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ADHESION AND DURABILITY OF A PVA POWDER MODIFIED SULFOALUMINATE CEMENT REPAIRING MORTAR

YING LIU*, QINGHUI YANG*, DELU ZOU*, HONGGEN ZHAO**, XUEYAN FAN*, XIN LIU*, #DONG GAO*

*Shandong Hi-Speed Urban and Rural Development Group CO., LTD, 250014, Jinan, China
**University of Jinan, 250014, Jinan, China

#E-mail: sdgsgd@163.com

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In this paper, sulfoaluminate cement (SAC) is modified with a Polyvinyl alcohol (PVA) powder to prepare a repair mortar for repairing buildings with clay bricks, in addition, the adhesion and durability were studied. The experimental results show that the PVA powder-modified sulfoaluminate cement repair mortar has excellent durability and adhesion with the clay brick. At the same time, it was found that the PVA modified sulfoaluminate cement can reduce the drying shrinkage and the cracks in the bonding interface, which is beneficial to improve the adhesion. In addition, the PVA powder can reduce the total porosity of the mortar, but the increase in the capillary porosity is unfavourable to the durability of the mortar. However, the durability results show that the PVA powder effectively improves the water permeability resistance, frost resistance and sulfate corrosion resistance of the SAC repair mortar and the interface between the SAC repair mortar and clay brick. Nevertheless, under a high-temperature environment, the compressive strength and tensile bond strength of the repair mortar decreased rapidly, and also decreased with an increase in the PVA content.

INTRODUCTION

Clay bricks are widely used in the wall structure of buildings [1-3]. In the long-term service process, building materials erode or will inevitably be eroded, leading to a decline in the building bearing capacity and even endangering the structural safety. In particular, clay bricks easily crack and peel off under the effect of dry and wet changes, temperature changes, freeze-thaw changes and other factors. Therefore, to solve the above problems, it is necessary to repair the damaged structures [4].

The interface between the repair material and the repair matrix is a porous weak area. This is due to the water absorption of the repair matrix, leading to an increase in the water cement ratio at the bonding interface. The higher water cement ratio leads to an increase in the size and number of AFt and $Ca(OH)_2$ crystals, and these crystals are oriented, thus forming a porous weak area [5-7]. Due to the porous structure, clay bricks exhibit the characteristic of high water absorption, so the weak area of the interface between the repair material and the clay brick will be very thick. At the same time, high water absorption will incur the high shrinkage of the repair materials, leading to a crack at the interface between the repair materials and the clay bricks, especially in the weak area. When affected by the external environment, the interface between the repair material and the matrix is more likely to be damaged, resulting in the repair material cracking and falling off and in the failure of the repair. Therefore, the repair materials for brick concrete structures should have better water retention and adhesion, which can effectively improve the weak area in the bonding interface.

Polymer-modified cement-based materials have become an important building repair and reinforcement material [8,9] due to its excellent adhesion [10-12], toughness [13,14], durability [15-18] and impermeability. The properties of polymer-modified cement-based materials largely depend on the properties of the polymers. Therefore, for the repair of a brick concrete structure, it is necessary to select a suitable polymer to prepare repair mortar to solve the problems encountered in the repair engineering of brick concrete structures. Polyvinyl alcohol (PVA) powder is a water-soluble polymer powder with the appearance of white flakes or a powdery solid. PVA powder with a partially hydrolysed and low degree of polymerisation has excellent water solubility and film forming characteristics at room temperature [19]. Existing studies have shown that PVA powders can effectively improve the properties of cement-based materials, including the adhesion, water retention and durability [20-22]. J. - H. Kim et al.

[22,23] found that PVA can effectively reduce the size and number of the interface transition zone, which may be a good effect on improving the weak area in the bonding interface.

Sulfoaluminate cement (SAC) has the characteristics of fast hardening and high early strength. Furthermore, compared with ordinary Portland cement, it has excellent impermeability, erosion resistance and low volume shrinkage [24]. Therefore, it can be used in the preparation of a rapid repair mortar to make it have excellent durability [25, 26]. At the same time, the lower volume shrinkage can effectively reduce the shrinkage cracks in the weak area and improve the bonding strength and repair quality. Then the SAC repair mortar is modified with PVA powder to further improve its adhesion and durability, and improve the weak area between the SAC repair mortar and the clay brick, which is expected to solve the problems encountered in the repair of buildings with clay bricks.

Therefore, due to the high water absorption of clay bricks, the adhesion of ordinary repair materials is low, and the bonding interface can be easily damaged due to the influence of the external environment. To solve these problems, PVA-modified sulfoaluminate cement was used to prepare a repair mortar. In this paper, the adhesion and durability of a PVA powder-modified sulfoaluminate cement repair mortar were studied. The adhesion research mainly focuses on the bonding strength between the SAC repair mortar and the clay bricks. The durability experiment includes the durability of the SAC repair mortar and the durability of the interface between the SAC repair mortar and the clay bricks.

Table 2. The mineral composition of the SAC (%).

C_4A_3S	C_2S	C_3A	CS	$CaCO_3$
44.24	24.99	7.86	15.20	7.71

Table 3. Main physical properties of the PVA powder.

Physical property	
Degree of polymerisation	500 ± 50
pH	5.0 – 7.0
Viscosity (mPa·s)	4.5 – 6.5
Volatile content (%)	≤ 5.0
Purity (%)	≥ 96.0

Table 1. Chemical compositions of the SAC.

CaO	Al_2O_3	SO_3	SiO_2	Fe_2O_3	TiO_2	K_2O	MgO	Other	Loss on ignition
48.98	19.32	15.93	8.47	1.96	1.24	0.94	0.73	0.65	1.98

EXPERIMENTAL

Materials

The cementitious material is 42.5 R sulfoaluminate cement (SAC) produced by China United Cement Group Co., Ltd. The chemical compositions and mine-ral composition of the SAC are listed in Table 1 and Table 2, respectively. The fine aggregate is the sand with a fineness modulus of 2.5. PVA was used to modify the SAC repair mortar, the physical property of the PVA powder is shown in Table 3. The water reducer is a polycarboxylate superplasticiser produced by Shandong Building Research Institute Co., LTD. The defoamer is tributyl phosphate produced by Shanghai Macklin Biochemical Co., Ltd. The citric acid produced by Sinopharm Chemical Reagent Co., Ltd is used as a retarder.

Specimen preparation

The proportions of the PVA powder modified SAC repair mortar is shown in Table 4. Firstly, the raw ma-terials were weighed according to the proportions in Table 4. Secondly, the PVA powder and SAC were mixed by a Y-type mixer for 30 min to achieve uniform distribution. The water reducer, retarder and defoamer were dissolved in the water. Finally, the PVA powder modified SAC repair mortar was mixed and prepared according to the standard GB/T 17671-1999. The samples were cured in a standard curing room with the temperature of 20 ± 2 °C with a relative humidity greater than 95 %.

Table 4. Proportions of the PVA powder modified SAC repair mortar.

