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Research Article

Investigation of Various Coating Resins for Optimal Anticorrosion and Mechanical Properties of Mild Steel Surface in NaCl Solution

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The primary objective of the research was to investigate the ideal resin coating on the mild steel surface among various resin coatings which are in use. These resin coatings are used as an anti-corrosive material for mild steel surfaces with enhanced mechanical properties. The resins (epoxy, polyurethane, polyester, and phenolic) on mild steel surface were applied by the pneumatic spray coating method. In addition, immersion test and salt spray test methods were followed using sodium chloride (NaCl) solution. Furthermore, the rate of corrosion and mechanical properties of mild steel coated with different resins was evaluated by conducting various experiments (immersion test, salt spray test, tensile strength test, and scratch hardness test) and was compared with a bare mild steel surface. The results of the current research showed that the mild steel surface coated with epoxy resin was found to be the most effective corrosion resistance material with better mechanical properties compared to other tested mild steel resin-coated surfaces.

1. Introduction

Mild steel plays a vital role in the lifespan of a civil engineering structure, and usually, the performance of carbon steels is hampered by its surface features such as surface texture and surface energy due to corrosion [1, 2]. It is causing a serious issue in the field of the construction industry due to loss of structural strength, reduced bond strength, ductility, and shear capacity [3, 4]. To avoid the corrosion problem and increase the tensile strength of mild steel, many attempts have been made so far by surface coating using inorganic coating, paints, resins, alloying additions, and many others. Different types of resins have been studied individually in the literature and found to be very effective in controlling the corrosion of civil structures. Many researchers have evaluated the anticorrosion properties of various types of resin coatings on mild steel surfaces. Epoxy-silane hybrid coatings have coating ratios between 1 to 3wt.% on galvanized steel which has improved the adhesion and corrosion behavior of the surface, whereas a further add up to 5wt.% resulted in reducing its corrosion/adhesion performance [5]. The cathodic delamination of polyurethane/multiwalled carbon nanotube composite coatings up to 0.5 wt.% on steel substrate has increased the corrosion protective performance in the NaCl solution proved by the scanning Kelvin probe (SKP) results [6]. Corrosion-performance evaluation studies in a 3.5wt.% NaCl electrolyte conducted via EIS and potentiodynamic polarization tests have shown that the MWCNT in polypyrrole (PPY) coating has considerably reduced the corrosion rate. Interestingly, PPY/MWCNT-COO-functionalized nanocomposite provided a higher corrosion resistance coating than PPY/MWCNT alone [7]. Mild steel coated with MWCNT/epoxy nanocomposite (0.75 wt.%) revealed a decrease in the corrosion rate up to 2.5×10^3 MPY and the protection efficiency increased up to 99.99% [8]. From the electrochemical measurements, it was found that the corrosion resistance of carbon steel has significantly improved by the hybrid coating in a 0.75% saline solution [9]. From another experimental study, it was observed that about 0.1 wt.% graphene oxide (GO) was the appropriate GO content to prepare nanocomposites of GO-epoxy with an optimum corrosion resistance [10].

It was found that MWCNTs were dispersed uniformly in the PU matrix from 4 to 6 wt. %, no aggregation and precipitation phenomena were observed in the fast spraying process [11]. B. Ramezanzadeh et al. [12] proved a coating of 0.1wt.% GO and PI-GO nanosheets to the polyurethane resin have enhanced its corrosion protection properties. Figure 1 shows the synthesis of waterborne epoxy resin (WEP) coating and fluorinated graphene (FG)-modified WEP coatings [13].

Research studies on individual resins coatings for mild steel surfaces have targeted better mechanical, physical, water, heat, resistance, and antimicrobial activity. However, very few research works were focused on identifying the optimum resin that produced the best anticorrosion and mechanical properties on the mild steel surface. Hence, the objective of the present study was to determine the ideal resin with anticorrosion and enhanced mechanical properties for a mild steel substrate. The resins (polyester, epoxy, polyurethane, and phenolic) were prepared by using the respective accelerator, hardener, and thinners. The prepared resins were used as coatings on the fabricated mild steel surface. Furthermore, the surface was subjected to corrosion analysis by performing an immersion and salt spray test. In addition, the tensile strength and scratch hardness tests were performed to evaluate the mechanical properties of the mild steel surface. The degree of anticorrosion performance and morphological characteristics of epoxy [5, 8–10, 14–24], polyurethane [6, 11, 12, 25, 26], phenolic [25, 27, 28], and polyester resins [29] as surface coatings for mild steel were compared and discussed.

