

Preparation and Properties of a Waterborne Contact Adhesive Based on Polychloroprene Latex and Styrene-Acrylate Emulsion Blend

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Abstract

Environmental protection and legislative pressure to eliminate the use of solvents in the adhesive industry have inspired the search for safer alternatives. In the area of contact adhesives, the waterborne route has proved to be of particular interest. Based on the synergistic effect of polychloroprene latex and styrene-acrylate emulsion, a waterborne contact adhesive consisting of polychloroprene latex (PCL) and styrene-acrylate emulsion (SAE) blend has been developed. In order to blend PCL with SAE easily and to accelerate the drying rate of the adhesive, boric acid was chosen for use in the PCL/SAE blend system. Effects of boric acid and SAE content on the properties of PCL/SAE blends, such as pH value, storage stability and set time, were investigated. At the same time, the effect of SAE content on the mechanical properties of PCL/SAE blend films was studied. The morphology of blend films was characterized by Atomic Force Microscopy. The adhesive performance of the waterborne contact adhesive was evaluated by peel and shear tests. The results showed that when the waterborne contact adhesive formulation contained 40 wt% styrene-acrylate emulsion (dry weight) and 1.25 wt% boric acid, it had a good shelf-stability, its set time was 5 min, and the blend film with this formulation was ductile and flexible with reasonably good tensile strength and very high elongation at break. And the blend films showed structure with a sea-island morphology. The waterborne contact adhesives derived from PCL/SAE blends were found to be comparable to the commercially available solvent-based contact adhesives. The synergistic effect of polychloroprene latex and styrene-acrylate copolymer emulsion was also discussed.

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Keywords

Polychloroprene latex, styrene-acrylate emulsion, blend, contact adhesive, synergistic effect

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List of Abbreviations

- PCL polychloroprene latex
SAE styrene-acrylate emulsion
BA butyl acrylate
St styrene
MMA methyl methacrylate
2-EHA 2-ethylhexyl acrylate
MAA methacrylic acid
2-HPMA 2-hydroxypropyl methacrylate
HBO₃ boric acid
PVC poly(vinyl chloride)
ABS acrylonitrile butadiene styrene

1. Introduction

A contact adhesive is a kind of adhesive which is dry to touch and will adhere to a surface instantaneously upon contact. Such adhesive relies on the auto-adhesive characteristics of the dried polymer, often enhanced by resin modification. The classic example is natural rubber [1]. However, natural rubber does not possess the performance expected of modern-day adhesives, and thus alternative elastomers are employed, the most widely used is polychloroprene [2–5]. Polychloroprene-based contact adhesive is largely solvent-borne [6, 7], but growing environmental and legislative pressures have inspired the search for safer alternatives [8]. Waterborne contact adhesives offer a safer alternative and polychloroprene latex (PCL) is available for their formulation [9–11]. Polychloroprene latex is probably one of the most widely used and versatile polymers ever developed as an adhesive base. Its inherent contactability, flexibility and adhesive ability make it a good choice for formulating waterborne contact adhesives [12, 13]. However, its lack of adhesion to a range of substrates and low initial bond strength must be overcome by formulating with other polymers.

Recently the polymer blending route has been investigated based on initial study showing much potential for improvement of product properties [14–16]. Careful choice of polymer type and blend ratio will lead to formulation of a new generation of water based contact adhesives. Styrene-acrylate copolymers have characteristic properties including good adhesion to a range of substrates, high initial tack and good barrier to water and gases [17]. These have led to the development of waterborne contact adhesives based on blends of polychloroprene latex and styrene-

acrylate emulsion, which combine the contactability of PCL and the adhesion of SAE.

However, it is hard to blend polychloroprene latex with styrene-acrylate emulsion, owing to the great differences between these two systems. For example, the blends easily coagulate over time. On the other hand, the use of water as a contact adhesive carrier instead of an organic solvent tends to greatly decrease the drying rate of the adhesive. Until recently, there have been only a few reports on waterborne contact adhesives based on blends of PCL and SAE.

