Effects of nano-silica and silica fume on properties of magnesium oxysulfate cement

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As a new type of material, magnesium oxysulfate (MOS) cement shows advantages of fire resistance, low alkalinity, light weight, and good decorative value. However, the low strength of MOS cement limits its large-scale applications in civil engineering, and strength can be increased by adding appropriate admixtures. By adding different dosages (1, 3, 5%) of nano-silica (NS) and silica fume (SF), this paper studied the effects of the dosages on the compressive strength and water resistance of MOS cement. The phase composition and microstructure of MOS cement hydration products were analyzed by X-ray diffraction and scanning electron microscopy. The hydration process and pore size distribution of MOS cement were measured by hydration heat release rate and mercury intrusion porosimetry. The results show that the use of NS and SF as admixtures can inhibit the direct hydration of MgO to form Mg(OH)₂ and promote the formation of the 5Mg(OH)₂·MgSO₄·7H₂O (5·1·7 phase), improve the strength and water resistance of MOS cement to a certain extent.

Key-words : Magnesium oxysulfate cement, Water resistant performance, Compressive strength, Hydration heat release, Porosity

1. Introduction

Magnesium oxysulfate (MOS) cement is a gas-hardening magnesium cementitious material formed by active magnesium oxide and magnesium sulfate solution (MSS).¹⁻³ MOS cement has many advantages in civil engineering, such as light weight, excellent fire resistance, low thermal conductivity and other characteristics.⁴⁻⁶ It can be used to produce lightweight insulation boards, insulation materials and refractory materials. The main raw materials for the production of MOS cement are magnesium oxide and magnesium sulfate. The temperature at which magnesite is calcined to magnesium oxide is only 650 °C, which is less than half of the ordinary portland cement production temperature (1450 °C), it has truly achieved low carbon, energy saving and environmental protection.⁷ Compared with magnesium oxychloride (MOC) cement, the application prospects of MOS are even broader.⁸ At present, research on magnesium cement is primarily limited to MOC, and there is little attention to MOS cement, mainly because of its low mechanical strength properties.⁹⁻¹¹ Therefore, if the strength properties of MOS cement can be improved, MOC cement will be replaced by MOS cement in some cases, especially under high temperature and water resistance conditions.

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The mechanical strength of MOS cement mainly depends on the composition of its hydration products. For example, zheng¹² found that the main hydration products of ordinary MOS cement are Mg₃Si₄O₁₀(OH)₂, MgCO₃ and xMg(OH)₂·yMgSO₄·zH₂O. In this cementitious system, Mg(OH)₂ is the product of incomplete hydration of magnesium oxide, its lamellar morphology and loose microstructure lead to the lower mechanical strength of MOS cement. According to previous work results, the xyz phase is a complete hydration product of magnesium oxide, which shows excellent mechanical strength in cement system. Dmediu and Coie¹³ found in their study that the MgO–MgSO₄–H₂O ternary system will generate 4 different phases at 30–120 °C, which are 5Mg(OH)₂·MgSO₄·3H₂O (5·1·3 phase), 3Mg(OH)₂·MgSO₄·8H₂O (3·1·8 phase), Mg(OH)₂·2MgSO₄·3H₂O (1·2·3 phase) and Mg(OH)₂·MgSO₄·5H₂O (1·1·5 phase). Deng¹⁴ modified MOS cement with s-type additives and found that the mechanical properties of MOS cement are significantly improved after modification, the reason is the appearance of a new crystal-line phase of basic magnesium sulfate. Runcesvski et al.¹⁵ modified MOS cement with organic acids and analyzed a new structure (5·1·7 phase).

