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Effect of Sandblasting Pressure on Corrosion Rate and Adhesion Strength in the Coating Process

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Abstract

Street lighting poles are an essential component of public street lighting (PSL) infrastructure and are commonly manufactured from low-carbon steel. However, this material is highly susceptible to corrosion if adequate surface protection is not provided. One of the most widely adopted protection methods is paint coating. Nevertheless, paint coatings remain vulnerable to mechanical damage, which may result in coating delamination and consequently reduce corrosion protection performance. Therefore, it is necessary to investigate process parameters that can improve coating adhesion while maintaining the corrosion resistance of the substrate. This study aims to evaluate the effect of sandblasting pressure on the corrosion rate and paint coating adhesion strength of low-carbon steel. Sandblasting was carried out at three pressure levels: 7, 8, and 9 bar. The corrosion behaviour was evaluated using the potentiodynamic polarisation method, while the coating adhesion strength was measured using a pull-off adhesion test. The results indicate that increasing the sandblasting pressure led to an increase in the corrosion rate. The specimen treated at 7 bar exhibited the lowest corrosion rate of 0.00428 mm/year, whereas the specimen treated at 8 bar showed the highest corrosion rate of 0.14998 mm/year. In contrast, higher sandblasting pressure improved the adhesion strength of the paint coating. The highest average adhesion strength of 2.73 MPa was obtained at 9 bar, while the lowest value of 2.28 MPa was recorded at 7 bar. These findings demonstrate that sandblasting pressure significantly influences the surface characteristics of low-carbon steel, thereby affecting both its corrosion behaviour and coating adhesion performance. The results provide useful insights for optimising surface preparation prior to painting and may contribute to improving the durability of protective coatings for street lighting applications.

Keywords: Adhesion Strength; Corrotion Rate; Sandblasting

Abstrak

Lampu jalan merupakan salah satu infrastruktur penting dalam sistem Penerangan Jalan Umum (PJU) yang umumnya menggunakan material baja karbon rendah. Material ini memiliki kerentanan terhadap korosi apabila tidak memperoleh perlindungan permukaan yang memadai. Salah satu metode proteksi yang paling banyak diterapkan adalah pelapisan menggunakan cat. Namun, metode ini masih memiliki kelemahan, terutama terhadap kerusakan mekanis yang dapat menyebabkan pengelupasan lapisan cat sehingga menurunkan efektivitas perlindungan terhadap korosi. Oleh karena itu, diperlukan penelitian untuk mengkaji parameter proses yang dapat meningkatkan kualitas daya lekat lapisan cat sekaligus mempertahankan ketahanan korosi material. Penelitian ini bertujuan untuk mengevaluasi pengaruh variasi tekanan pada proses *sandblasting* terhadap laju korosi dan kekuatan adhesi lapisan cat pada baja karbon rendah. Variasi tekanan yang digunakan dalam penelitian ini adalah 7 bar, 8 bar, dan 9 bar. Laju korosi dievaluasi menggunakan metode *potensiodinamik*, sedangkan kekuatan adhesi lapisan cat diuji menggunakan *pull-off adhesion test*. Hasil penelitian menunjukkan bahwa peningkatan tekanan *sandblasting* meningkatkan laju korosi. Spesimen dengan tekanan 7 bar menghasilkan laju korosi terendah sebesar 0,00428 mmpy, sedangkan spesimen dengan tekanan 8 bar menunjukkan laju korosi tertinggi sebesar 0,14998 mmpy. Sebaliknya, peningkatan tekanan *sandblasting* memberikan pengaruh positif terhadap kekuatan adhesi lapisan cat. Nilai kekuatan adhesi tertinggi diperoleh pada tekanan 9 bar dengan rata-rata sebesar 2,73 MPa, sedangkan tekanan 7 bar menghasilkan nilai adhesi terendah, yaitu sebesar 2,28 MPa. Temuan ini menunjukkan bahwa variasi tekanan pada proses *sandblasting* memberikan pengaruh yang signifikan terhadap karakteristik permukaan baja, yang selanjutnya memengaruhi ketahanan korosi dan daya lekat lapisan cat. Penelitian ini kemudian diharapkan dapat diaplikasikan pada pelapisan pada lampu jalan.

