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Xiao, J, Jiang, W, Yuan, D et al. (2 more authors) (2018) Effect of styrene–butadiene rubber latex on the properties of modified porous cement-stabilised aggregate. Road Materials and Pavement Design, 19 (7). pp. 1702-1715. ISSN 1468-0629

https://doi.org/10.1080/14680629.2017.1337042

Effect of styrene–butadiene rubber latex on the properties of modified porous cement stabilized aggregate

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Abstract: As road base materials, porous cement stabilized aggregates (PCSA) can reduce the erosion damage caused by the water inside pavement structure. However, due to the reduced deformation resistance and anti-cracking ability associated with the high porosity, the application of PCSA has been held back. A laboratory experiment was conducted in this study to improve the cracking properties of PCSA through the incorporation of styrene–butadiene-rubber (SBR) latex. The effects of SBR latex usage on permeability, compressive strength, flexural strength and anti-freezing ability of PCSA were investigated. In addition, the modification mechanisms of SBR latex on the PCSA properties were analyzed. Test results indicated that the air voids and permeability coefficient decreased with the increase of SBR latex dosages. The flexural strength and anti-freezing ability were improved when the SBR latex dosages is between 10% and 15%. 7 d compressive strength has a slightly decrease while the 28 d compressive strength increased. The significant increase of flexural strength and anti-freezing ability can be attributed to the interpenetrating matrices formation, stretching effect as well as flexibility enhancement after adding SBR latex.

Key words: Porous cement stabilized aggregate, Styrene-butadiene-rubber latex, Latex modified, Road base, Flexural and compressive strength

1 Introduction

Cement stabilized aggregates (CSA) have been widely used as road materials for the characteristics such as high strength, good integrity, stability and low cost (Pasetto, 2000; Hu et al., 2011, 2014; Jitsangiam et al., 2009). However, a shortcoming of CSA when used as road base is that the water penetrated into the pavement structure could not be removed in time. As a result, CSA would be eroded under the hydrodynamic pressure generated by wheel loading, which leads to premature pavement damage (Sha, 2001). For this purpose, the research on water stability of porous cement stabilized aggregate (PCSA) was performed in the past few years (Zeng et al., 2015).

Compared with conventional dense CAS, PCSA has higher coarse aggregate (particle size larger than 4.75mm) contents to form a coarse stone skeleton. Mortar produced from a mixture of fine aggregate and cement adhered to the coarse stone skeleton, as well as filled in the air voids. Due to the abundant presence of interconnected air voids, PCSA has good drainage ability but poor deformation resistance (Sha, 2008; Jiang et al., 2015).

In a number of previous studies, fly ash, rubber particles and polypropylene fibers were added in the CSA to improve its flexural strength (Farhan et al., 2015; Guthrie et al., 2001; Yu et al., 2011; Yang et al., 2014; Hu et al., 2012). Furthermore, research in the field of cement mortar and concrete material were referred to (Li et al., 2017; Ling et al., 2009). Polymers latex has been widely used to modify the mortar. The addition of latex could effectively increase the flexural strength and anti-cracking ability of hardened mortar due to the formation of elastic polymer films (Kardon, 1997).

Wang et al. (2005, 2006) studied the effect of styrene–butadiene rubber (SBR) emulsion on the degree of cement hydration. Their results showed that, the degree of cement hydration reaches the maximum value when SBR polymer-cement ratios (P/C) is 5%, 10% and 10% for the modified pastes hydrated for 3 d, 7 d and 28 d, respectively. Baueregger et al. (2015) assessed the influence of carboxylated styrene butadiene latex copolymer on Portland cement hydration and found that anionic styrene–butadiene latex generally retards both the aluminate and silicate reactions. The retardation effect of styrene-acrylate copolymer latex on cement hydration was reported by Kong et al. (2015). Similar studies were carried out to investigate the hydration behavior of the polymer modified jute fiber reinforced cement paste (Jo et al., 2015). Sun et al. (2008) investigated how polyacrylamide (PAM) alters the physicochemical and mechanical properties of concrete. Results demonstrated that PAM can effectively improve the flexural strength, bonding strength, dynamic impact resistance, and fatigue life of concrete, though it reduces the compressive strength to some extent. Huang et al. (2010) evaluated the effects of styrene butadiene rubber latex on permeability, compressive strength and split tensile strength of Portland cement pervious concrete. Results indicated that the addition of latex could increase the split tensile strength of pervious concrete. Ukrainczyk et al. (2013) conducted experiments on the properties of calcium aluminate cement (CAC) mortar modified with the styrene–butadiene-rubber (SBR) latex. Their study also showed that the addition of SBR latex could increase the flexural strength of cement mortar.