Sample	Cement (g)	Sand (g)	PVA (g)	Water (g)	Water reducer (g)	Retarder (g)	Defoamer (g)
Reference	450	1350	0	225	1.35	1.0	0.5
0.5 % PVA	450	1350	2.00	225	1.80	1.0	0.5
1.0 % PVA	450	1350	4.00	225	2.48	1.0	0.5
1.5 % PVA	450	1350	6.00	225	3.60	1.0	0.5

Before the preparation of the samples for tensile bonding strength, the clay bricks were immersed in water for 5 min to achieve saturated water absorption, which inhibits the water absorption of the clay bricks from the PVA powder modified SAC repair mortar. After being taken out from water, the surface of the clay bricks was dried with a dry towel, and then the PVA powder modified SAC repair mortar (40 × 40 × 10 mm) was placed on the upper surface of the clay bricks. Then put it into the standard curing room for curing.

Test methods

Compressive strength

The compressive strength was measured according to the standard GB/T 17671-1999. The specimen size was 40 × 40 × 160 mm and the loading rate was 2400 ± 200 $N \cdot s^{-1}$.

Tensile bonding strength

The specimens were taken out of the curing room and the sample surface was dried. The upper surface of the specimen and the upper fixture were bonded with epoxy resin. The tensile bonding strength can be tested after the epoxy resin is solidified. The loading rate was 5 ± 1 $mm \cdot min^{-1}$. If a failure occurs between the PVA powder modified SAC repair mortar and the clay brick, the result was the considered effective. The result was determined by the average of the nine effective values.

Dry shrinkage

The dry shrinkage rate of the PVA powder modified SAC repair mortar was measured according to the standard JC/T 603-2004. The samples were cured in the surroundings with a temperature of 20 ± 3 °C with a humidity of 50 ± 4 %. After curing for 24 h, the specimens were demoulded and the initial length was measured. The length of the specimen was measured again after 28 days, and the dry shrinkage rate was calculated according Equation 1.

$$S_{28} = \frac{(L_0 - L) \times 100}{250} \tag{1}$$

where S_{28} is the 28 day dry shrinkage rate (%); L_0 is the initial length (mm); L is the length (mm) measured after 28 days.

SEM

The interface between the PVA powder modified SAC repair mortar and the clay brick was observed using EVO/LS15 scanning electron microscope (SEM). Fresh broken samples were used to observe the microstructure of the SAC repair mortar. In order to satisfy the requirement of conductivity, samples were sprayed with gold in a vacuum for 90 s.

Pore structure

The pore structure of the SAC repair mortar with a hydration age of 28 days was measured by mercury intrusion porosimetry (MIP). In this experiment, automatic mercury porosimetry (Pore Master-60) is used to test the pore structure, and the test pressure range is 0 – $6 \cdot 10^4$ Psia.

Water permeability resistance

The impermeability pressure was measured according to the standard JGJ/T 70-2009. The specimen is a truncated cone with an upside and underside surface diameter of 70 and 80 mm, respectively. The height of the truncated cone is 30 mm. Firstly, the specimens was kept at 0.2 MPa for 2 h. Then the water pressure increased at the rate of 0.1 $MPa \cdot h^{-1}$. Finally, the impermeability pressure was recorded until the water seeped from the upside surface of the specimens.

The water absorption rate of the PVA powder modified SAC repair mortar was measured according to the standard JGJ/T 70-2009. The specimen size was 70.7 × 70.7 × 70.7 mm.

Specimens with the dimension of 40 × 40 × 160 mm were used to measure the water absorption height. The specimen was soaked in the water, and the part submerged into water was higher than 5 mm. After 48 h, the specimen was split into half with a press, and then the water absorption height was determined by the average value of the absorption height obtained at five different points.

The water permeability resistance of the bonding interface was characterised by measuring the tensile bonding strength loss after immersion in water for 6 days.

Frost resistance

The frost resistance was measured according to the standard GB/T 50082-2009. The reference sample was cured in the standard curing room. After 25 freeze-thaw cycles, the samples were taken out to test the tensile boning strength. After 50 freeze-thaw cycles, the samples were taken out to test the compressive strength and the weight was measured.

High temperature resistance

The high temperature resistance of the PVA powder modified SAC repair mortar was characterised by measuring the tensile bonding strength loss and compressive strength loss in a high temperature environment. During the test, the samples were placed in the environment with a temperature of 70 ± 2 °C for 6 days. After cooling to room temperature, the high temperature resistance was tested.

Sulfate corrosion resistance

The sulfate corrosion resistance was measured according to the standard GB/T 50082-2009. The sulfate corrosion resistance of the PVA powder modified SAC repair mortar was tested by the dry-wet cycling method. One dry-wet cycle consists of the following processes: Firstly, the samples were soaked in a 5 % Na_2SO_4 solution for 15 h. Secondly, the solution was drained and air-dried within 1 h. Finally, it is dried at 80 ℃ for 6 h, and then cooled for 2 h. The samples were measured every 30 dry-wet cycles, and the corrosion resistance coefficient was calculated according to Equation 2:

$$K_f = \frac{f_{cn}}{f_{c0}} \tag{2}$$

where K_f is the corrosion resistance coefficient; f_{cn} is the compressive strength (MPa) of the specimens subjected to the sulfate attack after *n* dry wet cycles. F_{c0} is the compressive strength (MPa) of the control specimens cured in a standard curing room.

RESULTS AND DISCUSSION

Effect of the PVA on the tensile bonding strength of the mortar

Table 5 shows the tensile bonding strength between the PVA powder modified SAC repair mortar and the clay brick. The tensile bonding strength obviously increases with an increase in the PVA powder content and reaches a maximum at 1.5 %. Compared with the SAC repair mortar without the PVA, the SAC repair mortar with 1.5 % PVA increased by 39, 19, 16 and 18 % by the 1, 3, 7 and 28-d specimens, respectively.

Table 5. Tensile bonding strength between the PVA powder modified SAC repair mortar and the clay brick.