Previous studies have shown that the main way to improve the strength of MOS cement is to add admixtures to MOS cement to inhibit the generation of Mg(OH)₂ and promote the formation of 5·1·7 phase.¹⁶⁻¹⁷ For example, adding phosphoric acid, amino trimethylene phosphonic acid...
and citric acid can significantly improve the compressive strength and water resistance of MOS cement by promoting the formation of the 5·1·7 phase. Wu et al. added a small amount of tartaric acid as a modifier to MOS cement and found that tartaric acid can inhibit the production of Mg(OH)₂ and promote the formation of 5·1·7 phase, which greatly improves the flexural and compressive strength.

The main objects of this study are nano-silica (NS) and silica fume (SF). NS has higher pozzolanic activity than SF, can initiate secondary hydration, shows nucleation and micro-aggregate filling effects, and has become a popular research topic. SF is often used as an auxiliary cementing material to improve the mechanical properties of concrete and reduce costs. At present, the research of NS is mainly based on ordinary portland cement. For example, A.S. Tulina and Genady Shakhmenko et al. found that adding 5% NS to a cement slurry can increase the strength of 3d and 7d by 118 and 80%, respectively. The experimental results showed that NS could significantly improve the early strength of the cement slurry. This is due to the promotion of NS on the early hydration of cement. A. Eisinas et al. believed that NS particles showed a strong surface adsorption ability, adsorbing Ca²⁺ in a cement slurry at the early stages of hydration, resulting in a decrease in Ca²⁺ content and a faster dissolution rate of C₃S in the clinker. Liu et al. found that the addition of SF at 5% when single-doping cement-based materials can generate better fluidity and higher mechanical properties.

In order to broaden the research of NS and SF in the field of magnesium cement, this paper studies the effects of NS and SF on the mechanical properties and water resistance of MOS cement. By changing the dosages of NS and SF, measuring and observing the compressive strength, hydration heat release rate, softening coefficient and pore size distribution of MOS cement. Combined with the phase composition and microstructure of its hydration products. Analyzing and researching the results. Which can be used as a reference for the promotion of MOS cement in practical application.

2. Materials and experimental procedures

2.1 Raw materials

(1) The magnesium oxide used in the experiment is light-burned magnesia (LBM) obtained by calcining magnesite (from Dashiqiao, Liaoning Province, China) at 750–850 °C. The chemical composition of LBM is shown in Table 1. The activity of MgO is determined by using the standardised hydration method of Dong is 59.04%.

(2) Magnesium sulfate. The magnesium sulfate (MgSO₄·7H₂O crystal) used in this study is analytically pure producing in Tianjin Dingsheng Xin Chemical Co, Ltd. Its particle size is 15 nm. Its microscopic appearance is shown in Fig. 1. The physical properties of NS is shown in Table 2.

(3) Nano-silica. The NS used in this study is analytically pure producing in Tianjin Dingsheng Xin Chemical Co, Ltd. Its particle size is 15 nm. Its microscopic appearance is shown in Fig. 1. The physical properties of NS is shown in Table 2.

(4) Silica fume. The SF used in this study is from Qinghai shanchuan machine bed foundry, where its chemical composition is shown in Table 3. Its microscopic appearance is shown in Fig. 2.

(5) Sodium citrate (CA). The CA is analytically pure producing in Beijing Chemical Plant.

2.2 Specimen preparation

The preparation process of MOS cement was as follows:

(1) Firstly, the molar ratio (LBM/MgSO₄) of MOS cement...
was determined, and MgSO$_4$·7H$_2$O was dissolved in deionized water to form a mass fraction of 28.9% MSS (the molar ratio of H$_2$O/MgSO$_4$ is 20.0). (2) Next, the LBMB powder, admixture, CA and powder were mixed and stirred well. (3) Then, the prepared MSS was added to form the MOS slurry by mechanical stirring. (4) Last, the evenly mixed slurry was rapidly injected into a steel mold of 20 mm × 20 mm × 20 mm, and samples were formed under the conditions of 20 °C ± 2 °C and a relative humidity of 50% ± 5%. After curing for 24 h, the mold was demoulded, naturally cured at room temperature, and tested after curing for the corresponding age (1, 3, 7, 28, 60 and 90 d). The raw material ratio of samples is shown in Table 4.