Previously, studies have been conducted to improve the performance of cement stabilized aggregate (CSA) and cement mortar by adding polymers latex, fibers and so on. However, polymers latex modified PCSA have not been comprehensively investigated yet. Unlike the dense CSA, both the strength of PCSA with different polymers latex dosages, and the effect on PCSA permeability, should be taken into account. Additionally, water is easy to remain in the material due to the presence of abundant interconnected air voids in PCSA. As a result, it is more prone to failure under the effect of freezing and thawing. Therefore, the ability of anti-freezing also needs to be evaluated. For this purpose, this paper aims to study the effect of raw material composition on the strength, permeability and anti-freezing ability of SBR latex modified PCSA, as well as the mechanism of interaction. Findings from this study can be used to guide the mix design and the performance evaluation of PCSA.

2 Materials

2.1 Aggregates

In this study, crushed limestone aggregates were used. Aggregates were obtained from quarries in Shaanxi Province of China which are mainly used for highway construction. The physical and mechanical properties of aggregates were measured in accordance to Chinese specification JTG E42 (Ministry of Transport, 2005). The aggregate properties are listed in Table 1.

Table 1

Properties of aggregates used in the tests.

Sieve diameters	Properties	Testing Methods	Test result
30-10 mm	Bulk specific gravity (g/cm^3)	T 0304-2005/ASTM C 127-88	2.791
	Water absorption (%)	T 0304-2005/ASTM C 127-89	0.820
	Crushing value (%)	BS 812-112	12.0
	Flat and elongated particles (%)	T 0312-2005/ASTM 4791	8.0
10-5 mm	Bulk specific gravity (g/cm^3)	T 0304-2005/ASTM C 127-88	2.812
	Water absorption (%)	T 0304-2005/ASTM C 127-89	0.911
	LA abrasion loss (%)	T 0317-2005/ASTM C 535	14.33

	Flat and elongated particles (%)	T 0312-2005/ASTM 4791	8.4
5-0.075 mm	Bulk specific gravity (g/cm^3)	T 0330-2005/ASTM C 128-93	2.681
	Sand equivalent	T 0334-2005/ASTM D 2419-09	65.7

The aggregate graduation of PCSA in this study is presented in Table 2.

Table 2

Gradation of PCSA for testing.

Sieve size (mm)	31.5	26.5	19.0	16.0	13.2	9.5	4.75	2.36	0.075
Percent passing (%)	100	95	70	57	48	35	9	5	1

2.2 Cement

The Portland cement used in this test was obtained from Qinling cement plant in Shaanxi Province of China. The main properties and specification criteria of Portland cement are listed in Table 3.

Table 3

Properties of cement.

Properties	Testing methods	Test result
Fineness (80μm square hole sieve), %	ASTM C 786	7.1
Initial setting time, min	ISO 9597	178
Final setting time, min	ISO 9597	227
3 d compressive strength, MPa	ISO 679	20.1
3 d flexural strength, MPa	ISO 679	4.9

2.3 SBR latex

SBR latex (density: 0.97 g/cm^3; glass transition temperature: 10^{o}C; pH value: 8 - 10; solid content: 46 - 48%) and tap water were used in the experiment. This type of SBR latex is found in good quantity in Shaanxi Province which has potential to be widely used in road construction projects.

3 Test methods

3.1 Sample Preparation

The following method was used to prepare PCSA. Firstly, aggregate and cement were mixed together in a mixer for 60 s. Then, water was added into the mix and the mixing process was continued for 120 s. At last, SBR latex was added and all the ingredients were mixed together for 120 s. There are two approaches to mold specimens both following Chinese standard specifications JTG E51 (Ministry of Transport, 2009): one is normal compaction (similar principles to the Marshall compaction), and the other is vibrating compaction. Since the PCSA has high interconnected air voids which means small contact areas between aggregate particles, it is not suitable to use normal compaction to mold specimens, for normal compaction would result in the breakage of aggregates in PCSA (Hu, 2004).