In this study, it was found that boric acid not only could blend polychloroprene latex with styrene-acrylate emulsion easily, but also could accelerate the formation of the dry film. And a novel waterborne contact adhesive based on blend of PCL and SAE has been developed. The storage stability and set time of the latex PCL/SAE blends, and the morphology and mechanical properties of the latex PCL/SAE blend films were investigated. The adhesive properties of the waterborne contact adhesives were examined, and the synergistic effect of polychloroprene latex and styrene-acrylate copolymer emulsion was also discussed.

2. Experimental

2.1. Materials

Monomers butyl acrylate (BA), styrene (St), methyl methacrylate (MMA), 2-ethylhexyl acrylate (2-EHA), methacrylic acid (MAA), 2-hydroxypropyl methacrylate (2-HPMA), emulsifiers Triton X-405 and sodium dodecyl sulfate (SDS), and neutralizer ammonia solution (25 wt%) were all technical grade obtained from Guangdong Carpoly Co. Ltd. (Jiangmen, China). Initiator potassium persulfate ($K_2S_2O_8$), sodium bicarbonate ($NaHCO_3$), potassium hydroxide (KOH), boric acid (HBO_3), and zinc oxide (ZnO) were of analytical grade and purchased from Guangzhou Chemicals Factory (Guangzhou, China). Polychloroprene latex (PCL) and stabilizer E-Mulvin W were purchased from Bayer (China) Ltd., Shanghai Polymer R&D Center. Deionized water was used throughout the styrene-acrylate emulsion preparation.

2.2. Preparation of Styrene-Acrylate Emulsion

The styrene-acrylate emulsion was based on 2-EHA-BA-MMA-St-MAA-HPMA copolymer prepared by semibatch emulsion polymerization technique with starved feeding. The monomers concentrations were adjusted to yield a polymer whose theoretical glass transition temperature was $-15^\circ C$, and it was calculated by using the Fox equation for random copolymers. Functional monomers MAA and 2-HPMA were both at a level of 2 wt% (based on total monomer charge). The weight percent solid content of the styrene-acrylate emulsion was designed to be 50%.

The styrene-acrylate emulsion was prepared in a 1 L glass reaction vessel fitted with a stirrer, water-cooled condenser, nitrogen bleed, thermocouple and feed vessels for initiator and monomers. Deionized water and sodium bicarbonate were

charged to the reaction vessel and heated to 80°C. A few minutes prior to addition of the monomers, a certain amount of initiator solution was added once to the reaction vessel, then a certain amount of monomers (8% charge of the total monomer) was fed at constant rate into the reaction vessel within 15 min, then kept it at 80°C to react for 15 min. Then the remaining monomers and initiator solution were fed to the reaction vessel at constant rate over a 4 h period. During the 4 h of feeding, the reaction temperature was controlled at 80°C. After feeding was over, the reaction temperature was also maintained at 80°C for 30 min, and then heated to 86°C to react for 1 h. Last, the reaction mixture was cooled to room temperature. The pH value of the emulsion was adjusted to 7–7.5 with aqueous ammonia solution.

2.3. Preparation of Waterborne Contact Adhesives by Blending PCL and SAE

Blending of PCL with SAE should be done carefully because there are great differences in the two systems. The procedure was to add boric acid solution to adjust the pH value of PCL first, and then slowly add SAE to the adjusted PCL with stabilizer E-Mulvin W solution. The whole process was carried out under mild stirring. Additionally, it is essential to incorporate acid acceptors into all adhesive compounds containing PCL to minimize the degradation of the adhesive due to release of hydrochloric acid from PCL. Zinc oxide solution has been shown to be an effective agent for this purpose. Other optional additives including tackifiers, antioxidants, viscosity modifiers, pigments, fillers, and preservatives may also be used in this adhesive formulation. The basic recipe for the waterborne contact adhesive was as follows: PCL 58.75 wt%, SAE 40 wt%, zinc oxide solution 1.25 wt% (based on the dry weight of the total adhesive components).

