

Review

Study the intermolecular interaction of polymethylhydrosiloxane modifying acrylic resin and their application on anticorrosion area

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ABSTRACT

A series of polymethylhydrosiloxane modifying acrylic resins (PSi-AR resins) have been designed and synthesized. Their properties have been studied by varying the relative content of the two components. Firstly, polymethylhydrosiloxane (PHMS) was modified with divinylbenzene (DVB) via electrophilic addition to endow it with the reactive functional groups. Then the modified PHMS (D-PHMS) was blended with acrylic monomers, initiator, and the mixed solvent, and the PSi-AR resins were obtained via solution polymerization. The structure and the thermodynamic properties of the resins, and the interface character, mechanical and anticorrosion properties of the corresponding coatings were studied systematically. In particular, the self-stratification properties of the PSi-AR resins have been studied in detail. Since the D-PHMS component tended to float on the top layer of the coating, the surface of the coating showed hydrophobic properties, with which the contact angle of the coatings was $>100^\circ$ and increased with the content of D-PHMS. With excellent mechanical and anticorrosion properties, the coatings demonstrate excellent performance, which can be potentially employed in paints for metal corrosion protection.

1. Introduction

With the development of the economy and social progress, the requirements for material protection are getting more specific. Simple protective or decorative functions have been difficult to meet people's needs for coatings [1]. In addition, the easiness of the treatment of the paint needs to be considered. For traditional methods, the coating process needs multiple steps, which consumes a lot of manpower and material resources [2,3]. Furthermore, the difference in interlayer adhesion between different layers will directly affect the mechanical properties of coatings [4–6]. In recent years, self-stratification coatings have attracted the attention of coating researchers with their simple process methods and special coating properties [7–9].

To be more specific, the self-stratification coatings have the following advantages: (1) a multi-coating system can be formed via a one-time coating process, which saves coatings materials and reduces the operating costs [10]; (2) the interlayer adhesion between various

layers of the coatings is improved [11,12]; (3) the flexibility and hardness of the coating film can be well tuned; (4) the internal pressure formed in the process of film formation or film repair can be eliminated, resulting in reduced permeability of and enhanced anti-corrosion performance of the coating [13]; (5) the self-stratification coatings can selectively penetrate the porous matrix to improve their adhesion property; and (6) the coatings' surface properties, such as gloss, wear resistance, sag resistance, chemical resistance, light resistance, and weather resistance, can be improved [14,15].

Silicone resin is a commonly film-forming resin with low surface tension. Due to its good chemical and thermal stability [16], it is often physically blended with other polymer resins to prepare coatings, sealants, adhesives and so on [17–19]. However, due to the difference in polarity between resins with different structures, the compatibility between the two phases is relatively poor, which can affect the mechanics and protective properties of the cured coatings [20–22]. To solve for the poor compatibility between Silicone resin and other polymer resins,

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researchers have designed and prepared a novel composite coating with a self-stratifying mechanism and explored its application [23,24]. Maude Jimenez et al. dissolved the silicone resins and biobased epoxy resins in various solvent blends, which were then applied on a composite substrate and cured under different conditions to obtain stratified coatings. They studied various parameters, including (i) the surface tension and the polarity of the resins, (ii) the volatility of the solvent, (iii) the curing temperature and (iv) the reactivity of the epoxy/amine reaction by a systematic approach. Neda Kargarfard and Michaela Gedan Smolka et al. prepared a self-stratification coating, through melt treatment, based on silicone/epoxy blend systems, which presents easy-to-use, eco-friendly, and industrial-favorable procedure properties [25].

Our research group has used epoxy resin and amino silicone oil as blended resins [26]. The peculiarity of the self-stratification coating is characterized by joining components with different polarities through chemical bonds, which provides the coating with reliable hydrophobicity (contact angle above 130°), good thermal tolerance (above 350°C), excellent toughness, chemical, corrosion resistance, and self-cleaning properties. In addition, aggregation-induced emission luminous (AIEgens) were introduced in the self-stratification coatings to trace their preparation and curing processes. The results showed that the knitting effect of chemical bonds between the blended polymer chains had no effect on the self-stratify formation of the coatings. On the contrary, the compatibility between the two phases of the polymer was improved, and the coatings exhibited good mechanical and anti-corrosion properties.

Based on our previous findings, we have designed and synthesized a novel self-stratification resin by knitting polymethylhydrosiloxane (PHMS) and acrylic resin with carbon bonds, which is stable in pH environments. Firstly, PHMS was modified with DVB, and then the modified PHMS with vinyl functional groups was blended and copolymerized with acrylate monomers by the method of free radical copolymerization. Through this method, acrylic and silicone resins are evenly dispersed in the organic solvent system. The effect of various component resins and the solvent polarity on the properties and morphology of the cured coatings with self-stratifying characteristics were then studied systematically.

2. Experimental section

2.1. Materials

Styrene (St, C.P.), isooctyl acrylate (2-EHA, C.P.), glycidyl methacrylate (GMA, C.P.), hydroxyethyl acrylate (HEA, C.P.) were obtained from Jiangsu Qiangsheng Functional Chemical Co. Ltd.; polymethylhydrosiloxane (PHMS, hydrogen content: 0.1) was purchased from Shanghai Xibao New Material Co. Ltd.; Divinylbenzene (DVB A.R.) was provided by Jiangsu Wuxi Jiasheng Pharmaceutical Chemical Equipment Co. Ltd.; Platinum catalyst (A.C.) was supplied by Shenzhen Ke Junqi Technology Co. Ltd.; Benzoyl peroxide (BPO A.R.) was obtained from China Pharmaceutical Group Chemical Reagent Co. Ltd. Butyl acetate (MEK C.P.) and Dimethylbenzene (DMB C.P.) were both provided by Jiangsu Qiangsheng Functional Chemical Co. Ltd.; Dodecenylsuccinic anhydride (DDSA A.R.) was provided by Jinan Xinlonghai Industry and Trade Co. Ltd. All chemicals were purchased from commercial sources and used directly as received without further process.