Kata kunci: Kekuatan Adhesi ; Laju korosi ; Sandblasting

1. Introduction

Street lighting is one of the essential infrastructures in public street lighting (PSL) systems. Various types of street lighting are designed to fulfil different functional requirements, including luminaires installed in pedestrian areas and public recreational spaces such as city squares. These lighting systems play a crucial role in providing adequate illumination and ensuring the safety and comfort of pedestrians during nighttime [5]. According to [9], street lighting is an important element of urban street furniture that contributes to visual comfort and shapes the character of urban spaces. Furthermore, the placement and design of street lighting influence public perception of an area, particularly in tourist destinations such as Malioboro.

Low-carbon steel is widely used as the primary material for manufacturing street lighting poles because of its good mechanical properties, widespread availability, and relatively low cost. However, this material is highly susceptible to corrosion if adequate surface protection is not provided [2]. Corrosion not only degrades the mechanical integrity of the material but also poses safety risks and increases infrastructure maintenance costs [4]. In outdoor environments, such as those where street lighting poles are installed, corrosion is likely to occur due to continuous exposure to rainfall, high humidity, and atmospheric pollutants.

Selecting an appropriate coating method is essential to prevent premature structural deterioration. Among the various surface protection techniques available, paint coating is the most commonly applied method for protecting street lighting poles. This method offers several advantages, including ease of application, cost-effectiveness, and flexibility in coating material selection. However, paint coatings are susceptible to physical damage, particularly coating delamination or peeling, which can significantly reduce their protective performance. Consequently, surface protection has become a critical aspect of surface engineering aimed at improving corrosion resistance and extending the service life of steel components.

In the field of surface engineering, the adhesion quality between a coating and its metallic substrate is strongly influenced by surface characteristics, including surface roughness, cleanliness, surface energy, and the presence of contaminants. Appropriate surface preparation promotes stronger mechanical interlocking and improved interfacial bonding, thereby enhancing coating adhesion while reducing the penetration of corrosive media through coating defects [3]. Several surface preparation techniques are commonly employed, including power tool cleaning, phosphating, and sandblasting. Previous research [6] reported that sandblasting produced lower coating adhesion strength than the other surface preparation methods investigated. However, that study employed a relatively low sandblasting pressure of 4 bar. In contrast, [7] demonstrated that increasing the sandblasting pressure to 6 bar resulted in a rougher surface profile and improved coating adhesion strength. Furthermore, [3] reported that sandblasting parameters, particularly the spraying angle and nozzle-to-surface distance, have a significant influence on surface roughness. A shorter spraying distance and a spraying angle closer to normal incidence produced a rougher surface profile, thereby improving the potential for mechanical interlocking between the coating and the substrate.

Despite these findings, studies investigating the influence of higher sandblasting pressures on both corrosion behaviour and coating adhesion strength remain limited. Therefore, this study aims to evaluate the effect of sandblasting pressures of 7, 8, and 9 bar on the corrosion rate and coating adhesion strength of low-carbon steel. By evaluating both corrosion behaviour and adhesion performance, this study seeks to provide technical recommendations for optimising sandblasting as a surface pre-treatment process prior to painting, thereby improving coating performance and reducing the maintenance costs of street lighting infrastructure.

2. Material and Method

Several tools and materials were required for this experiment :

2.1 Equipment and Materials

The equipment used to support this research included in table 1:

Table 1 Equipment

No	Experimental Procedure	Details
1	Specimen Preparation	a. Cutting saw, b. Caliper, c. File, d. Sandpaper
2.	Sandblasting	a. Compressor to provide air pressure during the sandblasting processes, b. Spray gun for spraying during the sandblasting processes
3.	Coating	a. Compressor to provide air pressure during the coating processes, b. Spray gun for spraying during the coating processes

For material characterisation, a chemical composition analyser was used to determine the elemental composition of the low-carbon steel specimens prior to the painting process. Adhesive glue was used to bond the 20 mm diameter dollies to the coated specimen surface for the adhesion test. A pull-off adhesion tester was employed to evaluate the coating adhesion strength, while a 20 mm diameter dolly served as the loading fixture during the test. Corrosion behaviour was evaluated using a potentiodynamic polarisation testing system. The materials used in this study consisted of low-carbon steel plate specimens, a primer coating, topcoat paint, thinner as a paint solvent, and Grade 60 glass beads as the abrasive medium for the sandblasting process.

