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Investigation on the properties of calcium sulfoaluminate cement waterproof repair mortar modified with ethylene-vinyl acetate powder

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ABSTRACT

In this paper, ethylene-vinyl acetate (EVA) powder and CSA cement were used to prepare the waterproof repair mortar, and the hydration and performance were studied. The results show that EVA powder prolongs the setting time and improves the fluidity of the waterproof repair mortar, which makes it more available to be applied in the practical engineering. EVA powder improves the impermeability and reduces water absorption of the waterproof repair mortar. Although EVA powder reduces the flexural and compressive strength of waterproof repair mortar, it still meets the requirements of rigid repair mortar in the standard of JC/T 2381-2016. EVA powder reduces the shrinkage of waterproof repair mortar, improves the interfacial transition zone and the bonding performance such as tensile bonding strength and flexural bonding strength. EVA powder inhibits the hydration of CSA cement for 6 h, and the inhibitory effect disappears at the hydration age of 3 d.
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1. INTRODUCTION

During the long-term service of the building structure, the mortar of the wall structure is easy to fall off due to carbonation, freeze-thaw cycle and wet-dry cycle. And the damage area expands with the extension of service age. It will not only worsen the living environment, but also pose a threat to personal and property safety. Moreover, with the development of economy and the improvement of living standards, people put forward higher requirements for the living. Therefore, it is urgent to repair the damaged building structures [1].

At present, the repair mortar can be divided into two categories [2]: (1) Cement-based repair mortar; (2) Polymer repair mortar. Polymer repair mortar is a kind of mortar with liquid resin as cementitious material. It exhibits excellent adhesion, impermeability and corrosion resistance. However, due to consuming large amount of polymer, the cost is high and the durability is poor, which greatly limits its large-scale application. Cement-based repair mortar is cheap and exhibits good mechanical properties and durability, but the adhesion and impermeability need to be further improved. Previous studies show that a small amount of polymer could effectively improve the bonding strength and impermeability of mortar. The cost is low and the preparation process is simple. Therefore, it is widely used in the repair engineering [3].

EVA powder is a dispersible polymer powder, which can be added to the cement mortar to improve fluidity and adhesion [4,5,6]. Moreover, the polymer powder can form films in the mortar and block the diffusion and transmission of water [7,8,9]. CSA cement has been widely used in repair engineering because of its rapid hardening, high early strength, low shrinkage and good adhesion [10,11]. Moreover, compared with OPC, the impermeability of CSA cement is better, which is more suitable for preparing the waterproof repair mortar.

In this paper, EVA powder and CSA cement are used to prepare waterproof repair mortar. The effects of EVA powder on the fluidity, setting time, mechanical properties, adhesion and impermeability of CSA cement repair mortar were studied. Besides, the hydration properties of CSA cement modified by EVA powder were analyzed by XRD and DSC-TG. The morphology of EVA powder in CSA cement matrix and the interface transition zone between waterproof repair mortar and OPC mortar were observed by SEM.

2. EXPERIMENTAL PROCEDURES

2.1 Materials

42.5 R CSA cement produced by China United Cement Group Co., Ltd is used as cementing material. The mineral composition and chemical composition are shown in Table 1 and Fig.1, respectively. P.O 42.5 OPC is produced by Shandong Cement Co., Ltd. EVA powder is produced by Wacker Chemical (China) Co., Ltd. Table 2 shows the physical properties of the EVA powder. The physical properties of sand are shown in Table 3. The water reducer is polycarboxylate superplasticizer produced by Shandong Building Research Institute Co., LTD. Analytical tributyl phosphate and citric acid are used as defoamer and retarder, respectively.

2.2 Sample preparation

Firstly, EVA powder and CSA cement were mixed by a Y-type mixer for 30 min. Secondly, the water reducer, retarder and defoamer were dissolved in the water. Finally, the EVA powder modified CSA cement repair mortar was mixed and prepared according to the standard of GB/T 17671-1999. The samples were cured in surroundings with the temperature of 20±2 ºC and relative humidity of 95%.