| Specimen type | Molar ratio (LBM/MgSO$_4$) | Quality ratio (MSS/LBM) | Quality ratio (NS/LBM) | Quality ratio (SF/LBM) | Modifier ratio (CA/LBM) |
|---------------|---------------------------|------------------------|-----------------------|----------------------|------------------------|
| C             | 8                         | 89.1%                  | 0                     | 0                    | 0.5%                   |
| NS1           | 8                         | 89.1%                  | 1%                    | 0                    | 0.5%                   |
| NS2           | 8                         | 89.1%                  | 3%                    | 0                    | 0.5%                   |
| NS3           | 8                         | 89.1%                  | 5%                    | 0                    | 0.5%                   |
| SF1           | 8                         | 89.1%                  | 0                     | 5%                   | 0.5%                   |
| SF2           | 8                         | 89.1%                  | 0                     | 10%                  | 0.5%                   |
| SF3           | 8                         | 89.1%                  | 0                     | 20%                  | 0.5%                   |

(illustrative: C denotes the control group, NS and SF denote the added substance, and (1,2,3) denote different dosages of the admixtures. For example, NS1 represents the experimental group, where the NS mass is 1% of the mass of LBM, SF is not added, the molar ratio is 8, and the water-cement ratio is 0.51. CS, NS3S and SF1S are the name for the experimental group of materials soaked in water for 90 days after curing CS, NS3 and SF1 for 28 days.)

2.3 Specimen analysis

(1) Compressive strength: the compressive strength was determined according to the testing standard GB 175-2007 (“Common portland cement”). The compressive strength of MOS cement samples after curing for 1 day, 3 days, 7 days, 28 days, 60 days and 90 days and soaking in water for 30 days, 60 days and 90 days were measured on a testing machine with a maximum force of 300 kN at a constant loading rate of 2.4 kN/s.

(2) X-ray diffraction (XRD) and scanning electron microscopy (SEM) analyses: the MOS cement was ground into paste powder (D90 < 35 μm) to test its crystal phase composition by using XRD (D/max-2500PC). Where the acceleration voltage was set to 30 kV and the scan area (2θ range) was 5 to 70 degrees. Finally, we used “Highscore” software to determine the type of the product by comparison with a standard diffraction peak. The microstructure of the MOS samples were observed by SEM (JSM-5610V) on the fractured surfaces after gold coating.

(3) Hydration heat release rate: the hydration heat release rates of MOS cement paste with different types of samples were tested by using a Calmetrix-I-Cal 4000HPC four-channel isothermal calorimeter according to the direct method in the standard of GB/T 12959-2008 (“Test methods for heat of hydration of cement”).

(4) Mercury intrusion porosimetry (MIP) test: the porosity and pore size distribution of MOS cement samples after curing for 28 days and soaking in water for 90 days were measured by mercury intrusion method (Auto Pore IV 9500). Where the pressure range of the instrument was 1.38 to 228 kPa, the testable aperture range was 5 nm to 1100 μm, and the contact angle of mercury with the substance is 135 degree.

3. Results and discussion

3.1 Compressive strength

In practical engineering applications, cement is widely used in industrial and civil construction projects, and the improvement of cement performance is of great significance. Studies have shown that the strength properties of MOS cement depend on the amount of hydration product (5·1·7 phase), that exists in the cement.27