Vibrating compaction was used to mold specimens. In the process of compaction, aggregate particles moved and rearranged closely under the vibration head. As a result, the breakage of coarse aggregates was significant reduced. Vibration frequency used in the test was 28 Hz, and excitation force was 6800 N. Compaction time was 30 s.

In this study, two sizes of specimens were prepared. Cylindrical specimens (150 mm in diameter and 150 mm in height) were prepared according to Chinese standard specifications JTG E51 (Ministry of Transport, 2009) for the test of compressive strength, permeability and anti-freezing ability. Beam specimens (400 mm in length, 100 mm in width and 100 mm in height) were prepared for the test of flexural strength. Specimens were cured at 20°C and 95% relative humidity.

3.2 Air voids test method

Underwater weighing method was used for determining the air voids of PCSA. Firstly, submerge the specimen in a water bath at 20°C for 6 h then weigh it underwater (m_1). Next, remove the specimen from the water and dry it in an oven at 105°C for 12 h (until constant weight is achieved). After that, cool the specimen in air at room temperature for 2 hours then determine the mass (m_2). At last, measure the diameter (d) and height (h) of the specimen four times for each dimension. The average value of each dimension was used for calculating the volume. The air voids (VV) were calculated using Equation 1.

$$VV = 1 - \frac{m_2 - m_1}{\pi\left(\frac{d}{2}\right)^2 h\rho} \tag{1}$$

where VV is the air voids; ρ is the density of water at temperature of 20°C, the value of 0.99822 g/cm^3 was used.

3.3 Permeability measurement

As shown in Fig. 1, the permeability was measured using the constant head permeameter. Head difference between the first overflow outlet and the second was 10 cm. The volume of water (Q) collected from the second water outlet and the corresponding testing time (t) were recorded. The permeability coefficient (k) was calculated using Equation 2.

$$k = \frac{Q}{\pi \times r^2 \times t} \tag{2}$$

where k is the permeability coefficient (cm/s); t usually is 30 s; Q (mL) is the water flow in 30 s; r is the radius of specimen, the value of 7.5 cm was used.

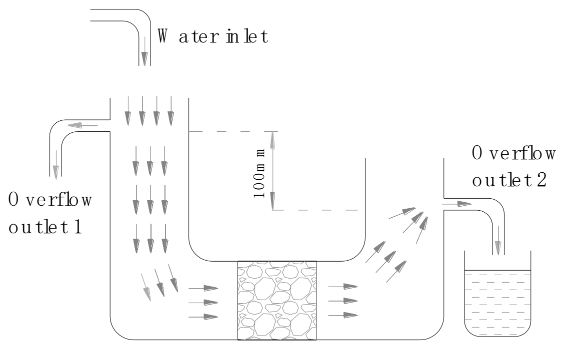


Fig. 1. Schematic plot of permeameter.

3.4 Strength

3.4.1 Compressive strength

Cylindrical specimens with 150 mm in diameter and 150 mm in height were used for the compressive strength test. The number of specimens in each test group was six. To conduct the test, the specimen was imposed a vertical load continuously, at a constant speed of deformation of 1 mm/min, until the peak load (P) is reached. The compressive strength (R_c) was calculated using Equation 3.

$$R_c = \frac{P}{A} \tag{3}$$

where R_c is the compressive strength (MPa); P is the peak load (N); A is the cross-section area of specimen (mm^2).

3.4.2 Flexural strength

The flexural strength of prismatic specimens with dimensions 100 mm × 100 mm × 400 mm size were determined with a four-point bending test. The number of specimens in each test group was six. Universal testing machine was used for the test with a loading rate of 50 mm/min. The peak load (P) was recorded. The flexural strength (R_s) was calculated using Equation 4.

$$R_s = \frac{PL}{b^2 h} \tag{4}$$

where R_s is the flexural strength (MPa); P is the peak load (N); L is the distance between the two bottom fulcrums (300 mm); b is the width of specimen (100 mm); h is the height of specimen (100 mm).

3.5 Anti-freezing ability

The evaluation of the anti-freezing ability (AFA) could be described as follows. Eight cylindrical specimens with 28 d curing time were divided into two groups. One group was then subjected to additional 5 freeze-thaw cycles. Each cycle consisted of applying -18°C temperature for 16 h and then 20 °C temperature for 8 h. Then, Compressive strength test was conducted with both groups. The anti-freezing ability was defined as a ratio of compressive strength after and before 5 cycles of freezing and thawing, as shown in Equation 5.

$$AFA = \frac{R_{DC}}{R_c} \times 100 \tag{5}$$

where AFA is the ratio of compressive strength after and before 5 cycles of freezing and thawing cycles which represent the anti-freezing ability of the material (%); R_{DC} is the compressive strength of specimen after 5 freeze-thaw cycle (MPa); R_c is the compressive strength of specimen without freeze-thaw cycle (MPa).

