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Investigation on the water resistance of the fly-ash modified magnesium phosphate cement

Sihui Sun¹, Runqing Liu¹, Xingke Zhao^{1*}, Yao Zhang², Yuanquan Yang³

¹Shenyang Ligong University, Nanping RD 6, New Hunnan District, Shenyang, China, 110159

²China Railway Construction Bridge Engineering Bureau Group CO.,LTD, Dalian, China, 116021

³Faculty of Infrastructure Engineering Dalian University of Technology, Dalian, China, 116024

Corresponding author and e-mail: Zhao Xingke, 157371978@qq.com

Abstract: In order to improve the water resistance of magnesium phosphate cement (MPC), the flexural strength, compressive strength, strength retention rate and mass retention rate under different immersion conditions, were tested by XRD and SEM methods by adding 30%, 35%, 40%, 45% and 50% fly ash. The mechanism of fly ash improving the water resistance of magnesium phosphate cement was analyzed. The results show that when fly ash content is 35%, the mechanical properties of magnesium phosphate cement (MPC) reach the optimal, and the strength retention rate and mass retention rate are improved. Fly ash modified by magnesium phosphate cement produces no new hydration products. After it is soaked in water, a large number of flake like k-struvite are produced on the surface of MgO particles. Few cracks forms on the surface, which reduces the porosity and enhances the compactness, thus improving the water resistance of MPC cement.

1. Introduction

Magnesium phosphate cement has been discovered and used as early as 1939, which is made of MgO, phosphate, retarder, admixture and so on. Magnesium phosphate cement is different from ordinary Portland cement, which is mainly composed of three kinds of materials. Its preparation method is simple, preparation process is low energy consumption as well as is low water demand. Magnesium phosphate cement has the advantages of rapid setting and hardening, early strength. It can well meet the requirements of urgent repair and construction in wartime. Therefore, magnesium phosphate cement has a broad application prospect in military engineering. With the development of research on magnesium phosphate cement, the excellent performance has been recognized by the academic community. In recent years, there has been further development in the fields of biomedicine, oil well solidification, waste solidification, radioactive wastes solidification, 3D printing technology, etc. However, magnesium phosphate cement's strength obviously decreases in the humid environment or in contact with water, which will inevitably have an impact on its durability. Therefore, the study on the water resistance of modified magnesium phosphate cement has become one of the hot topics in this field.

Fly ash, as an admixture, has been widely used in building materials. Adding fly ash to magnesium phosphate cement can not only change the color of magnesium phosphate cement but also make it



similar to the color of common cement pavement. It can also improve the performance of magnesium phosphate cement paste and mortar. Liu Kai believes that the appropriate addition of fly ash can improve the strength of magnesium phosphate cement. Wang Hongtao believes that fine fly ash, on the one hand, can extend the setting time of magnesium phosphate cement and improve its fluidity. Under the condition of maintaining the fluidity, it can reduce the water-solid ratio and improve the strength. Zhang Siyu studied the influence of fly ash on the expansion performance of magnesium phosphate cement and found that the expansion rate was the highest when the fly ash content was 30%. Ding Zhu believes that when fly ash content is 40%, the strength of magnesium phosphate cement reached the maximum. The results show that fly ash has an active effect, micro-aggregate effect, morphological effect and adsorption effect in magnesium phosphate cement. This paper mainly studies the influence of different fly ash content on the water resistance of magnesium phosphate cement, through the test and analysis of macro strength and micro performance, and the mechanism of improving the water resistance of magnesium phosphate cement by fly ash is further discussed.

2. Experimental details and methodology

2.1. Materials

Dead burned magnesia was prepared by magnesite (mainly including $MgCO_3$) burnt at about $1500^\circ C$ for 4 hours, then crushed and ground into particles with different sizes. The chemical composition the MgO was shown in Table 1.

Table 1. Chemical composition of the magnesia/%

oxide	MgO	SiO ₂	CaO	Al ₂ O ₃	Fe ₂ O ₃
content /%	92	0.7	1.36	0.3	0.3

KH_2PO_4 , abbreviated as P, is produced by Tianjin Binhai Fuli chemical plant with a content of 98.56%. Chemical composition of the KH_2PO_4 is shown in Table 2.

Table 2. Chemical composition of potassium dihydrogen phosphate /%

composition	KH_2PO_4	Water		chloride	Fe	As	Heavy metal	KCl	Ph
		water	insoluble substance						
content	98.56	2.12	0.04	0.1	0.001	0.001	0.001	34	4.52

In this work, borax was used as retarder. Its chemical formula is $Na_2B_4O_7 \cdot 10H_2O$, chemically pure, abbreviated as B. The content is no less than 99.4%. The chemical composition of borax is shown in Table 3.

Table 3. Chemical composition of borax /%

composition	$Na_2B_4O_7 \cdot 10H_2O$	carbonate	Water insoluble substance	sulfate	Fe
content	95	0.2	0.002	0.2	0.005

Grade II fly ash (F) is chosen, which belongs to the low calcium ash, its specific surface area is about $280 \text{ m}^2 / \text{kg}$, the chemical composition of fly ash analysis as shown in Table 4.