2.2 Method

An experimental research method was employed in this study to evaluate the effect of sandblasting pressure on the corrosion behaviour and coating adhesion strength of low-carbon steel. The experimental approach involved comparing the performance of specimens subjected to different sandblasting pressures under controlled conditions. Low-carbon steel plates were used as the substrate material. Two specimen sizes were prepared according to the requirements of the respective tests. Specimens measuring 50 mm × 50 mm × 2 mm were used for the pull-off adhesion test, while specimens measuring 25 mm × 50 mm × 2 mm were prepared for the potentiodynamic corrosion test. To facilitate understanding of the experimental procedure, the sequence of the research methodology is presented in Table 2. :

Table 2 Summary of Process Parameters

No	**Type of Process**	**Description**
1.	Sandblasting	c. Using glass beads grit 60 material with spraying pressure variations of 7, 8, and 9 bar. d. Spraying angle of 90°. e. Spraying distance of 5 cm.
2.	Coating	c. Paint coating thickness of 3 layers (one primer coat and two iron paint coats). d. Spraying distance of 20 cm. e. Spraying pressure of 7 bar.

During the sandblasting process, Grade 60 glass beads were used as the abrasive medium. The specimens were treated at three different blasting pressures of 7, 8, and 9 bar, while the spraying angle and nozzle-to-surface distance were maintained at 90° and 5 cm, respectively. Following surface preparation, the specimens were coated using a spray gun. The coating system consisted of three layers, comprising one primer coat followed by two topcoat layers. The paint was applied at a spraying distance of 20 cm and an air pressure of 7 bar. A total of 12 specimens were prepared for the experimental programme, including nine specimens for the pull-off adhesion test and three specimens for the potentiodynamic corrosion test. Coating adhesion strength was evaluated using a pull-off adhesion tester, whereas corrosion behaviour was assessed using the potentiodynamic polarisation method. The overall experimental procedure is illustrated in the flowchart shown in Figure 1:

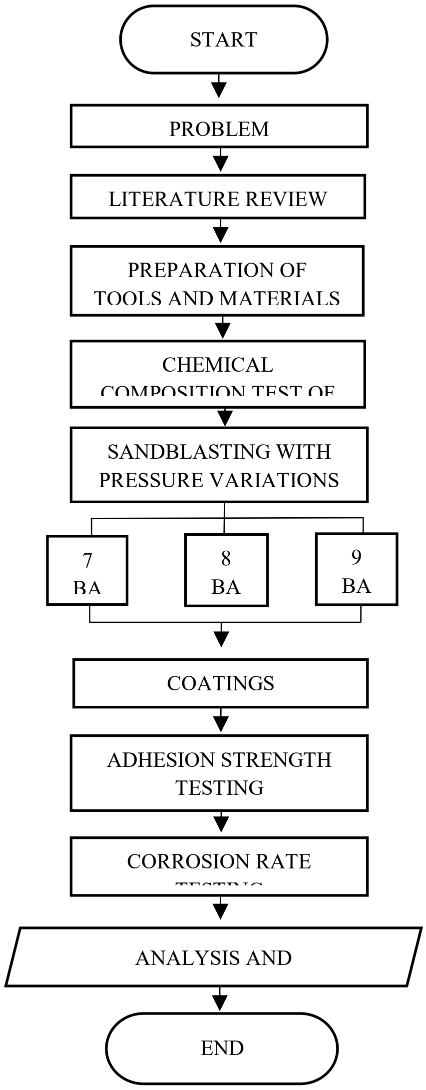

Figure 1. Flowchart

3. Results and Discussion

3.1 Corrotion Rate Testing

Corrosion behaviour was evaluated using the potentiodynamic polarisation method in a sodium chloride (NaCl) solution as the electrolyte. This test was conducted to determine the corrosion behaviour of the low-carbon steel specimens after sandblasting and prior to painting under different sandblasting pressure conditions. The corrosion tests were performed using a CorTest potentiostat connected to a computer running CS Studio 6 software. The testing procedure was carried out in accordance with ASTM G102. A conventional three-electrode electrochemical cell was employed for the potentiodynamic polarisation test. The working electrode (WE) was the low-carbon steel specimen under investigation. The counter electrode (CE) was used to complete the electrical circuit and provide accurate current measurements and was made of an inert metallic material, such as platinum or graphite. The reference electrode (RE) was used to maintain a stable reference potential during the measurements. In this study, either a saturated calomel electrode (SCE) or an Ag/AgCl reference electrode was employed. The experimental setup for the potentiodynamic corrosion test is shown in Figure 2.

