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Properties of latex blends and its modified cement mortars

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Abstract

In this paper, the mechanical properties of three latex blends and the mechanical properties and chloride diffusivity of the latex-modified mortars are studied. The relationships between the properties of polymer films formed from latex blends and the properties of the latex blend-modified mortars are illustrated. The test results showed that the modified mortar with the blend of styrene–acrylic ester (SAE) and styrene–butadiene rubber (SBR) showed synergistic effect; especially the flexural strength of the SAE/SBR blend-modified mortars was about 20–40% higher than that of monolatex-modified mortars. However, the vinyl chloride–vinylidene chloride copolymer (PVDC)/SBR and PVDC/SAE blends-modified mortars showed antisynergistic effect. The compressive strength of the modified mortars increased with the increasing of the tensile strength of the latex films, while the flexural strength of the modified mortars did not depend on the tensile strength of the latex films. When PVDC with the mass fraction of 0.2 or SAE copolymer emulsion with mass fraction of 0.4 was blended into SBR latex, the latex blend-modified mortars showed lower chloride diffusivity. The chloride diffusivity of the modified mortars increased approximately linear with the tensile strength of the latex blend films, and decreased with increase of the elongation at rupture of the latex blend films. When the elongation at rupture of the latex blend films increased from 200–300% to more than 800%, the chloride diffusivity of the modified mortars decreased from $10–15 \times 10^{-12}$ to $3–4 \times 10^{-12}$ m^2/s.

Keywords: Latex blend; Latex blend-modified mortar; Mechanical properties; Chloride diffusivity

1. Introduction

The polymer-modified mortars show good property in different aspects when a different polymer is used. The vinyl chloride–vinylidene chloride (PVDC)-modified mortar showed lower chloride diffusivity and the styrene–butadiene rubber (SBR)-modified mortar showed higher flexural strength. However, the single latex-modified mortars exhibit also some obvious shortages. For example, the SBR or the chloroprene rubber latex had almost no modification on the chloride diffusivity of the mortars, and the PVDC-modified mortars presented bad workability when polymer–cement ratio was higher than 0.1 [1].

Blending is an important way to develop new polymers [2]. Through blending, the advantages of different polymers can be combined and a new kind of material with special property can be developed [3]. In recent years, the research and application of polymer latex blends have become a very active area of science work in order to meet the special requirement [4–8]. In the area of coatings, the traditional method to achieve the good property of film forming and good resistance to pollution is the use of film-forming agent or volatile solvent [9,10]. Because the requirement of environment protection became stricter, the volatile organic compound (VOC) will be more and more restricted. Latex blending is just a new important way to develop new coatings without VOC [7].

Although the researches upon latex blends for coatings were frequently reported, there was little report upon the latex blend for the modification of cement mortar and concrete [11]. Moreover, there are only a few latexes that can be used for the modification of cement mortar and concrete [12]. Thus, the relationships between the properties of polymers and the mortars were still not well developed. In this paper, the latex blends composed from two of three latexes were used for the modification of cement mortar in

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order to combine the strong point of the different latexes and to investigate the relationships between the properties of polymers and the mortars.

2. Experimental

2.1. Materials

The type and properties of latexes used are listed in Table 1. Portland cement type PII 525R, according to Chinese standard GB 175, and standard sand, according to Chinese standard GB 178, were used for preparing the specimens.

2.2. Specimen preparation and test methods

2.2.1. Films of latex blends

The two latexes for blending were mixed thoroughly manually. In forming the films, the mixed latexes were brushed onto glass three times with the time interval of 3 h. After drying for 3 days, the formed films were peeled from the glass. The tensile strength and elongation at rupture of the films were measured according to GB 13022.

2.2.2. Polymer-modified mortars

The mortar specimens were prepared with polymer–cement ratio (mass) of 0.10, water–cement ratio (mass) of 0.45 and sand–cement ratio (mass) of 2.5 according to GB177. Specimens with the dimension of $40 \times 40 \times 160$ mm (for mechanical test) and $\varphi 100 \times 50$ mm (for chloride diffusivity test) were prepared. The specimens were demolded after 2 days. A curing regime of 5 days in water followed by 21 days in air was used. The compressive strength and the flexural strength were measured according to GB177.

The chloride diffusivity was determined with electrically accelerated methods [13]. The specimens were vacuum-saturated with anode electrolyte before the test. The vacuum saturation involved vacuuming the specimens for 1 h, introducing the anode electrolyte into the vacuum chamber and maintaining the vacuum for 12 h. Finally, the specimens were kept in the anode electrolyte for a further 12 h. Thirty-volt DC and 8-h test duration were selected as the electrically accelerated test parameters. Fig. 1 is the schematic illustration of the test setup.

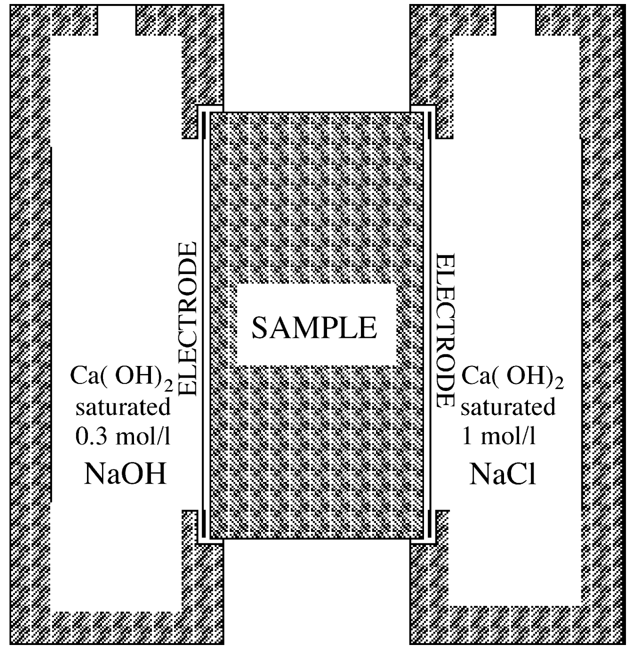

Fig. 1. Schematic diagram of migration test setup.