Table 4. Chemical composition of fly ash /%

composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	TiO ₂	SO ₃	Loss
content	39.5	26.8	15.5	4.1	1.5	2.8	0.6	8.4

The sand used in the experiment is ISO standard sand.

The test water is ordinary tap water.

2.2. Sample preparation

The optimal mixture ratio was selected through the preliminary foundation test. The magnesium to phosphorus by molar ratio is 4:1. Borax was 16% of the magnesia. The fly ash is 30%, 35%, 40%, 45%, and 50% replacement of the sum mass of magnesia and KH_2PO_4 , respectively. Raw materials were weighted and poured into the stirring container for 2min at low speed. After that water was added and the mixture was stirred quickly at high speed for 1min. The stirred magnesium potassium phosphate cement slurry was rapidly poured into the mold with size of 40mm×40mm×160mm sample. The sample was vibrated for 1min30s to make the mixture compacted. The sample was removed from the mold within 30min~1h after the sample hardened.

2.3. Experimental methods

2.3.1. Water resistance

In this paper, the strength retention rate is used to evaluate the water resistance of materials. According to the strength loss, the strength retention rate K value (accurate to 0.01) was proposed as the index evaluation of the water resistance of the MPC specimen. The strength retention K value is defined as follows:

$$K_t = \frac{f}{F} \times 100\% \quad (1)$$

K_t -- strength retention rate of MPC specimen for t days;

F -- unconfined compressive strength, MPa, of hydrotropic specimens;

F -- unconfined compressive strength of natural curing of MPC specimens, MPa.

When the value of strength retention rate K is small, it means that the strength loss of magnesium phosphate cement after immersion in water is small, it means that the water resistance of magnesium phosphate cement is well at this time, and the water resistance is poor if the value of K is high. Therefore, the strength retention rate can directly characterize the water resistance of magnesium phosphate cement in the same system.

Softening coefficient, as the traditional evaluation index of resistance to water, was not used, due to that in the softening coefficient test (according to the standard JGJ51-2002), compressive strength of the specimens need to be dried to constant weight under 105~110°C in advance, and the main hydration products of magnesium phosphate cement $\text{MgKPO}_4 \cdot 6\text{H}_2\text{O}$ (MKP) can however decomposed in the temperature of 60~70°C. Thus softening coefficient was not used here as an evaluation index for water resistance of magnesium phosphate cement.

2.3.2. SEM & XRD Text:

Ultima IV X-ray diffractometer manufactured by Japan Rigaku company was used for phase identification. The microstructure of S-3400N microcomputer electron scanning microscope manufactured by German company HITACHI was used to perform microstructure test.

3. Results and discussion

The flexural strength and compressive strength development of magnesium potassium phosphate cement samples with different content of fly ash, which were immersed in static water (changing water every 8 hours), were tested. The strength retention rate and mass retention rate (see Table 6 for specific values) were calculated to characterize the water resistance of the magnesium potassium phosphate cement. The mechanism of water resistance of magnesium phosphate cement modified by fly ash is discussed through phase identification and morphology analysis, which provides theoretical basis and scientific guidance for the engineering practice of long-term contact between magnesium phosphate cement and water.

Table 5. Flexural and compressive strength of magnesium phosphate cement with fly ash

fly ash	Flexural strength /MPa					The compressive strength /MPa				
	30%	35%	40%	45%	50%	30%	35%	40%	45%	50%
8d	8.4	8.6	7.8	7.4	7.3	32.7	33.5	29.3	24.7	23.3
7d+1d*	8.2	8.4	7.7	7.3	7.1	31.3	32.3	28.7	23.0	22.8
7d+1d**	8.1	8.3	7.6	7.1	6.9	30.7	31.8	26.5	21.6	20.6
14d	9.1	9.2	9.0	8.9	8.8	36.1	37.1	36.5	33.3	32.8
7d+7d*	8.7	8.9	8.5	8.3	8.1	33.3	34.8	32.3	29.1	28.3
7d+7d**	8.5	8.8	8.4	8.2	7.9	32.2	33.9	31.8	27.8	27.1

Note: * means no water immersion, ** means water immersion every 8 hours, and no * means curing in air

Table 6. Strength and quality retention of magnesium phosphate cement with fly ash

fly ash	Strength retention /%					Quality retention /%				
	30%	35%	40%	45%	50%	30%	35%	40%	45%	50%
7d+1d*	95.7	96.4	97.9	93.1	89.1	—	—	—	—	—
7d+1d**	98.3	94.9	90.4	87.4	88.4	—	—	—	—	—
7d+7d*	92.2	93.9	88.4	87.3	86.3	99.6	99.7	99.7	99.3	99.6
7d+7d**	88.6	91.5	87.1	83.4	82.6	99.4	99.4	99.3	98.6	99.1

Note: * means no water immersion, and ** means water immersion every 8 hours

3.1. Influence of fly ash content on mechanical properties of magnesium phosphate cement

3.1.1. Influence of fly ash content on flexural strength of magnesium phosphate cement

Magnesium phosphate cement with different fly ash content is cured in the air for 8d. After curing in the air for 7d, then it was soaked in static water for 1d*. The specimens cured in the air for 7 days, soaked in water (every 8 hours) for 1d**, is shown in Table 1. The specimens cured in the air for 14 days and 7 days, then soaking in static water for 7d* and in air for 7 days, then soaked in water for 7** days, is shown in Figure 2.