2.2. Synthesis of the self-stratification resin

Firstly, DVB-modified-PHMS (D-PHMS) resin was synthesized via the addition reaction. DVB and PHMS were uniformly mixed with 2:1 mol ratio between DVB and PHMS (active hydrogen), and then the Platinum catalyst (0.5 %) was added at room temperature. The reaction temperature was raised to 150°C and the mixture was stirred for 30–60 min. After the system was cooled to room temperature, the designed D-PHMS was obtained.

Secondly, the self-stratification resin was synthesized by solution polymerization. The obtained D-PHMS was mixed with acrylic monomers (St, 2-EHA, HEA, and GMA) and initiators. Then, the mixture was gradually dropped, in a duration of 3 h, into the xylene/butyl acetate mixed solution under stirring at 90°C . The dripping process lasted for 3 h. Then, the temperature was raised to and maintained at 110°C for another 6 h. After cooling to room temperature, PHMS-modified acrylic resin was obtained, and named as PSi-AR-X (where x represents the relative quality of D-PHMS). Fig. 1(a) represents the synthesis process for PSi-AR-X resin.

2.3. Preparation of the PSi-AR-X coatings

To explore the correlation between the morphology and properties of the cured coatings made from PSi-AR-X resins, steel panels and silica glass were selected as substrates, on which the coatings form. Steel panels were polished using sandpaper and then washed with alcohol to remove dust before being coated. A series of PSi-AR-X resins, along with the curing agent DDSA, were then blended well and coated onto the treated steel panels and silica glass (wiped with alcohol cotton balls) via the winding bar. The coatings were dried at room temperature for 6 h and then cured at 180°C for 0.5 h. Fig. 1(b) shows the coating and curing process for PSi-AR-X coatings.

2.4. Characterizations

FTIR spectra were collected by a Nicolet iS10 Fourier Transform Infrared Spectrometer (Thermo Electron Corporation, USA), in the range of $4000\text{--}500\text{ cm}^{-1}$ with a resolution of 4 cm^{-1} . DSC analysis was carried out by the Diamond DSC 8000 Differential Scanning Calorimeter apparatus, and the heating and cooling cycles were conducted between -50°C and 120°C at a rate of $10^\circ\text{C min}^{-1}$ under a 50 mL min^{-1} flow of nitrogen. The thermal stability of the coatings was analyzed by a Diamond TG-DTA thermogravimetric analyzer (Perkin Elmer Instruments). Contact angle measurements were conducted with a Theta Lite Contact Angle Meter from Biolin Scientific in Germany using distilled water ($\gamma = 72.8\text{ mN m}^{-1}$; $\gamma_d = 21.8\text{ mN m}^{-1}$; $\gamma_p = 51\text{ mN m}^{-1}$). SEM-EDX analyses were performed on a Hitachi S4700 (Tokyo, Japan) with a field emission gun, at 13.0 kV and 25 μA . To facilitate cross-section analyses, the tested coatings were cut in liquid nitrogen. The anti-corrosion properties of the coatings were tested by using the American Gamry electrochemical workstation. A 3.5 % NaCl solution is used as the corrosion medium. For Tafel polarization curve tests, the polarization curve scan rate was 2.5 mV/s, and the dynamic potential scan range was 1–1.5 V (relative to open circuit potential). The exposed area of the coating was 9.6 cm^2 . AC impedance tests were conducted at a frequency range of 100KHz to 0.01 Hz with an AC amplitude of 10 mV (relative to open circuit potential). The sample film was cut into specific dimensions, weighed (m_0), and immersed in deionized water for 70 h. The surface moisture was wiped off and weighed (m_1) every 10 h. Each sample was measured three times and the average value was taken. The water absorption rate was calculated according to the following equation:

$$M = (m_1 - m_0)/m_0 \times 100\%$$

3. Results and discussion

3.1. The structure analysis of the synthesized resins

With the reactive Si-H group, PHMS resin acts as the electrophilic reagent to react with electron-rich organic compounds via electrophilic addition reaction. FTIR measurement was carried out to confirm reaction products. As seen in Fig. 2(a), the strong broad absorption peaks near 1080 cm^{-1} and 1024 cm^{-1} are attributed to the Si—O—Si chemical bond, and the peaks at 1260 cm^{-1} and 806 cm^{-1} correspond to the symmetric stretching vibration of C—Si—C. The peak at 2125 cm^{-1} for