2.4. Experimental Techniques

2.4.1. Particle Size, Zeta Potential and Viscosity Measurements

Particle size and Zeta potential of PCL and SAE were measured by a particle size analyser (Mastersizer S, Malvern, Instruments Ltd., England) at 25°C. Circumvolved Viscometer (Brookfield Engineering Labs., USA) was also employed to measure the viscosity of PCL and SAE.

2.4.2. Room Temperature Stability

A 500-ml polyethylene bottle was filled to capacity with a test sample, sealed with a cap, and allowed to stand at room temperature (25°C, 50% humidity). The sample was visually examined at various time intervals. If the sample had not congealed, it was considered stable. The storage stability is reported in days.

2.4.3. Elevated Temperature Stability

A test sample was kept in an oven at 50°C and observed at regular intervals (on a daily basis) to see if it had coagulated. If coagulation was observed, then the time period at the previous observation was noted as the 'Elevated Temperature Stability' value. If the test was discontinued before coagulation was observed, the value would be recorded as 'greater than'. For example, '> 15 days' indicated that the test was discontinued at 15 days and the composition had not coagulated.

2.4.4. Set Time

Multiple test coupons were prepared as follows: 10.16 cm × 10.16 cm high-pressure laminated sheets were evenly sprayed with the test adhesive, then they were laid flat on a counter where air movement was not noticeable and timing was started using a stop watch. After the film was dry, tack free (finger touch method), two laminated pieces with the film on them were pressed together. Immediately, one test coupon was tested to determine if a bond had formed by pulling them apart in 180 degree peel mode. A bond was formed if one of the laminate surfaces was substantially void of adhesive. Stopped timing when the two films formed a bond. If the films did not form a bond (there was a substantial amount of the adhesive remaining on each laminate), the test coupon was tested every 15 s until the bond was formed. The total time required to dry the film and form a film to film bond was then recorded as the set time and was reported in minutes.

2.4.5. Mechanical Property Measurement

Dumbbell-shaped film samples were prepared by coating the latex blends on molded sheets. The films were dried at ambient temperature for 24 h followed by a 12 h bake at 80°C and then kept for 4 days at ambient conditions. The thickness of the film sample was measured with a bench thickness gauge. Tensile tests were done on an Instron Universal Testing Machine 3367 according to ASTM D412 using dumbbell-shaped specimens. The tests were conducted at 25°C and at a crosshead speed of 50 mm/min with a 3-cm grip distance. In each case five samples were tested and the average value was reported.

2.4.6. Morphology Analysis

The morphology of PCL/SAE blend films was investigated by atomic force microscopy (AFM). AFM images were obtained as follows. A NanoScope multimode AFM (CSPM3000, BenYuan Nano Apparatus Ltd., China) was used, and AFM scans were performed in the tapping mode with untreated silicon cantilevers, under ambient conditions. The scan speed used was 1.0 Hz for all images.

2.4.7. Adhesive Strength

Adhesive strength values of PCL/SAE blend contact adhesives were obtained from T-peel, 180 degree peel and tensile shear tests. The tests were carried out in accordance with ASTM-D 1876, D903 and D3528 standard methods, respectively. The T-peel and 180 degree peel strength were both measured at a crosshead speed of 100 mm/min, and the tensile shear strength was measured at a crosshead speed of 5 mm/min until bond failure. The test machine used was Instron Universal Testing Machine Model 3367. The values obtained were averages of five replicates.