Table 1
Properties of latexes used

Type of latex	Abbreviation	Solid content (%)	Average particle size (μm)
Carboxylic styrene–butadiene rubber latex	SBR	48	0.30
Vinyl chloride–vinylidene chloride copolymer latex	PVDC	43.2	0.12
Styrene–acrylic ester latex	SAE	57	0.20

3. Results and discussion

3.1. Properties of latex blend films

The tensile strength and elongation at rupture of the films formed from latex blends are shown in Figs. 2–5. From these figures, we can see that the tensile strength and elongation at rupture of the latex blend films change with the mass fraction of the component of the blend.

It is clear from Fig. 2 that the tensile strength of SBR is higher than that of PVDC, and the tensile strength of the SBR/PVDC blends is lower than that value, as if the strength of the components were proportionally added. When the mass fraction of the PVDC is more than 0.2, the tensile strength of the blends is almost equal the tensile strength of the PVDC. That means that the blends are not homogeneous systems. In the blends, the PVDC phase builds up the continuous phase, so that it determines the strength of the blends. In the latex blend systems, the component with smaller particle size tends to build up the continuous phase [4,14]. In the SBR/PVDC blends, the average particle size of PVDC is 0.116 μm while that of SBR is 0.3 μm—that is why the PVDC determines the strength of the SBR/PVDC blends.

Fig. 3 shows the mechanical properties of SBR/styrene–acrylic ester (SAE) blends. Though the relationship between the properties and the mass fraction of the component is not linear, the blends seem more homogenous in the aspect of

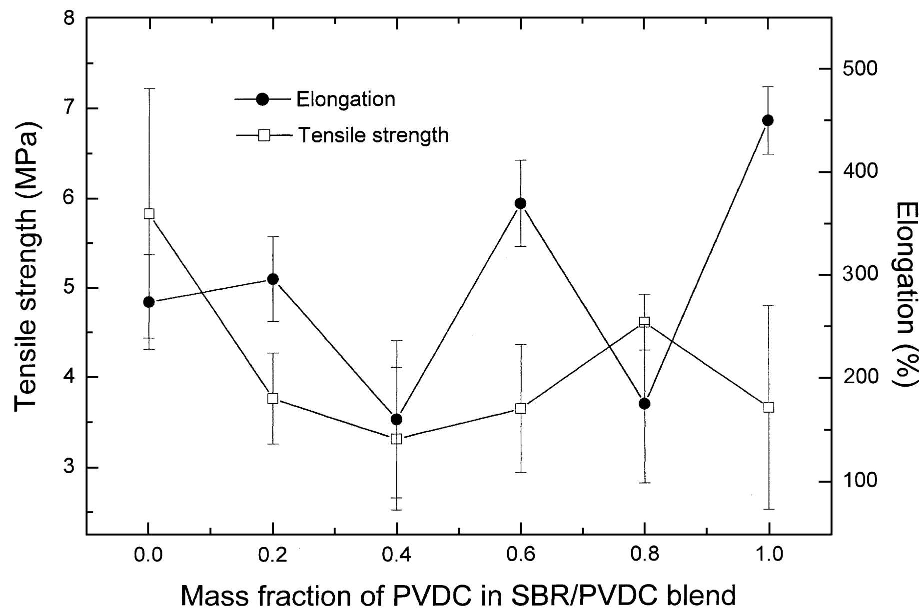

Fig. 2. The mechanical properties of SBR/PVDC blend film.

smaller deviation from the linear relationship and smaller error bar of the data. From the aspect of the mechanical properties, the blend of SAE and SBR is a system with a certain compatibility. The blends with SAE latex mass fraction of more than 0.4 show a tensile strength in the level of pure SAE. This means that the component SAE acts as controller due to its smaller particle size of 0.20 (Table 1). If the mass fraction of SAE is smaller than 0.2, the blend shows a tensile strength and an elongation in the level of pure SBR. In this case, SBR seems to build up the continuous phase.

Fig. 4 shows the mechanical properties of the blends of PVDC and SAE. It is clear from Fig. 4 that the relationship between the properties and the mass fraction of the components is almost linear, although the tensile strength curve shows positive deviation and the elongation curve shows negative deviation. All these blends in the test also showed good transparence. These illuminate that PVDC is compatible with SAE and the blends of PVDC and SAE are homogenous systems. The positive deviation of the tensile strength of the blends demonstrates the strong interaction between the molecules of PVDC and SAE.