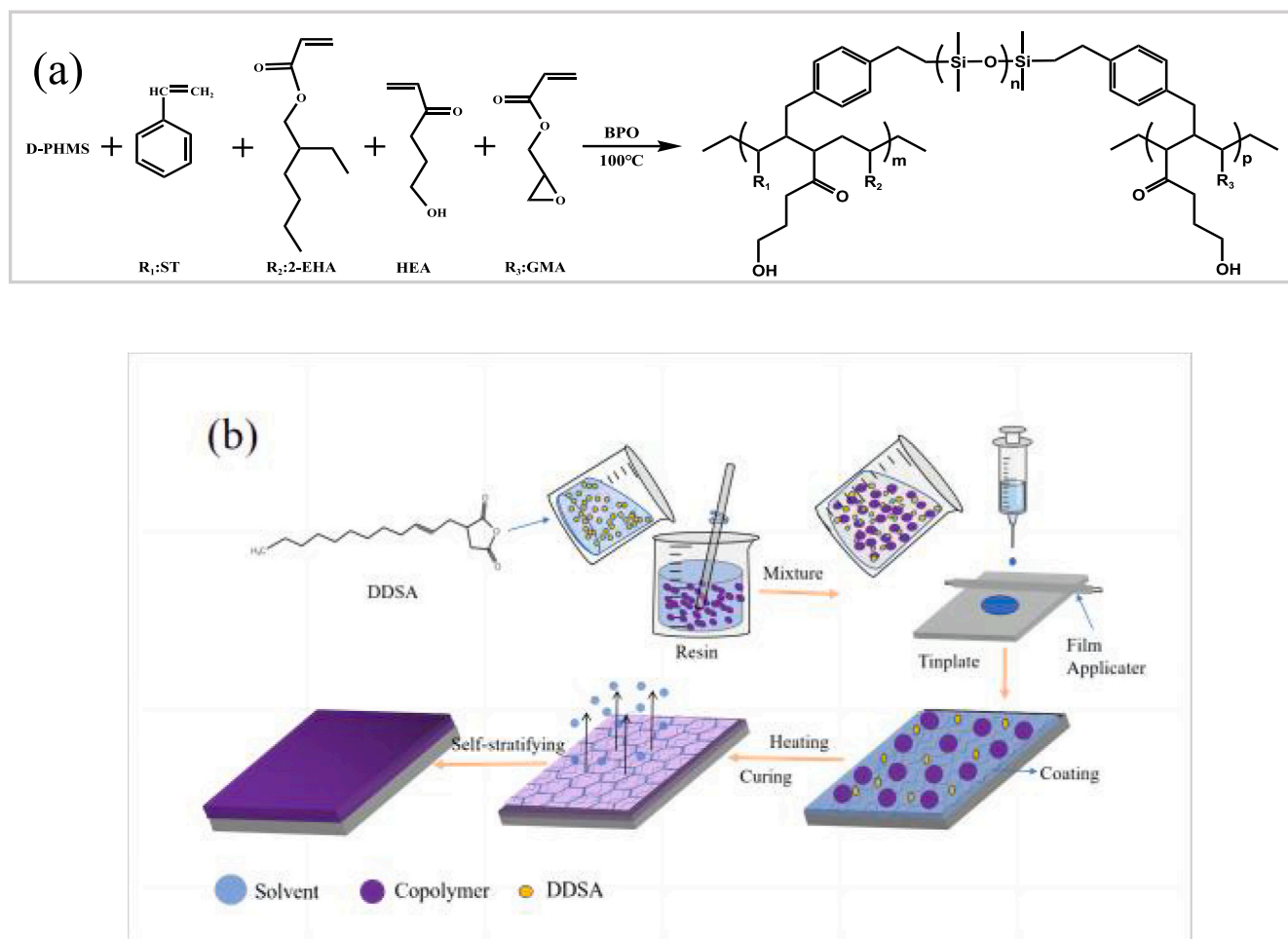


Fig. 1. The schematic diagram for synthesis of (a) PSI-AR-X coatings; (b) the coating and curing process of PSI-AR-X coatings.

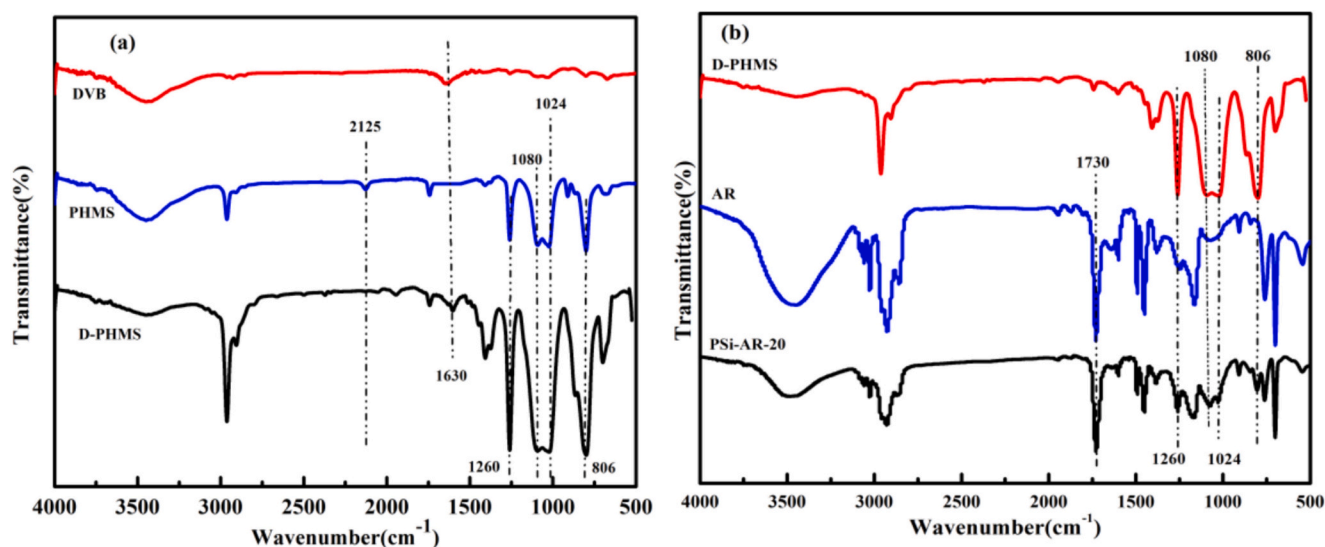


Fig. 2. Comparison of the FTIR of raw materials and products of (a) D-PHMS, (b) PSI-AR-20.