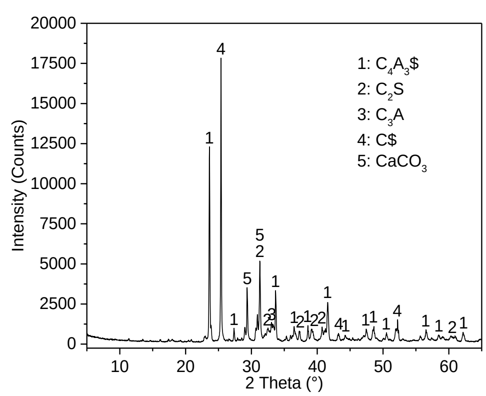


Figure 1. XRD pattern of CSA cement

Table 1. Chemical composition of CSA cement (expressed in oxides) /%

Chemical composition	CaO	SO_3	Al_2O_3	SiO_2	MgO	Fe_2O_3	TiO_2	K_2O	Na_2O	Others	LOI
Content (%)	44.88	16.3	16.1	8.62	3.26	2.46	0.65	0.29	0.19	0.51	5.56

Table 2. Physical properties of EVA powder

Physical properties	
Model	EVA-328N
Hardness	medium
Particle size (μm)	1~7
Solid content (%)	99±1
Ash content (%)	10±2
Apparent density (g/l)	490±50
Minimum film forming temperature (℃)	0

Table 3. Physical properties of sand

Physical properties	
Mud content (%)	2.89
Apparent density (kg/m^3)	1796
Bulk density (kg/m^3)	1419
Voidage (%)	20
Water content (%)	0.33
Firmness (crushing index)	Ⅱ
MB value (g/kg)	2.20
Stone powder content (%)	2.42
Saturated surface dry water absorption (%)	0.89

2.3 Test methods

The fluidity of the mortar was determined according to the Chinese standard of GB/T 2419-2005. The setting time, impermeability pressure and water absorption rate of the mortar were tested according to the Chinese standard of JGJ/T 70-2009. The compressive strength and flexural strength of the mortar were tested according to the Chinese standard of GB/T 17671-2020. The shrinkage of the mortar was determined according to the Chinese standard of JC/T 2381-2016. The tensile bonding strength and flexural bonding strength of the repair mortar with the ordinary Portland cement mortar were tested according to the Chinese standard of JC/T 2381-2016.

The microstructure of the hardened mortar was observed using EVO/LS15 scanning electron microscope. The X-ray diffraction test was conducted using D8 Advance X-ray diffractometer with Cu Kα radiation at a voltage of 40 kV and a current of 40 mA, with a step size of 0.02° and a scan speed of 2°/min. DSC-TG analysis was conducted on Mettler Toledo TGA/DSC thermal analyzer. The reactive gas and the protective gas are Air and Ar, and the gas flows are 30 ml/min and 50 ml/min, respectively. The sample weight is 30 ± 2 mg.

3. RESULTS AND DISCUSSIONS

3.1 Fluidity

The fluidity of EVA powder modified CSA cement waterproof repair mortar is shown in Table 4. The fluidity of CSA cement waterproof repair mortar without EVA powder is only 135 mm, and the fluidity is poor. With the increase of EVA powder content, the fluidity of EVA powder modified CSA cement waterproof repair mortar increases. With 5.0% EVA, the fluidity is 165 mm. EVA powder can improve the fluidity of repair mortar, which may be due to that polymer particles are attached to the surface of cement particles. The active group in EVA and its surface activity will form an electrostatic barrier, which blocks cement flocculation and thereby improves the fluidity of cement mortar [12].

Table 4. Effect of EVA powder on fluidity of CSA cement mortar

EVA content (%)	0	1.0	2.0	3.0	4.0	5.0
Fluidity (mm)	135	141	149	155	160	165

To improve the fluidity of CSA cement waterproof repair mortar, polycarboxylate superplasticizer is added. To prolong the setting time of waterproof repair mortar, citric acid was added as a retarder. Under the combined effects of polycarboxylate superplasticizer and citric acid, the fluidity of waterproof repair mortar is controlled within the range of 170±2 mm. In addition, to reduce the bubble in mortar due to the air entraining effect of EVA powder, tributyl phosphate was added. The mix proportion of EVA powder modified CSA cement waterproof repair mortar is shown in Table 5.