2. Experimental Procedure

2.1. Materials. Polyurethane resin (FINESTER-1100) is a two-component polyurethane composition based on acrylic polyol and isocyanate. Epoxy resin (FINE COAT-EP 200A & B) is a two-component epoxy clear lacquer, cured with polyamide hardener. It cures at room temperature (above 10°C). Polyester Resin (PS) (FINESTER – 1100) is a medium viscosity modified ISO polyester resin. Phenolic Resin (PH) INSUFINE-VI 610 is an impregnating varnish based on alkyd and phenolic resins. The epoxy, polyurethane, polyester, and phenolic resins were purchased from the Fine Finish Organics Pvt. Ltd., Navi Mumbai, India. Mild steel panels were purchased from Shubh M L Shah and Sons Steel Pvt. Ltd., Mumbai, India. A pneumatic spray gun was purchased from Burhani hardware, Dahanurd, India. The technical specifications of epoxy resin, polyurethane resin, polyester resin, and phenolic resins are listed in Table 1.

2.2. Preparation of Resins and Mild Steel Surface. The polyester resin coating was prepared by adding 10 gm of polyester resin (PS) (FINESTER-1100) with accelerator-1100 and catalyst-1100 in the ratio of 100 : 1 : 1 by weight, and further, 20 mL of the thinner 643 was added for curing purposes (Figure 1). The curing was performed at room temperature between 25 and 40°C. The epoxy resin coating was prepared by first adding 10 gm of FINE COAT (EP 200 A) with EP 200 B hardener in the ratio of 2 : 1 and then the thinner of grade 643 was added (20 ml) (Figure 1). Polyurethane coating was prepared by first adding 10 gm of polyurethane resin (PU) (PU 500 A) with PU 500 B hardener (1 : 1) ratio (Figure 2). Furthermore, for phenolic resin coating, 10 gm of phenolic resin (INSUFINE-VI610) was taken for the coating purpose (Figure 2).

The surface of mild steel sheets was blasted with emery paper 80 grit size and washed with acetone to clean and remove the oxides present on the surface of mild steel. Furthermore, the specimens were dried at room temperature for 1 hour and were coated with resin. The prepared epoxy, polyurethane, polyester, and phenolic resins were sprayed on the surface of mild steel through a pneumatic spray gun. Finally, the coated mild steel specimens were dried at room temperature for 48 hours and annealed at 150°C for 1 hour in a hot-air oven. The distance maintained between the spraying gun and the specimen was about 100–150 mm to obtain the required thickness (160–180 μm) of the coating layer. Mild steel specimens coated with the different resin of 12 mm diameter were cut to a length of 300 mm for performing a tensile test. Furthermore, a flat mild steel specimen of size $125 \times 60 \times 6\ \text{mm}^3$ was used for the scratch hardness test.