Figure 3 shows the compressive strength of MOS with different ratios of admixtures and curing times. It can be found from Fig. 3(a) that the strength of control group C at different curing times is lower than that of the NS experimental group. NS can significantly increase the early strength of the cement paste but has less influence on the later strength. Magnesium cement with 5%NS has good mechanical properties; for example, when C and NS3 are compared, the compressive strength of C at 1 d is 13.2 MPa, and the compressive strength of NS3 is 17.9 MPa. After the first day, the compressive strength of experimental group NS3 was 35% higher than that of the control group. After 90 d, the compressive strength of C was only 78.9 MPa, while the compressive strength of NS3 was 90 MPa. The compressive strength of NS3 in the experimental group was increased by 14% in 90 days compared with the control group C. As curing time increased, the effects of NS on the MOS cement strength were gradually reduced. This may be because as more NS is incorporated, there are more growth sites for hydration products and nucleation of nanomaterials, which leads to higher early strength of the cement paste. After 28 days curing, due to the smaller particle size of the incorporated NS, the size of the formed nucleus is smaller, and more crystal nuclei cannot continue to grow, thus affecting the strength growth of the magnesium cement paste. It can be found from Fig. 3(b) that when the incorporation of SF is 5%, the experimental group shows higher mechanical properties than the control group.
and the difference in compressive strength increases as curing time increases. On the contrary, the effects of incorporating 10 and 20% SF are not obvious. The compressive strengths of SF1 at 1 and 90 d were 13.8 and 83.8 MPa, respectively. Compared with control group C, the 1 d strength increased by 0.6 MPa, and the 90 d strength increased by 5 MPa. The compressive strengths of SF2 and SF3 were lower than that of the control group over the same curing period. As SF content increased, the difference became more obvious. It may be due to the filling effect of SF at the beginning of the incorporation of a small amount of SF, where the SF can easily fill the pores due to low surface area, which increases the compactness of the sample, resulting in an increase in strength. However, as the amount of SF increases, excessive SF cannot continue to fill the pores, resulting in a decrease in strength. It may also be due to the replacement of cement by SF, where, as the amount of the admixture increases, the relative amount of MgO in the MOS cement decreases, and the amount of the 5·1·7 phase is correspondingly reduced, thereby, lowering the overall strength of the cement.

### 3.2 Phase transformation and SEM

According to Wu et al., the addition of tartaric acid to magnesium cement can promote the formation of the 5·1·7 phase. With the addition of silicon-based minerals, the early strength of magnesium cement is improved, and the mechanism of early strength improvement of MOS cement was investigated using XRD. Figure 4 shows the XRD patterns of MOS cement cured with various admixtures for one day. It can be seen from Figs. 4(a) and 4(b) that when 5% NS and 5% SF are added, the diffraction peak of 5·1·7 is gradually increased. This shows that NS and SF can promote the growth of the 5·1·7 phase to a certain extent, improve the compressive strength of MOS cement. The reason may be that the fine particle sizes of NS and SF promote high pozzolanic activity and good cement adaptability, promote the hydration reaction of cement paste and the growth of the 5·1·7 phase. Mg(OH)$_2$·MgSO$_4$·H$_2$O gel was generated to refine the grains. It is also possible that SiO$_2$ in NS and SF reacts with Mg(OH)$_2$ to form hydrated magnesium silicate, which inhibits the formation of Mg(OH)$_2$ and promotes the growth of the 5·1·7 phase. The diffraction peaks of the 5·1·7 phase in SF2 and SF3 were found to be lower than that of the control group, and the diffraction peak of SiO$_2$ was significantly higher than that of the control group, which further confirms the conjecture that excess SF content does not continue to fill the pores.
and leads to a decrease in strength. The addition of an appropriate amount of admixture promotes the formation of the 5·1·7 phase, which is the fundamental cause of the high early strength of the experimental group.

Figures 5(a)–5(c) and Figs. 6(a)–6(c) show the SEM diagrams of MOS cement after curing for 1 day and 3 days with different admixtures. It can be seen from the figure, during the MOS cement curing for one day, the 5·1·7 phase whiskers in the control group were short and disordered. On the contrary, the 5·1·7 phase whiskers in the NS and SF groups were slightly longer than those in the control group, resulting in an increase in strength. During the MOS cement curing for three days, the 5·1·7 phase whiskers in the control group and the experimental group were significantly longer, which was also the reason for the significant increase change in the early strength of

Fig. 5. SEM images of MOS cement with different admixtures cured for 1 day.