PHMS is attributed to the stretching vibration of Si—H, which significantly reduces to zero after reaction, proving that the reaction has been carried out effectively and PHMS and DVB are connected by chemical bonds. D-PHMS exhibits an absorption peak at 1630 cm^{-1} for the C=C functional group, with which the synthesized D-PHMS can react with the

acrylate monomers via radical polymerization. Fig. 2(b) presents the FTIR spectra of D-PHMS, AR (acrylic resin), and the synthesized copolymer PSI-AR-20. The peak at 1730 cm^{-1} corresponds to the stretching vibration of acrylic ester. The peaks at 806 cm^{-1} , 1024 cm^{-1} , and 1260 cm^{-1} are assigned to the characteristic peaks of the PHMS

component, which indicates that the PSi-AR-20 has been successfully synthesized.

3.2. The effect of PHMS on the synthesized hybrid resins

To study the interference of the knitted PHMS on the thermodynamic properties of hybrid resins, Differential Scanning Calorimetry (DSC) measurement was conducted. As presented in Fig. 3(a), the T_g value of AR resin is 39.8 °C, which is close to the value calculated from FOX formula. Interestingly, the T_g values of the prepared composite PSi-AR-X coatings increase gradually with the copolymerized D-PHMS. Although the Si-O-Si polymer segments exhibit flexible properties, the multi-reactive groups on the D-PDMS lead to higher crosslinking density of the system, which inhibits the free movement of the polymer chains and increase the T_g value of the cured coatings.

AR and PSi-AR-20 were then taken as examples, and the impact of PHMS on the heat resistance of the cured coating was studied via TGA measurement. As shown in Fig. 3(a), the heat resistance of the PSi-AR-20 coating is better than that of the pure AR coatings, in which the thermal decomposition temperature can be increased up to 23 °C. The covalent bond energy of Si-O-Si (450 kJ/mol) of PHMS is much larger than those of the C-C covalent bond (332 kJ/mol) and the C-O covalent bond (326 kJ/mol). In addition, the excellent heat resistance of silicone resin is related to the flexible helical structure of silicone molecules. When the test temperature rises, the spiral structure of the Si-O-Si chain extends and the distance between molecules increases with higher temperature [27].

In general, the mechanical properties of the cured polymer coatings are closely related to its T_g value. As discussed above, the crosslinking density of polymer chains gradually increases with the content of D-PHMS. In Table 1, pencil hardness is increased with the content of D-PHMS, which follows the same pattern with the T_g value of the cured polymer coatings. Although the coating's adhesion property is ruined by the copolymerized D-PHMS, the adhesion value of cured coatings can be kept above 1 MPa due to the interaction of hydrogen bonds and polar bonds of the acrylic resin component with the metal substrate, which are good enough to be applied in practical use. Besides, it is worth noting that the cured coating maintains good flexibility and shock resistance.

3.3. The self-stratification behavior of the synthesized hybrid resins

According to the principle that solvents and polymer resins with similar polarity are easy to dissolve with each other [28], the synthesized hybrid resins, e.g. PSi-AR-X, can form a self-stratified coating by changing their composition and the type of solvents. In general, the Hansen solubility spheres can be used as a tool for confirming the feasibility of self-stratification film formation. Three parameters, e.g. δ_d (dispersion force interactions), δ_p (polar force interactions), and δ_H

Table 1

The influence of D-PHMS on the mechanical properties of the cured coatings.

Test name	Flexibility (mm)	Pencil hardness	Shock resistance (kg-cm)	Adhesion (MPa)
Acrylic resins	0.5	HB	50	1.53
PSi-AR-5	0.5	H	50	1.47
PSi-AR-10	0.5	H	50	1.39
PSi-AR-15	0.5	2H	50	1.23
PSi-AR-20	0.5	2H	50	1.18

(hydrogen bonding interactions) are used to describe the cohesive energy densities of the polymer resins. By analyzing the overlap area of the spheres (V), the compatibility of the polymer components is determined, which can aid the design and optimization of self-stratification coatings. Based on the structure and polarity characteristics of the composite resin, xylene, and ethyl acetate were selected as weak-polarity and high-polarity solvents, respectively, and the relative mass ratio between them was set at 2:1.

Previous studies have shown that a prerequisite condition for delamination is an overlap factor $V < 80$ %. However, meeting this condition does not necessarily guarantee delamination occurs [29]. The occurrence of phase separation can be affected by various factors such as solvents, surface tension, compatibility, and curing process [22]. This model only analyzes the solubility parameters of two polymers and obtains an overlap factor of 53.6 %, which is much lower than 80 %, indicating that PSi-AR-X can undergo phase separation during its curing process. Detailed information is presented in the Supplementary Documents.

To confirm the self-stratification behavior that has occurred during the film-forming process, understanding the dispersion behavior of the components in the cured coating is critical. Therefore, PSi-AR-20 was taken as the example, and the cross-section and the surface morphology of the cured coating were examined by SEM and the relevant EDS-mapping measurement. The coating had a total thickness of ~200 μm (see Fig. 4).

Although the surface of the coating appears to be smooth, the cross-section of the dried coating shows a hierarchical structure from top to bottom. The relative content of the elements at different positions of the dried coating (Top layer and Base layer) are summarized in Table 2, the Si element tends to concentrate in the top positions of the coating, which may reduce the surface tension of the coating.