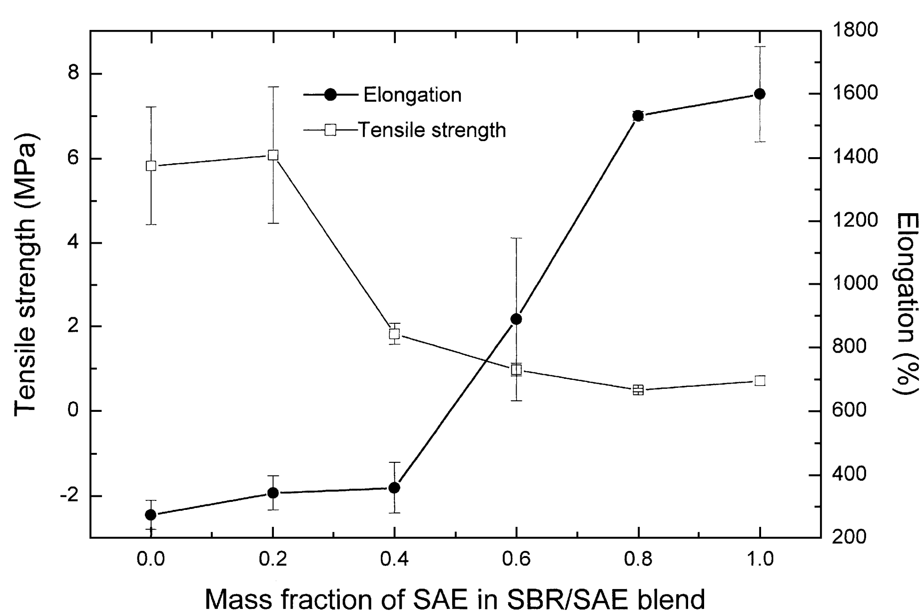

Fig. 3. The mechanical properties of SBR/SAE blend films.

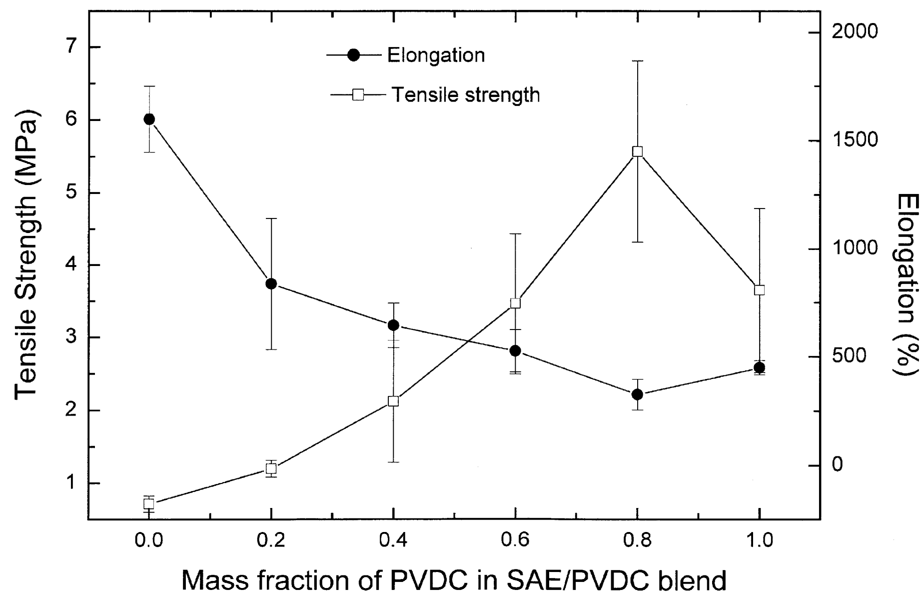

Fig. 4. The mechanical properties of SAE/PVDC blend films.

3.2. Mechanical properties of latex blend-modified mortars

The compressive and flexural strength of the latex blend-modified mortars are shown in Figs. 5–8.

Regardless of monopolymer or latex blend used, the compressive strength of polymer-modified mortars is obviously lower than that of the cement mortar. Among the polymer-modified mortars, the SBR-modified mortar showed the highest compressive strength while the SAE-modified mortar showed the lowest compressive strength (Fig. 5).

The cement mortar in this study had a high flexural strength of 9.1 MPa (Fig. 6). Among the polymer-modified mortars, no other than SBR and some SAE/SBR blends-modified mortars showed a higher flexural strength than that of the cement mortar (Figs. 6 and 7). Regularly, the polymer-modified mortar shows higher flexural strength than cement mortar [15]. However, the regular results were usually obtained by the same fluidity of the mortars. Because most latexes have a water-reducing effect, the higher flexural strength of the latex-modified mortars includes the contribution of the lower water–cement ratio. On the other hand, the flexural strength of the polymer-modified mortar seemed to show dependence on the type of cement. In our previous work [1], the same latexes (PVDC and SBR) were used, but the flexural strength of all the modified mortars was higher than cement mortar under equal water–cement ratio. The difference is the cement used. In the previous work, ordinary Portland cement PO 525 was used, while in this study a Portland cement of Type II (PII 525R, early strength) was used. In addition, the properties of the polymer have also influenced the strength of the polymer-modified mortar and concrete. In a general way, the rubber latex tends to decrease the compressive strength, while the thermoplastic dispersion, especially the polymer with more rigid segments in the molecule chain, tends to increase the compressive strength [16,17].

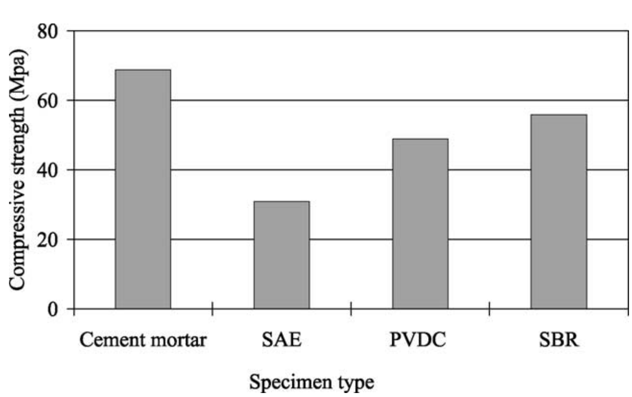

Fig. 5. Compressive strength of monolatex-modified mortars.