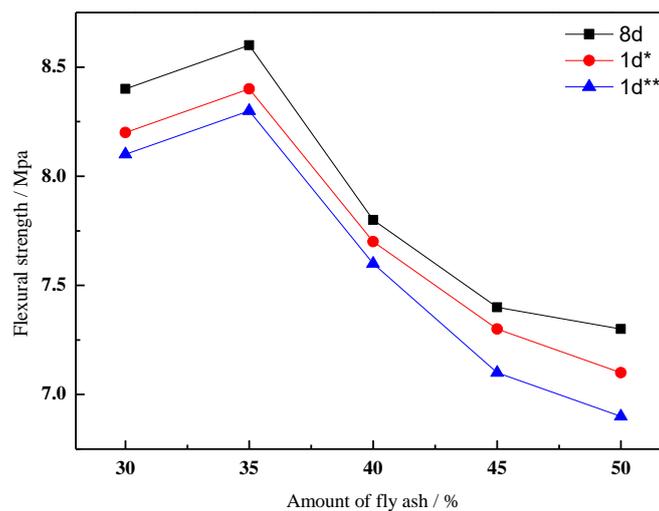


Figure 1. Effect of fly ash content on flexural strength of magnesium phosphate cement in different soaking conditions(soaking for one day)

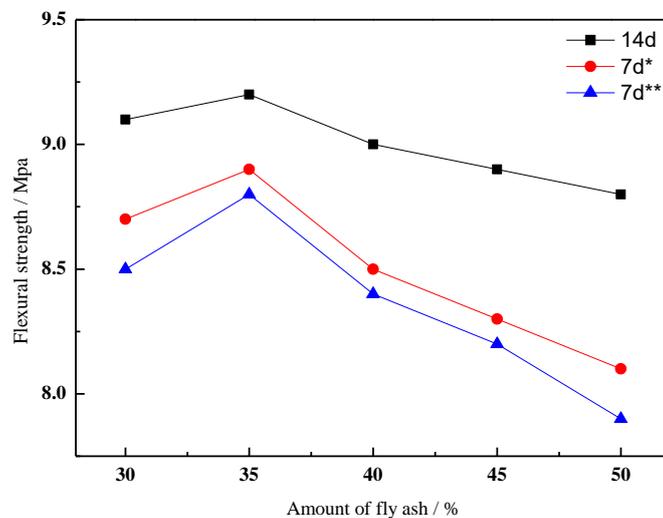


Figure 2. Effect of fly ash content on flexural strength of magnesium phosphate cement in different soaking conditions(soaking for seven days)

Fig.1 presents the flexural strength of fly ash containing magnesium phosphate cement soaked in water for 1d* and 1d**. The flexural strength of the MPC cured in the air in the three curves in the Figure is better than that soaked in water for 1d* on the whole, while the flexural strength of the MPC soaked in static water is better than that soaked in water every 8 hours. This indicates that the flexural strength of MPC adulterated with fly ash will shrink in water, and the flexural strength of MPC will shrink more in the dynamic water environment. The flexural strength of MPC increased first and then decreased with the increase of fly ash content. The group with good flexural strength shown in the Figure is magnesium phosphate cement with a fly ash content of 35%. The yield of this group has the best flexural strength whether maintained in the air for 8d (8.6mpa) or in static water for 1d*(8.4mpa) and changed water for 1d**(8.3mpa). The flexural strength of MPC with fly ash content of 50% is the lowest. As shown in Figure 2, the flexural strength of magnesium phosphate cement with different fly ash contents soaked for 7d* and 7d**, and the flexural strength trends of MPC curing in the air is the same as that in Figure 1. The flexural strength of the MPC cured in the air is higher than that of the MPC soaked for 7*days, while the flexural strength of the MPC soaked in static water is better than that of the MPC soaked in water changed every 8 hours. Moreover, the flexural strength after soaking in water for 7d decreased more than that after curing in air. The flexural strength of MPC increases first and then decreases with the increase of fly ash content. When the peak value of 8d curing in the air is 35%, it is 14d(9.2MPa), 7d*(8.9MPa) and 7d**(8.8MPa), respectively. The variation trend of the flexural strength of each fly ash content at the soaking 7d* and 7d** is similar to that in Figure 1. As shown in Figure 1, the MPC with a fly ash content of 50% has the lowest flexural strength.

When the fly ash content is 35%, the flexural strength of soaked MPC is higher than that of other content, indicating that when the fly ash content is 35%, the micro-aggregate effect of fly ash in magnesium phosphate cement reaches the maximum. The fly ash particles are evenly distributed in the cement slurry, reducing the porosity and increasing the compactness of the cement slurry. Magnesium phosphate cement slurry is relatively viscous. Adding fly ash can enhance its fluidity and promote the expulsion of bubbles in the slurry to increase the compactness. However, if the fly ash content is too large, a large amount of unreacted fly ash will lead to a decrease in strength.

