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Study on the improvement of water resistance of magnesium phosphate cement by steel slag

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Abstract: Steel slag powder was used as a mixed material of magnesium phosphate cement (MPC) to improve its mechanical water resistance. The mechanism of steel slag on MPC was studied through the composition and microstructure test of MPC hydration products. The results showed that the strength of magnesium phosphate cement gradually decreased with the increase of immersion time after adding steel slag. Adding 15% steel slag could improve the water resistance of MPC, make the structure compact and reduce the strength loss rate.

1. Introduction

Magnesium phosphate cement (MPC) is a new type of rapid hardening cement cementitious materials, mainly composed of burned MgO, water soluble phosphate and retarder, which is prepared according to appropriate proportion. The hydration products of MPC depends on the used phosphate, for example, when the phosphate is potassium dihydrogen phosphate, the main hydration product of MPC is MgKPO4 6H2O (MKP) [1]. Compared with the traditional Portland cement, MPC has a rapid hardening, high early strength, good bonding properties, abrasion resistance, dry shrinkage, frost resistance, energy saving and environmental protection advantages [2-6]. However, many studies have shown that the water resistance of MPC is poor [7, 8]. After soaking the samples of MPCBM natural curing 28d and above, Seehra found that the strength was reduced by about 15% [9]. With the studies going on, many researchers found that the mineral admixture could improve the mechanical properties and water resistance of MPC [10, 11, 12]. Zheng found that the strength retention ratios of MKPCs with the combination of fly ash and silica fume at 56 days are found to be significantly higher than those without fly ash and silica fume [13]. Chen studied the latex powder, silica fume and fly ash on the water resistance of MPC and found that latex powder was better than that of silica fume and fly ash on the water resistance improvement of MPC, but its modification effect was limited, the shrinkage of MPC was too large [14]. The poor water resistance of MPC has bad effect on its durability, which greatly limits the widely application of MPC. Therefore, how to improve the water resistance of MPC is one of the most difficult problems to be solved. In this paper, steel slag was used to the modification of MPC. In addition, according to the analysis of strength loss, XRD and SEM to evaluate the effect of steel slag on the water resistance property of MPC.

2. Test situation

2.1 Raw material

MgO is calcined by magnesite at 1600 ℃ and its chemical components and physical properties are shown in Table 1. Potassium dihydrogen phosphate and borax are pure chemical with a content of 98% and 99.5% respectively. Steel slag finely grounded, and its chemical composition physical properties are shown in Table 2.

Tab.1 Physical and chemical properties of MgO

Materials	MgO[%]	SiO_2[%]	Al_2O_3[%]	CaO[%]	Fe_2O_3[%]	Specific surface [m2/kg]	Density[g/cm3]
MgO	92	4	1.4	1.6	1.3	805.9	3.46

Tab.2 Physical and chemical properties of steel slag

Materials	CaO [%]	Fe_2O_3 [%]	SiO_2 [%]	Al_2O_3 [%]	MgO [%]	MnO [%]	P_2O_5 [%]	Loss [%]	Specific surface [m^2/kg]	Density [g/cm^3]
Slag	38.2	24.9	18.3	6.87	5.05	2.49	1.39	2.8	657	3.62

2.2 Mix proportion

The mix ratio of MPC is shown in Table 3, where P/M is the molar ratio of phosphate to magnesia, the dosage of retarder and steel slag is the mass fraction of magnesia, W/B is the water to binder ratio.

Tab.3 The mix of MPC

Sample	P/M	Borax /[%]	W/B	steel slag /[%]
A	1/4	5	0.14	0
B	1/4	5	0.14	15

2.3Test method

2.3.1 Strength test method

The specimens were cured in air (20 ±2℃ with a relative humidity of 70%) for 28 d, then soaked in water respectively for different ages. The compressive strengths of the specimens at 30 days, 60 days, and 90 days were tested according to Method of Testing Cements-Determination of Strength (GB/T17671-1999)

2.3.2 Micro test

The samples for micro tests were taken from the broken specimens after the compressive strength test. The hydration product morphologies and chemical components of the samples were analyzed by QUANTA FEG 250 environmental scanning electron microscope (SEM) and D8 ADVANCE X ray diffract meter (XRD) respectively.

3. Results and discussion

3.1. The influence of steel slag on the strength of MPC after soaking in water.

The compressive strength of samples A and B immersed in water for different ages was tested. The results are shown in Fig 1. And the strength loss rate of samples are shown in Fig 2.