Fig. 6. SEM images of MOS cement with different admixtures cured for 3 days.
MOS cement. Compared with the 5·1·7 phase whiskers in the control group, the whiskers in the experimental group were arranged in order and the structure was close, which improved the strength support of the cement.

Figures 7(a)–7(c) shows the SEM images of MOS cement cured after 28 days with different admixtures, which allows for better observation of the 5·1·7 microtopography analyzed at the solid–liquid interface. The results showed that the 5·1·7 phase was a needle-like structure, and the 5·1·7 phase in the control group was disorderly arranged, scattered to the periphery, and loose, resulting in low strength. The 5·1·7 phases of the experimental groups NS3 and SF1 compared with the control group showed thicker and longer 5·1·7 phase needle shapes with better and tighter arrangement, which provided strength support for the cement.

According to research on the hydration process of portland cement,27),28) the hydration process can be divided into five stages: namely the pre-induction period, the induction period, the acceleration period, the deceleration period, and the stable period. Figure 8 is a graph showing the hydration heat release and hydration heat release rate with different amounts of MOS cement. From the heat release rate data in Figs. 8(a) and 8(d), it was observed that with the increase of NS and SF content, the five periods of the hydration process do not change significantly, indicating that NS and SF as admixtures do not change the setting time of the MOS cement and do not show a retarding or procoagulant effect. From the heat release rate data in Figs. 8(b) and 8(e), the maximum heat release rate value per unit time showed a gradual decrease, which implied that at the same water-binder ratio, the cement particle reaction was reduced due to the addition of the admixture, which is of great significance in preventing the cracking of concrete in practical applications. In Figs. 8(c) and 8(f), it can be seen that the early stage total heat release of the experimental group is directly proportional to the increase of the NS content, and the addition of SF also significantly improves the total heat release at the early stages of MOS, where 5% addition was optimal. This is due to the role of NS and SF in promoting hydration when the cement and water begin to react. The Mg²⁺ and OH⁻ of the MOS cement mixture rapidly dissolve in the solution, and the addition of NS and SF rapidly consumes Mg²⁺ and OH⁻ in the solution. As a result, the hydration rate is accelerated by the addition of the admixture, indicating that the total hydration heat release increases with the decrease of Mg²⁺ and OH⁻. An increase in early heat release leads to the formation of more hydration products. Combined with the XRD patterns, it was found that the increase of the 5·1·7 phase is more obvious, and the 5·1·7 phase is the strength phase. Therefore, the early strength improvement effect of NS3 and SF1 is relatively obvious, which conforms to the strength change trend shown in Fig. 3.

3.3 Water resistance

Figure 9 shows the compressive strength and softening coefficient of MOS cement after water soaking. As shown in Fig. 9, the strength and softening coefficient of the experimental group and the control group decreased after soaking in water, and the overall decrease of the control group was much larger than that of the experimental group. After soaking in water for 90 days, cracks appeared on the surface of the control group. When NS and SF were added as admixtures, it was found that the experimental group showed higher strength after water soaking for 90 days, and
the softening coefficient was greatly improved. Additionally, the water resistances of NS3 and SF1 were better. For example, the compressive strength and softening coefficient of NS3S increased by 22.2 MPa and 0.2 respectively, and the compressive strength and softening coefficient of SF1S compared with CS increased by 11.3 MPa and 0.13, indicating that the presence of the admixture enhanced the water resistance of the magnesium cement.