4 **Effects of material composition on PCSA performance**

The experiments were designed as follows: Firstly, the appropriate cement content and mixing water amount was fixed according to the results of compressive strength test. Then, the effects of SBR latex's dosage on PCSA's performance were studied. Each mix composition of PCSA were tested using six replicate specimens, and the arithmetic mean was taken for the result.

4.1 Cement content

Based on previous research results and common experience (Zhang, 2011), the mixing water amount was fixed at 3.8%, and five types of PCSA were prepared with cement content of 6%, 7%, 8%, 9% and 10%. The cement content was presented as a percentage of the total mass of aggregates. The mixing water amount was calculated based on the total weight of aggregates and cement. Results of the 7 d compressive strength for PCSA with different cement contents are presented in Fig. 2. The error bars represent ± standard deviation (SD) from six independent trials. It can be seen that the higher the cement content, the higher the 7 d compressive strength of PCSA is.

It was also found that there was not enough cement paste between the coarse aggregate particles when the cement content was less than 7%. Therefore, the compressive strength was relatively low. However, when the cement content reached 10%, the abundant cement paste would move down along the interconnected air voids during vibrating compaction. As a result, it led to the heterogeneous distribution of the air voids, which means the air voids at the bottom of the specimens are smaller than the upper part. And this would lead to a reduction in permeability. In view of the above considerations, the cement content was fixed at 9% in this study.

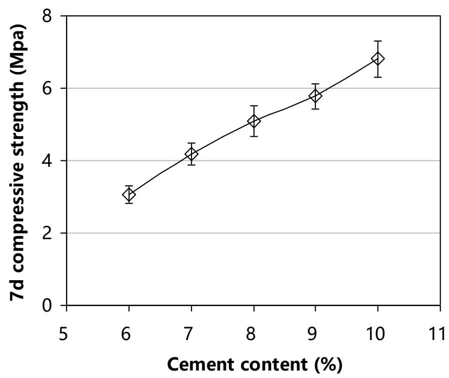


Fig. 2. Relationship between cement content and 7 d compressive strength of PCSA.

4.2 Mixing water amount

In order to investigate the appropriate mixing water amount, the cement content was fixed at 9%, and five types of PCSA were prepared with mixing water amount of 3.6%, 3.7%, 3.8%, 3.9% and 4.0%. Fig. 3 shows the test results of the 7 d compressive strength for PCSA with different mixing water amount. The error bars represent ± SD from six independent trials. The results show that, with the mixing water amount increased from 6% to 10%, the 7 d compressive strength of PCSA increased first and then began to decline. It can be seen that there is an optimum mixing water amount of 3.8% which made the 7 d compressive strength the highest.

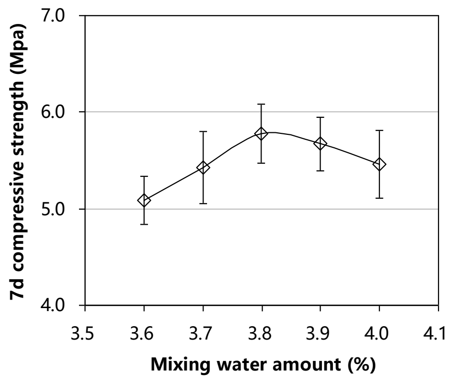


Fig. 3. Relationship between mixing water amount and 7 d compressive strength of PCSA.

4.3 SBR latex dosages

4.3.1 Effects of SBR latex dosages on optimum mixing water amount

In order to investigate the effects of SBR latex dosages on PCSA performance, the cement content was fixed at 9%. According to previous research results (Wang et al., 2006; Baueregger et al., 2015; Yang et al., 2009), five types of PCSA were prepared with SBR latex dosages of 0%, 5%, 10%, 15% and 20%, and SBR latex dosages was calculated as a percentage of the weight of cement. The optimum mixing water of PCSA with different SBR latex dosages was determined according to the 7 d compressive strength of PCSA, as shown in Fig. 4. The error bars represent ± SD from six independent trials. It can be seen that there is a negative linear correlation between SBR latex dosages and the optimum mixing water amount, which means the addition of SBR would reduce the optimum mixing water amount. The two main reasons can be: 1) there is amount of water in the SBR latex, and 2) polymer particles in latex exert ‘ball bearing’ action (Ukrainczyk et al., 2013; Ohama, 1995), such as the entrained air and the dispersing effect of surfactants.