3. Results and Discussion

3.1. Characterization of PCL and SAE

Latex blending strongly depends on the colloidal characteristics of the latex such as particle size and its distribution, surface charge property of the particle, viscosity,

etc. So, it is important to know the colloid characteristics of the latex. The main colloidal characteristics of the PCL latex and SAE emulsion are shown in Table 1. A narrow particle size distribution of SAE (polydispersity index 0.015) with an average particle diameter 109 nm and a relatively broad distribution of PCL (polydispersity index 0.043) with an average particle diameter 124 nm were observed. The Zeta potential values of PCL and SAE were -64 mV and -48.8 mV, respectively at the pH 8.2. The apparent viscosities of PCL latex and SAE emulsion were 100 mPa s and 136 mPa s, respectively.

3.2. Effect of Boric Acid on Properties of Blends

Commercially available polychloroprene latex has a pH value from 11 to 13. Previously, it was believed that below a pH of 9, polychloroprene latex would lose its storage stability. Styrene-acrylate emulsion commonly has a pH value below 8. Owing to the differences in these two systems, it is difficult to blend polychloroprene latex with styrene-acrylate emulsion. For example, the blends have a tendency to coagulate over time. Thus it is essential to find a way which can lower the pH value of polychloroprene latex whilst maintaining its stability. A number of experimental results showed that adding boric acid solution enabled the pH of polychloroprene latex to be lowered whilst still maintaining good shelf life, which made it easy to blend polychloroprene latex with other resinous dispersions. It can be seen from Table 2 that by adding boric acid into polychloroprene latex, the pH value of the PCL is below 9, while its storage stability is still good. For the other pH conditioning agents, they lowered the pH value of polychloroprene latex, however, they

Table 1.
Main colloidal characteristics of PCL latex and SAE emulsion

	Mean particle size (nm)	Viscosity (mPa s)	Zeta potential (mV)
PCL	124	100	-64
SAE	109	136	-48.8

Table 2.
The effect of boric acid (HBO_3) on properties of blends

Sample	pH	Room temperature stability (days)	Elevated temperature (50°C) stability (days)	Set time (min)
PCL	11.8	>180	>15	8
PCL + HBO_3	8.5	>180	>15	5
PCL + NH_4Cl	9	<2	<1	not tested
PCL + HCl	7.8	<1	<1	not tested
PCL + SAE	9.2	<90	<5	9
PCL + HBO_3 + SAE	8.2	>180	>15	5

Table 3.The effect of HBO₃ content on properties of blends*

HBO ₃ content (wt%)	pH	Room temperature stability (days)	Elevated temperature (50°C) stability (days)	Set time (min)
0.25	9.0	<120	<5	8
0.5	8.6	<150	11	7
1	8.3	>180	>15	5.5
1.25	8.2	>180	>15	5
1.5	8.0	<150	10	4.5
2	7.8	<90	<5	4
2.5	7.7	<90	<5	4

*The SAE content is 40 wt%.

inevitably resulted in loss of stability of PCL. For example, when the same weight of ammonium chloride solution was added to the equivalent polychloroprene latex, it was found that as soon as the pH value dropped to less than 9.5, it resulted in loss of stability and coagulation of the latex. A similar loss of stability was also noted when dilute hydrochloric acid was added to the sample instead of ammonium chloride. The set time is a vital parameter for a contact adhesive, it gives an indication how quickly the adhesive can bond the parts. From the table it can be easily seen that the set rate of polychloroprene latex containing boric acid is much higher than that of polychloroprene latex without boric acid. As mentioned above, it was concluded that boric acid not only can blend polychloroprene latex with styrene-acrylate emulsion easily, but it also can accelerate the formation of the bond. Therefore, boric acid was used in the PCL/SAE blend systems.

The effect of HBO₃ content (0.25–2.5 wt%, by weight based on the dry weight of the total adhesive component) on the contact adhesive properties was also studied (Table 3). From the table, it can be seen that for HBO₃ content in the range of 1–1.25 wt%, the set time of the contact adhesive is about 5 min, whilst the adhesive has good storage stability. In the formulations, a HBO₃ content of 1.25 wt% was chosen as the optimal content. In addition, it was found that it was preferable to add HBO₃ to the polychloroprene latex as 5 wt% solution. The process involved first dropping HBO₃ solution into the polychloroprene latex under mild stirring, then blending it with styrene-acrylate emulsion and with stabilizer E-Mulvin W solution.