Sample	Hydration age (d)			
	1	3	7	28
Reference	1.20(0.07)	1.61(0.05)	1.73(0.06)	2.02(0.08)
0.5 % PVA	1.40(0.08)	1.70(0.07)	1.87(0.06)	2.07(0.06)
1.0 % PVA	1.55(0.07)	1.83(0.06)	2.06(0.05)	2.20(0.05)
1.5 % PVA	1.67(0.07)	1.92(0.09)	2.01(0.08)	2.39 (0.08)

The old matrix shows good volume stability, while the repair mortar exhibits shrinkage due to the cementitious material's hydration and water loss. Therefore, cracks commonly occur at the interface between the old matrix and the repair mortar. Figure 1 shows the dry shrinkage rate of the PVA powder-modified SAC repair mortar. With an increase in the PVA powder content, the dry shrinkage rate of the PVA powder-modified SAC repair mortar decreased. The drying shrinkage rate of the SAC repair mortar with the 1.5 % PVA is merely 0.04 %, which is 37.18 % lower than the SAC repair mortar without the PVA. It is mainly ascribed to the following reasons: (i) After the formation of the PVA films existing in the SAC repair mortar, the water loss inside the mortar slows down, which thereby reduces the dry shrinkage; (ii) The PVA films existing in the pores of the SAC repair mortar can reduce the capillary tension caused by water loss in the pores, which is the main driving force of dry shrinkage [27,28]. Therefore, the decrease in the dry shrinkage can reduce the number and width of the cracks at the interface between the SAC repair mortar and the clay brick

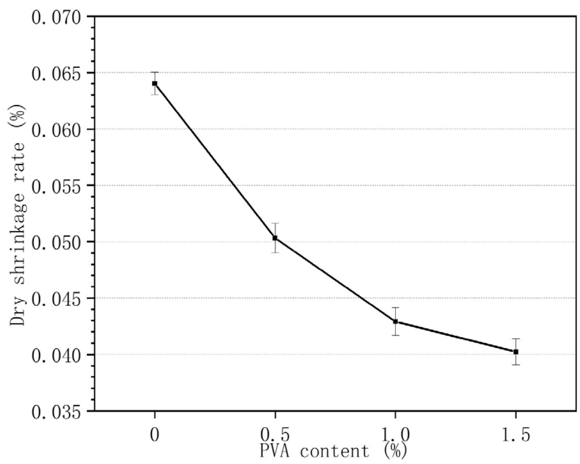


Figure 1. Dry shrinkage rate of the PVA powder modified SAC repair mortar.

Figure 2 shows the SEM photos of the interface between the SAC repair mortar and the clay brick at the hydration age of 28 days. For the SAC repair mortar without the PVA powder, there is an obvious crack at the interface. For the PVA powder modified SAC repair mortar, no obvious crack occurs at the interface, which improves the bonding strength between the PVA powder modified SAC repair mortar and the clay brick.

The improvement in the adhesion of the PVA powder-modified repair mortar is mainly due to the following reasons: (i) the PVA powder can form polymer films or polymer bridges in the cracks and the interface of the SAC repair mortar and the clay brick, which can strengthen the connection between the mortar and the clay brick [29,30]; (ii) the PVA powder can re-duce the dry shrinkage of the SAC repair mortar, and reduce the cracks that occur at the interface bet-ween the SAC repair mortar and the clay brick;

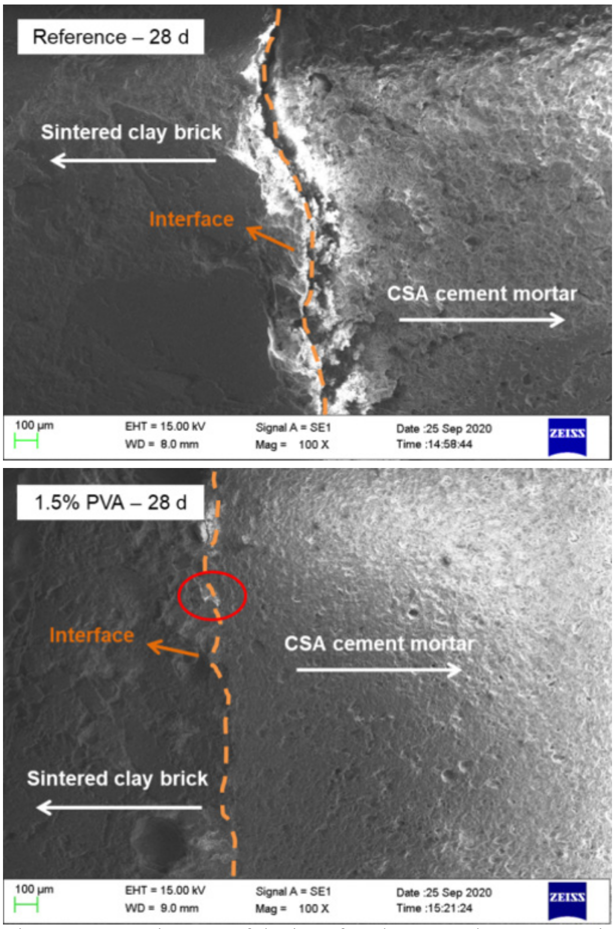


Figure 2. SEM images of the interface between the SAC repair mortar and the clay brick at the hydration age of 28 days.

(iii) the PVA powder could reduce the thickness of the interfacial transition zone, and enhance the bonding strength between the PVA powder modified SAC repair mortar and the clay brick [19, 22, 23].

Effect of the PVA content on the durability of the SAC repair mortar

Pore structure

The strength, durability and permeability of cement-based materials are closely related to the pore structure. D. A. Silva et al. [31] divided the pores in hardened cement paste into gel pores, medium capillaries, large capillaries and entrained air. The capillary pores with a pore diameter of 10-1000 nm had the most significant effect on the permeability and durability. Figure 3 shows the pore size distribution and cumulative porosity of the PVA powder modified SAC repair mortar. With an increase in the PVA powder content, the pores with a pore size greater than 1000 nm and less than 100 nm decreased, but the pores with pore sizes of 100 – 1000 nm increased. In general, with the increase in the PVA powder content, the total porosity of SAC repair mortar decreases. The capillary pores with a pore size of 10 – 1000 nm of the SAC repair mortar with 0.5 % PVA are reduced, but the SAC repair mortar with 1.0 and 1.5 % PVA are increased. Although the increase in the capillary pores will lead to higher permeability, the capillary porosity is not the only factor affecting the permeability. The connectivity of the capillary pores is also an important factor affecting the permeability of the SAC repair mortar [32, 33].