Table 5. EVA powder modified CSA cement waterproof repair mortar mix proportion

Sample	Cement (g)	Sand (g)	EVA content (%)	Water (g)	Water reducer (%)	Defoamer (%)	Retarder (%)	Fluidity (mm)
Blank group	450	1350	0	225	0.50	0	0.2	170±2
1.0% EVA	450	1350	1.0	225	0.40	0.2	0.2	170±2
2.0% EVA	450	1350	2.0	225	0.30	0.2	0.2	170±2
3.0% EVA	450	1350	3.0	225	0.20	0.2	0.2	170±2
4.0% EVA	450	1350	4.0	225	0.15	0.2	0.2	170±2
5.0% EVA	450	1350	5.0	225	0.10	0.2	0.2	170±2

3.2 Setting time

The setting time of EVA powder modified CSA cement waterproof repair mortar is shown in Fig.2. With the increase of EVA powder content, the setting time is extended. The formation of framework structure of ettringite and aluminum glue is closely related to the setting time of CSA cement. The addition of EVA powder prolongs the setting time, inhibits the early hydration of $C_4A_3\$$, and reduces the amount of the hydration products. It is mainly caused by the following reason: EVA powder is attached to the surface of CSA cement particles in the early stage of hydration, which hinders the early dissolution of $C_4A_3\$$ and thereby inhibits the formation of hydration products[6].

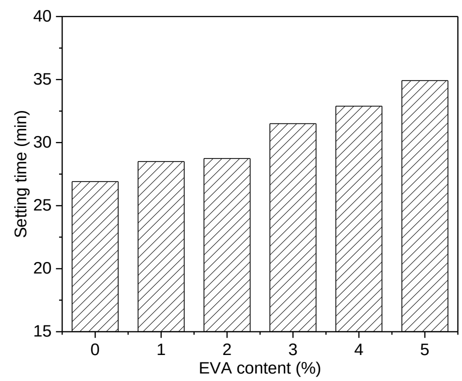


Figure 2. Setting time of EVA powder modified CSA cement waterproof repair mortar

3.3 Impermeability and water absorption

To characterize the waterproof and impermeability of the repair mortar, the impermeability pressure and water absorption are tested, the results are shown in Fig.3. With the prolonging of the hydration age, the impermeability pressure of waterproof repair mortar increases significantly. It is due to that, with the prolonging of the hydration age, the amount of the cement hydration products increase, and the mortar structure becomes more compact, blocking the transmission of water, and thereby improving the impermeability. With the increase of EVA powder content, the impermeability pressure of waterproof repair mortar also increases significantly. At hydration age of 3 d, the impermeability pressure of the repair mortar without EVA powder is only 1.5 MPa, the repair mortar mixed with 5.0% EVA powder can reach 3.6 MPa which increases by 140%. It is mainly due to that EVA powder can form polymer films in the pore inside the mortar, block the diffusion and transmission of water in the mortar. With the prolonging of the hydration age and the increase of EVA content, the content of water absorption decreases slightly.

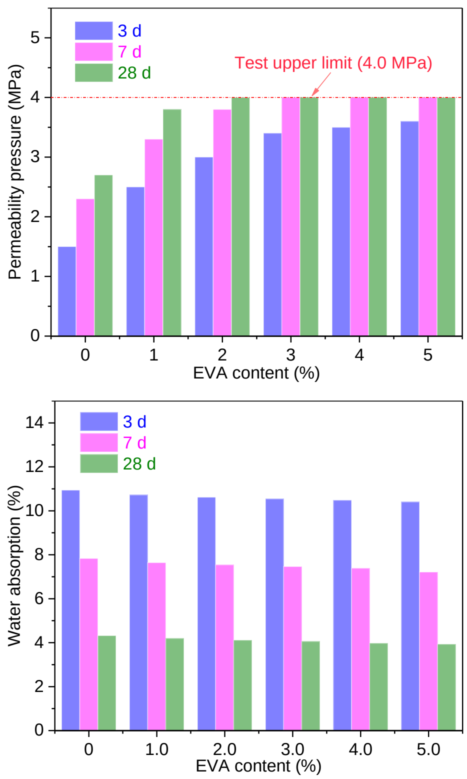


Figure 3. Impermeability pressure and water absorption of EVA powder modified CSA cement waterproof repair mortar

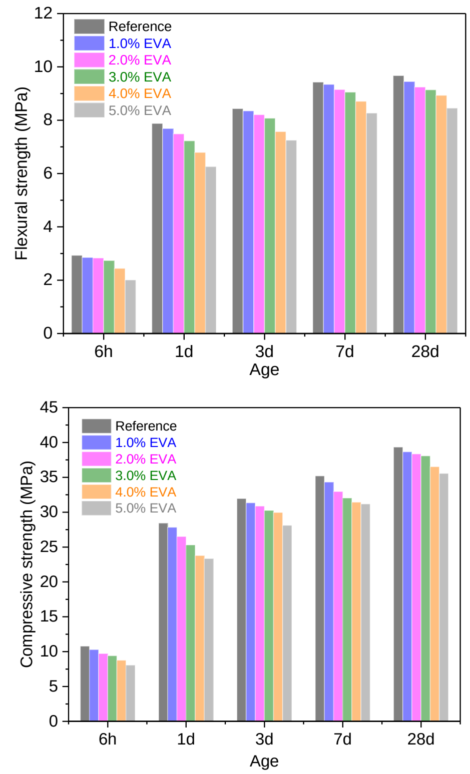


Figure 4. Flexural strength and compressive strength of EVA powder modified CSA cement waterproof repair mortar

