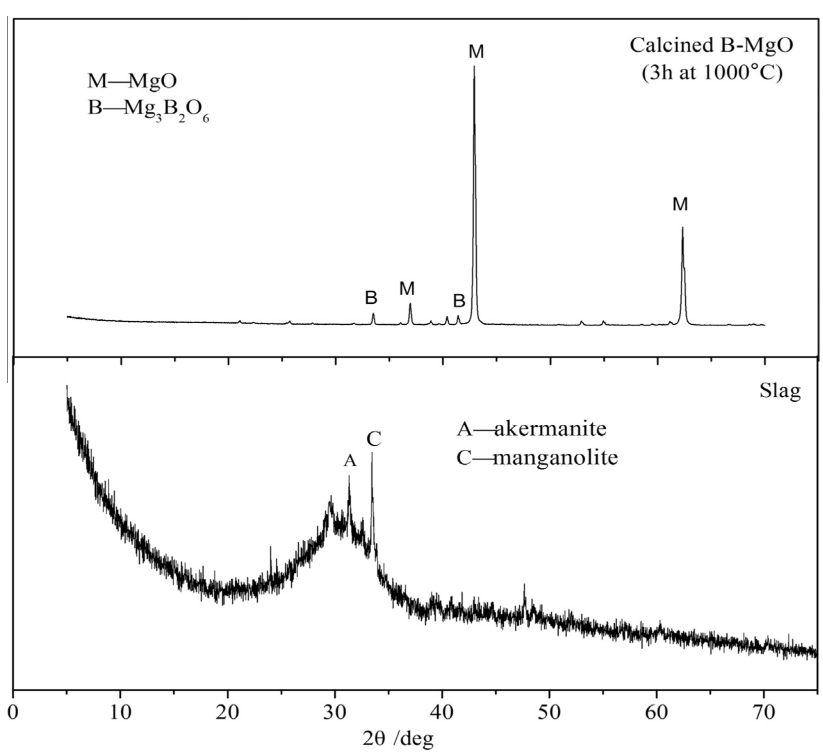

Fig. 1. XRD pattern of the raw materials.