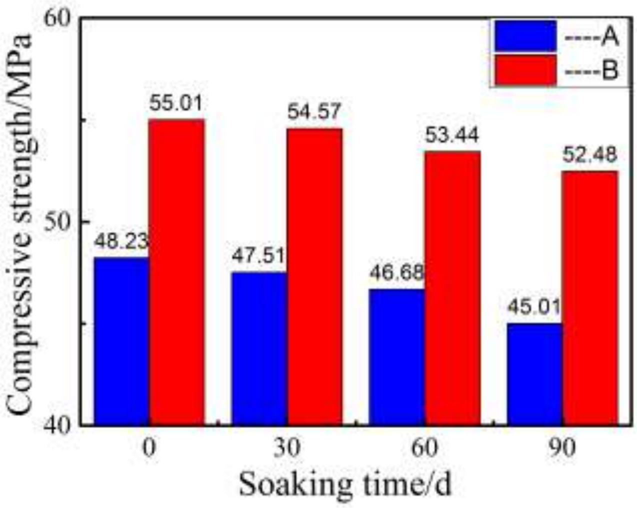

Fig 1. The Compressive strength of MPC samples soaked in water at different ages

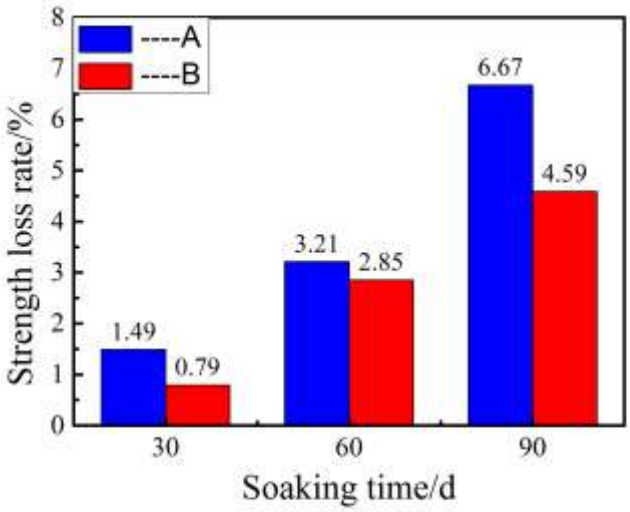

Fig 2 . Strength loss rate of sample in water for different time

Fig. 1 shows that, before soaking, the compressive strength of sample B is larger than sample A, which indicated that steel slag has a good effect on the compressive strength of MPC due to the micro-aggregate effect and higher elastic modulus of steel slag. With the increasing of soaking time,

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the compressive strength of sample A and B decreased. Compared with the control sample, after soaking 90d, the compressive strength of sample with slag just decreased 2.53MPa, and the strength was 4.59%, which is lower than the sample without slag. The reason is mainly due to the dissolution of the hydration products and unreacted phosphate in MPC, which will result in poor compactness of MPC and the decrease of compressive strength. While the adding of steel slag can reduce the pore content and improve the matrix density, which can reduce the ion dissolution rate and improve the water resistance of MPC. At the same time, C2S and C3S in steel slag hydration may generate C-S-H and Ca $(OH)_2$, the continuous accumulation of Ca $(OH)_2$ makes the environmental alkaline increase, and the dissolution of MKP crystals and gels is weakened. Besides, $Ca(OH)_2$ can further react with SiO_2 in steel slag to form C-S-H gel, which makes the structure compact and promotes the development of compressive strength.