Figure 2. Corrosion Testing Equipment

Prior to the corrosion test, most of the specimen surface was masked with black adhesive tape, leaving only the designated exposure area in contact with the electrolyte. This masking procedure was intended to prevent the electrolyte from spreading to unintended areas of the specimen, thereby ensuring a well-defined exposed surface area and improving the accuracy and repeatability of the electrochemical measurements. The corrosion rate was calculated based on the polarisation method using the corrosion current density Icorr obtained from the potentiodynamic polarisation curves. The calculation required several parameters, including the material density, equivalent weight, and corrosion current density. The corrosion rate was then determined using the following equation.

$$CR = K\frac{EWxI_{corr}}{D} \qquad (1)$$

Where: CR = Corrotion Rate (mm/yr),
K = Constant (0,00327 mmpy)
D = Density (gram/cm^3), Carbon Steel Density (7,86 gram/cm^3)
Icorr = Current Density (µA/cm^2), 1 Ampere = 1.000.000 microampere (µA)
EW = Equivalent weight of the electrode material (gr).

$$EW = \frac{1}{Nq}, Nq = \frac{wi}{\frac{ai}{ni}} \qquad (2)$$

Where: Nq = Total Equivalent
wi = Weight Fraction
ai = Ion Valence
ni = Atomic Weight
EW = Equivalent Weight

Example calculation of corrosion test results for the 7 bar pressure variation:

$$EW = \frac{1}{Nq}, Nq = \frac{wi}{\frac{ai}{ni}} \quad (3)$$

$$Fe = \frac{0,9965}{\frac{55,845}{3}} = 0,05353$$

$$C = \frac{0,00038}{\frac{12,011}{2}} = 0,000063$$

$$Mn = \frac{0,00162}{\frac{12,011}{4}} = 0,000539$$

$$Si = \frac{0,0002}{\frac{28,085}{4}} = 0,000028$$

$$P = \frac{0,00026}{\frac{30,974}{5}} = 0,000041$$

$$Nq\ total = 0,05353 + 0,000063 + 0,000539 + 0,000028 + 0,000041 = 0,054201$$

$$EW = \frac{1}{0,054201} = 18,449 \text{ g/equiv}$$

$$CR = K\frac{EWxI_{corr}}{D} \quad (4)$$

$$CR = 0,00327\ mmpy\ x\ \frac{18,449 \text{ g/equiv } x\ 5,5991 \times 10^{-7}\ A/cm^2}{7,874\ gram/cm^3}$$

$$CR = 0,00327\ mmpy\ x\ \frac{18,449 \text{ g/equiv } x\ 0,55991\ \mu A/cm^2}{7,874\ gram/cm^3}$$

$$CR = 0,00428 \text{ mmpy}$$

Table 3 Results of Icorr Calculation

No.	Specimen	i_{corr} (A/cm^2)	i_{corr} $(\mu A/cm^2)$
1	7 bar	$5,5991 \times 10^{-7}$	0,55991
2	8 bar	$1,9576 \times 10^{-5}$	19,576
3	9 bar	$2,0112 \times 10^{-6}$	2,0112

Table 4 Corrosion Rate Calculation Results

No.	Specimen	i_{corr} $(\mu A/cm^2)$	Corrotion Rate (mmpy)	Category
1.	7 bar	0,55991	0,00428	*outstanding*
2.	8 bar	19,576	0,14998	*good*
3.	9 bar	2,0112	0,015409	*outstanding*

As shown in the table 3 & 4, the specimen treated with a sandblasting pressure of 7 bar exhibited the lowest corrosion rate among all the tested conditions. The corrosion rate increased markedly at 8 bar, before decreasing at 9 bar. The corrosion behaviour observed under each sandblasting pressure is discussed in detail below.