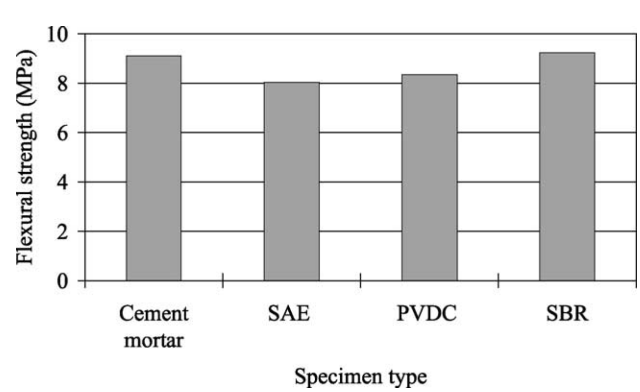

Fig. 6. Flexural strength of single latex-modified mortars.

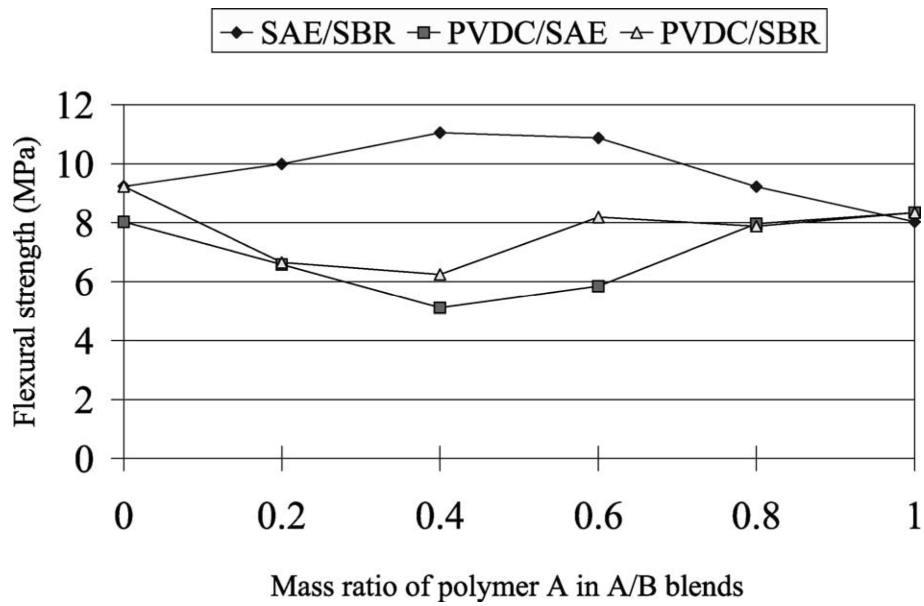

Fig. 7. Flexural strength of latex blend-modified mortars.

Figs. 7 and 8 show the relationship between the strength of the latex blend-modified mortar and the mass ratio of the component of the blend. The flexural strength and compressive strength curves of SAE/SBR blend-modified mortars bulge upwards. This demonstrates that blending the two latexes benefits the mechanical properties. The best mass ratio of SAE/SBR is about 2/3 while the blend-modified mortar obtained its highest flexural strength, which is 40% higher than that of the SBR-modified mortar. However, the strength curves of PVDC/SAE or PVDC/SBR blends-modified mortars bend downwards. These demonstrate the disadvantage of blending.

Whether the relationship between the properties of the latex blend films and the mass ratio of the blends is similar to that between the properties of the latex blend-modified mortars and the mass ratio of the blends depends on the blend system. For SAE/SBR and PVDC/SBR blends, the relationships were similar. In detail, the SAE/SBR blend showed synergistic effect both in blend films and in modified mortars, while the PVDC/SBR blend showed antisynergistic effect both in blend films and in modified mortars. The good synergistic effect of SAE/SBR blend in the modified mortar may not only be from the good compatibility of the two polymers but also from the building of the

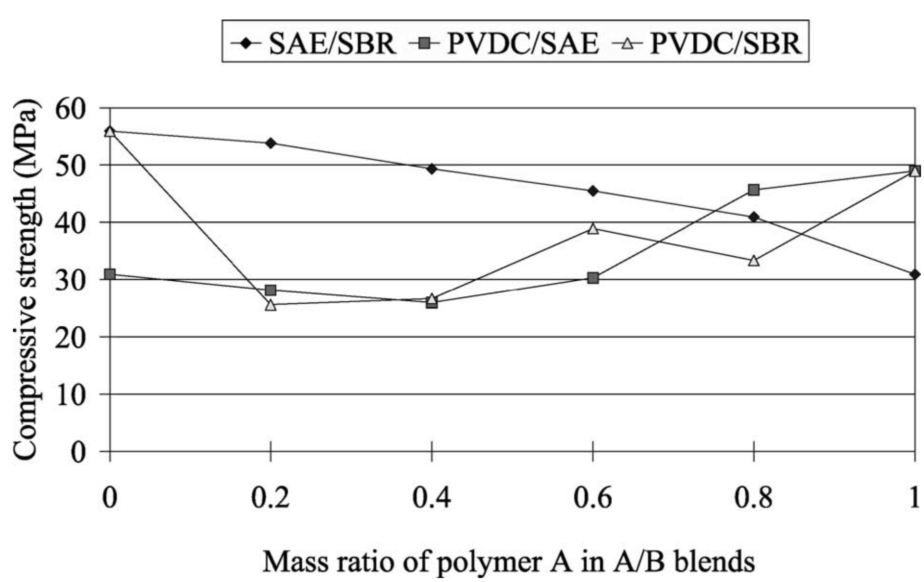

Fig. 8. Compressive strength of latex blend-modified mortar.