3.3. Effect of SAE Content on Properties of Blends

PCL has good properties, however, its lack of adhesion to a range of substrates and low initial bond strength must be overcome by formulating with other polymers. Styrene-acrylate copolymers have good properties such as high initial tack, and good adhesion to a wide range of substrates. The incorporation of SAE into PCL greatly improved the adhesive properties of PCL. In the experiment, it was found

Table 4.
The effect of SAE content on properties of blends *

SAE content (wt%)	Initial viscosity (mPa s)	Viscosity after 30 days (mPa s)	Room temperature stability (days)	Set time (min)
0	100	105.7	>180	5
10	101.3	cannot test	<1	5
20	104.9	cannot test	<30	5
33	106.2	142.6	<120	5
40	111.6	128.5	>180	5
50	115.4	129.1	>180	5
60	122.3	130.9	>180	7
66	125.7	131.3	>180	9
75	130.1	134.8	>180	12

* Each formulation contained 1.25 phr 5 wt% HBO₃ solution based on hundred parts of the dry weight of the total adhesive component.

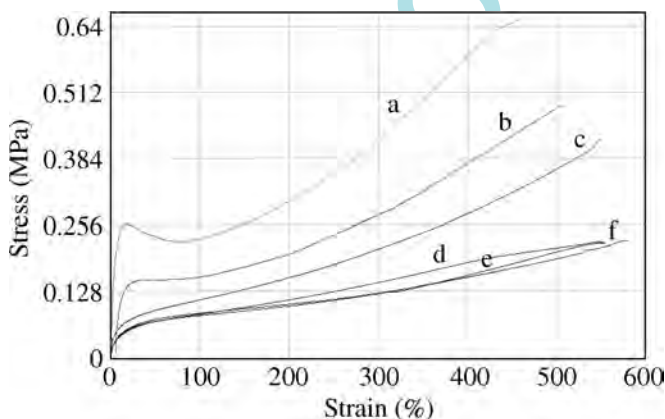


Figure 1. Stress–strain curves of the PCL/SAE blend films with various SAE contents (a: 0 wt%, b: 33 wt%, c: 40 wt%, d: 50 wt%, e: 60 wt%, f: 66 wt%).

that the SAE content in the formulation had considerable effect on the stability and the set time of the PCL/SAE blends (Table 4). From Table 4, it is concluded that when the SAE content is in the range of 40 wt% to 60 wt%, the PCL/SAE blends have good storage stability, and the set time is 5–7 min. In the formulations, SAE content of 40 wt% was chosen as the optimal content.

3.4. Effect of SAE Content on Mechanical Properties of Latex Blend Films

Figure 1 shows the stress–strain behavior of the PCL/SAE blend films under tension. The stress–strain curves give an idea of the mode of deformation of the blends under an applied load. The stress–strain curve of the PCL/SAE blend film without SAE shows obvious yield point with relatively high elongation (curve a). This indi-

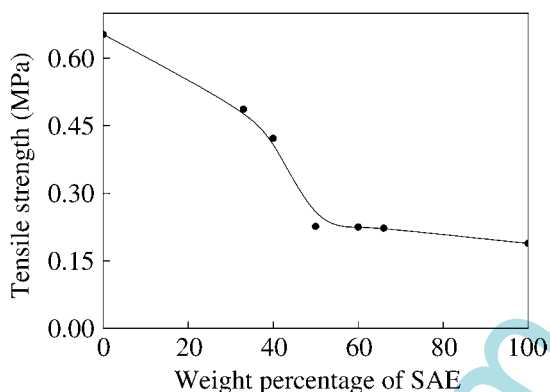


Figure 2. Effect of SAE content on tensile strength of PCL/SAE blend films.

cates that the PCL film is hard and flexible. The hard characteristic of the PCL/SAE blend film gradually shifted to soft characteristic when the amount of SAE was increased (curves b–f). The stress–strain curves of the PCL/SAE blend films exhibited no yield point up to SAE content of 40 wt%. It can also be seen that the modulus of the PCL/SAE blend films decreased with an increase of SAE content.