The specimen treated at 7 bar exhibited the lowest corrosion current density Icorr of 0.55991 μA/cm², corresponding to the lowest corrosion rate of 0.00428 mm/year. According to the corrosion rate classification, this value falls within the outstanding category, indicating excellent corrosion resistance. At a blasting pressure of 7 bar, the impact energy of the abrasive particles was relatively low, resulting in minimal plastic deformation of the substrate surface. Although the surface roughness increased compared with the untreated condition, the surface remained relatively homogeneous, reducing the likelihood of localised electrochemical cell formation. Consequently, metal dissolution proceeded at a slower rate, leading to lower Icorr and corrosion rate values. This relatively stable surface condition effectively suppressed the corrosion process.

In contrast, the specimen treated at 8 bar exhibited a substantial increase in the corrosion current density to 19.576 $\mu A/cm^2$, resulting in the highest corrosion rate of 0.14998 mm/year. This finding indicates that a sandblasting pressure of 8 bar produced the surface condition most susceptible to corrosion attack. The higher impact energy of the abrasive particles is likely to have induced greater plastic deformation, residual stresses, and increased surface topographical irregularities. These features create regions with higher surface energy that are more prone to oxidation upon exposure to the electrolyte. As a result, the electrochemically active surface area increases, accelerating the electrochemical reactions and consequently increasing the corrosion rate. Nevertheless, the measured corrosion rate remains within the good corrosion resistance category, indicating that the material still possesses satisfactory corrosion resistance. Furthermore, the measured value is considerably lower than the corrosion rate generally regarded as critical for structural steel, suggesting that the material remains suitable for practical applications under appropriate service conditions.

The specimen treated at a sandblasting pressure of 9 bar exhibited a lower corrosion current density Icorr than the specimen treated at 8 bar, with a value of 2.0112 $\mu A/cm^2$, corresponding to a corrosion rate of 0.015409 mm/year. According to the corrosion rate classification, this value falls within the outstanding category, indicating excellent corrosion resistance. Theoretically, increasing the sandblasting pressure increases the kinetic energy of the abrasive particles, which is expected to produce a rougher surface. However, excessively high blasting pressure may also induce work hardening (strain hardening) in the near-surface region as a result of more severe plastic deformation. This phenomenon increases the dislocation density, resulting in a mechanically denser and more stable surface layer. Furthermore, the higher impact energy facilitates more effective removal of oxide films, surface contaminants, and residual corrosion products remaining from the fabrication process. A cleaner surface promotes the formation of a more uniform passive oxide film when the material is exposed to a corrosive environment. Such a passive layer can hinder charge transfer during the electrochemical reactions, thereby reducing the corrosion current density and the corrosion rate. Although the higher sandblasting pressure increased the surface roughness, the resulting surface profile appears to have been more uniform and controlled than that produced at 8 bar, leading to improved corrosion resistance.

Based on the corrosion rate classification, the specimens treated at 7 bar and 9 bar both fall within the outstanding category, whereas the specimen treated at 8 bar is classified as good. These differences demonstrate that relatively small changes in surface condition caused by variations in sandblasting pressure can produce substantial changes in the corrosion current density. This observation is consistent with the fundamental principle of potentiodynamic polarisation testing, in which Icorr is highly sensitive to changes in the surface condition of metallic materials. Overall, the experimental results indicate that all sandblasted specimens exhibited excellent corrosion resistance, as the measured corrosion rates were below 0.2 mm/year. According to the corrosion resistance classification, such values suggest that the material is suitable for long-term service in mildly to moderately corrosive environments. Nevertheless, the specimen treated at 8 bar exhibited the highest electrochemical activity, resulting in the highest corrosion rate among the three sandblasting pressure conditions investigated.

The relationship between sandblasting pressure and corrosion rate was found to be non-linear, exhibiting a fluctuating trend rather than a continuous increase. The specimen treated at 7 bar exhibited the lowest corrosion rate, which may be attributed to its relatively smoother surface compared with the other pressure conditions. Increasing the blasting pressure to 8 bar resulted in a substantial increase in the corrosion rate, which is likely associated with the higher surface roughness produced under this condition. When the pressure was further increased to 9 bar, the corrosion rate decreased; however, it remained higher than that of the specimen treated at 7 bar, which exhibited the lowest surface roughness. Overall, although the corrosion rate did not increase monotonically with sandblasting pressure, the general trend indicates that higher blasting pressures produced rougher surfaces, which were associated with higher corrosion rates. A similar relationship between surface roughness and corrosion behaviour was reported by [10], who observed that specimens with rougher surfaces exhibited higher corrosion rates than those with smoother surfaces. This behaviour was attributed to the increase in the effective surface area exposed to the surrounding environment as surface roughness increased. A larger exposed surface area provides more active sites for electrochemical reactions, thereby promoting oxidation and accelerating the corrosion process. Conversely, smoother surfaces have fewer active sites and a smaller effective exposure area, resulting in lower corrosion rates.