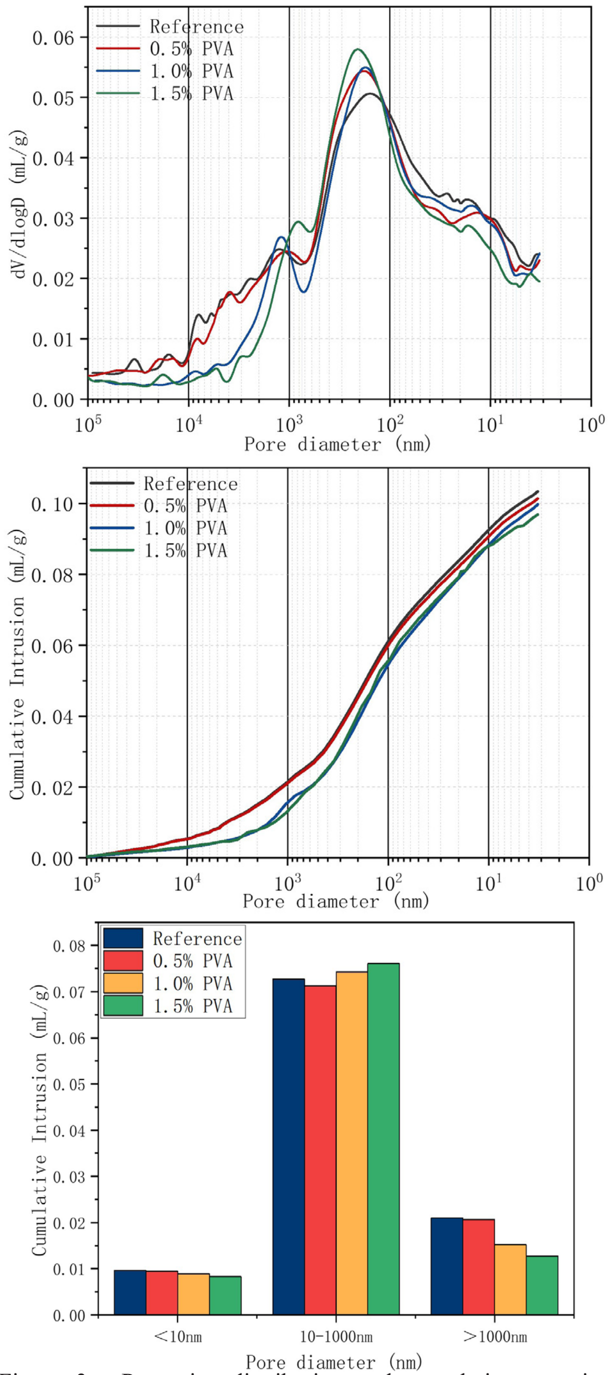


Figure 3. Pore size distribution and cumulative porosity of the PVA powder modified SAC repair mortar.

A large number of studies have shown that polymers can increase the capillary pores of some pore sizes of hardened cement pastes [31, 34-36]. Researchers

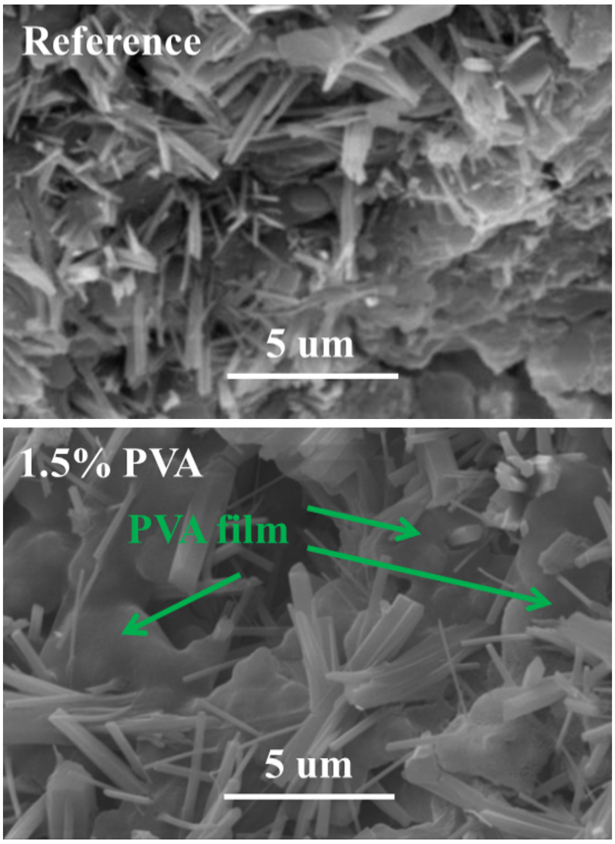


Figure 4. SEM photos of the SAC repair mortar at the hydration age of 28 days.

believe that this may be caused by the mercury intrusion porosimetry test method [31, 35, 36]. The high-pressure mercury intrusion during the test will destroy the polymer phase in the capillary pores and increase the capillary porosity. Moreover, R. Voc Ïka et al. [37] believe that the low connectivity of the pore will cause the pore size distribution shown in the MIP results to move to a smaller size. Figure 4 shows the SEM photos of the SAC repair mortar at the hydration age of 28 days. Comparing the two SEM photos, it can be seen that the hydration product (including AFt, AFm and C-S-H gels) is filled with a large number of films formed by the PVA powder. This will change the pore structure of the SAC repair mortar, reduce the porosity and the pore connectivity. The decrease in the pore connectivity may also be the reason for the increase in the capillary pores with a pore size of 10 – 1000 nm of the SAC repair mortar shown in the MIP results.

Water permeability resistance

The water permeability resistance is an important factor, which determines the durability of cement-based materials. Poor water permeability will make it easy for water to penetrate into the interior. When the environment temperature is low or contains corrosive medium, cement-based materials are easily damaged by freeze-thaw cycles or erosion. Therefore, it is of significance to study the water permeability resistance of the PVA powder modified SAC repair mortar. In this paper, the water permeability resistance of the PVA powder modified SAC repair mortar is characterised by the impermeability pressure, water absorption rate and water absorption height.

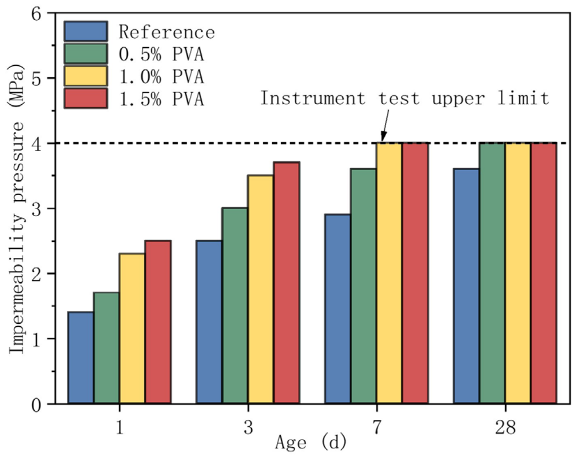


Figure 5. Impermeability pressure of the PVA powder modified SAC repair mortar.

Figure 5 shows the impermeability pressure of the PVA powder modified SAC repair mortar. With the increase in the PVA contents, the impermeability pressure of the PVA powder modified SAC repair mortar increases significantly, which proves that the impermeability of the SAC repair mortar is improved due to the formation of the PVA film in the pores of the SAC repair mortar. At the hydration age of 1 d, the impermeability pressure of the Reference, 0.5, 1.0 and 1.5 % are 1.4, 1.7, 2.3 and 2.5 MPa, respectively. Compared with the Reference, the impermeability pressure of the 0.5, 1.0 and 1.5 % PVA increases by 21.8, 64.3 and 78.6 %, respectively. Therefore, the PVA powder is effective admixture to improve the early age impermeability pressure of the SAC repair mortar.

At the hydration age of 7 days, the impermeability pressure of the specimen without PVA powder reaches 2.9 MPa. For the sample of 1.0 and 1.5 % PVA, the impermeability pressure for the specimen reaches the upper limit (4.0 MPa) of the equipment. At the hydration age of 28 days, the impermeability pressure of the 28 day - specimen with 0.5 % PVA also reached the test upper limit of the equipment.