The study of tensile strength and elongation is important for film forming materials in assessing their characteristics. A contact adhesive is required to be soft. Films obtained from low T_g SAE copolymers are soft compared with those from PCL due to the crystallization of PCL. Therefore, PCL is suitably modified by SAE. The effect of SAE content on the mechanical properties of the blend films was investigated. The results for the tensile properties of the PCL/SAE blend films containing varying amounts of SAE are shown in Fig. 2. It was found that PCL film showed a higher tensile strength because of its strain-induced crystallization. The tensile strength of PCL/SAE blend films first decreased with the increase of the SAE content, and then leveled off when the SAE content was above 50%. The reason is that adding SAE as flexibilizer increased the distance between rubber molecular chains, and reduced the interaction of rubber molecules. Consequently, this led to the sliding motion of rubber chains and resulted in the reduction of the tensile strength. From Fig. 3, the elongation at break of PCL/SAE blend films increased with increasing SAE amount and then leveled off when the SAE content was above 40 wt%. Based on tensile strength and elongation at break values, the optimal content of SAE was found to be 40 wt%, and for this blend the tensile strength was 0.4864 MPa, the elongation at break was 518.5%.

3.5. AFM Morphology Analysis

AFM images of PCL, SAE and PCL/SAE blend films recorded using the tapping mode are shown in Fig. 4. SAE surface topography showed a flat continuous film with R_{rms} (root mean square) roughness of 1.91 nm (Fig. 4a). In contrast, PCL film showed uniform distribution of hills and valleys and R_{rms} value was found to be 13.8 nm (Fig. 4b). Different surface morphologies were observed in the case

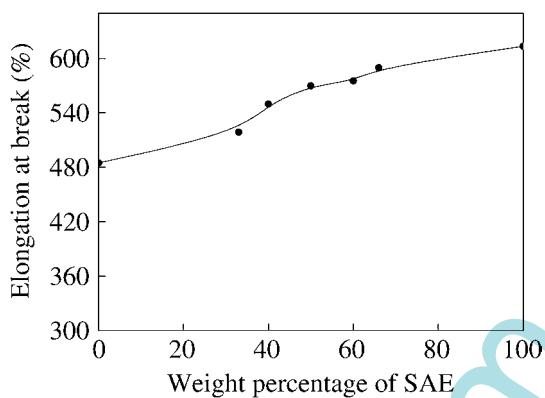


Figure 3. Effect of SAE content on elongation at break of PCL/SAE blend films.