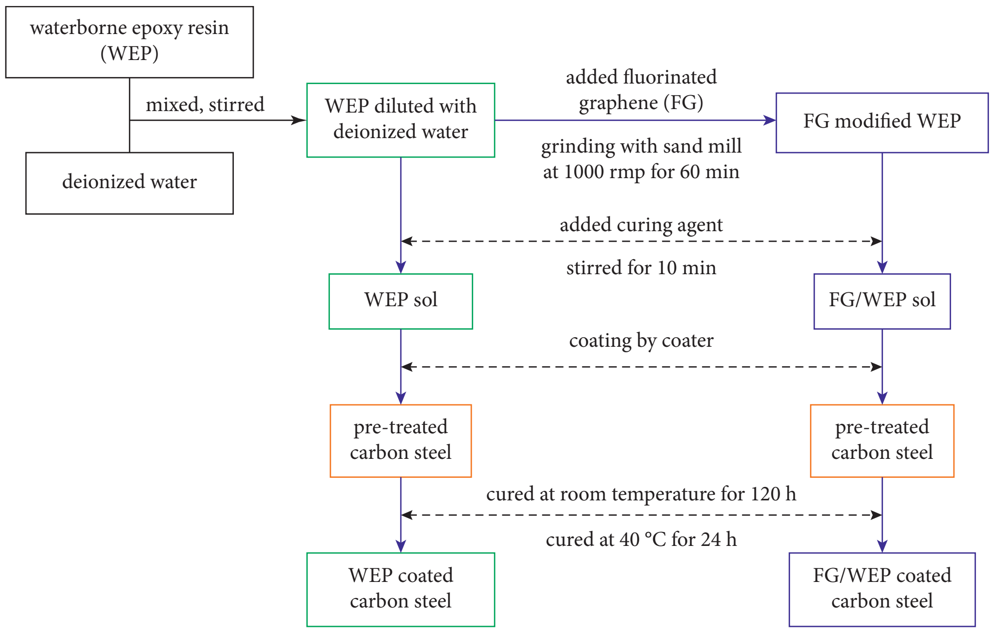

Figure 1: Synthesis of waterborne epoxy resin (WEP) coating and fluorinated graphene (FG)-modified WEP coatings [13].

Table 1: Technical specifications of resin.

Sl. No.	Resin specifications: Epoxy	Polyurethane	Polyester	Phenolic
1	Color: clear and can be dyed as per the requirement	Color: colorless (PU500/A and PU500/B)	Viscosity range, MPa.s.@30°C: 300–500	Color: yellow
2	Finish: glossy	Finish: glossy	Acid value, mg of KOH/g: 10–20	Viscosity @25°C (B4 flow cup): 30–40 sec
3	Mixing ratio Base : hardener = 2 : 1 (by volume)	Mixing ratio (PU500A : PU500B) 1 : 1 (by weight)	Color, gardener: <1	Finish: glossy
4	Pot life 14–16 hours @30°C	Viscosity at 25°C: 15 ± 5 MPa·s	Specific gravity: 1.10–1.12	Bond strength, at 30°C: 25
5	Theoretical covering capacity: 12 sq.m./lit @25 microns dft.	Solid content: 60 ± 2%	Volatile content (max.): 40	Volume resistivity at 30°C: 1–1.5 × 10^{16} cm after immersion
6	Application method: air-assisted/airless spray/brush	Application method: brush/Spray	—	—
7	—	Continuous operating temperature: 155°C	—	—

*denotes as supplied by the manufacturer.

2.3. Morphological Studies. The corrosion behavior on the surface of mild steel specimens coated with different resins was evaluated by morphological studies using a field emission scanning electron microscope (FESEM). The corroded surface was gold coated by a sputtering unit and FESEM was operated at an accelerating voltage of 20 kV.

2.4. Corrosion Studies by Immersion Test. The corrosion resistance properties of epoxy, polyurethane, polyester, and phenolic resins coated on mild steel surface were subjected to immersion method. The resin-coated samples were immersed in the aqueous 3.5% NaCl solution for 336 hours, and the corrosion rate was determined by the weighing

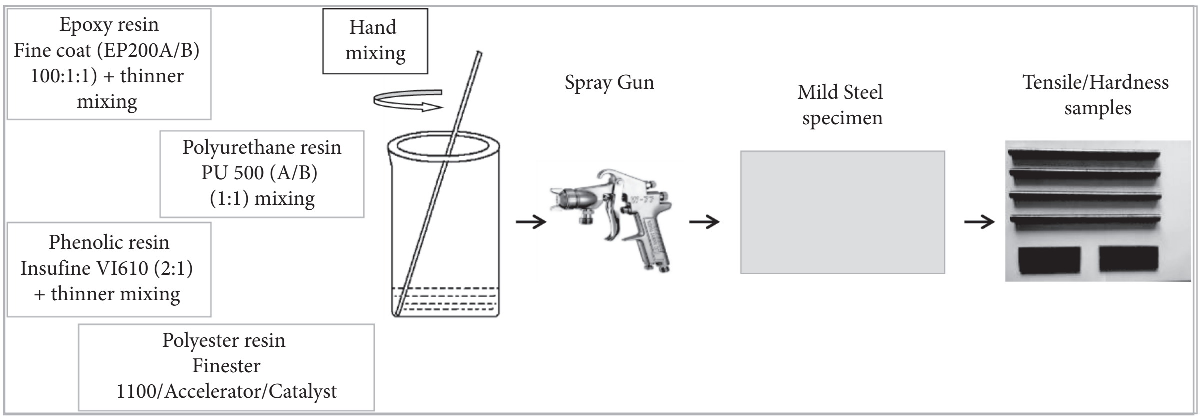

Figure 2: Schematic representation of the coating process of mild steel specimen.

method. The weight of the steel sample coated with a resin was measured before and after immersion to determine the corrosion rate. A minimum of three samples per composition were tested for obtaining an averaged corrosion response. The corrosion resistance properties obtained for bare and resin-coated mild steel samples are listed in Table 2.