3.1.2. Influence of fly ash content on compressive strength of magnesium phosphate cement

As shown in Figure 3, magnesium phosphate cement with different content of fly ash is cured in air for 8d, after curing with in air for 7d, soak in static water for 1d* and after curing in air for 7d, change

water (every 8 hours) to soak for 1d** the change in compressive strength. As shown in Figure 4, it is maintained in the air for 14 days, curing in the air for 7d and then soaking in static water for 7d* and curing in the air for 7d and then soaking in water for 7d** changes in compressive strength.

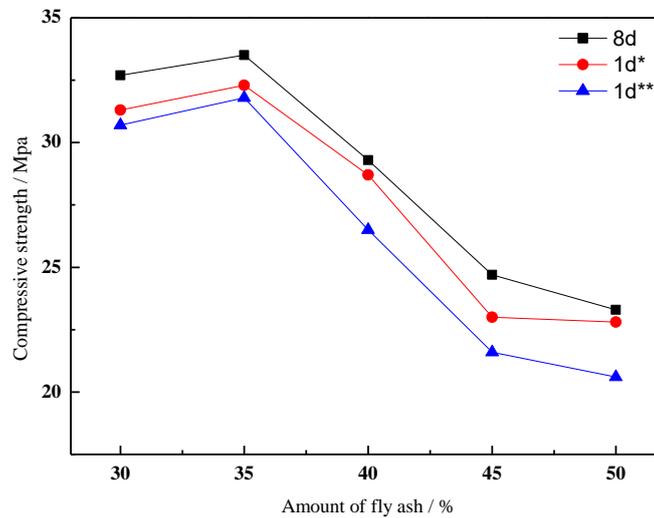


Figure 3. Effect of fly ash content on compressive strength of magnesium phosphate cement in different soaking conditions(soaking for one day)

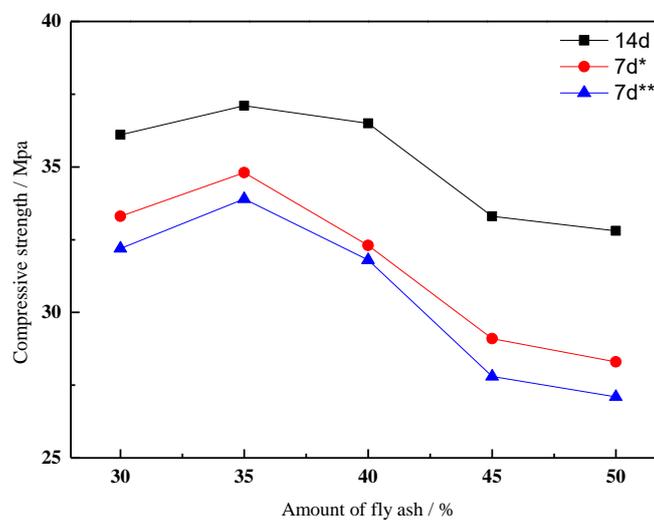


Figure 4. Effect of fly ash content on compressive strength of magnesium phosphate cement in different soaking conditions(soaking for seven days)

As shown in Figure 3, the compressive strength of magnesium phosphate cement soaked in water for 1d* and 1d** with different fly ash content. The general trend of the flexural strength development is quite similar to that of flexural strength in Figure 1 and Figure 2. The compressive strength of MPC cured in the air is generally better than that soaked in unchanged water for 1d*, while the compressive strength of MPC soaked in static water is better than that of MPC changed in water every 8 hours. This indicates that the compressive strength of MPC adulterated with fly ash will shrink in water, and the compressive strength of MPC will shrink more in a dynamic water environment. The compressive

strength of MPC increased first and then decreased with the change of fly ash content. When the fly ash content is 35%, the compressive strength of this group is relatively good, whether it is maintained in the air for 8d(33.5MPa) or in static water for 1d*(32.3MPa) and changed water for 1d**(31.8MPa). The compressive strength of MPC with 50% fly ash content is the lowest. As shown in Figure 4, the compressive strength of different fly ash contents on magnesium phosphate cement soaked in water for 7d* and 7d**. The trends of the three compressive strength curves are the same as that of the curve shown in Figure 3. The compressive strength of MPC cured in the air is generally better than that soaked in water for 7 days, while the compressive strength of MPC soaked in static water is better than that soaked in water every 8 hours. Moreover, the compressive strength after soaking in water for 7d decreased significantly compared with that after curing in air. The compressive strength with 35% of fly ash at 14d, 7d* and 7d* is still the highest in the whole. The compressive strength starts to decline when the content of fly ash is more than 35%. When the content of fly ash is 50%, the compressive strength is the lowest and decreases greatly.

Through analysis on compressive strength and flexural strength, it is found that when the content of fly ash is 35%, the compressive strength and flexural strength after soaking are the best. Therefore, when the fly ash content of magnesium phosphate cement is 35%, the micro-aggregate effect and morphological effect reach the maximum among the five contents. The fly ash particles are evenly distributed in the cement slurry, which reduces the porosity, increases the compaction of the cement slurry, and also enhances the fluidity, promotes the expulsion of bubbles in the slurry, and increases the compaction. However, if the fly ash content is too large and the micro-aggregate effect reaches its limit, the excess fly ash will lead to a decrease in strength. When the content of fly ash exceeds 35%, the content of fly ash is too large, and a large amount of unreacted fly ash will lead to a decrease in strength.