The water absorption rate of the PVA powder modified SAC repair mortar is shown in Figure 6. The water absorption rate decreases with the increase in the PVA contents. The water absorption rate of the 1-d specimen is the highest, the specimen without PVA is 15.20 %, and the specimen with 1.5 % PVA is 12.82 %. The water absorption rate of the 28-day specimen is the lowest. The water absorption rate of the specimen without the PVA is 4.64 %, and that of specimen with 1.5 % PVA is 3.32 %. Similar results were obtained with the water absorption height. It can be seen from Figure 7, with the increase in the PVA content, the water absorption height of the PVA powder modified SAC repair mortar gradually decreases.

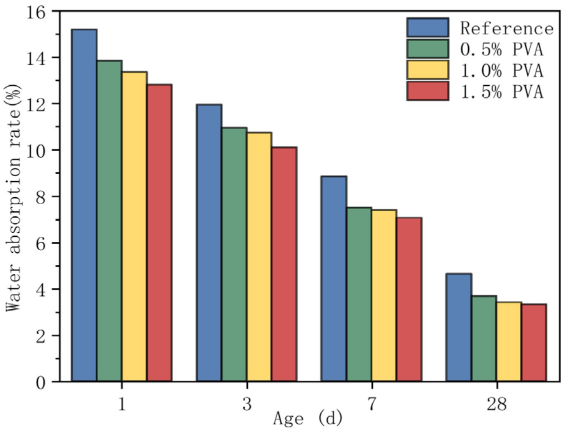


Figure 6. Impermeability pressure of the PVA powder modified SAC repair mortar.

The results of the impermeability pressure, water absorption rate, and water absorption height show that the PVA can improve the water permeability resistance of the SAC repair mortar. However, the pore structure test results show that the capillary porosity of the SAC repair mortar with the PVA increases, which is generally considered to be the reason for improving the permeability. This indicates that the capillary porosity is not the only factor affecting the permeability. Because PVA forms a film in the pores of the SAC repair mortar, the porosity and pore connectivity of the mortar are reduced, which is an important reason to improve the impermeability [38, 39]. At the same time, the PVA powder can improve the interfacial transition zone, reduce the defects in the interfacial transition zone, and reduce the diffusion channels of the water in the mortar, which is also conducive to improving the water permeability resistance of the SAC repair mortar.

Figure 8 shows the tensile bonding strength and tensile bonding strength loss between the PVA powder modified SAC repair mortar and the clay brick after immersion. It can be seen that the tensile bonding strength of the SAC repair mortar after soaking in water still shows an increasing trend with the increase in the PVA content. However, compared with standard curing specimens, the tensile bonding strength of the soaking sample decreases. This is mainly due to fact that when the water diffuses to the bonding interface between SAC repair mortar and clay brick, the increase in the water will increase the capillary pressure, leading to microcracks and reducing the tensile bonding strength [40, 41]. The clay brick

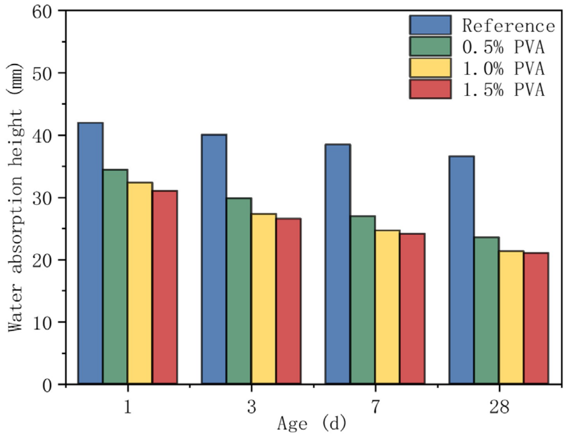


Figure 7. Water absorption height of the PVA powder modified SAC repair mortar.

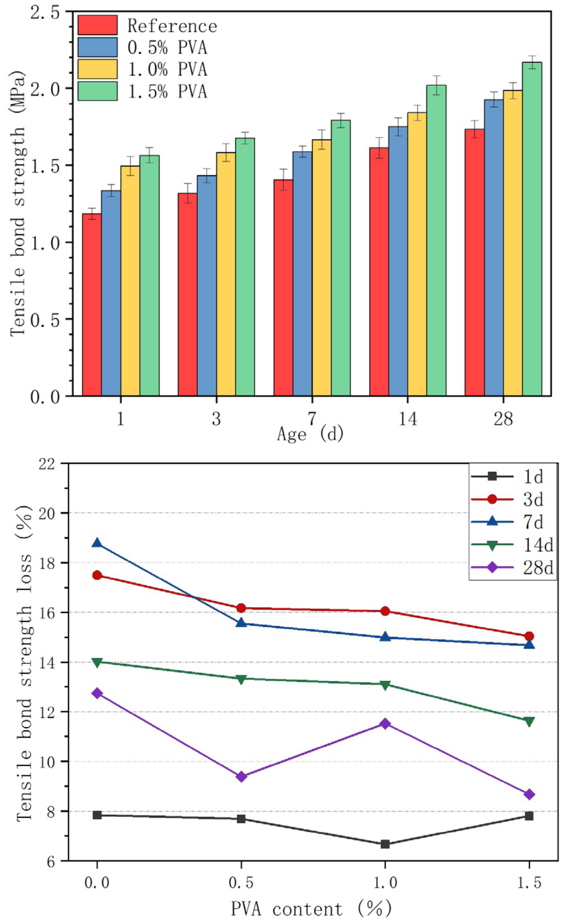


Figure 8. Tensile bonding strength and tensile bonding strength loss between the PVA powder modified SAC repair mortar and the clay brick after immersion.

water absorption is especially strong; thus, it is easier for the water to diffuse into the SAC repair mortar and clay brick interface.

For the specimens with a hydration age of 1 day, due to the low degree of hydration, the tensile bonding strength still significantly increases after immersion, so the loss of tensile bonding strength is low and the change is not evident with the increase in the PVA content. However, for the specimens with hydration ages of 3, 7, 14 and 28 days, the tensile bonding strength loss significantly decreased with the increase in the PVA content. PVA can form polymer films in the cracks and air voids of the interface between the SAC repair mortar and the clay brick, which can block the water infiltration. At the same time, the reduction in the crack width of the bonding interface by the PVA will also reduce the water entering the bonding interface. Therefore, the loss of the SAC repair mortar tensile bonding strength is caused by the water immersion decreases.