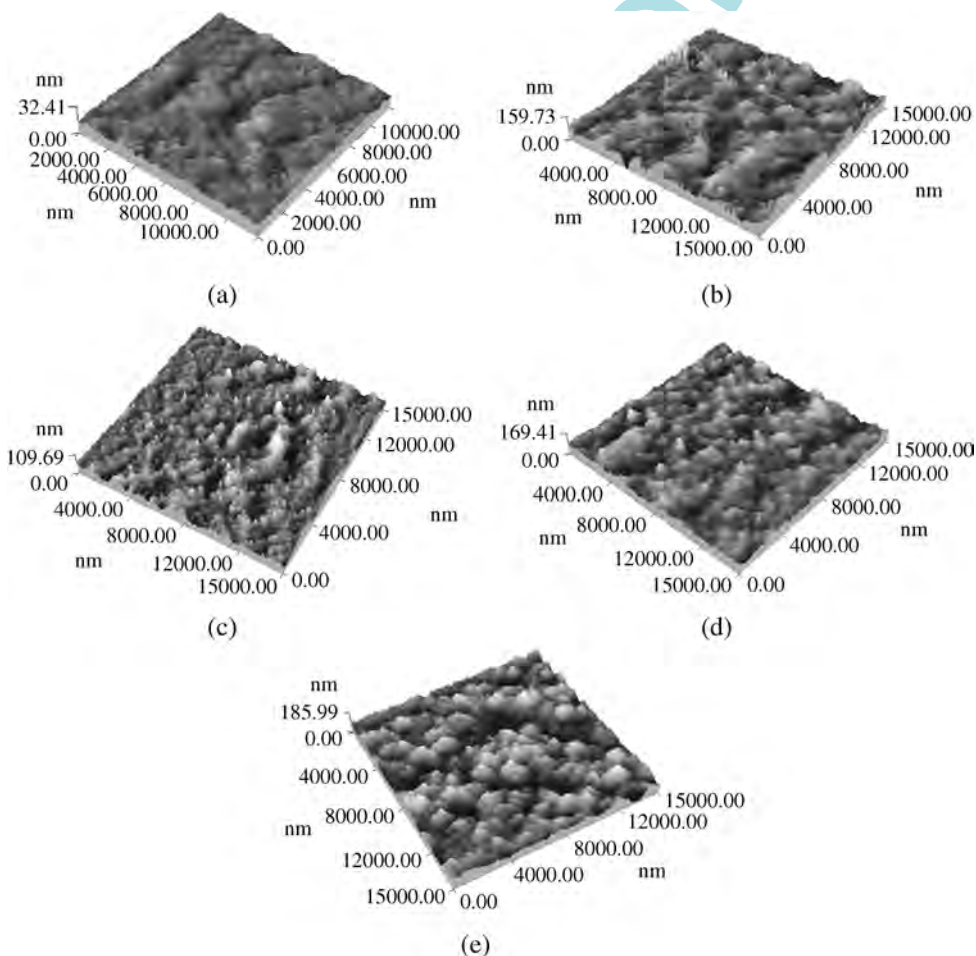


Figure 4. 3-D AFM images of pure SAE and PCL and of PCL/SAE blend films with various SAE contents. (a) SAE, (b) PCL, (c) 40 wt% SAE, (d) 50 wt% SAE and (e) 60 wt% SAE.

of various SAE contents (Fig. 4c–4e). The blend containing 40 wt% SAE showed structure with a sea–island morphology and roughness of $R_{\text{rms}} = 15 \text{ nm}$ (Fig. 4c). It may be assumed that dark areas (the disperse phase) are SAE-rich phase and bright areas (the continuous phase) are PCL-rich phase. Thus, the PCL/SAE blend of 60/40 wt% had a two-phase structure, when SAE dispersed phase was uniformly distributed in the continuous PCL matrix. Similar results were also reported by Jankauskaite *et al.* [18] in the blend system of polychloroprene and piperylene–styrene. Both the lateral size and height of the surface hills became larger, when SAE content was further increased (Fig. 4d and 4e). For the PCL/SAE blend of 40/60 wt%, the roughness of R_{rms} value was equal to 21.3 nm (Fig. 4e).

3.6. Performance of Waterborne Contact Adhesive

Tables 5 and 6 compare the performance of the present adhesive with a commercially available solvent-based contact adhesive. It can be seen from tables that the present waterborne adhesive is comparable to the commercially available solvent-based contact adhesive.

The present adhesives can be widely used for a variety of substrates. The materials bonded together can be the same or of different compositions. Suitable substrates include wood, metal (such as cold-rolled steel), fabric, paper, foam, plastic

Table 5.

T peel strength (canvas to canvas) of adhesives*

Drying condition	Cure time	T peel strength (N/mm)	
		1	2
Room temperature, 30 min	30 min	0.2	0.3
70°C, 20 min	30 min	4.5	4.2
Room temperature, 30 min	7 days	5.3	5.5

* 1 — the present waterborne contact adhesive containing 40 wt% SAE and 1.25 phr 5 wt% HBO_3 (dry weight), 2 — a commercially available solvent-based contact adhesive.