2.5. Mechanical Properties

2.5.1. Tensile Strength Test (A370 : 2017). The effects of epoxy, polyurethane, polyester, and phenolic resins coated on mild steel surfaces were studied to determine their tensile strength properties. The tensile test was carried out by using a universal testing setup (A370 : 2017) to determine its ultimate tensile strength, yield load, and yield stress. For ensuring repeatability of the results, three samples were tested for each category of the resin-coated mild steel specimens. The ultimate tensile strength of plain mild steel and samples coated with different resins are presented in Table 2.

2.5.2. Scratch Hardness Test. The flat mild steel sample of a dimension of $120 \times 60\,mm^2$ was subjected to scratch hardness testing according to IS 101 (Part-5, Sec.2):1988. The minimum load required to cause the failure was noted as the hardness of the resin-coated mild steel surface. All the resin-coated specimens were tested in a batch of 3 samples to obtain accurate results, which are recorded and reported in Table 2.

3. Results and Discussion

The cumulative result of the obtained average values of corrosion resistance, ultimate tensile strength, toughness, and scratch hardness test of the bare and resin-coated mild steel specimens are listed in Table 2.

3.1. Corrosion Properties of Resin Coating. The average value of the corrosion resistive properties obtained from the immersion test for all the types of resin-coated mild steel samples is plotted as shown in Figure 3. The epoxy resin-coated mild steel sample exhibited the maximum corrosion resistivity of 4102.29 mil, followed by phenolic resin (1414.97 mil), polyester resin (1233.38 mil), and polyurethane resin (635.85 mil) coated samples in comparison to the uncoated mild steel surface, as shown in Figure 3. It was observed also that the epoxy resin-coated samples have yielded the maximum corrosion resistance property, which can be accounted for its chemical structure that induces high chemical resistivity and good adhesion properties under a wide range of corrosive conditions. This enables the mild steel specimen to remain intact even in highly humid and corrosive conditions.

3.2. Mechanical Properties

3.2.1. Stress-Strain Curve (A370 : 2017). Figure 4 depicts the stress-strain curve for different resins coated mild steel specimens. This curve is utilized for evaluating the tensile strength and toughness of the resin-coated samples. It can be observed that the ratio of stress and strain was proportional for all the types of resin-coated mild steel samples under small applied tensile force. A straight line between zero to stress value around 300 MPa can be also observed. When the force applied is greater, the samples experience elastic deformation as seen from curves. Further loading induces plastic deformation in the samples and results in a fracture. It is observed that the epoxy-coated mild steel specimen has yielded higher ultimate strength in comparison to other samples due to the difference in the elastic modulus between the two materials that make the best microstructure design in handling the applied load gradually.

3.2.2. Tensile Strength Test (A370 : 2017). The average value of ultimate tensile strength obtained from UTM for all the types of resin-coated samples in comparison to plain mild steel specimen is plotted, as shown in Figure 4(a). The samples coated with epoxy resin showed a maximum ultimate tensile strength of $505.82\,N/mm^2$, followed by phenolic resin ($491.47\,N/mm^2$), polyurethane resin ($485.63\,N/mm^2$), and polyester resin ($474.54\,N/mm^2$) in comparison with mild steel surface, as shown in Figure 5(a). The samples

Table 2: Anticorrosion and mechanical test results.

Sl. No.	Specimen	Corrosion resistance by resin (mils)	Ultimate tensile strength (N/mm^2)	Toughness (N/mm)	Scratch hardness (mg)
1	Plain mild steel	—	456.23 ± 9.12	—	150.00 ± 3
2	Polyurethane resin	635.85 ± 12.71	485.63 ± 9.71	5893.224	800.00 ± 16
3	Epoxy resin	4102.29 ± 82.04	505.82 ± 10.12	7057.32	700.00 ± 14
4	Polyester resin	1233.38 ± 24.66	474.54 ± 9.49	6738.417	300.00 ± 6
5	Phenolic resin	1414.97 ± 28.29	491.47 ± 9.82	5394.345	300.00 ± 6