Frost resistance

Volume expansion occurs when the water in the internal voids and capillary channels of the mortar condenses into ice at low temperatures, and causes supercooled water to migrate. In this process, various pressures will be generated. When these pressures exceed the bearing range of the mortar, microcracks will be formed. With the freeze-thaw cycle, the cracks will increase and expand, continuously intensifying the destruction until complete destruction. The compressive strength loss and mass loss of the PVA powder modified SAC repair mortar after freeze-thaw cycle is shown in Figure 9. As can be seen from the figure, due to the damage of the freeze-thaw cycle, the compressive strength and mass of the PVA powder modified SAC repair mortar decreased significantly after 50 freeze-thaw cycles. Figure 10 shows the photos of the PVA powder modified SAC repair mortar after the freeze-thaw cycle. After the freeze-thaw cycle, the SAC repair mortar without the PVA is se-riously damaged, the surface falls off in a large area, and the aggregate is exposed. The SAC repair mortar with 0.5 % PVA damage is also very serious, but it is slightly better than that without the PVA. Although the SAC repair mortar with 1.0 and 1.5 % PVA is also damaged, only a small area of the surface falls off, and the damage is not as serious. At the same time, with the increase in the PVA contents, the compressive strength loss and mass loss of the SAC repair mortar are significantly reduced regardless of the samples at the hydration age of 1, 3, 7, 14, and 28 days. The compressive strength loss and mass loss of samples with a hydration age of 28 days were the lowest. The compressive strength loss of the SAC repair mortar with the 0, 0.5, 1 and 1.5 % PVA are 50.74, 44.26, 39.15 and 35.78 %, respectively, and the mass losses are 2.38, 1.71, 1.38 and 1.02 % respectively. PVA can improve the frost resistance of the SAC repair mortar, it is mainly ascribed to the following reasons: (i) PVA can reduce the porosity and connecting holes of the SAC repair mortar, which have a great impact on reducing the freeze-thaw damage. (ii) The improvement of the interfacial transition zone by the PVA powder is also helpful to perform the frost resistance of the SAC repair mortar.

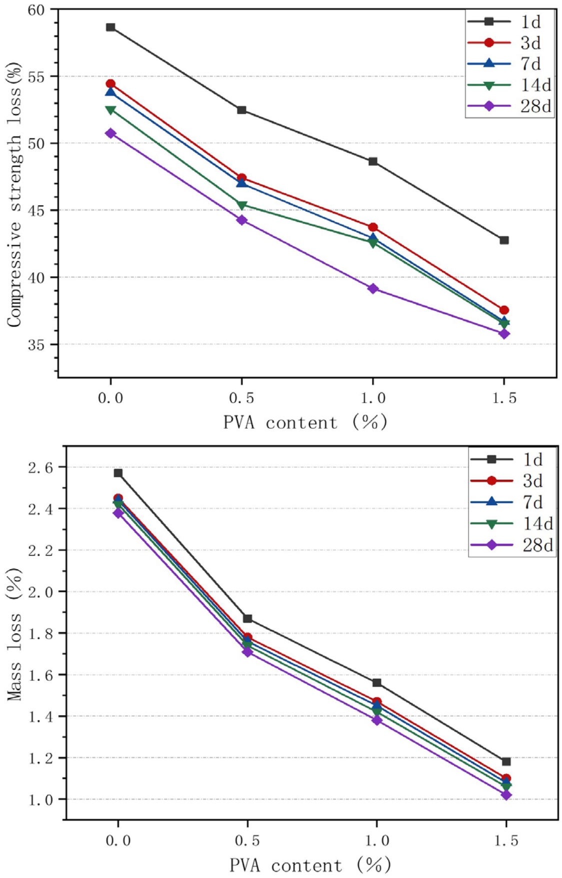


Figure 9. Compressive strength loss and mass loss of the PVA powder-modified SAC repair mortar after the freeze-thaw cycles.

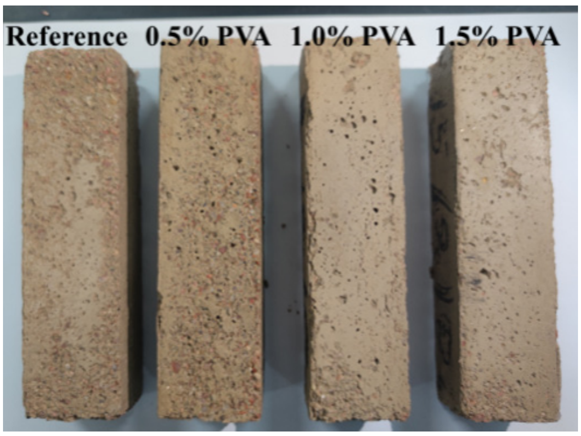
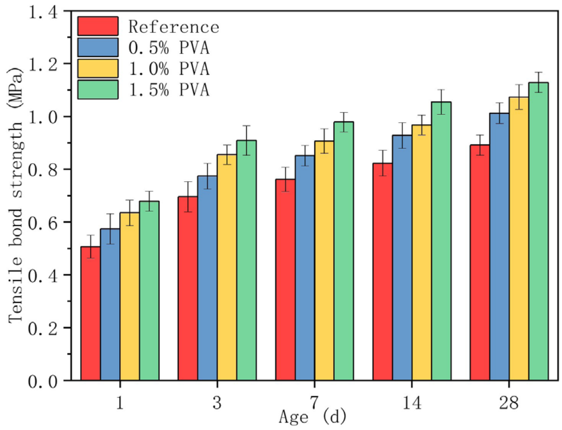


Figure 10. Photos of the PVA powder modified SAC repair mortar after the freeze-thaw cycles.

Figure 11 shows the tensile bonding strength and tensile bonding strength loss between the PVA powder modified SAC repair mortar and the clay brick after the freeze-thaw cycles. After 25 freeze-thaw cycles, the tensile bonding strength of the specimens decreases rapidly. The loss of tensile bonding strength of the PVA powder modified SAC repair mortar is much faster than that of the compressive strength. This is not only because there are a large number of cracks, pores and other defects in the bonding interface between the PVA powder modified SAC repair mortar and the clay brick, which makes a large amount of water enter the interface and causes more significant freeze-thaw damage, but also makes the interface more vulnerable to damage. Moreover, due to the very high water absorption of the clay brick, a large amount of water will enter the bonding interface through the clay brick. In addition, the volume expansion rate during the freeze-thaw cycle is different from that of repair mortar, which will cause more cracks at the interface.



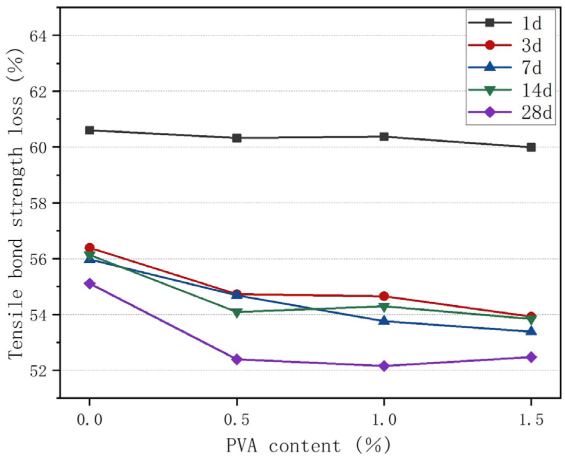


Figure 11. Tensile bonding strength and tensile bonding strength loss between the PVA powder modified SAC repair mortar and the clay brick after freeze-thaw cycles.