Based on these findings, it can be concluded that sandblasting pressure influences the corrosion rate through the changes it induces in surface roughness. However, this relationship is not strictly linear but exhibits a fluctuating behaviour. In general, the corrosion rate tended to increase with increasing sandblasting pressure, with the specimen treated at 7 bar exhibiting the lowest corrosion rate and the specimen treated at 9 bar showing a higher corrosion rate. Nevertheless, the specimen treated at 8 bar displayed an anomalously high corrosion rate, indicating that factors other than surface roughness may also have contributed to the observed corrosion behaviour.

3.2 Adhesion Strength

The pull-off adhesion test was conducted to evaluate the adhesion strength of the paint coating on low-carbon steel surfaces subjected to different sandblasting pressures. The test was performed using a pull-off adhesion tester in accordance with ASTM D4541 [24]. A 20 mm diameter dolly was bonded to the coated surface of each specimen using a two-component epoxy adhesive mixed at a 1:1 ratio. The bonded specimens were allowed to cure for 24 hours to ensure complete hardening of the adhesive and secure attachment of the dolly to the coating surface before testing. The dolly bonding procedure is illustrated in Figure 3.

Figure 3. Example of a Test Sample Ready for Testing

After the adhesive had cured for 24 hours, any excess epoxy surrounding the dolly was carefully removed using a dolly cutter prior to the pull-off test. This step ensured that the applied tensile load acted only on the area directly bonded between the dolly and the coating, thereby minimising the influence of excess adhesive on the test results. Subsequently, a quick coupling was attached to the head of the dolly, and the pull-off adhesion test was performed by gradually applying tensile force using the hydraulic pump of the pull-off adhesion tester until the dolly detached from the specimen surface. The maximum tensile stress recorded at the point of failure was taken as the coating adhesion strength. The visual appearance of the pull-off test results is presented in Figure 4.

Figure 4. Condition of the Specimen After Adhesion Strength Testing

Furthermore, the calculation of adhesion strength values was based on the ASTM D4541 standard. The required data included the maximum pull-off force when the coating detached (*F*), adhesion strength (*σ*), and the dolly surface area (*A*). The steps for calculating adhesion strength according to[8] are as follows:

$$\sigma = \frac{4F}{\pi d^2} \quad (5)$$

Dimana σ = Adhesion Strength (Mpa)

F = Maximum Pull-Off Force when the Coating Detaches (N)

A = Dolly Surface Area (mm^2)

π = 3,14 or 22/7

d = Dolly Diameter (mm), 20 mm

Example calculation of adhesion strength for the 7 bar pressure variation:

$$\sigma = \frac{4F}{\pi d^2} \quad (6)$$

$$2{,}05 = \frac{4F}{3{,}14x20^2}$$
$$4F = 2{,}05x1256$$
$$4F = 2574{,}8$$
$$F = \frac{2574{,}8}{4}$$
$$F = 643{,}7 \text{ N}$$

In addition to providing quantitative adhesion strength values, the pull-off test also yielded qualitative information regarding the failure modes that occurred during testing. The pull-off process, as illustrated in Figure 4, reveals the failure patterns observed after the dolly detached from the coated specimen surface. One of the failure modes observed was adhesive failure, characterised by the complete detachment of the coating from the substrate, leaving the test area entirely free of coating material. In contrast, cohesive failure occurred when fracture took place within the coating layer itself, resulting in only partial removal of the coating from the test area. A third failure mode, glue failure, was identified when the coating remained completely intact after testing, indicating that failure occurred within the adhesive used to bond the dolly rather than at the coating–substrate interface. The quantitative pull-off adhesion strength results, together with the corresponding failure mode classifications, are summarised in Table 5 and Table 6.