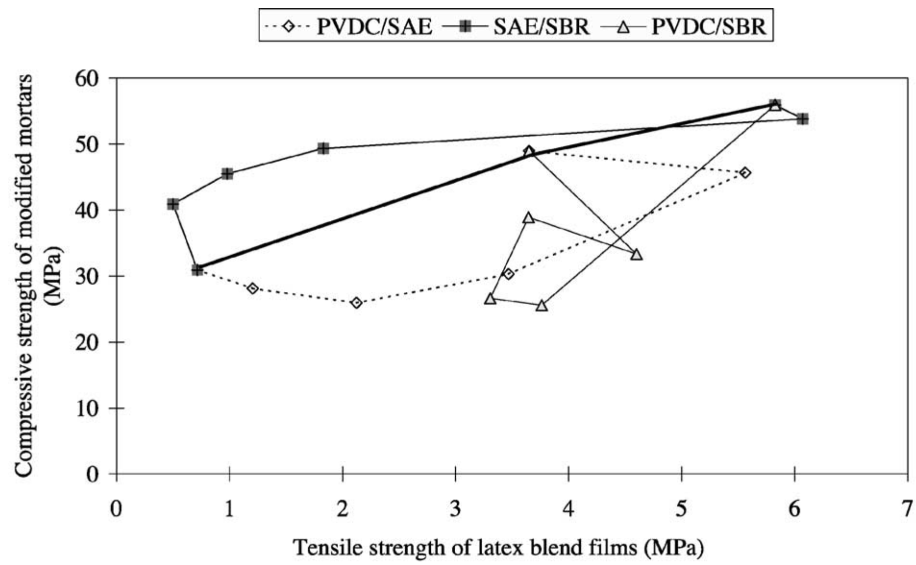

Fig. 9. The compressive strength of modified mortars vs. the tensile strength of latex blend films.

common carbonate of the carboxyl groups in both polymers. It is quite another situation for the PVDC/SAE blend. The blend films showed good synergistic effect, but the blend-modified mortars showed antisynergistic effect. This demonstrates that something occurred in the mortar, which decreased the compatibility of the two components. One possible reason may be that PVDC degraded to release HCl [18], so that PVDC and SAE became incompatible.

3.3. The relationship between the mechanical properties of blend films and blend-modified mortars

Figs. 9 and 10 illustrate the compressive and flexural strength of the latex blend-modified mortars vs. the tensile strength of the blend films. The lines are linked according to the order of the mass ratio of the latex blend. The bold curves in the figures express the behaviors of the monolatex-modified mortars. For the monolatex-modified mortars, the compressive strength increases with increasing of the tensile strength of the latex films (Fig. 9) while the flexural strength does not depend on the tensile strength of the latex films (Fig. 10). The compressive and flexural strength curves of SAE/SBR-blend modified mortars lie above the bold curves while the curves of PVDC/SAE and PVDC/SBR blend-modified mortars lie under the bold curves. These figures denote that the strength of the latex films of PVDC/SAE and PVDC/SBR blend is not exerted in the mortars. These behaviors are attributed to the poor compatibility of PVDC with SAE or SBR in the mortar.

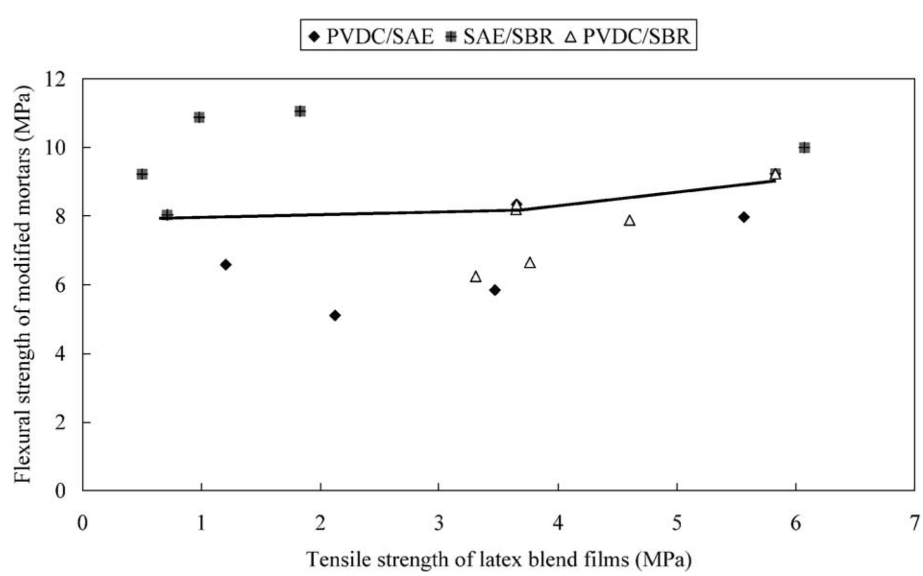

Fig. 10. The flexural strength of modified mortars vs. the tensile strength of latex blend films.

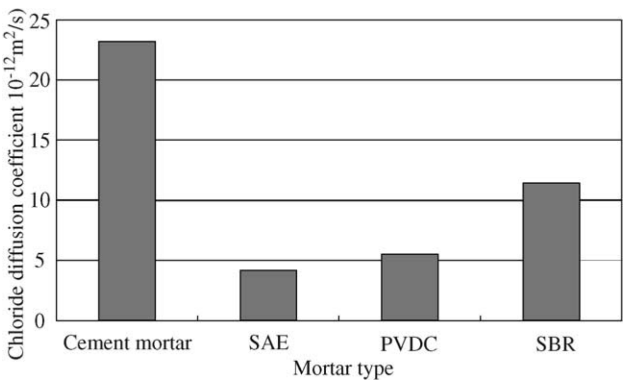

Fig. 11. Chloride diffusivity of latex-modified mortar (P/C = 10%).