However, with the increase in the PVA content, the tensile bonding strength loss decreases gradually. After the hydration age exceeds 3 days, the tensile bonding strength loss of the SAC repair mortar with the PVA decreases rapidly compared with that of the SAC repair mortar without the PVA. However, with the increase in the PVA content, the decreasing trend of the tensile bonding strength loss is not apparent. PVA can reduce the cracks at the interface between the SAC repair mortar and the clay brick, making the bonding interface not easily damaged. In addition, the PVA film formed in the bonding interface can slow down the transmission and diffusion of water at the interface between the SAC repair mortar and the clay brick. Therefore, the freeze-thaw damage and the loss of tensile bond strength are reduced.

Sulfate corrosion resistance

A previous investigation has demonstrated that, compared with Portland cement, sulfoaluminate cement exhibits good sulfate corrosion resistance due to its compact structure, low porosity and particular mineral composition. However, due to the long-period sulfate attack, the mechanical properties of sulfoaluminate cement will also decline. However, polymers can further improve the sulfate corrosion resistance of sulfoaluminate cement due to the polymer film formation in the pores [42, 43]. PVA powder has excellent film formation characteristics, which can form a polymer film in sulfoaluminate cement pores, block the channels for diffusion and transmission capacity of water, which then improves its sulfate corrosion resistance.

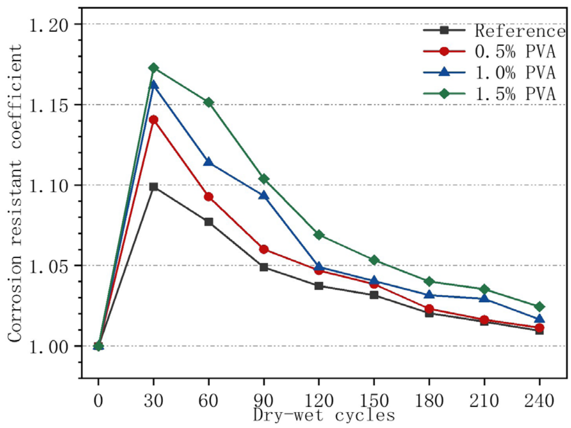


Figure 12. Corrosion resistance coefficient of the PVA powder modified SAC repair mortar.

Figure 12 shows the corrosion resistance coefficient of the PVA powder-modified SAC repair mortar. The results show that the corrosion resistance coefficient of the PVA powder-modified SAC repair mortar decreased gradually with the increase in the dry-wet cycles. However, after 240 dry-wet cycles, the corrosion resistance coefficient was still greater than 1. With the increase in the PVA powder content, the corrosion resistance coefficient of the SAC repair mortar increases, which proves that the sulfate corrosion resistance is improved. It is mainly ascribed to the following: The PVA powder dissolves rapidly while mixing in the mortar. When prolonging the hydration age, water is consumed by the hydration of cement and the PVA films form uniformly in the hardened mortar. Therefore, the channels for the diffusion and transmission of water are partially blocked, which thereby inhibits the diffusion and transmission of sulfate.

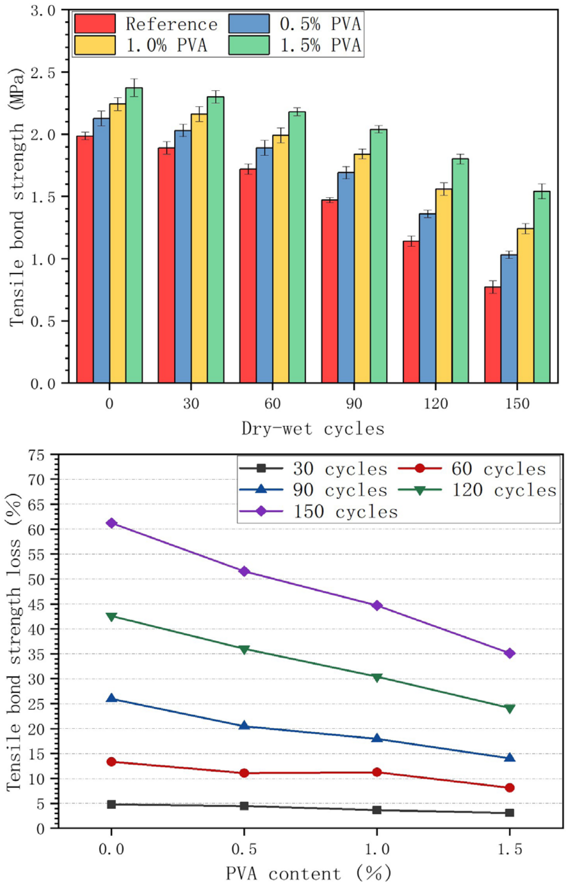


Figure 13. Tensile bonding strength and tensile bonding strength loss between the PVA powder modified SAC repair mortar and the clay brick experiencing the sulfate corrosion.

The tensile bonding strength and tensile bonding strength loss between the PVA powder-modified SAC repair mortar and the clay brick experiencing sulfate corrosion are shown in Figure 13. When the specimens experiencing 30 dry-wet cycles, the tensile bonding strength merely shows a slight decrease. However, after 30 dry-wet cycles, the tensile bonding strength decreases significantly. Although the compressive strength of the PVA powder modified SAC mortar did not decrease significantly compared with the standard curing sample after 240 dry-wet cycles, but the tensile bonding strength between the PVA powder modified SAC mortar and the clay brick decreases significantly. It is mainly ascribed to the following reason: the PVA film could obstacle the transmission of sulfate inside the PVA powder modified SAC mortar, however, it is easy to transport in the porous clay bricks. Therefore, the expansive ettringite is easily formed at the interface between the PVA powder modified SAC mortar and clay brick, which thereby lowers the bonding strength.

With the increase in the PVA powder content, the tensile bonding strength between the PVA powder-modified SAC repair mortar and the clay brick increases and the tensile bonding strength loss decreases with the increase in the PVA content. It is ascribed that the PVA film at the interface between the SAC mortar and clay brick could be obstacle in the contact between SAC mortar and the sulfate. Therefore, less expansive ettringite forms at the interface and causes less damage. After 150 dry-wet cycles, the tensile bonding strength of SAC repair mortar with 1.5, 1, 0.5 % and without the PVA powder decreased by 35.12, 44.7, 51.54 and 61.22 %, respectively.

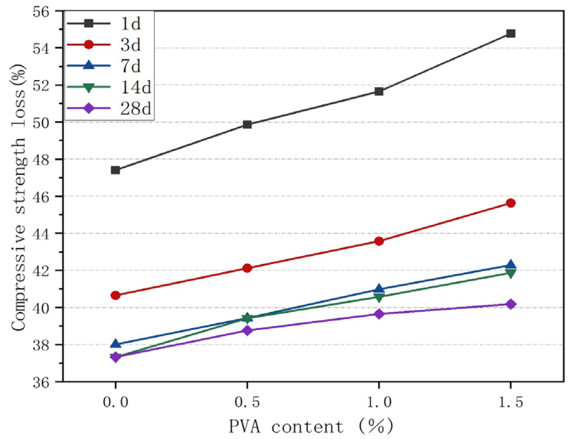


Figure 14. Compressive strength loss of the PVA powder modified SAC repair mortar under high temperature conditions.