3.2. Influence of fly ash content on the immersion durability of magnesium phosphate cement

3.2.1. Influence of fly ash content on the strength retention rate of magnesium phosphate cement

Strength retention ratio is an indicator of water resistance of materials. The water resistance of material directly affects its durability. The compressive strength of magnesium phosphate cement mixed with fly ash was tested by soaking it in static water for 1d* and 7d*, respectively. The compressive strength of specimens soaked in alternative water for 1d** and 7d**, and their strength retention rate was calculated to study the water resistance of MPC mixed with fly ash as shown in Figures 5 and 6.

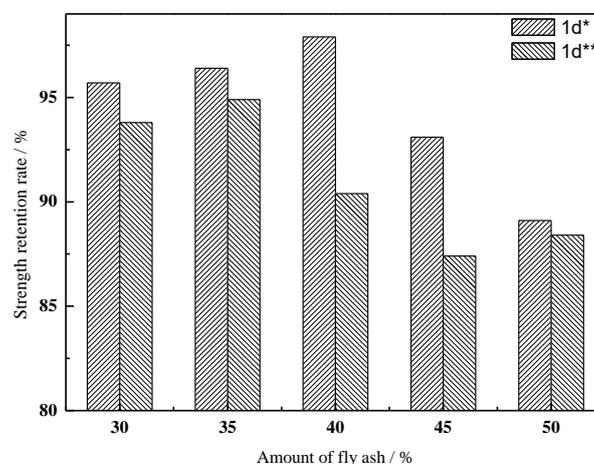


Figure 5. Strength retention rate of fly ash of MPC in soak 1d* and 1d**

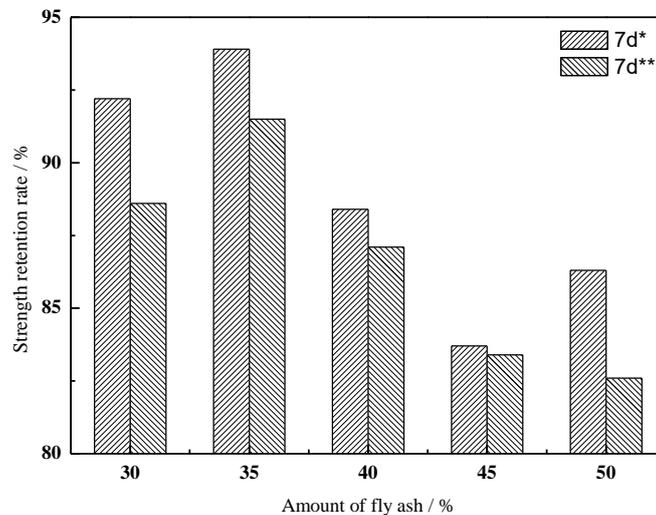


Figure 6. Strength retention rate of fly ash of MPC in soak 7d* and 7d**

As shown in Figure 5, the strength retention rate of fly ash-doped magnesium phosphate cement soaked in water for 1d* and 1d** changes. The strength retention rate of magnesium phosphate cement soaked in static water for 1d* changes with the highest strength retention rate when the fly ash content is 40%, followed by the component with the content of 35%. The trend is to increase first and then decrease. The strength retention rate of magnesium phosphate cement soaked in water for 1d** changes, and the peak value of the strength retention rate does not appear in the component with fly ash content of 40%, but in the component with fly ash content of 35%. The strength retention rate of the components with fly ash content of 50% is the lowest in static water. The strength retention rate of the components with fly ash content of 45% in the immersion water is the lowest compared with the other four groups. Considering the two soaking methods of standing water and changing water comprehensively, the components with a fly ash content of 35% in the five dosages have a better strength retention rate, that is better water resistance. As shown in FIG. 6, the strength retention rate of fly ash-doped magnesium phosphate cement soaked for 7d* and 7d** changes. The overall trend of change is first higher and then lower. For MPC soaked in static water for 7d*, the strength retention rate with the fly ash content of 35% is the highest, followed by the component with the content of 30%. The peak value of strength retention rate of magnesium phosphate cement soaked in water for 7 days also appears in the component of fly ash content of 35%, and the changing trend is first increased and then decreased. At the same time, the strength of components with fly ash content of 50% in static water increased, but the retention rate of strength in changing water was the lowest. When the two soaking methods of standing water and changing water are taken into comprehensive consideration, the components with a fly ash content of 35% are still included in the five contents, and the strength retention rate is better, in other words, the water resistance is better.