To further explain the improvement in water resistance of MOS with the incorporation of NS and SF, the control group before and after soaking and the samples with improved performance (NS3 and SF1) were selected. The phase composition and microstructure of the hydration products under different substitution rates of the admixtures were analyzed by XRD and SEM to better understand the molecular mechanism. Therefore, as the main research object, the effect on the water resistance of magnesium cement was studied. The XRD image after 90 days of soaking water is shown in Fig. 10. As shown in the figure, the intensities of the MgO diffraction peak in the experimental group and the control group were significantly reduced after water immersion for 90 d, while the
strengths of the Mg(OH)$_2$ diffraction peaks was further enhanced, where a small amount of the 5·1·7 phase was increased. The reason for this phenomenon may be that a small amount of low-activity MgO in the raw material undergoes slow hydration in a long-term aqueous environment, resulting in a weak alkaline environment, and a small amount of 5·1·7 phase is formed in reacting with unreacted hydrated MgSO$_4$.$\cdot$1·7. However, the main reason leading to the strength decrease of MOS cement is that most of the remaining MgO has secondary hydration in water, which leads to the continuous formation of low-density flake Mg(OH)$_2$ in the cement, where the structure gradually loosens and finally cracks, leading to reduced strength. The diffraction peak strengths of Mg(OH)$_2$ in the experimental group after soaking in water was further reduced compared with that in the control group after soaking in water. It can be inferred that the addition of NS and SF can inhibit the continuous hydration of the MOS cement in water to generate Mg(OH)$_2$ crystal phases, which lead to decrease cement strength. It also has a protective effect on the 5·1·7 phase crystal, effectively preventing high levels of hydrolysis, thereby maintaining a higher strength and improving the water resistance.

Figure 11 shows the microstructures of hydration products at different admixture substitution rates. It can be found from Fig. 11(a) that compared with 28 days of curing age in Fig. 7(a), a large number of needle-like structural materials were found before water soaking, which interlaced with each other and formed a crystalline network. The structure was relatively dense, and combined with the XRD diagram, the crystal was mainly the 5·1·7 phase. After soaking in water, the needle substance in the hole changed, where almost all the needle crystals disappeared, and the whiskers of the 5·1·7 phase in the remaining pores shortened. A significant amount of the 5·1·7 phase was hydrolyzed to form large, flaky Mg(OH)$_2$ after soaking in water, and its strength was much lower than that of the needle-like 5·1·7 phase with higher porosity and a looser structure, which promoted a significant amount of contact between water and the internal crystals, causing crystal hydration and poor water resistance. In comparing Figs. 11(b) and 7(b), there are a large number of needle-shaped 5·1·7 phase crystals before and after soaking in water when the admixture is added into the MOS cement. The differences are that the whiskers of the 5·1·7 phase after soaking water become shorter and the crystals become...
rods, providing strength support. Many crystals are bonded together after water soaking, protecting the 5·1·7 phase and preventing further hydrolysis, thereby improving the water resistance of the MOS cement, which is mutually confirmed by the XRD analysis.

### 3.4 Porosity

According to previous studies, the mechanical properties of cement depend on the type and content of the cement slurry hydration products, which are closely related to the influence of pore structure inside the slurry. Figure 12 shows the cumulative porosity of the MOS cement, and the pore distribution state of the MOS cement is shown in Table 5. It can be seen from Fig. 12 and Table 5 that the pore size distribution of the control group C is significantly different from that of the experimental groups NS3 and SF1. Compared with the control group, the average pore size and mesopores (10 nm < D < 100 nm) of the NS3 were significantly reduced, and a small hole appears. This is because the particle size of the NS raw material used in the experiment is 15 nm, and several mesopores are filled in the slurry. The NS particles will generate small pores in the pore-filling process, resulting in a large decrease in the mesopores and average pore size. Compared with the control group, the average pore size and mesopores of the SF1 phase increased, and the macropores (D ≥ 100 nm) showed a significant decrease. According to the laser particle size analysis, the particle size of the SF is generally 300 nm. The SF will produce many mesopores while filling the large pores, and the increase of the mesopores is much larger than that of the macropores, resulting in an increase in the average pore size.