3.4. The surface and interface properties of coatings and their water resistance properties

With the self-stratification behavior of the PSi-AR-X resins, more PHMS components tend to float on the surface of the coating, which

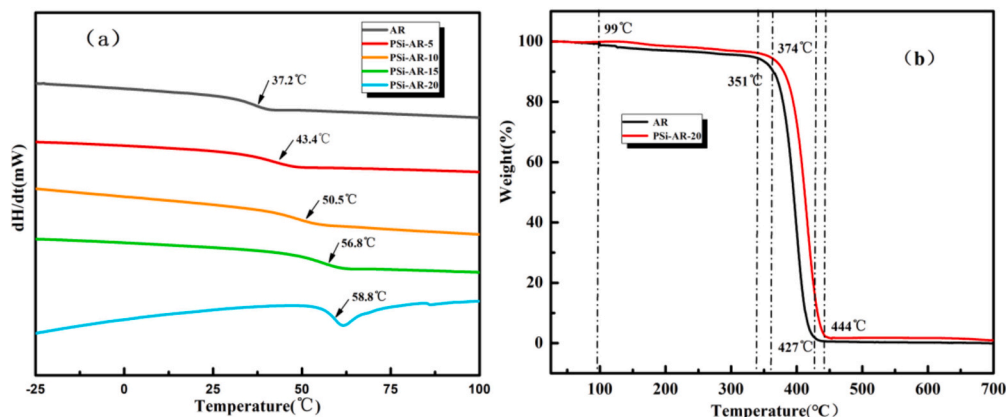


Fig. 3. (a). DSC spectra of acrylic resin with different D-PHMS contents. (b). TGA measurement of AR and PSi-AR-20.

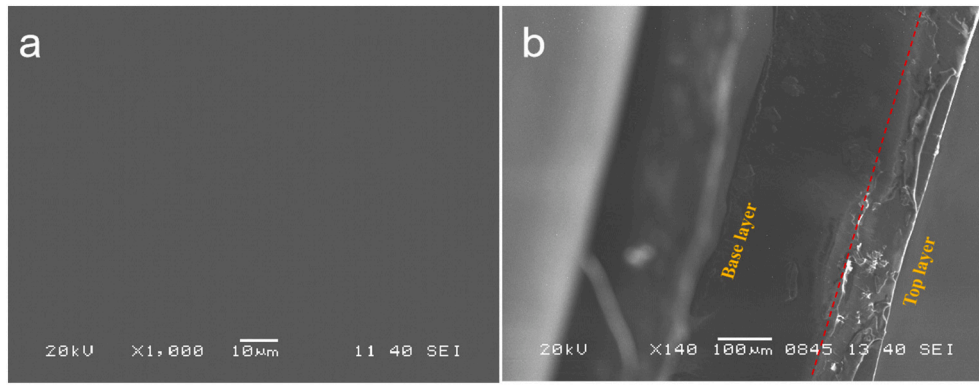


Fig. 4. SEM images of the cured PSI-AR-20, the surface morphology (a), and the cross-section morphology (b).

Table 2

The element contents at different positions of the PSI-AR-20 coatings.

Position	C(%)	O(%)	Si(%)
Top layer	71.92	25.43	2.65
Base layer	72.30	27.49	0.21

contributes to the hydrophobicity of the cured coatings. The water contact angle (WCA), surface free energy (SFE) and water absorption rate were then measured to evaluate the effect of PHMS on the surface properties of the cured coatings. To minimize the effect of surface roughness on water contact angles, coatings were prepared under the same conditions with a film thickness of $110 \pm 4 \mu\text{m}$.

Fig. 5(a) shows the WCA and SFE results of various PSI-AR-X samples. For classic acrylic resin-based coating, its WCA and SHA values are 75° and 43 mJ/m^2 respectively, which presents the hydrophilic nature. When the acrylic resin is knitted with PHMS via a chemical bond, the contact angle and surface tension of the cured coating increase linearly with the gradual increase of D-PHMS content. The cured coatings gradually show hydrophobic properties. When the content of D-PHMS reaches 20 %, the coating shows superhydrophobic properties (WCA and SHA values of the PSI-AR-X coating reach 122.28° and 42.8 mJ/m^2 , respectively).

With the increased content of D-PHMS, the hydrophobic properties of the coating enhance, and their water absorption properties change accordingly. As shown in Fig. 5(b), water absorption rates of pure acrylic-resin-based coating gradually increase with time, while the water absorption rates of PSI-AR-X coating tend to be stable with the

immersed time, and its value gradually decreases with the higher content of D-PHMS. When the content of D-PHMS exceeds 15 %, the coatings' water absorption value is lower than 0.3 %. The hydrophobicity of the coating inhibits the penetration of water, which is beneficial to effectively improve the coatings' corrosion resistance properties.

3.5. Durability of anti-fouling performance

Due to the low surface tension, the cured coating shows hydrophobic properties which can be applied to anti-fouling areas [30,31]. However, excellent durability is also indispensable in practical applications. In this part, PSI-AR-20 was taken as the example. Fig. 6 displays its anti-fouling performance under various harsh conditions, including oil immersion, boiling water treatment, and cyclic wiping. As shown in Fig. 6(a), the coated tinplate was placed in an oil bath at 120°C for 2 h firstly (a(1)), then immersed in ethanol (dyed red) for 2 min (a(2)). It can be seen that the ethanol shrank rapidly on its surface and slid off within 2 s when the tinplate was removed from the ethanol (a(3)). Besides, even after continuously flushing with boiling water onto the coated glass slide for 30 s, the anti-graffiti performance of the coating was not weakened (Fig. 5b), and the adhered clay on the coating surface can be easily washed off with a small amount of water, leaving no stains (in Fig. 5c). The durability of the coating was further evaluated through writing and erasing cycle tests, as illustrated in Fig. 6(d). After 500 cycles, the blue oil-based ink still shrank on the coating and left no trace after wiping, confirming that the coating has superior durability.