It is unexpected that the compressive strength of the latex blend-modified mortar increased with increasing of the tensile strength of the latex blend films while the flexural strength of the mortars did not depend on the tensile strength of the latex blend films. Because the polymer-modified mortar has obviously lower compressive strength than that of the cement mortar, the polymer in the mortar can be usually observed as pores [19]. The results here indicated that the polymer did not behave as "true pores" for the compressive strength of mortar. The little dependence of the flexural strength of mortar on the tensile strength of the latex films can be ascribed to the intrinsic high flexural strength of the cement mortar. This means that the polymers had, in any way, no contribution to the flexural strength of the modified mortars.

3.4. Chloride diffusivity of latex blend-modified mortars

3.4.1. Relationship between the chloride diffusivity and the composition of the latex blend

The chloride diffusivity of monolatex-modified mortars is shown in Fig. 11. The latex-modified mortars have significant lower chloride diffusivity than that of cement mortar. The effect of the latex has the order, as follows: SAE > PVDC>SBR. The relationship between the chloride diffusivity of latex blend-modified mortars and the mass ratio of the blend is illustrated in Fig. 12. It is clear from Fig. 12 that the blends of SAE/SBR and PVDC/SBR show synergistic effect in definite mass fraction range while the blends of PVDC/SAE show antisynergistic effect in all mass fraction ranges. Concretely, the blend of PVDC/SBR with a small mass fraction of PVDC can obviously reduce the chloride diffusivity of the modified mortar, and the mortar modified with the blends of SAE/SBR with the mass fraction of SAE in the range of 0.4–1.0 shows low chloride diffusivity almost in the same level. This is very favorable for practical use because the modified mortar with SAE/SBR blend with more SBR mass fraction has higher compressive and flexural strength (Figs. 7 and 8).

3.4.2. Relationship between the chloride diffusivity and the mechanical properties of the mortar

The relationship between the chloride diffusivity of the latex blend-modified mortars and its compressive strength and flexural strength is shown in Figs. 13 and 14. It seems from Fig. 13 that the chloride diffusivity of the latex blends-

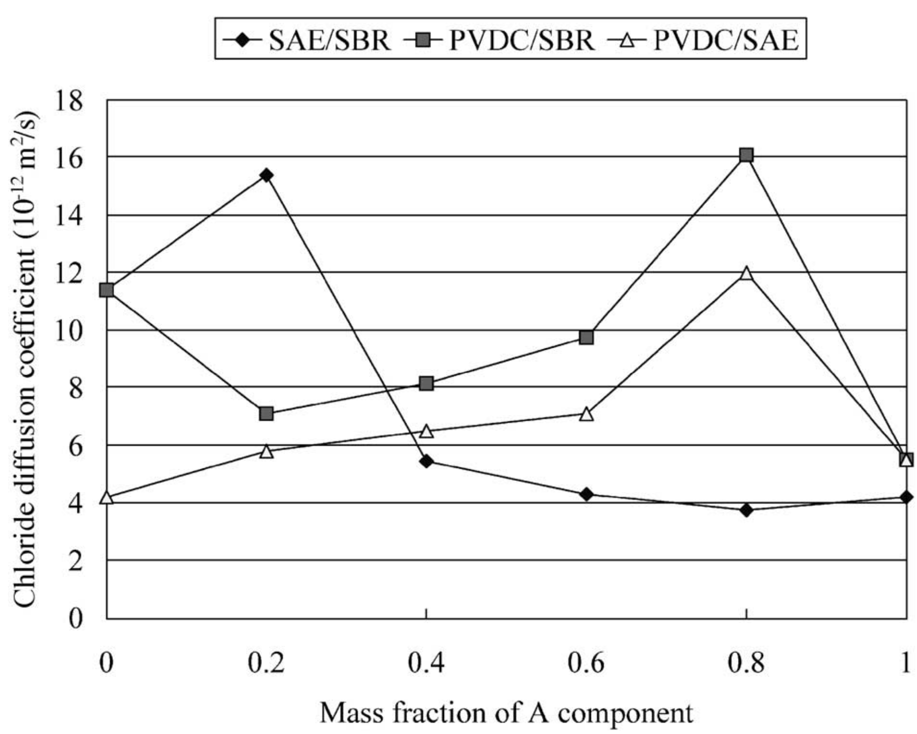

Fig. 12. Chloride diffusivity of latex blends (A/B)-modified mortars (P/C = 10%).

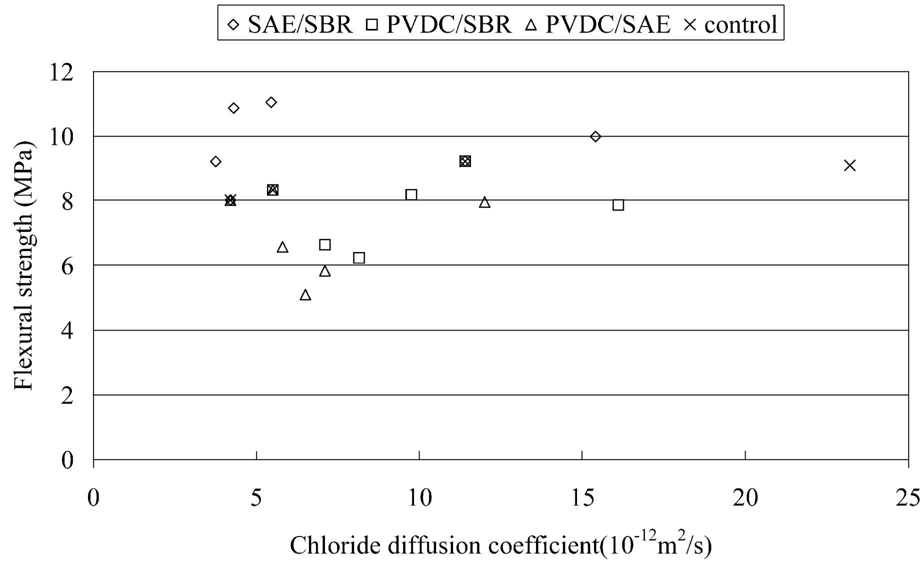

Fig. 13. The chloride diffusivity of latex blend-modified mortar vs. its flexural strength.