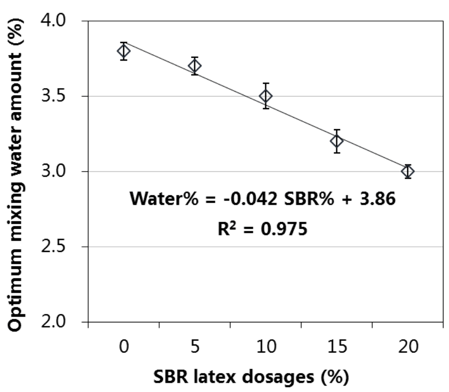


Fig. 4. Relationship between SBR latex dosages and optimum mixing water amount.

4.3.2 Effects of SBR latex dosages on permeability

The air voids and permeability coefficient of PCSA with different SBR latex dosages are presented in Fig. 5. The error bars represent ± SD from six independent trials. The results illustrate that the air voids and permeability coefficient decreased with the increase of SBR latex dosages. The reason can be explained by the fact that small holes in PCSA are filled by SBR polymer particles, thus the mixture get more compacted.

A permeability coefficient of 0.7 cm/s is approximately equivalent to 600 m/day. As to pavement surface mixture, a minimum permeability coefficient value of 100 m/day was suggested by NCAT and ASTM International (D 7064-04) (Mallick, 2000). It can be concluded from the above that, although the addition of SBR latex has a negative impact on the permeability coefficient of PCSA, the mixture still has good drainage ability.

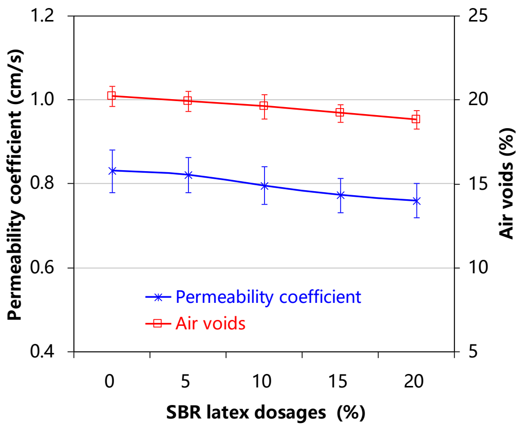


Fig. 5. Coefficient of permeability and air voids of PCSA with different SBR latex dosages.

4.3.3 Effects of SBR latex dosages on compressive strength

Table 4 gives the 7 d and 28 d compressive strength of PCSA with different SBR latex dosages. The 7 d compressive strength sees a slightly decrease after adding the SBR latex. In contrast to the 7 d compressive strength, the addition of SBR latex has positive effects on increasing the 28 d compressive strength of PCSA. When the SBR latex dosages was 15%, the 28 d compressive strength increased by 5.28% compared with PCSA without SBR latex. When the SBR latex dosages increased to 20%, the percentage of increase in PCSA's 28 d compressive strength fell back to 3.08%.

Table 4

7 d and 28 d compressive strength of PCSA with different SBR latex dosages.

Cement contents (%)	SBR latex dosages (%)	Mixing water amount (%)	7 d compressive strength			28 d compressive strength		
			Average value (MPa)	SD[a]	Rate of change (%)	Average value (MPa)	SD[a]	Rate of change (%)
9	0	3.8	5.78	0.37	-	7.49	0.52	-
9	5	3.7	5.67	0.32	-1.90	7.45	0.32	-0.53
9	10	3.6	5.63	0.27	-2.60	7.62	0.38	1.74
9	15	3.4	5.58	0.32	-3.46	7.88	0.46	5.21
9	20	3.2	5.55	0.37	-3.98	7.72	0.50	3.07

a SD represent standard deviation from six independent trials.

4.3.4 Effects of SBR latex dosages on flexural strength

Table 5 shows the 7 d and 28 d flexural strength of PCSA with different SBR latex dosages. The results illustrate that the flexural strength of PCSA firstly increased then decreased when the SBR latex dosages increased from 0% to 20%. The flexural strength appeared to be maximized when the SBR latex dosages was about 15%. It can be seen that in general, the addition of SBR latex improved the flexural strength of PCSA, and the promotion of early (e.g. 7 days) flexural strength was more significant.