Comparing C and CS, NS3 and NS3S, and SF1 and SF1S, the mesopores and small pores of the control group after soaking in the water will increase; however, the ratio of macropores (D ≥ 100 nm) and the average pore size decrease. There may be two reasons for this phenomenon. First, since the molar ratio of the MOS cement sample is 8, it was found that the MgO diffraction peak of the sample is greatly reduced after soaking and the Mg(OH)2 and 5·1·7 phase diffraction peaks increase, indicating that MgO is not completely reacted before water soaking leading to further hydration to form Mg(OH)2 and the 5·1·7 phase. The formation of the Mg(OH)2 and 5·1·7 phase fill a portion of the pores, especially the pores of the macropores. The large reduction in macropores plays a leading role, so the average pore size of the control group samples after water soaking is reduced. Secondly, the control group sample contains a large amount of (MgSO4·nH2O) crystal hydration products, and the (MgSO4·nH2O) crystal hydration product can be dissolved in water. During long-term water soaking, a portion of the crystal dissolves in water, and the gel dissolution leads to an increase in the ratio of the mesopores and small pore. At the same time, after natural drying, a layer of white powder will appear on the surface. The reason for this phenomenon is that the substance in the sample is dissolved in water and precipitated on the surface of the sample.

**Fig. 12.** Cumulative porosity of MOS [D is pore diameter (nm)].

**Table 5.** Statistics of pore distribution of MOS cement

| Specimen type | Average pore diameter | ≤10 nm/% | 10–100 nm/% | ≥100 nm/% |
|---------------|-----------------------|----------|-------------|-----------|
| C             | 49.02                 | 2.58     | 64.00       | 33.42     |
| CS            | 48.44                 | 3.88     | 72.04       | 24.08     |
| NS3           | 35.14                 | 4.89     | 54.73       | 40.38     |
| NS3S          | 23.09                 | 6.13     | 61.19       | 32.68     |
| SF1           | 49.37                 | 1.3      | 74.38       | 24.32     |
| SF1S          | 42.55                 | 4.09     | 78.51       | 17.40     |

SF1 phase increased, and the macropores (D ≥ 100 nm) showed a significant decrease. According to the laser particle size analysis, the particle size of the SF is generally 300 nm. The SF will produce many mesopores while filling the large pores, and the increase of the mesopores is much larger than that of the macropores, resulting in an increase in the average pore size.
confirming the possibility of dissolution of the \((\text{MgSO}_4 \cdot n\text{H}_2\text{O})\) crystallization hydration product.

4. Conclusion

In this study, the effects of the addition of NS and SF on the mechanical properties and water resistance of MOS cement, combined with XRD, SEM, hydration heat release rate and MIP. the following were concluded:

• (1) When 5%NS and 5%SF are added into MOS cement, the mechanical properties of MOS cement are improved, and the early compressive strength is the most obvious enhancement. This is primarily because the addition of an admixture promotes the growth of the 5·1·7 phase. The 5·1·7 phase in magnesium cement is the strength phase, which provides strength support for MOS cement.

• (2) The early stage total heat release of NS is directly proportional to the dosages increase, and the addition of SF also significantly improves the early total heat release of MOS cement. The best properties were observed with the incorporation of 5%SF, where the total heat release in the early stage was improved and the increase in the 5·1·7 phase was more obvious, which leads to the early increase in strength. The maximum heat release per unit time decreases as the dosages of the admixture increases, which is of great significance to prevent cracking of mass concrete.

• (3) After soaking in water, the whiskers of the 5·1·7 phase of the experimental group become shorter, the crystals become rods (providing strength support), and a large number of crystals are bonded together after water soaking to protect the 5·1·7 phase crystal and avoid further hydrolysis, thereby improving the water resistance of the magnesium cement.

• (4) When NS and SF are added to MOS cement, the phases of the hydration products change and improve the pore structure of the cement. After water soaking, the unreacted MgO of the sample will continue to hydrate to form Mg(OH)\(_2\) and the 5·1·7 phase, thereby forming a portion of the macropores, which results in a lower average pore size than before soaking in water.

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