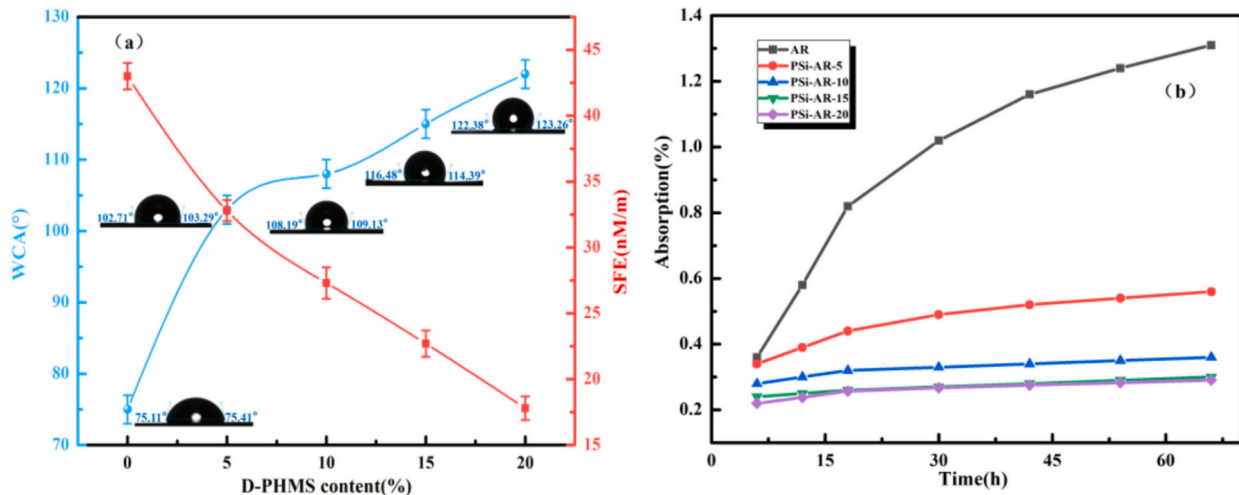


Fig. 5. (a) The WCA and (b) the water absorption property of the cured coatings with various content of PHMS.

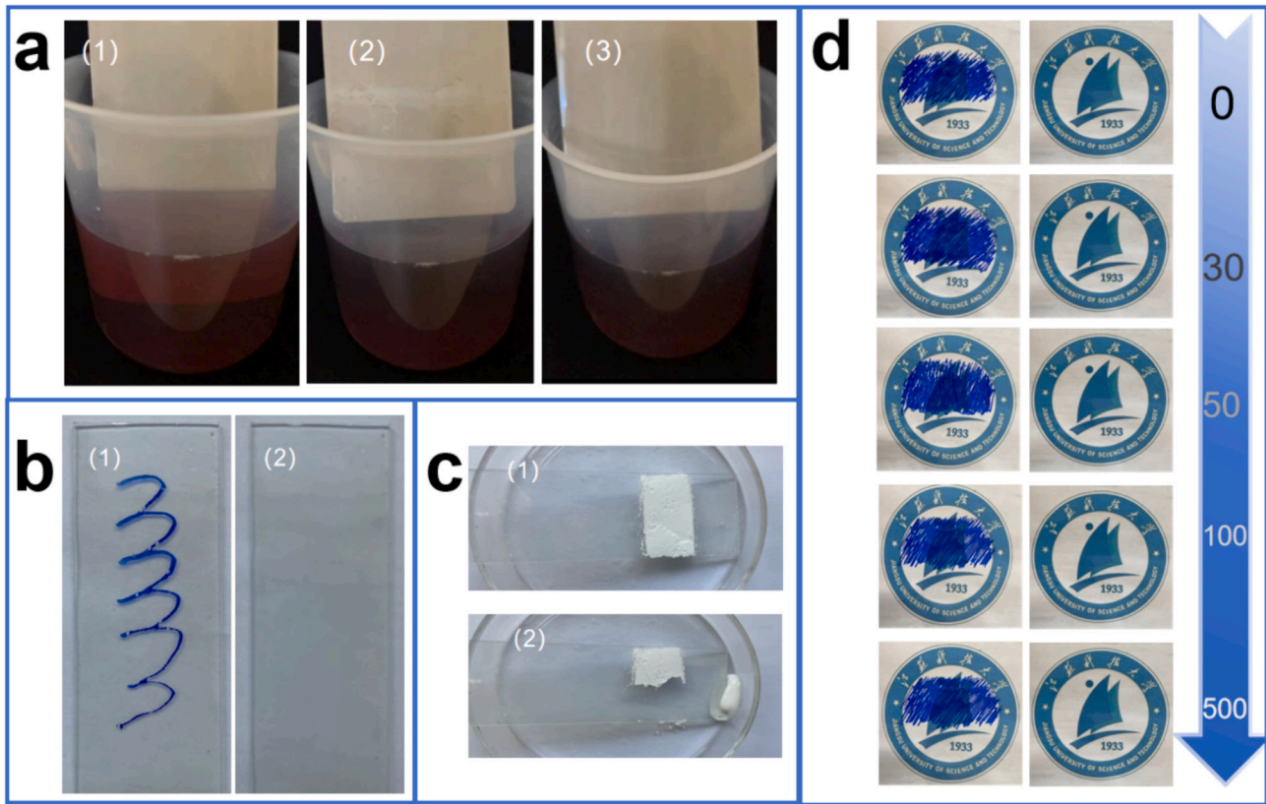


Fig. 6. The anti-fouling performance of the PSI-AR-20 coating (a) after immersing in the oil bath at 120 °C for 2 h, (b)&(c) after flushing with boiling water for 30 s, and (d) after 0, 50, 150, 300 and 500 cycles of writing and wiping.

3.6. The corrosion resistance performance analysis

PSi-AR-X samples were coated and cured onto the test steel plates, which were then immersed in the 3.5 % NaCl solution, and then the Tafel polarization curves and AC impedance spectra were collected, to study the effect of copolymerized D-PHMS on the anti-corrosion properties of the cured coatings.