Usually, the softening coefficient of the material is higher than 85%, which can be applied in the wet or water-soaked environment, that is, the water resistance of the material is better. The preliminary test found that the strength retention rates of pure magnesium phosphate cement on 1d* and 1d** were 89.4% and 88.1%, respectively, and that on 7d* and 7d** were 81.2% and 79.1%, respectively. The strength retention rate of fly ash - doped magnesium phosphate cement was studied. Therefore, fly ash can improve the water resistance of MPC. When the fly ash content is 35%, the water resistance of magnesium phosphate cement is better than the other four groups. The reason is that when the fly ash content is 35%, it is caused by the activity and physical filling effect of fly ash, which increases the density of magnesium phosphate cement and reduces the porosity. However, when the content exceeds

35%, the micro-aggregate effect of fly ash reaches its limit, and the excess fly ash is in an inert state and does not participate in the reaction to form a dense system. The fly ash is still in a dispersed state, and there are a large number of pores between the particles, resulting in a drop in water resistance. At the same time, because fly ash is composed of oxides of silicon, calcium, aluminum, iron, and other elements, as well as unburned carbon, part of the metal oxides, will participate in the reaction, making the contact part of fly ash and magnesium phosphate cement matrix form a close connection, and consume the phosphate in the MPC slurry. Therefore, adding fly ash can adjust the water resistance of magnesium phosphate cement.

3.2.2. Influence of fly ash content on the quality retention rate of magnesium phosphate cement

Magnesium phosphate cement soaked in water will be eroded. The mass will have varying degrees of loss. According to the retention degree of the soaked magnesia phosphate cement mass, the water resistance of the soaked magnesia phosphate cement is studied directly, which also reflects the water resistance of the soaked magnesia phosphate cement to a certain extent. This paper mainly studies the mass retention of fly ash-doped magnesium phosphate cement soaked for 7d* and 7d** in two soaking methods of static water and changing the water, as shown in Figure 7.

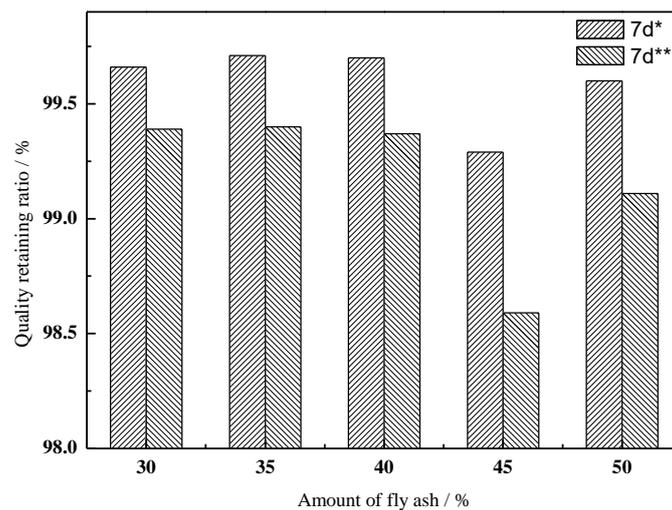


Figure 7. Quality retaining ratio of fly ash of MPC in soak 7d* and 7d**

As shown in Figure 7, represents the change in the mass retention rate of fly ash-doped magnesium phosphate cement soaked for 7d* and 7d**. When the fly ash content is 30%, 35%, and 40%, the mass retention rate is similar. The quality retention rate of the components with fly ash content of 50% is lower than that of the first three groups, while that of the components with fly ash content of 45% is greater than that of the other four groups. This also corresponds indirectly to strength retention. Changes in the mass retention rate of magnesium phosphate cement soaked in water for 7 days ** found that the overall mass retention rate was lower than that soaked in static water for 7 days *, and the peak value appeared in the component with a content of 35%. The overall change rule was similar to that soaked in static water. The mass retention rate of components with fly ash content of 45% drops greatly under the way of changing the water. After comprehensive consideration of the two soaking methods of standing water and changing water, the components with a fly ash content of 35% are still included in the five contents, with good quality retention rate and resistance to water erosion. When fly ash content is 35%, micro-aggregate effect and morphological effect reach the best, which makes the cement slurry dense with fewer structural pores, and to some extent alleviates the dissolution of water on the hydration product of magnesium phosphate cement, and the hydration

product is less dissolved. Therefore, when fly ash content is 35%, the quality retention rate of magnesium phosphate cement is higher.

3.3. Mechanism analysis of the influence of fly ash on the water resistance of magnesium phosphate cement

The water resistance of magnesium phosphate cement doped with fly ash is analyzed. On the one hand, the smaller fly ash particles can fill the pores of the cement stone and increase the density of the cement stone itself. On the other hand, since the active SiO_2 of fly ash can react with Mg^{2+} in magnesium phosphate cement to generate MgSiO_3 . It can not only reduce the concentration of Mg^{2+} in magnesium phosphate cement but also plug the pores in the cement stone to reduce the corrosion of water. Some scholars have also studied that Al_2O_3 in fly ash can also generate $\text{Al}(\text{OH})_3$ colloidal substance in magnesium phosphate cement, which plays the same role in cement as MgSiO_3 . Some scholars have shown that due to the hydrophobicity of fly ash, adding magnesium phosphate cement can reduce the water flow in the cement stone and reduce the concentration of Mg^{2+} .