modified mortars is independent of the flexural strength of the mortars. However, it is apparent from Fig. 14 that the chloride diffusivity of the latex blends-modified mortars increases unfortunately with increasing of the compressive strength of the mortars. Because the polymer as soft particle results in a decrease of the compressive strength of the mortar, this indicated that the softer the polymer is, the lower chloride diffusivity the modified mortar has. The softer polymer particle will show better adhesive and/or filling properties and leads to lower chloride diffusivity.

3.4.3. Relationship between the chloride diffusivity and the mechanical properties of latex blend films

It is just our purpose to investigate the relationship between the properties of polymer itself and the properties of the polymer-modified mortars. Through blending, we can easily get more polymers with different properties. The chloride diffusivity of the latex blends-modified mortars vs. the tensile strength of the latex blend films is illustrated in Fig. 15. It is clear from Fig. 15 that the chloride diffusivity of the modified mortars increases almost linear with increasing of the tensile strength of the latex blend films.

Fig. 16 shows the relationship between the chloride diffusivity of the mortars and the elongation at rupture of the latex blend films. It is also apparent that the chloride diffusivity of the mortars decreases with increasing of the elongation at rupture of the latex blend films. When the elongation at rupture of the latex blend films increased from 200–300% to more than 800%, the chloride diffusivity of

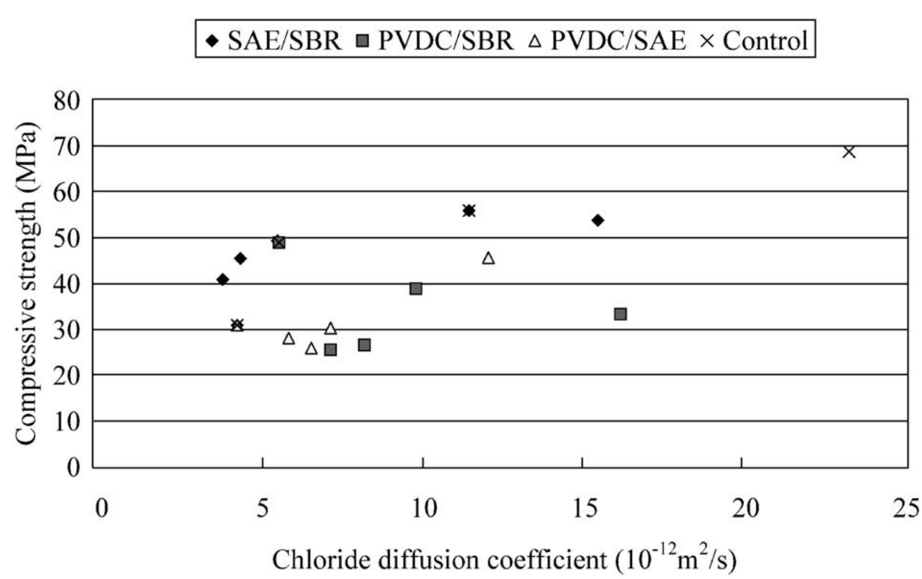

Fig. 14. The chloride diffusivity of latex blend-modified mortar vs. its compressive strength.

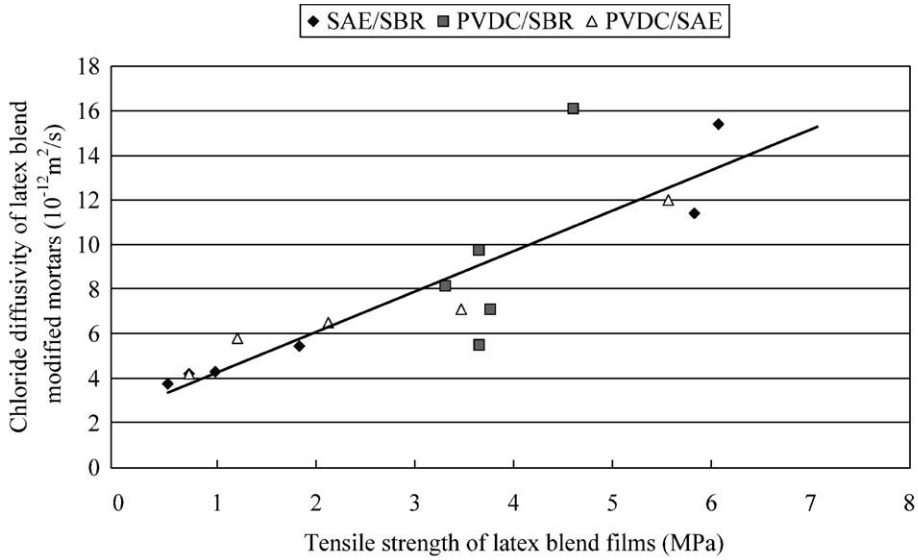

Fig. 15. The chloride diffusivity of the mortars vs. the tensile strength of the polymer films.

the modified mortars decreased from $10-15 \times 10^{-12}$ to $3-4 \times 10^{-12}$ m^2/s.