Table 5 Adhesion Failure Results

Variation (sandblasting Pressure)	No. Specimen	*Adhesive Failure* (%)	*Cohesive Failure* (%)	*Glue Failure* (%)
7 bar	1	65	30	5
	2	55	25	20
	3	45	45	10
8 bar	4	60	30	10
	5	35	45	20
	6	45	40	25
9 bar	7	80	10	10
	8	65	20	15
	9	40	25	35

Table 6 Adhesion Strength Test Results

Variation (sandblasting Pressure)	No. Specimen	Maximum Pull-Off Force When the Coating Detaches F (N)	Adhesion Strength σ (MPa)	Average Adhesion Strength σ (MPa)
7 bar	1	643,7	2,05	
	2	697,8	2,22	2,28
	3	813,26	2,59	
8 bar	4	810,12	2,58	2,57
	5	668,82	2,13	
	6	945,14	3,01	
9 bar	7	1183,78	3,77	
	8	888,62	2,83	2,73
	9	502,4	1,6	

As shown in the table 5 & 6, the average coating adhesion strength increased progressively with increasing sandblasting pressure from 7 to 9 bar. The specimens treated at 9 bar exhibited the highest average adhesion strength, followed by those treated at 8 bar, while the 7 bar specimens showed the lowest adhesion performance. A detailed discussion of each pressure condition is presented below.

The specimens treated at a sandblasting pressure of 7 bar exhibited adhesion strength values ranging from 2.05 to 2.59 MPa. Among the three observed failure modes, adhesive failure was the predominant mode, accounting for approximately 45–65% of the failure area. Cohesive failure represented the second most common failure mode, ranging from 25–45%, whereas glue failure accounted for only 5–20%. The predominance of adhesive failure indicates that failure occurred primarily at the interface between the coating and the steel substrate. The relatively low average adhesion strength of 2.28 MPa suggests that a sandblasting pressure of 7 bar was insufficient to generate an optimum surface profile for effective mechanical interlocking, resulting in an interfacial bond that was weaker than the internal strength of the coating system.

For the specimens treated at 8 bar, the adhesion strength ranged from 2.13 to 3.01 MPa, with an average value of 2.57 MPa. Compared with the 7 bar condition, the proportion of adhesive failure decreased to approximately 35–60%, whereas the proportions of cohesive failure and glue failure increased to approximately 30–45% and 10–25%, respectively. This shift in failure mode distribution indicates an improvement in the interfacial bonding between the coating and the substrate. Accordingly, the coating–substrate interface approached, or in some cases exceeded, the internal strength of the coating or adhesive system, resulting in improved adhesion performance compared with the specimens treated at 7 bar.

The specimens treated at 9 bar exhibited adhesion strength values ranging from 1.60 to 3.77 MPa. One specimen produced a relatively low adhesion strength of 1.60 MPa, which reduced the overall consistency of the results. Nevertheless, the highest individual adhesion strength of 3.77 MPa was also obtained under this condition. Among the observed failure modes, adhesive failure remained predominant, accounting for approximately 40–80% of the failure area, whereas cohesive failure decreased to 10–25% and glue failure ranged from 10–35%. Although the proportion of adhesive failure increased, the average adhesion strength also increased compared with the lower pressure conditions. This result suggests that the higher sandblasting pressure produced a rougher surface profile, thereby enhancing mechanical interlocking between the coating and the substrate and increasing the overall adhesion strength. However, the relatively wide variation in the measured values indicates that the adhesion performance at 9 bar was less consistent than that observed at 7 and 8 bar, which may reflect local variations in surface characteristics or coating application.

However, the relatively rough substrate produced at 9 bar also introduced greater variability in the adhesion results, as demonstrated by Specimen 3, which exhibited a significantly lower adhesion strength of 1.60 MPa. Several factors may have contributed to this result. During the painting process, environmental disturbances, particularly airflow, caused slight movement of the specimen, which may have affected coating uniformity and consequently reduced the measured adhesion strength. In addition, during the pull-off test, the specimen with the lowest adhesion strength exhibited a relatively high proportion of glue failure. As shown in Table 4, glue failure accounted for approximately 35% of the failure area, indicating that failure occurred partially within the adhesive layer rather than exclusively at the coating–substrate interface. This may have prevented the pull-off test from fully reflecting the actual coating adhesion strength. Nevertheless, despite the variability observed in one specimen, the overall results indicate that increasing the sandblasting pressure produced a greater improvement in adhesion strength than the reduction caused by isolated test inconsistencies.