3.6.1. Tafel polarization curve

Tafel polarization curves can be employed to assess the anti-corrosion performance of coatings by measuring the changes in the corrosion current density with the applied potential, and the corrosion rate (C.R.) can be calculated by using Tafel polarization data and the Tafel Eq. (1). The Tafel equation relates the corrosion current density (I_{corr}) to the corrosion rate (C.R) and various constants as follows. C.R is the corrosion rate (here given in mm/year), I_{corr} is the corrosion current density (in A/cm^2) obtained from the Tafel polarization curves, n is the number of electrons involved in the electrochemical reaction, F is the Faraday's constant ($96,485\text{C}/\text{mol}$), ρ is the density of the corroded metal (typically in g/cm^3). According to Faraday's law, the corrosion current density of the coating is proportional to the corrosion rate. The lower the corrosion current density, the slower the corrosion rate of the coating. Hence, a coating's corrosion potential (E_{corr}) and Tafel slopes reveal its susceptibility to corrosion, with a more positive E_{corr} and steeper slopes indicating improved corrosion resistance. Comparing Tafel polarization curves for different coatings allows for the selection and evaluation of coatings with superior corrosion protection properties.

$$\text{C.R (Corrosion Rate)} = I_{\text{corr}} / (n.F.\rho) \quad (1)$$

Fig. 7 shows the Tafel polarization curves of PSI-AR-X coatings at various contents of D-PHMS, obtained after the coated plates were soaked in 3.5 wt% NaCl solution for 60 days. According to Table 3, the C. R. of the coating decreases from 1.85×10^{-1} to 1.77×10^{-2} mm/year

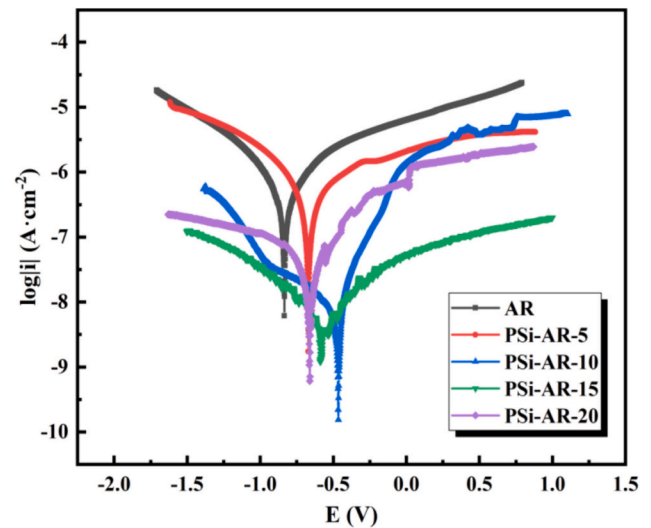


Fig. 7. Tafel polarization curves of PSI-AR-X coatings at various contents of D-PHMS.

Table 3

The Tafel extrapolation results obtained from Fig. 7.

Sample	Electrochemical corrosion parameter		$C_R(\text{mm}/\text{y})$
	E_{corr} (V)	i_{corr} (A/cm^2)	
Acrylic resins	-0.82421	7.874×10^{-6}	1.85×10^{-1}
PSi-AR-5	-0.71873	1.886×10^{-6}	4.42×10^{-2}
PSi-AR-10	-0.48591	7.542×10^{-7}	1.77×10^{-2}
PSi-AR-15	-0.69253	8.163×10^{-7}	1.91×10^{-2}
PSi-AR-20	-0.71364	9.347×10^{-7}	2.19×10^{-2}

first, and then increases to 2.19×10^{-2} mm/year at 0 % to 20%wt D-PHMS, and i_{corr} present a same pattern of change. The knitted low-polarity Si-O polymer imparts the coatings with excellent water-repellent properties, and the multifunctional D-PHMS provides the coating with a denser structure. However, excess amount of D-PHMS may affect the cross-linking reaction between the epoxy resin and the curing agent, leading to an incomplete curing of the coatings, thereby

reducing their corrosion resistance. The results confirm that the addition of an appropriate amount of D-PHMS can effectively slow down the corrosion process of the coating in the harsh environment.

3.6.2. EIS measurements

Carbon steel sheets coated with different materials were immersed in a 3.5 wt% NaCl solution to investigate the corrosion process of the cured