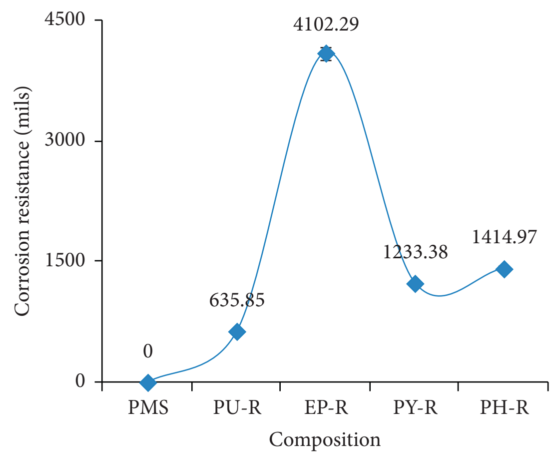

Figure 3: The corrosion resistance of the samples.

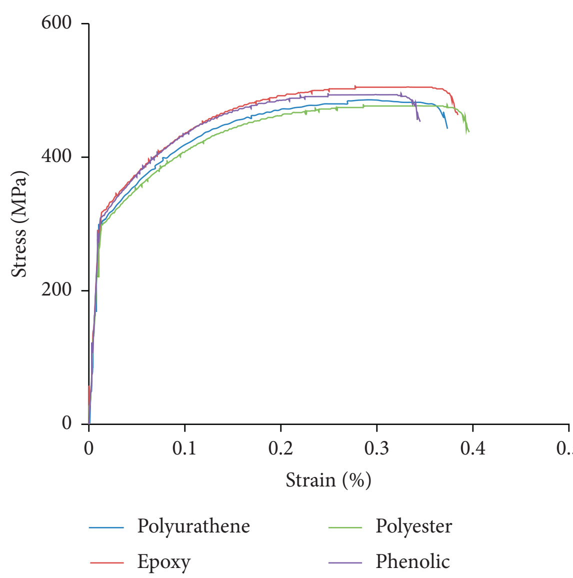

Figure 4: Representative stress-strain curves of samples coated with different polymer resins.

coated with epoxy resin showed the maximum percentage of increase in ultimate tensile strength in comparison to mild steel samples by 9.80%. It is because of the multi-coordination sites formed by the hydroxyl and amine groups that form a 3D cross-linked polymeric network for metals [30]. The good physical properties of epoxy resin such as toughness, flexibility, and abrasion resistance are superior to almost all thermoplastics in elevated temperature performance, whereas phenolic resin showed 7.72%, polyurethane showed 6.05%, and polyester resin revealed the least increase of 3.85% w.r.t the mild steel samples without coating.

3.2.3. Toughness Test of Mild Steel Samples. The toughness of resin-coated mild steel specimens is illustrated in

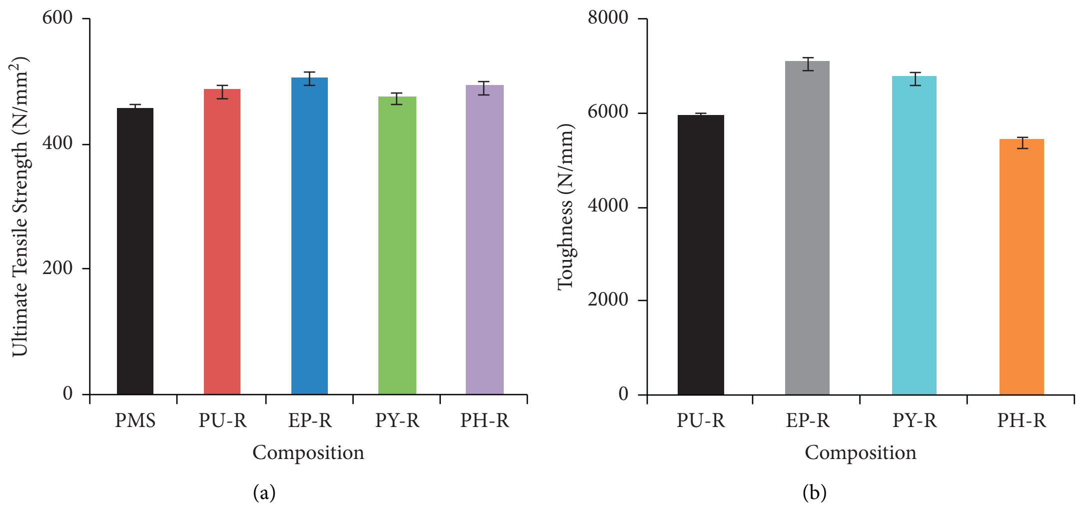

Figure 5: Experimentally calculated (a) ultimate tensile strength and (b) toughness of samples.