Table 5

7 d and 28 d flexural strength of PCSA with different SBR latex dosages.

Cement contents (%)	SBR latex dosages (%)	Mixing water amount (%)	7 d tensile strength			28 d tensile strength		
			Average value (MPa)	SD[a]	Rate of change (%)	Average value (MPa)	SD[a]	Rate of change (%)
9	0	3.8	1.67	0.10	-	2.23	0.15	-
9	5	3.7	1.77	0.08	5.99	2.30	0.15	3.14
9	10	3.6	1.91	0.07	14.07	2.50	0.12	12.11
9	15	3.4	1.96	0.09	17.13	2.57	0.14	15.25
9	20	3.2	1.89	0.12	13.17	2.44	0.17	9.42

a SD represent standard deviation from six independent trials.

4.3.5 Effects of SBR latex dosages on anti-freezing ability

The results of the tests for the anti-freezing ability (AFA) are presented in Fig. 6. The error bars represent ± SD from six independent trials. It can be seen that AFA value increased when SBR latex dosages increased. A steep initial gain in AFA occurred when the SBR latex dosages increased from 0% to 10%, followed by a moderate AFA gain when the SBR latex dosages continued to increase to 20%. The general trend indicated that the addition of SBR latex could improve anti-freezing ability of PCSA.

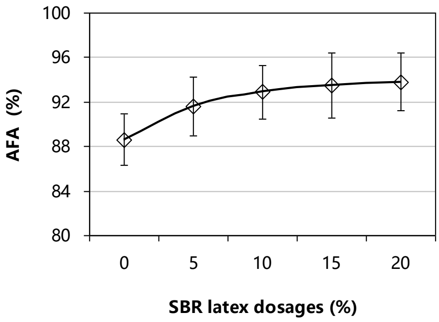
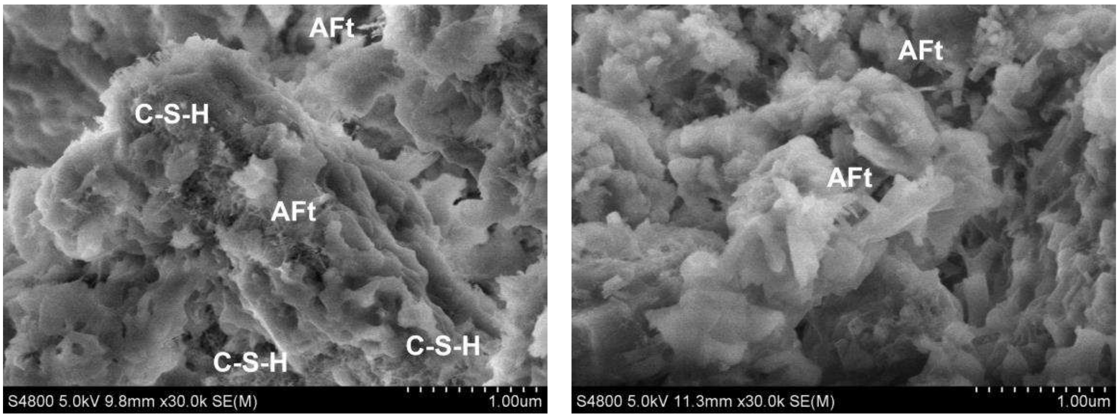


Fig. 6. Effect of SBR latex dosages on anti-freezing ability of PCSA.