The fact that the chloride diffusivity of the mortar decreased with increasing of the elongation at rupture of the polymer films and with decreasing of the tensile strength of the polymer films demonstrates that increase in the strain ability of the polymer will decrease the chloride diffusivity of the polymer-modified mortar. It is well known that the microcracks in mortar are induced by the drying shrinkage of the cement hydrates. For the polymer-modified mortars, the drying process is slowed down due to the polymer film formed in the mortar on one side. On the other side, because the cement hydrate is wrapped in or adhered to by the polymer films or particles, if the polymer film has adequate elongation, the cracks produced due to drying are still bridged by the polymer films, so that they remain with high resistance to chloride permeation. It is doubtless that the larger the elongation at rupture of the film and the thicker the film, the wider that the cracks can be bridged. The technical information of Clarient reported that a flexible slurry film with a thickness of 2000 μm had a crack-bridging capacity of 6.3 mm; if the thickness of the film is decreased to 800 μm, its crack-bridging capacity is decreased to 1.6 mm [20]. In the polymer mortar with relative low polymer–cement ratio of 0.10, the polymer films in the mortar are very thin (a few micrometers) and

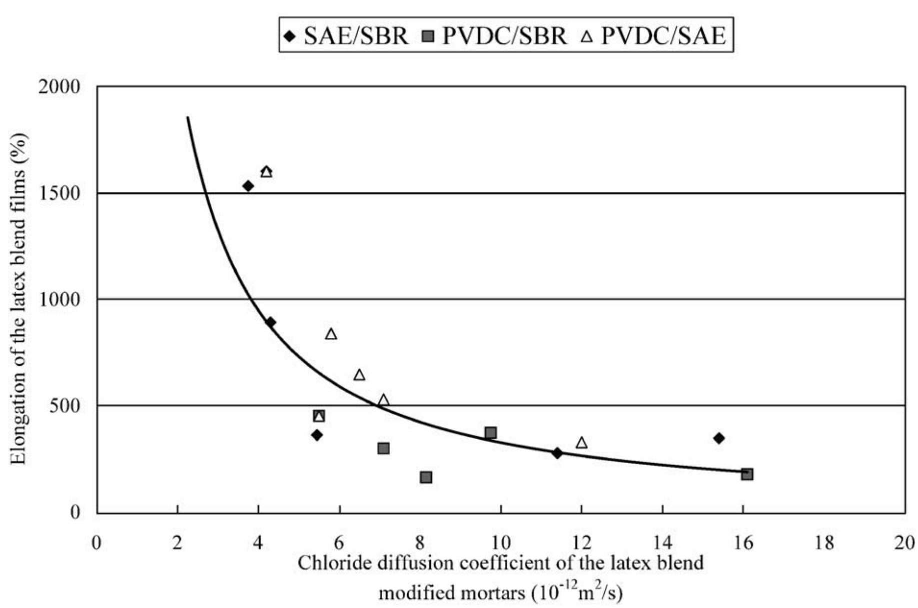

Fig. 16. The chloride diffusivity of the mortar vs. the elongation of the polymer films.

not complete [21]; only the polymer film having a large elongation can bridge wide cracks.

4. Conclusion

The latex blends were used for the study of the properties of the polymer-modified mortars. Through blending, we can easily get more polymers with different properties, so that we could deeply study the relationships between the properties of the modified mortars and the properties of the polymers. In the current study, the following conclusions were obtained.

(1) The tensile strength of the latex blend films of SAE/SBR blend and SAE/PVDC blend showed nearly linear relation with the mass fraction of the component. This demonstrates the good compatibility of the component in the case of blend films. However, the tensile strength of the PVDC/SBR blends films was much lower than that of arithmetical addition. This indicates the poor compatibility of PVDC and SBR.

(2) The SAE/SBR blends and PVDC/SBR blends-modified mortars showed similar behavior as the blend films with respect to the mechanical properties. In detail, the SAE/SBR blends-modified mortars showed good synergistic effect in the relationship between the mechanical properties of the mortars and the mass fraction of the blends while the PVDC/SBR blends showed antisynergistic effect. If the mass ratio of SAE/SBR was between 2/3 and 3/3, the flexural strength of the blends-modified mortars was 20–40% higher than that of monolatex-modified mortar. Contrarily, the SAE/PVDC blends-modified mortars showed behavior opposite to the blend films. This may be attributed to the degradation of PVDC in the mortar.

(3) The compressive strength of the latex blend-modified mortars increased with increasing of the tensile strength of the latex blend films while the flexural strength of the latex blend-modified mortars was independent of the tensile strength of the latex blend films.

(4) With suitable mass ratio of the latex blends of SAE/SBR or PVDC/SBR, the blends-modified mortars showed lower chloride diffusivity. Concretely, when PVDC with a mass fraction of 0.2 or SAE copolymer emulsion with a mass fraction of 0.4 was blended into SBR latex, the latex blend-modified mortars showed lower chloride diffusivity and also good mechanical properties.

(5) The chloride diffusivity of the latex blend-modified mortars decreased with decreasing of the compressive strength of the modified mortars while it was independent of the flexural strength of the modified mortars.

(6) The chloride diffusivity of the modified mortars increased approximately linear with increasing of the tensile strength of the latex blend films, and decreased with the increase of the elongation at rupture of the latex blend films. When the elongation at rupture of the latex blend films increased from 200–300% to more than 800%, the chloride diffusivity of the modified mortars decreased from $10–15 \times 10^{-12}$ to $3–4 \times 10^{-12}$ m^2/s.

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