Based on the experimental results, sandblasting pressure influenced both the failure mode and the coating adhesion strength. The 8 bar condition exhibited an increased proportion of cohesive failure, indicating improved interfacial bonding compared with the 7 bar condition. At 9 bar, although the proportion of adhesive failure increased, the average adhesion strength also increased. This suggests that the higher sandblasting pressure generated a rougher surface profile, thereby enhancing mechanical interlocking between the coating and the steel substrate.

The improvement in adhesion strength may be attributed to the increased penetration of the paint into the microscopic valleys formed during the sandblasting process, resulting in a stronger mechanical bond after curing. As shown in the experimental results, the average adhesion strength increased with increasing sandblasting pressure. The highest average adhesion strength was obtained at 9 bar (2.73 MPa), followed by 8 bar (2.57 MPa) and 7 bar (2.28 MPa). These findings are consistent with those reported by [1], who concluded that rougher surfaces generally promote stronger adhesion between the coating and the substrate.

Overall, the adhesion strengths obtained in the present study were lower than those reported by [6], who achieved an adhesion strength of approximately 3 MPa. The highest average value obtained in this study was 2.73 MPa. This difference may be attributed to variations in the sandblasting process parameters, particularly factors such as the nozzle-to-surface distance and spraying angle, which were not fully controlled or reported. These parameters are known to have a significant influence on the resulting surface profile and, consequently, on coating adhesion performance.

Despite these limitations, the results clearly demonstrate that increasing the sandblasting pressure improved the coating adhesion strength. In general, higher blasting pressures produced stronger coating adhesion through enhanced mechanical interlocking. An additional contribution of the present study, compared with previous investigations, is the simultaneous evaluation of both coating adhesion strength and corrosion behaviour, enabling a more comprehensive assessment of the influence of sandblasting pressure on coating performance.

With respect to corrosion behaviour, the relationship between sandblasting pressure and corrosion rate was found to be non-linear, exhibiting a fluctuating trend. The specimen treated at 7 bar, which had the lowest surface roughness, exhibited the lowest corrosion rate of 0.00428 mm/year. The corrosion rate increased substantially to 0.14998 mm/year at 8 bar, before decreasing to 0.015409 mm/year at 9 bar. Although the corrosion rates fluctuated with increasing sandblasting pressure, all measured values remained within the good to outstanding corrosion resistance categories. These findings indicate that the coated specimens maintained satisfactory corrosion resistance and are therefore considered suitable for street lighting pole applications under mildly to moderately corrosive service conditions.

4. Conclusion

The results demonstrate that sandblasting pressure significantly influences the corrosion behaviour of coated low-carbon steel through changes in surface characteristics produced during surface preparation. The relationship between sandblasting pressure and corrosion rate was found to be non-linear, exhibiting a fluctuating trend. Although the specimen treated at 7 bar exhibited the lowest corrosion rate (0.00428 mm/year), the corrosion rate generally increased with increasing blasting pressure, reaching 0.015409 mm/year at 9 bar. An anomalously high corrosion rate (0.14998 mm/year) was observed at 8 bar, suggesting that factors other than surface roughness may also influence the electrochemical behaviour of the coated substrate. Sandblasting pressure also had a significant effect on coating adhesion strength. Increasing the blasting pressure enhanced coating adhesion, with the average adhesion strength increasing from 2.28 MPa at 7 bar to 2.73 MPa at 9 bar. This improvement is attributed to enhanced mechanical interlocking between the coating and the substrate resulting from the rougher surface profile generated during sandblasting. Considering both corrosion resistance and coating adhesion, a sandblasting pressure of 9 bar provided the most favourable overall performance. Although the 7 bar condition produced the lowest corrosion rate, it also resulted in the weakest coating adhesion. In contrast, the 9 bar condition achieved the highest average adhesion strength while maintaining an excellent corrosion resistance level (0.015409 mm/year, classified as *outstanding*). These findings indicate that increasing the sandblasting pressure to 9 bar improves surface preparation sufficiently to enhance coating adhesion without causing a substantial reduction in corrosion resistance. Consequently, a sandblasting pressure of 9 bar is recommended as the optimum operating condition within the range investigated for coating low-carbon steel street lighting poles, offering an effective balance between corrosion protection and coating durability.

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