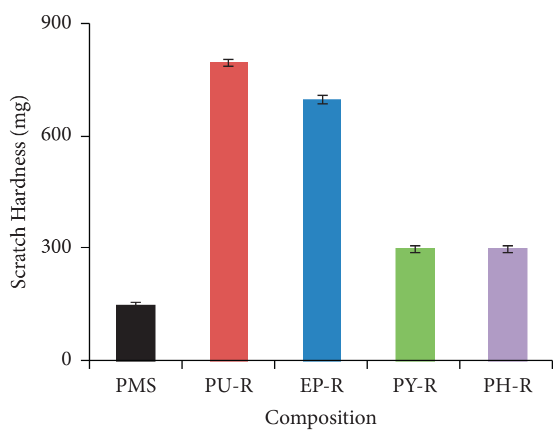

Figure 6: Scratch hardness of samples.

Figure 5(b). It can be observed that the toughness value of the resin-coated mild steel specimens was comparatively higher than the bare mild steel sample. The epoxy resin-coated sample exhibited the highest toughness index with 7057.32 N/mm compared to the phenolic resin-coated sample with 5394.345 N/mm, polyurethane resin-coated sample with 5893.224 N/mm, and polyester resin-coated sample with 6738.417 N/mm. The enhancement in the toughness result for the epoxy-coated samples is due to the two-component epoxy clear lacquer, cured with polyamide hardener and good comparative tracking index > 500 V. This is due to the extension of the 3D polymeric network by the hydroxyl and amine group present in the epoxy matrix [30]. In addition, the physical properties of epoxy resin are comparatively better than polyurethane, polyester, and phenolic resins.

3.2.4. Scratch Hardness Test. The hardness test results of bare mild steel and various types of resin-coated samples are shown in Figure 6. The scratch hardness of the polyurethane resin-coated sample revealed the maximum hardness (800mg), followed by an epoxy resin-coated sample with 700 mg. Polyester and phenolic resin-coated samples showed the least increase of hardness (300 mg) in comparison to pure mild steel samples. The scratch hardness of polyurethane resin-coated samples yielded the highest because the layer of polymer used here can protect the base material from corrosion, weathering, abrasion, and other processes that would protect the material from degradation over time.

3.3. Morphology. The morphology of various types of resin-coated mild steel samples before and after corrosion areas is depicted in Figure 7. Figures 7(a) and 7(b) show the images of FESEM of the polyurethane resin before and after the mild steel samples were exposed to corrosion. Figure 6(b) depicts the corrosion developed on the surface. Figures 7(c) and 7(d) show the images of epoxy resin-coated samples. Figure 7(d) indicates that epoxy resin has successfully protected the mild steel surface with minimum rust on its surface. Figures 7(e) and 7(f) show polyester resin-coated samples before and after oxidization, and Figure 7(f) indicates a high level of