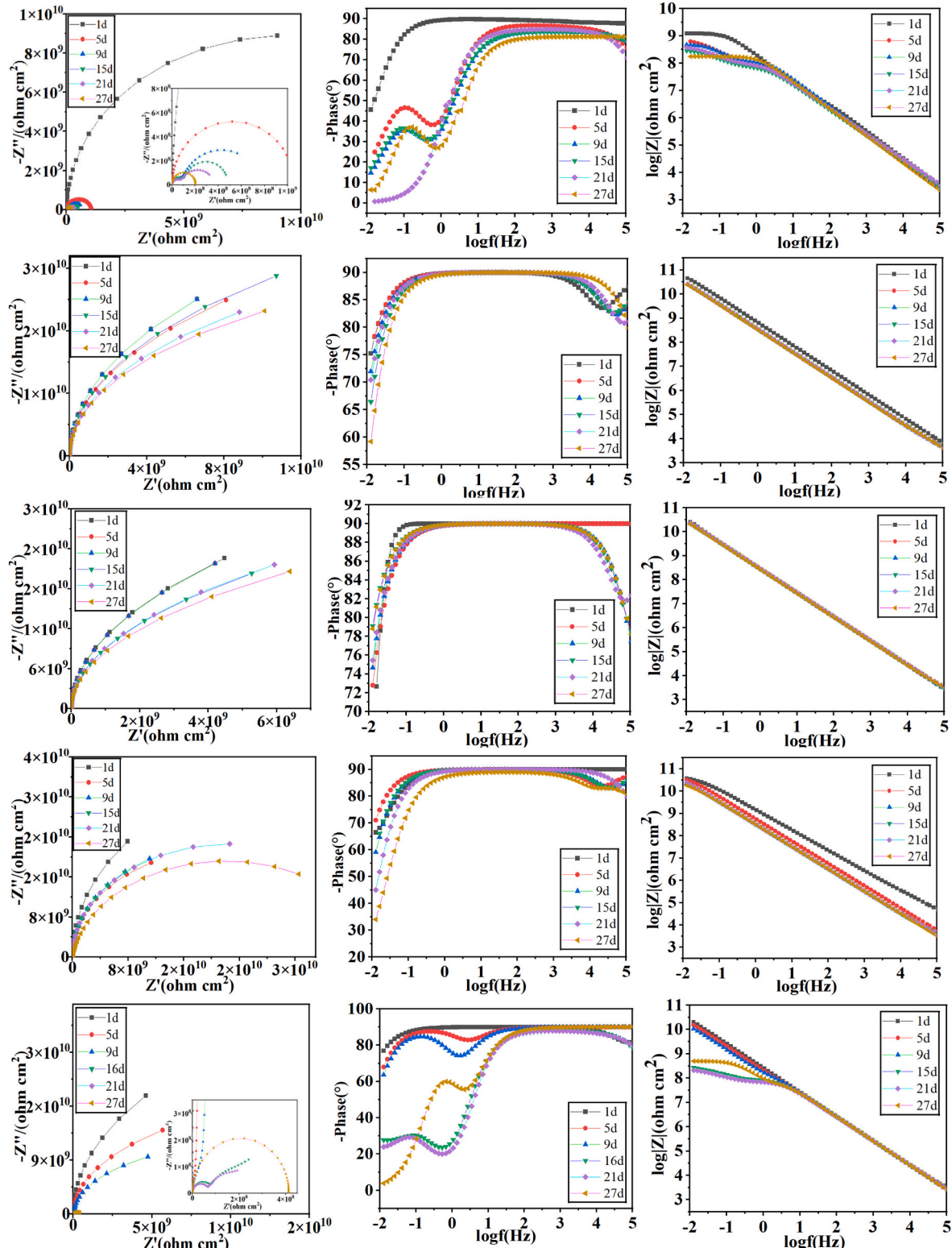


Fig. 8. (a) Nyquist plots, (b) bode plots, and (c) phase plots after their fitting the neat (acrylic resin) and modified resins (PSi-AR-5,10,15,20).

coatings. Fig. 8a displays the Nyquist diagram for various coatings after fitting. The impedance radius arcs consistently decreases with prolonged immersion time, indicating a decrease in the anticorrosion properties of the coatings over time, a common phenomenon for many coated substrates [32–35]. For pure AR coating, two capacitance loops appeared after being immersed for 9 days, suggesting that the corrosive media penetrated the coating and corroded the metal surfaces. At the same time, the corrosion products, e.g. the dissolvable metal ions have transferred from the metal surface to the electrolyte solution. In contrast, when D-PHMS is copolymerized with acrylic resin, the corrosion resistance of the coating has been significantly enhanced. As for the PSI-AR-X(5,10,15) coatings, no capacitance loop appeared during the entire test, indicating that these coatings effectively inhibited the penetration of corrosive media on the metal surface during the test time. However, there are also limits to the relative content of D-PHMS, for the sample PSI-AR-20, the capacitance loop appeared in the late stages of testing. Although the copolymerized D-PHMS can form the aquaphobic layer to inhibit the penetration of corrosive media, excessive content of D-PHMS in the coating system might damage the coatings' adhesion property, which will reduce the long-term corrosion protection properties of the cured coating.

Fig. 8b presents the phase angle diagram for the coatings over time. The width of the platform approaching “ -90° ” serves as an indicator of the coating's corrosion resistance, with a broader platform suggesting a better performance. For PSI-AR-X (5,10,15) coatings, they all have a relatively broad platform (maintain stability over 20 days), which means that they have relatively good anti-corrosion properties.

Additionally, Fig. 8c presents corresponding Bode diagrams for all the samples, demonstrating a similar pattern to the impedance spectrum. Notably, for the PSI-AR-X coatings, the impedance can be one or two orders of magnitude higher than that of the pure acrylic resin-based coating, due to the $|Z|$ value being at 0.01 Hz. In addition, PSI-AR-(5,10,15) coatings maintain robust stability over 21 days, unlike the other two coatings, which experience continuous drops of $\log|Z|$ value. However, for PSI-AR-20 coating, its impedance decreases from 10^{10} to $10^8 \Omega \cdot \text{cm}^2$ at the low-frequency zone, indicating a relatively poor long-term anti-corrosion ability.

The long-term corrosion resistances of the PSI-AR-(10,15) coatings surpass those of other PSI-AR-X coatings, suggesting the optimal modification with D-PHMS occurs in the range of 10–15 % loadings.

4. Conclusion

In summary, acrylic resins have been successfully modified with PHMS via effective chemical bonding. Due to the polarity difference between the components, the hybrid resins can form a self-stratified structure during the curing process. The chemical structures and the morphology of these coatings have been characterized by FTIR spectroscopy and SEM imaging. The cured films had good hydrophobicity, heat resistance, as well as corrosion resistance. Therefore, their potential applications as anti-smudge materials are promising. With excellent properties, we believe that these materials are ideal candidates for future applications in anti-corrosion coatings.

CRediT authorship contribution statement

Xinyu Wang: Conceptualization. **Qiyuan Li:** Investigation. **Kai Yang:** Data curation. **Yashi Shao:** Validation. **Shangui Zhang:** Investigation. **Hui Yan:** Writing – review & editing. **Weili Li:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.porgcoat.2024.108632>.

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