Table 6.

Tensile shear strength (plywood to plywood) of adhesives*

Drying condition	Cure time	Tensile shear strength (MPa)	
		1	2
Room temperature, 30 min	30 min	0.3	0.3
70°C, 10 min	30 min	0.7	0.5
Room temperature, 10 min	7 days	1.8	2.0

* 1 — the present waterborne contact adhesive containing 40 wt% SAE and 1.25 phr 5 wt% HBO_3 (dry weight), 2 — a commercially available solvent-based contact adhesive.

Table 7.

180 degree peel strength values (substrate to canvas) for the present waterborne contact adhesive*

Substrate	180 degree peel strength (kN/m)
PVC	0.9
ABS	0.8
Plywood	1.3
Galvanized steel	0.6
PU sponge	Sponge damage

* The present waterborne contact adhesive containing 40 wt% SAE and 1.25 phr 5 wt% HBO₃ (dry weight), drying condition: 50°C, 30 min and cure time: 24 h.

(such as poly(vinyl chloride)), polystyrene, and so on. Table 7 presents test results for peel strength between various substrates used in the decorative laminate industry to canvas. Five substrates were tested: poly(vinyl chloride) (PVC), acrylonitrile butadiene styrene (ABS), galvanized steel, plywood, and PU sponge. The galvanized steel was cleaned with solvent to remove oils and oxides. It can be concluded that the present contact adhesive exhibits good performance on a wide variety of substrates.

3.7. Synergistic Effect of Polychloroprene Latex and Styrene-Acrylate Emulsion

The polychloroprene latex and styrene-acrylate emulsion blend combines the contactability of PCL and the adhesion of SAE, and thus produces a desirable synergistic effect. In the experiments, it was found that incorporation of styrene-acrylate emulsion into polychloroprene latex significantly altered its adhesion properties. The improvement of adhesion properties of PCL/SAE blends was attributed to the synergistic effect of PCL and SAE. In the polychloroprene latex and styrene-acrylate emulsion blend system, SAE component offers good wetting ability to substrates, increases the effective copolymer concentration at substrate/blend interface [18], and improves the initial tack of the adhesive. At the same time, the PCL component possesses excellent crystallization ability, and enhances the cohesive strength of the adhesive matrix. So a desirable synergistic effect is produced when SAE is incorporated into PCL.

4. Conclusions

A waterborne contact adhesive based on polychloroprene latex and styrene-acrylate emulsion blend has been developed. The storage stability and set time of the PCL/SAE blends, and the mechanical properties and morphology of the PCL/SAE blend films were investigated with special reference to the effect of SAE content. The adhesive performance of the waterborne contact adhesive was evaluated by both peel and shear tests. The following conclusions were reached:

- (1) Boric acid can lower the pH value of polychloroprene latex whilst maintaining its good storage stability, and thus makes it easy to blend polychloroprene latex and styrene-acrylate emulsion. Boric acid also can accelerate the formation of the bond for the PCL/SAE blend contact adhesive.
- (2) When the waterborne contact adhesive formulation contained 40 wt% styrene-acrylate emulsion (dry weight) and 1.25 wt% boric acid, it had good shelf stability, its set time was 5 min, and the blend film with this formulation was ductile and flexible with reasonably good tensile strength and very high elongation at break. The PCL/SAE blend film surface showed a sea–island morphology.
- (3) The performance of this waterborne contact adhesive was found to be comparable to that of solvent-based contact adhesives.
- (4) In the polychloroprene latex and styrene-acrylate emulsion blend system, SAE component offers good wetting ability to substrate, increases the effective copolymer concentration at the substrate/blend interface, and improves the initial tack of the adhesive. At the same time, the PCL component possesses excellent crystallization ability, and enhances the cohesive strength of the adhesive matrix. So a desirable synergistic effect is produced when SAE is incorporated into PCL.

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