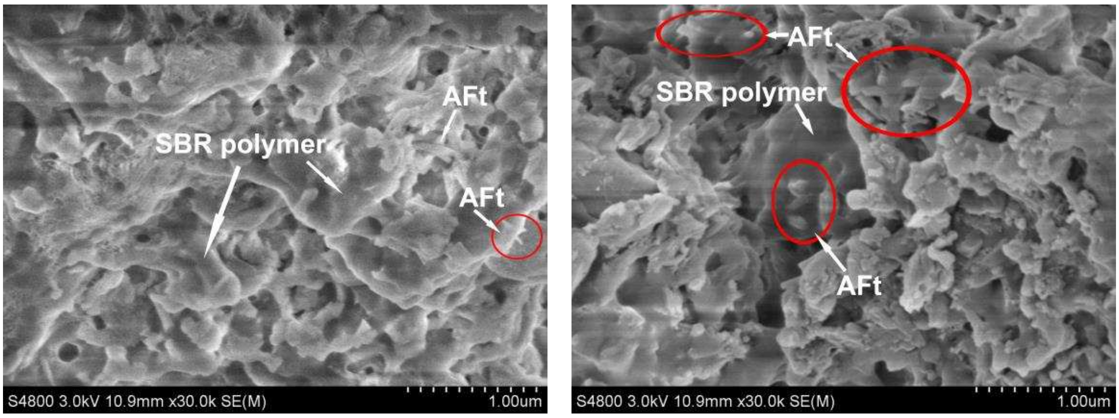
In general, the addition of SBR latex will improve the PCSA's flexural strength, as well as anti-freezing ability. However, the addition of SBR latex also resulted in increased costs. It is estimated that the material cost increases by about 20% with the addition of 10% SBR latex (Alibaba, 2017).

5 Mechanism of SBR latex modification

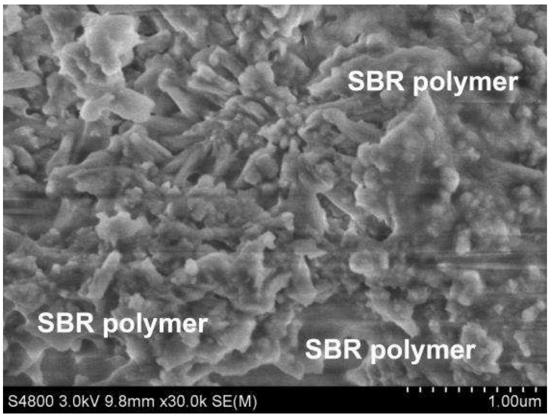
Scanning Electron Microscope (SEM) was used for further analysis and interpretation of the experiment results. The results were obtained using micro-images of PCSA with SBR latex dosages of 0%, 10% and 20% after curing for 7 d, as shown in Fig. 7.



(a) 0% SBR (b) 5% SBR



(c) 10% SBR (d) 15% SBR



(e) 20% SBR

Fig. 7. SEM pictures of PCSA with different SBR latex dosages.

Fig. 7a shows the SEM picture of PCSA without SBR latex. Abundant cement hydration products, such as calcium silicate hydrates (C-S-H) and ettringite (AFt), could be found. C-S-H appears in the form of a coating product around aggregate particles. The coating product presents elongate tobermorite-like gels. AFt is elongated into a needle-like shape. These products indicate that hydration of cement was adequate, which is an essential requirement for the formation of strength. The AFt could be seen in the surface of PCSA with 5% SBR latex (Fig. 7b), while C-S-H was significant less than Fig. 7a for the reason of SBR latex covering. When the SBR latex dosages reaches 10% to 15%, the smooth-faced polymer was evident in the SEM picture (Fig. 7c and Fig. 7 d), as well as some Aft raised in the surface of SBR latex. And no obvious C-S-H was found. The surface of particles was covered by a dense polymer “skin” when the dosages of SBR latex reaches 20% (Fig. 7e), which makes hydration products hard to observe.

As is evident from Fig. 7, the addition of SBR latex results in a significant retardation of cement hydration. This effect is more obvious with the dosages of SBR latex increased (Ukrainczyk et al., 2013; Kong et al., 2015). Meanwhile, the SBR polymer and cement hydration products commingle and create two interpenetrating matrices which work together, as well as the bonding strength of SBR polymer itself, compensating for strength reduction due to insufficient hydration. As mentioned above, the 7 d compressive strength of PCSA decreased slightly when the SBR latex dosages increased from 0% to 20% while the 28 d compressive strength of PCSA increased slightly due to the effects of further hydration at late ages (7 d to 28 d).

Flexural strength of PCSA increased significantly by adding SBR latex. The reason can be explained by the fact that the SBR polymer and cement hydration products commingle and create two interpenetrating matrices which work together. On the one hand, SBR polymer has good flexibility and resilience which improves the deformation resistance of PCSA. On the other hand, the polymer formed a polymer “skin” surrounding the aggregate particles. When cracks appear on the surface of particles, SBR polymer in the fracture formed a stretching band to suppress the development of cracks (Fig. 8). However, when the dosages of SBR latex increased to 20%, the flexural strength of PCSA decreased compared with the dosages of 10% and 15%. This is due to the fact that polymer films in the mortars become thicker, and the excessive polymers strongly retard or suppress the cement hydration confirming the findings by other researchers (Bishop et al., 2006; Chakraborty et al., 2013; Jo et al., 2014), as well as the low mechanical capacity of SBR polymer in the mortar.