3.3.1. XRD composition analysis of fly ash - doped magnesium phosphate cement

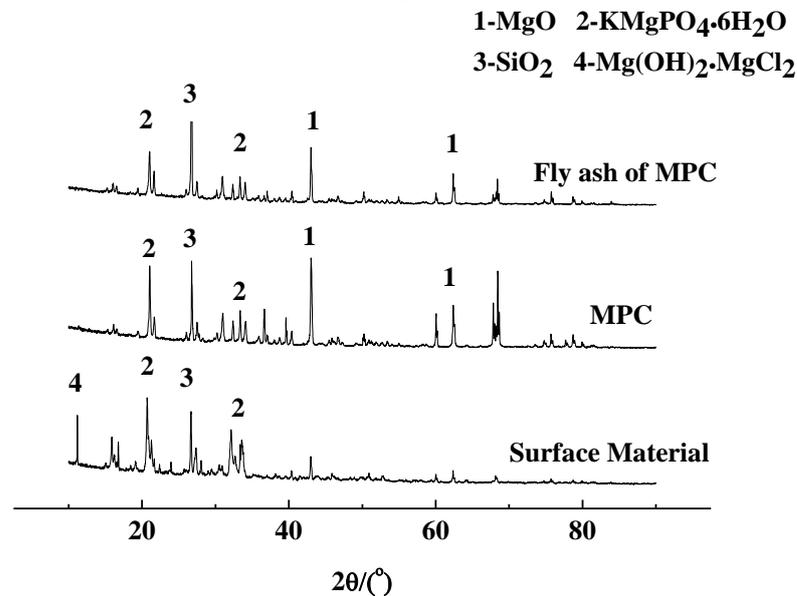


Figure 8. Influence of fly ash on the XRD analysis

Figure 8 is the XRD component analysis of fly ash magnesium phosphate cement. From the XRD curves of pure magnesium phosphate cement powder, the main peaks correspond to unhydrated MgO , SiO_2 and $\text{KMgPO}_4 \cdot 6\text{H}_2\text{O}$, respectively. $\text{KMgPO}_4 \cdot 6\text{H}_2\text{O}$ is the main hydration product, while SiO_2 is carried by fly ash itself. Comparing XRD of fly ash magnesium phosphate cement with pure magnesium phosphate cement powder, it is found that the composition of hydrated material is basically the same, but the main peak is lower than that of pure magnesium phosphate cement. $\text{Al}(\text{OH})_3$ is not detected because of the existence of the material itself, but because of the error in the sample preparation process, it is difficult to detect it, which needs further study. There is no MgSiO_3 in magnesium phosphate cement mixed with silica fume. The reason is that SiO_2 ionizes into SiO_3^{2-} and needs strong acid environment. The environment after hydration of magnesium phosphate cement is weak alkaline. SiO_2 is not allowed to ionize into SiO_3^{2-} . There is no MgSiO_3 in solution. The main peaks of XRD are SiO_2 , $\text{KMgPO}_4 \cdot 6\text{H}_2\text{O}$ and $\text{Mg}(\text{OH})_2 \cdot \text{MgCl}_2$. It shows that Mg^{2+} and PO_4^{3-} ions in the cement body spill out from the cement body after being immersed in water to regenerate bird droppings and other products on the cement surface. There is no Cl^- raw material in $\text{Mg}(\text{OH})_2 \cdot \text{MgCl}_2$, but the analytical Cl^- is introduced by tap water for immersion. According to the generated substances on the surface of cement, researchers found that a part of bird dung stone and

unhydrated MgO in magnesium phosphate cement mixed with fly ash would be ionized by water shock to remove Mg^{2+} and PO_4^{3-} ions, leaving voids on the surface, which reduced the strength of cement and affected the water resistance of cement.