3.4 Compressive strength and flexural strength

Fig.4 shows the flexural strength and compressive strength of EVA powder modified CSA cement waterproof repair mortar at hydration age of 6 h, 1 d, 3 d, 7 d and 28 d. At each hydration age, the flexural strength and compressive strength of the waterproof repair mortar decrease gradually with the increase of EVA powder. The reasons for the reduction of mortar strength are as follows [4,10]: (1) EVA powder inhibits the hydration of calcium sulphoaluminate; (2) EVA powder reduces the structural continuity of CSA cement mortar.

At hydration age of 28 d, the flexural strength and compressive strength are 8.45 MPa and 35.55 MPa, respectively. The strength losses are 12.65% and 9.63%, respectively. Although EVA powder reduces the mechanical properties of CSA cement waterproof repair mortar, it can still meet the requirements of standard JC/T 2381-2016 on mechanical properties of rigid repair mortar, with 28 d flexural strength≥6.0 MPa and compressive strength≥30.0 MPa.

3.5 Bonding strength

For the repair mortar, the most important performance is the bonding strength with the old substrate. The tensile bonding strength and flexural bonding strength between EVA powder modified CSA cement waterproof repair mortar and the OPC mortar are tested. The results are shown in Fig.5.

The addition of EVA powder improves the bonding performance of CSA cement waterproof repair mortar. At the hydration age of 28 d, the tensile bonding strength and the flexural bonding strength of the waterproof repair mortar with 5.0% EVA are 1.25 MPa and 3.34MPa, respectively. Compared with the CSA cement waterproof repair mortar without EVA powder, the tensile bonding strength and the flexural bonding strength increase by 30.4% and 32.0%, respectively. It may be due to that the polymer film fills the crack between the waterproof repair mortar and the repair structure, which enhances the connection between them. Besides, some groups in EVA molecules may react with ions in the cement hydration products, which enhances the connection between the waterproof repair mortar and the OPC mortar [13].

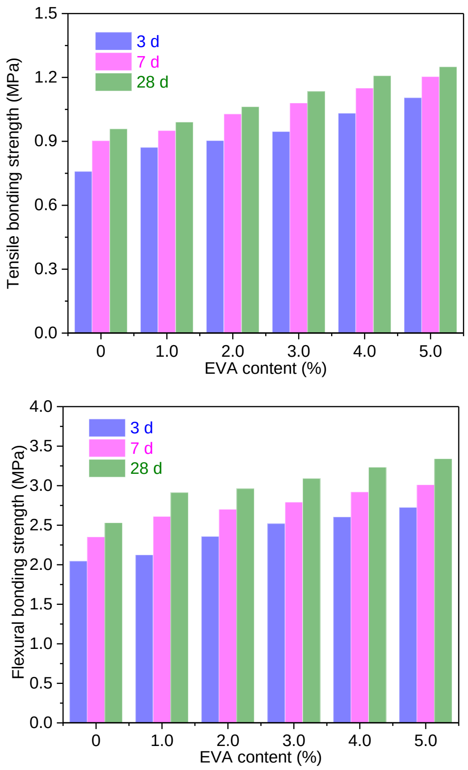


Figure 5. Tensile bonding strength and flexural bonding strength of EVA powder modified CSA cement waterproof repair mortar

3.6 Shrinkage

If the shrinkage of the repair mortar is too large, it will lead to cracks at the bonding interface between the repair mortar and the old substrate, which reduces the bonding strength. The influence of EVA powder on the shrinkage of CSA cement based waterproof repair mortar is shown in Fig.6.

With the increase of EVA powder content, the shrinkage of waterproof repair mortar decreases. When the content of EVA powder reaches 5.0%, the shrinkage is merely 0.042%, which is 33.9% lower than that of the blank. It indicates that the EVA films in the hydration product of CSA cement can reduce the stress in the mortar, limit the volume change and decrease the shrinkage of waterproof repair mortar [14]. In addition, the previous studies also indicate that polymers can reduce the shrinkage of cement mortar [15,16]. It is also an important reason for improving the bonding performance.