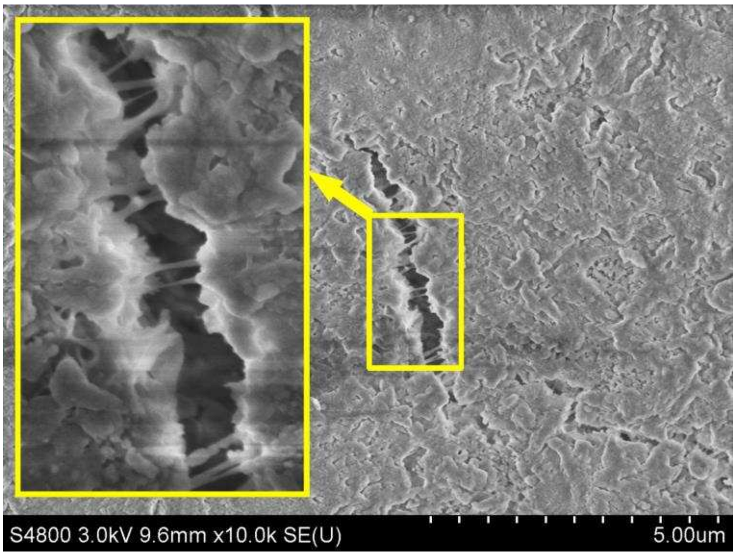


Fig. 8. SEM pictures of PCSA in cracks.

Additionally, the enhancement of PCSA’s anti-freezing ability after adding SBR latex could also be attributed to the flexibility of the material, as well as filling and compacting effects.

6 Summary and conclusions

The main findings of this study can be summarized as follows.

(1) The addition of latex could effectively improve the flexural strength and anti-freezing ability of PCSA provided that a good permeability is maintained. The optimum dosage of SBR latex was recommended as 10% to 15% by the mass of cement. The same approach (e.g. mix design, dosage increments) can be used for experimental testing of other performances of the mixture. The findings from this study can be used to optimize the mix design and the performance of PCSA.

(2) The 7 d compressive strength of PCSA has slightly decreased after adding SBR latex, and the magnitude of reduction increased with increasing SBR latex dosages. However, the addition of SBR latex has positive effects on improving the 28 d compressive strength. The reason can be explained by the fact that the addition of SBR latex results in a significant retardation of cement hydration. And this effect is more obvious with the dosages of the latex increased. However, the long-term compressive strength of PCSA improved with the curing time increased.

(3) The flexural strength of PCSA increased first and then began to flatten, or slightly decline when the SBR latex dosages increased from 0% to 20%. The flexural strength appeared to be maximized when the SBR latex dosages reaches 15%.

(4) When the SBR latex dosages increased from 0% to 20%, the anti-freezing ability of PCSA increased, and the air voids decreased, as well as the permeability. The rate of increase of anti-freezing ability became low when the SBR latex dosages exceed 10%.

(5) The mechanism of flexural strength and anti-freezing ability increased dramatically due to the interpenetrating matrices formation, stretching effect as well as flexibility enhancement after adding SBR latex. However, adverse effect was that the polymer could form a polymer "skin" surrounding the aggregate particles, which retarded or suppressed the cement hydration.

(6) The addition of SBR latex will improve the PCSA's flexural strength, as well as anti-freezing ability. However, the addition of SBR latex also resulted in increased costs. Therefore, the PCSA performance requirements and the cost should be carefully weighed and evaluated in practice. Further studies can be carried out by incorporating low cost materials, such as silica fume or fly ash, to improve the antifreeze properties of PCSA, as well as the long-term performance of PCSA in the field.

Acknowledgements

This project was supported by the National Natural Science Foundation of China (Grant No. 51608043), Natural Science Basic Research Plan in Shaanxi Province of China (Grant No. 2015KJXX-23), Fundamental Research Funds for the Central Universities (Grant No. 310828161013), and Supported by Key Laboratory of Highway Construction & Maintenance Technology in Loess Region，Ministry of Transport (Grant No. KLTLR-Y13-18).

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