3.3.2. SEM Micromorphology Analysis of Magnesium Phosphate Cement Mixed with Fly Ash

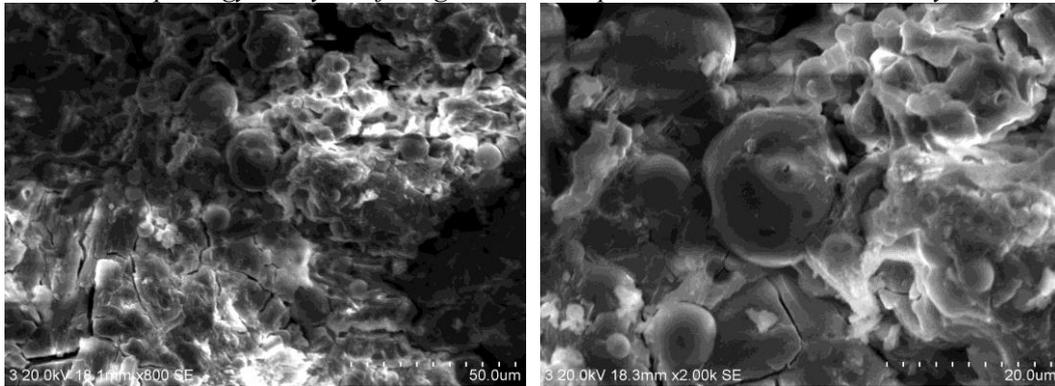


Figure 9. Influence of fly ash on the SEM picture

As shown in Fig. 9, the scanning electron microscopy (SEM) image of the cement mixed with fly ash and magnesium phosphate after 7 days immersion. It can be clearly seen from the Figure that there are many micro-cracks on the surface of the cement paste. These crevices are caused by corrosion of water. At the same time, fly ash particles with different sizes between 5um and 20um can be observed. Fly ash particles are closely connected with magnesium phosphate cement. It shows that fly ash has activity in magnesium phosphate cement. However, the parts closely connected with fly ash are denser and have fewer cracks. Fly ash particles of different sizes can be evenly distributed in the system filled with pore and capillary pore. Improve the pore structure of the structure. In Figure 9, amorphous flocs are formed on the surface of fly ash. This is because the oxides of silicon, calcium, aluminum, iron and other elements in fly ash, as well as the unburned carbon composition, participate in the reaction. The contact part between fly ash and magnesium phosphate cement matrix is closely connected. It also consumes phosphate in MPC paste. The water resistance of magnesium phosphate cement can be improved by using fly ash. Improve the water resistance of magnesium phosphate cement.

4. Conclusion

(1) The mechanical properties of MPC cement can be improved by adding fly ash into MPC cement. The flexural strength and compressive strength of modified MPC after immersion increase with the content of fly ash. They all showed the trend of increasing first and then decreasing. When the content of fly ash is 35%, the compressive strength and flexural strength of modified MPC are the best.

(2) With the increase of fly ash content, the overall trend of strength retention rate and mass retention rate of MPC cement increases first and then decreases, but the magnesium phosphate cement with 50% content slightly rises. When the content of fly ash is 35%, the water resistance is the best, the strength retention rate is more than 95%, and the mass retention rate is more than 99.5%.

(3) The XRD analysis of magnesium phosphate cement mixed with fly ash shows that no new hydration products are formed. The surface substances of the cement paste after soaking are $KMgPO_4 \cdot 6H_2O$ and $Mg(OH)_2 \cdot MgCl_2$. SEM scanning electron microscopy showed that the surface of cement paste had fewer micro-pore, compact structure, better micro-aggregate effect and morphological effect of fly ash. It was evenly distributed in the system, filled with pore and capillary, and improved the water resistance of magnesium phosphate cement.

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References

- [1] Lin Wei, SUN Wei, Li Zongjin. 2010. Study on the Effects of Fly Ash in Magnesium Phosphate Cement. *Journal of Building Materials*, 13(6), 716-721.
- [2] Mao Min, Wang Zhi, Wang Qingzhen, Hu Qianwen, You Chao 2011. Influencing Factors on Water Resistance of Magnesium Phosphate Cement and Its Improving Measures. *Fly Ash Comprehensive Utilization* (6), 15-18.
- [3] Liu Kai, Li Dongxu. 2011. Review of Magnesia-phosphate Cement Based Materials . *Materials Reports*, 25(13), 97-100.
- [4] Wang Hongtao, Wu Mingchuan, Tang Chunping. 2005. The effect of Ground Fly Ash on the Properties of Phosphate Cement-based Composites. *Fly Ash Comprehensive Utilization* (6), 38-40.
- [5] Zhang Siyu, Shi Huisheng. 2009. Performances and Applications of Magnesium Phosphate Cement-based Composites modified by Fly Ash. *Fly Ash Comprehensive Utilization* (1), 54-56.
- [6] Ding, Z., & Li, Z. 2005. Study of high early strength cement based on fly ash, magnesia and phosphate. *Materials Technology*, 20(3), 136-141.
- [7] Zhou Xuyang, Yang Jianming. 2013. Effect of Fly Ash on Properties of Magnesium Potassium Phosphate Cement Paste. *Journal of Jiangsu University (Natural Science Edition)*, 2013, 34 (6):730-735.
- [8] Sarkar A K. 1990. Phosphate Cement-based Fast-setting Binders [J]. *Ceram Bull*, 69(2): 234-238.
- [9] Luo Yali. 2010. Experimental Study on Magnesium Phosphate Cement With High Early Strength and its Applications (Shanghai: Shanghai Jiao Tong University).
- [10] Mao Min, Wang Zhi, Wang Qingzhen. 2011. Influencing Factors on Water Resistance of Magnesium Phosphate Cement and Its Improving Measures. *Fly Ash Comprehensive Utilization*, 15-18.
- [11] Nelson N O, Mikkelsen R L , Hesterberg D L., 2003 Struvite Precipitation in Anaerobic Swine Lagoon Liquid: Effect of pH and Mg:P Ratio and Determination of Rate Constant. *Bioresource Technology*, 89(3) :229 – 236.
- [12] Y Quanbing, Z. Beirony, Zh. Shuqing et al., 2000, Properties and Application of Magnesia-phosphate Cement Mortar for Rapid Repair of Concrete. *C.C.R* 30(11): 1807-1813.
- [13] Li Dongxu, Li Pengxiao, Feng Chunhua. Research on Water Resistance of Magnesium Phosphate Cement. *Journal of Building Materials*, 2009(9):505-508 525.
- [14] D.A.Hall, R.Stevens, B.El-Jazairi. 2001. The Effect of Retarders on the Microstructure and Mechanical Properties of Magnesia-phosphate Cements Mortar. *C.C.R*, 31(3):389-396.