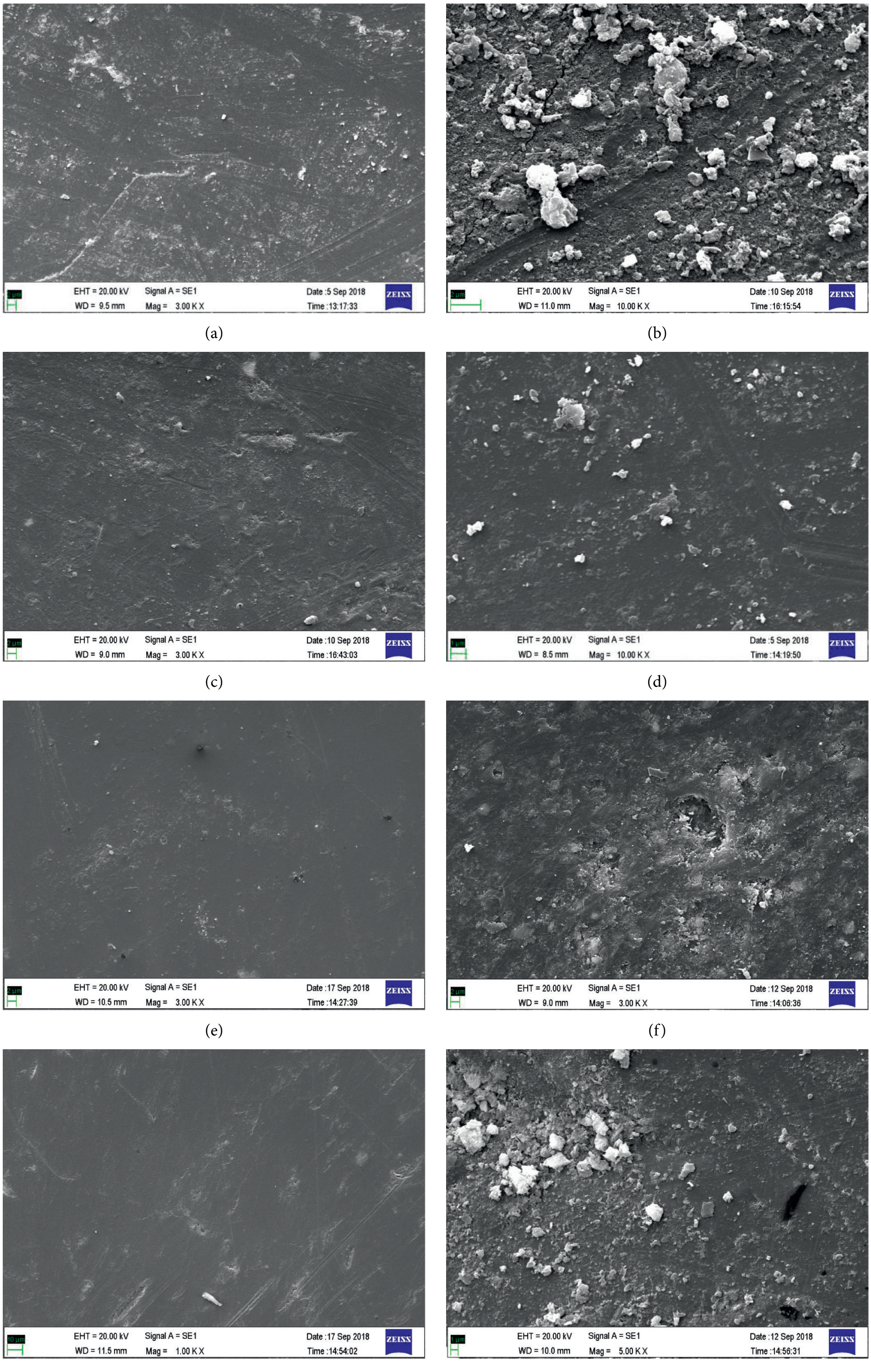

Figure 7: FESEM images of samples coated with polyurethane resin (a) before corrosion and (b) after corrosion, epoxy resin (c) before corrosion and (d) after corrosion, polyester resin (e) before corrosion and (f) after corrosion, and phenolic resin (g) before corrosion and (h) after corrosion.

corrosion. It is also worthy to notice the rusted surface (Figure 7(h)) on the mild steel sample coated with phenolic resin earlier after exposure to corrosion in comparison to before exposure (Figure 7(g)). It can be observed that the mild steel samples coated with the epoxy resin (Figure 7(d)) showed the lowest corrosion in comparison to polyurethane, polyester, and phenolic resins. The morphology results are in agreement with the results of the ultimate tensile strength and corrosion resistive in which the epoxy resin-coated mild steel specimens yielded the best performing results.

4. Conclusions

In summary, the outcomes of this study are as follows:

(i) Mild steel samples coated with epoxy resin exhibited very good resistance to corrosion. There was a remarkable increase in the rate of tensile strength of mild steel specimens coated with the epoxy resin.

(ii) It was found that the surface morphology of mild steel specimens with epoxy resin coating exhibits minute rust particles compared with other resins and plain mild steel.

(iii) Scratch hardness of polyurethane resin-coated mild steel specimen yielded better hardness in comparison to other mild steel specimens due to the presence of acrylic polyol and isocyanate. This induces better hardness to the coating surface. However, the corrosion resistance and tensile property are less than the epoxy coated samples.

(iv) FESEM analysis shows the samples coated with epoxy resin observed to have the least corroded surface compared with the other resin-coated surfaces.

(v) Since epoxy resin FINECOAT-EP 200 is a two-component epoxy clear lacquer, cured with polyamide hardener, coated samples showed superior results in comparison with the polyurethane, phenolic, and polyester resins. Epoxy resin is the most suitable resin for surface coating of mild steel to shield from corrosion and also to enhance mechanical properties.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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