3.2. XRD analysis

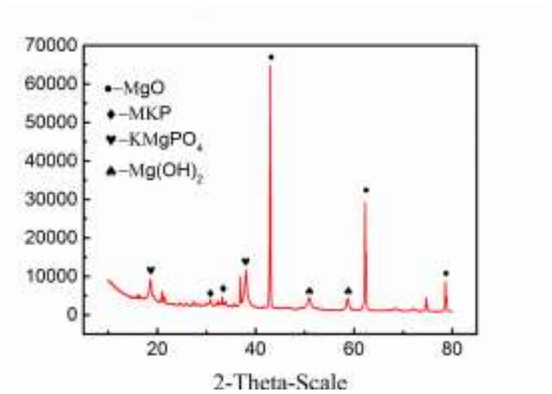

Fig 3.XRD Atlas of sample A

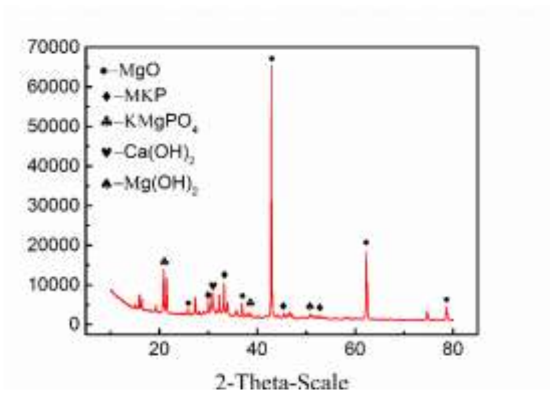

Fig 4.XRD Atlas of sample B

The sample A and B were soaked in water for 30d, and then taken out, dried and lapping to the specified fineness for XRD test. The results were shown in Figure 3, 4. It can be seen that after soaking, all the samples have a large number of $MgKPO_4$ $6H_2O$（MKP）, $KMgPO_4$, unreaction MgO, and a small amount of $Mg(OH)_2$. By contrast, it can find that the diffraction maximum intensity of MKP and $KMgPO_4$ is obviously improved after adding steel slag, and there is a small amount of $Ca(OH)_2$ generation. This is mainly because the addition of steel slag increased the nucleation efficiency of MPC hydration products, reduced the nucleation barrier in the reaction process, and promoted the reaction degree of MPC matrix. Therefore, after adding steel slag, the content of MKP and $KMgPO_4$ increases, the structure of MPC matrix is compact and the strength is increased. Figure 4 shows that there was Ca $(OH)_2$ generation in MPC after adding steel slag, it may be due to the occurrence of CaO hydration reaction in water, it may also be due to the hydration of C2S and C3S in steel slag to produce Ca $(OH)_2$ and C-S-H gel. The hydration reaction increased the bonding properties of the MPC matrix, made the structure more compact and enhanced and improved the water resistance.

3.3. SEM analysis

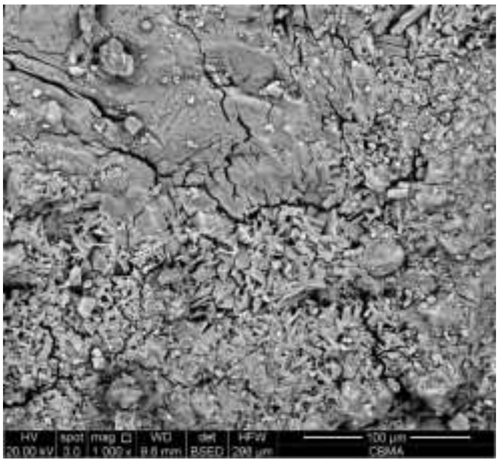

Fig 5.SEM Atlas of sample A

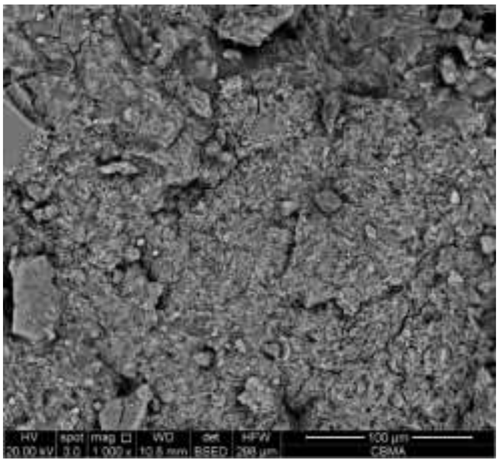

Fig 6.SEM Atlas of sample B

The SEM result of samples A and B after soaking 30 days is shown in Fig 5&6. By contrast it can be seen that there are many cracks in the MPC sample without slag and the matrix is loose, which indicated that the adding of steel slag could optimize the internal pore structure of MPC and improve its water resistance. This result is consistent with the analysis of section 3.1&3.2.

4. Conclusion

(1) With the increase of soaking time, the compressive strength of MPC gradually decreased.

(2) Under the same soaking time, the loss rate of steel slag-MPC strength is lower than that without slag.

(3) The main hydration products of MPC are MKP, but when steel slag is added to MPC, there is a small amount of $Ca(OH)_2$ generation.

(4) Steel slag can improve the water resistance of MPC. When soaked in water at the same time, the steel slag -MPC is weakly eroded and the crack is smaller.

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