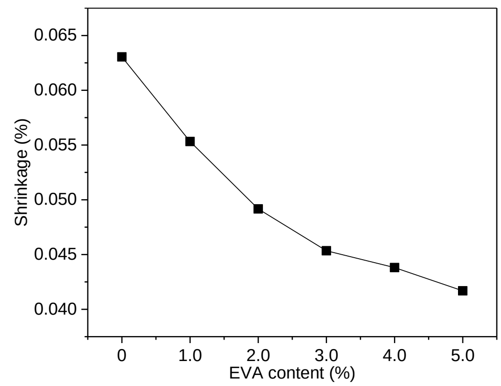
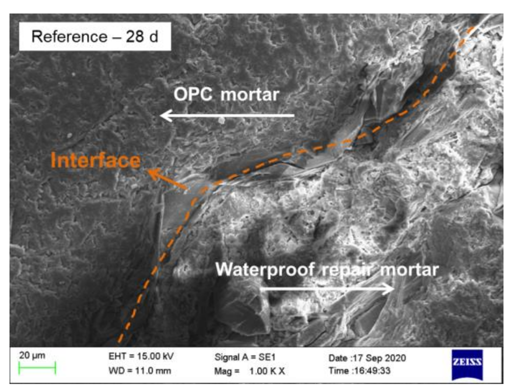


Figure 6. Shrinkage of EVA powder modified CSA cement waterproof repairing mortar

3.7 Interface transition zone

The interface transition zone between the repair mortar and the old substrate is a weak area, and damage is very easy to occur in this area [17]. The bonding quality of the interface transition zone determines the bonding performance. The morphology of the interface transition zone is shown in Fig.7.

For the reference sample, there are obvious cracks at the interface transition zone between the waterproof repair mortar and OPC mortar. After adding 5.0% EVA powder, the crack width is significantly reduced. It is mainly caused by the following reasons: (1) EVA powder improves the fluidity of waterproof repair mortar, makes it easier to fill the cracks and voids on the surface of the matrix structure, increases the contact area of the bonding interface; (2) The addition of EVA powder reduces the shrinkage of waterproof repair cement mortar and reduces the cracks in the bonding interface; (3) Some groups in EVA react with ions in the hydration products of CSA cement OPC to form chemical bonds, which increases the connection between the repair mortar and the old substrate and thereby inhibits the formation of cracks [18,19,20,21].



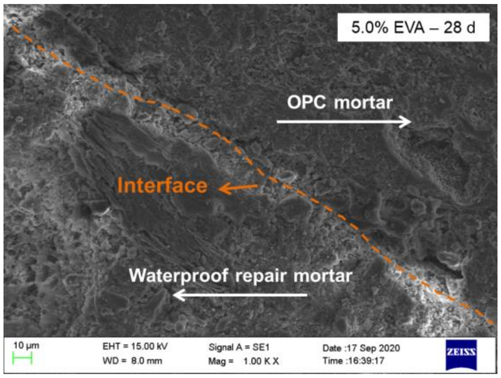


Figure 7. Interfacial transition zone between EVA powder modified CSA cement waterproof repairing mortar and OPC mortar

3.8 Morphology of EVA in CSA cement mortar

The existing form of polymer in mortar has an important influence on the waterproofness and impermeability of waterproof repair mortar. The morphology of EVA films in the hardened CSA cement waterproof repair mortar with 5.0% EVA at the hydration age of 28 d was observed by SEM(Fig.8). The flake EVA films is distributed among the hydration products of CSA cement mortar. These polymer films can effectively hinder the diffusion and transmission of water and improve the waterproof and impermeability of CSA cement waterproof repair mortar.