High temperature resistance

In recent years, the unusually hot temperatures have been increasing worldwide. When the cement mortar, especially those containing polymers, is exposed to sunshine, the temperature can reach 50 – 70 °C. It affects the durability of the polymer, which thereby lowers the mechanical properties of a polymer modified cement mortar. The results of the high-temperature resistance are shown in Figure 14 and Figure 15. The compressive strength and tensile bonding strength of the PVA powder modified SAC repair mortar at different hydration ages decreased significantly. The high-temperature environment will cause the components of the sample to expand. However, the different expansion rates of the cement, aggregate, and clay bricks resulted in the formation of micro-cracks in the interface transition zone and the bonding interface, the reduction of compressive strength, and tensile bonding strength [44-46]. Another important reason for the decrease in the mechanical properties of the SAC repair mortar is that it generates significant damage to the microstructure in the capillary porosity domain, increasing porosity [47].

The compressive strength and tensile bonding strength obviously decrease with the increase in the PVA contents. Moreover, the tensile bonding strength loss and compressive strength loss increase with the increase in the PVA contents. The strength loss of the SAC repair mortar with 1.5 % PVA is the most important. Compared with the standard curing specimens, the tensile bonding strength and compressive strength of the specimens with a hydration age of 1 day are reduced by 75.02 and

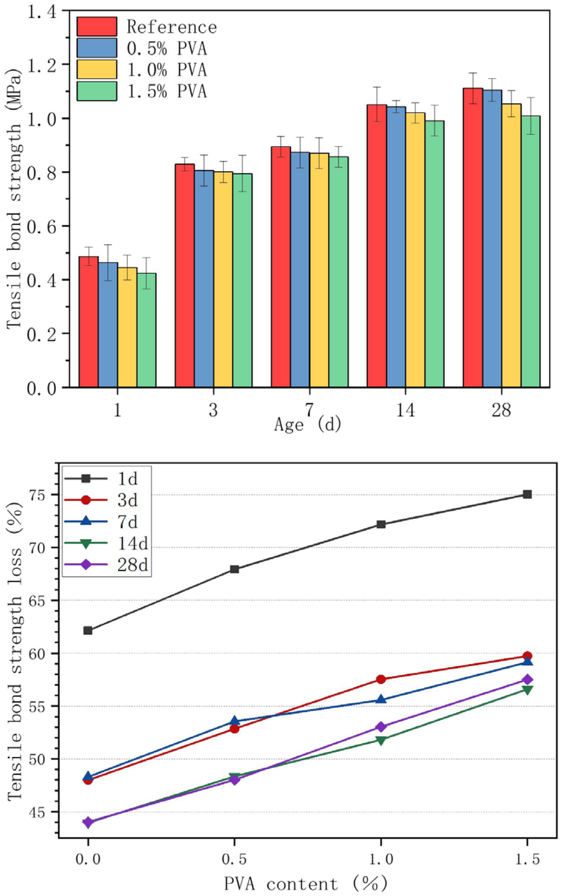


Figure 15. Tensile bonding strength and tensile bonding strength loss between the PVA powder modified SAC repair mortar and the clay brick under high temperature conditions.

54.77 %, respectively, while the specimens with hydration age of 28 days are reduced by 57.51 and 40.18 %, respectively. The strength loss of the SAC repair mortar without the PVA is also significant. Compared with the standard curing specimens, the tensile bonding strength and compressive strength of specimens with hydration age of 1 day are reduced by 62.13 and 47.41 %, respectively, while the specimens with hydration age of 28 days are reduced by 44.04 and 42.33 %, respectively. This shows that the PVA will significantly reduce the high-temperature resistance of the SAC repair mortar. After reaching the glass transition temperature, the mechanical properties of the PVA will dramatically decrease, and the PVA film in the pores will be destroyed [45,46,48]. The PVA powder modified SAC repair mortar under a high-temperature environment for a long time will even lead to internal PVA decomposition. This will cause the PVA powder that filled the gaps inside the SAC repair mortar to become a defect. Therefore, the compressive strength and tensile bonding strength of the specimens with the PVA are lower than without the PVA, which continuously decrease with the increase in the PVA content.

CONCLUSIONS

In this paper, PVA is used to modify a sulfoaluminate cement mortar to prepare a repair mortar, and the influence of adhesion and durability of SAC repair mortar was mainly studied. The main conclusions are as follows:

(1) PVA powders can effectively improve the tensile bonding strength between the SAC repair mortar and the clay brick. By observing the interface between the SAC repair mortar and the clay brick by SEM, it was found that the PVA powder can reduce the width and number of cracks at the bonding interface, which is beneficial to improving the bonding strength. Moreover, the decrease in the amounts of cracks in bonding interface is mainly related to the decrease in the drying shrinkage after adding PVA.

(2) PVA has a great influence on the pore structure of the SAC repair mortar. PVA can significantly reduce the total porosity of the SAC repair mortar. However, the capillary pores with a pore size of 10 – 1000 nm of the SAC repair mortar with 0.5 % PVA are reduced, but the SAC repair mortar with 1.0 and 1.5 % PVA are increased.

(3) PVA can significantly improve the water permeability resistance of the SAC repair mortar. With the increase in the PVA content, the impermeability pressure of the PVA powder modified SAC repair mortar increases, and the water absorption rate and water absorption height decrease consequently. Although the tensile bond strength decreased after immersion, the tensile bonding strength loss between the SAC repair mortar and the clay brick decreases with the increase in the PVA content.

(4) Under a high-temperature environment, the compressive strength and tensile bonding strength of the PVA powder modified SAC repair mortar decrease rapidly. The loss of the compressive strength and tensile bonding strength increases with the increase in the PVA content.

(5) The frost resistance of the SAC repair mortar with the PVA was significantly improved. Although the compressive strength, mass and tensile bonding strength are significantly reduced after the freeze-thaw cycles, the loss of compressive strength, mass and tensile bonding strength are reduced with the increase in the PVA content.

(6) PVA can improve the sulfate corrosion resistance of the SAC repair mortar. With the increase in the PVA content, the corrosion resistance coefficient of the SAC repair mortar increases. After 240 dry-wet cycles, the corrosion resistance coefficient is still greater than 1, indicating that the mortar has excellent sulfate resistance. However, the tensile bonding strength between the SAC repair mortar and clay brick decreased rapidly, and the tensile bond strength loss decreased with the increase in the PVA content.

PVA modified SAC repair mortar has excellent durability and good adhesion with clay bricks. The bonding interface between PVA modified SAC repair mortar and clay brick especially shows good durability. Therefore, the PVA modified SAC repair mortar can be used as an excellent repair material for brick concrete structures.

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