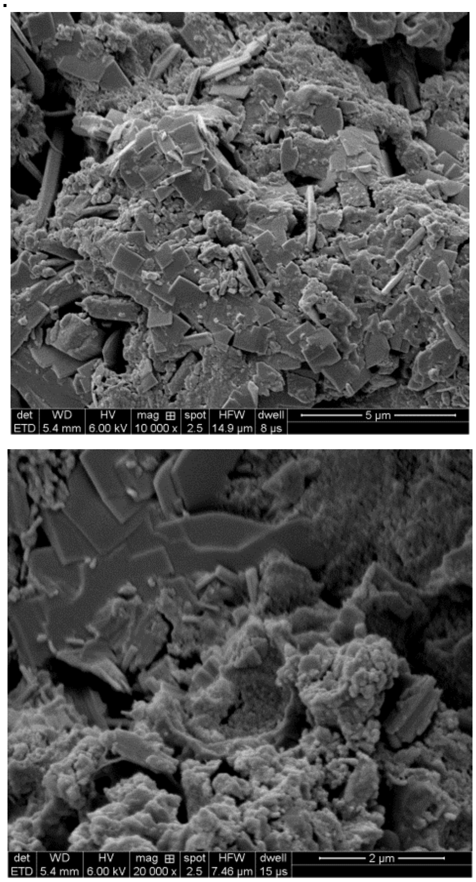


Figure 8. Morphology of EVA in the hardened CSA cement repair mortar at the hydration age of 28 d

3.9 XRD analysis

To analyze the influence of EVA powder on the hydration products of CSA cement, the hydration products of CSA cement modified by EVA powder at the hydration age of 6 h and 3 d were analyzed by XRD. The results are shown in Fig.9.

At the hydration age of 6 h, $C_4A_3\$$ in CSA cement reacts with gypsum to form ettringite. With the increase of EVA powder content, the diffraction peak intensity of ettringite decreases, and the diffraction peak intensity of $C_4A_3\$$ and gypsum increases. It indicates that EVA powder inhibits the early hydration of CSA cement and the formation of ettringite. It is mainly due to that the EVA molecules adhere to the surface of CSA cement particles, which hinders the dissolution of $C_4A_3\$$ and gypsum, reduces the concentration of calcium ion, aluminum ion and sulfate in the hydration liquid phase, and thereby inhibits the early formation of ettringite. The higher the content of EVA powder, the more EVA molecules attached to the surface of cement particles, and the stronger the inhibiting effect on the early hydration of CSA cement. At the hydration age of 3 d, the diffraction peak intensities of $C_4A_3\$$, gypsum and ettringite of CSA cement hydration samples with different amounts of EVA powder are similar, which indicates that the inhibiting effect of EVA powder on CSA cement hydration has disappeared.

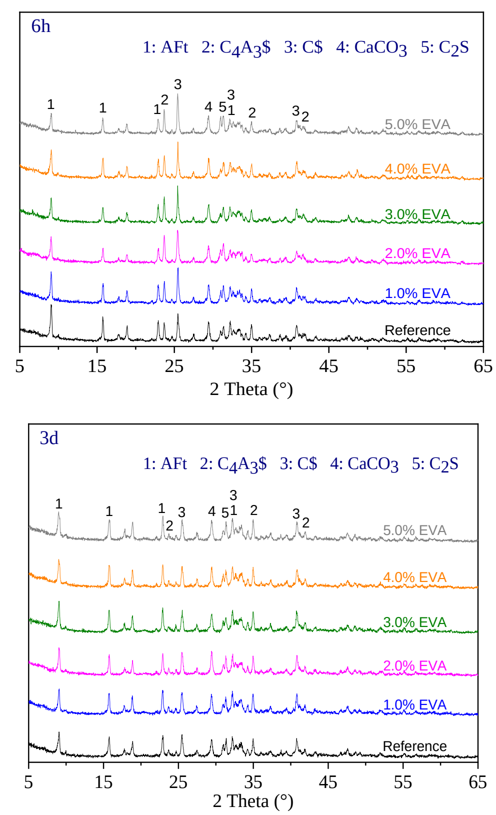


Figure 9. XRD patterns of CSA cement hydration samples at the hydration age of 6 h and 3 d

4. CONCLUSIONS

In this paper, EVA powder and CSA cement are used to prepare the waterproof repair mortar. The following conclusions are draw:

(1) In the range of 0% ~ 5.0%, EVA powder can improve the fluidity of CSA cement waterproof repair mortar and prolong its setting time.

(2) With the increase of EVA powder content, the impermeability pressure of the waterproof repair mortar increases, the water absorption decreases, and the waterproof and impermeability are significantly improved.

(3) EVA can effectively improve the bonding strength of the waterproof repair mortar. Although EVA can reduce the flexural strength and compressive strength of the waterproof repair mortar, it can still meet the strength requirements of standards for rigid repair mortar.

(4) EVA powder can reduce the shrinkage of the waterproof repair mortar, improve the interface transition zone between waterproof repair mortar and repair structure, and increase the bonding performance of the repair mortar.

(5) EVA powder inhibited the hydration of CSA cement at the hydration age of 6 h. The inhibiting of EVA powder on the hydration disappears at the hydration age of 3 d.

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