International Journal of Eco-Innovation in Science and Engineering (IJEISE) Vol. 07 (2), 2026 (53-59)
https://ijeise.upnjatim.ac.id/ E-ISSN: 2721-8775

Article

The Effect of Primer Coating Application and Variations of Secondary Coating Thickness on Adhesion and Corrosion Rate of Carbon Steel Material

Imah Luluk Kusminah[1], Wiwik Dwi Pratiwi[2], Ikhlas Syarofie[3], Erik Wahyu R.W.[3], Dika Anggara[3], M. Karim Al Amin[3], Ni'matut Tamima[4]

[1,3] Department of Welding Engineering, Politeknik Perkapalan Negeri Surabaya, Indonesia
[2] Department of Waste Processing Engineering, Politeknik Perkapalan Negeri Surabaya, Indonesia
[4] Department of Sustainable Energy Engineering Technology, Politeknik Perkapalan Negeri Surabaya, Indonesia
*Corresponding author: imahluluk@ppns.ac.id | Phone number: +6282336249977

Received: 06th November 2025; Revised: 14th March 2026; Accepted: 20th July 2026;
Available online: 30th November 2026; Published regularly: May and November

Abstract

Paint coating is a crucial stage in carbon steel fabrication to enhance aesthetics, protection, and mechanical strength. The coating system typically consists of primer, secondary, and top coat layers. This study investigates the effect of primer coating application and variations in secondary coating thickness on adhesion strength, coating defects, and corrosion rate of ASTM A36 carbon steel. Specimens were prepared by sandblasting to Sa 2½ cleanliness level, followed by applying Hempadur 15570/15571 primer and Hempadur Mastic 45880 secondary coating with varying thicknesses. Tests included Pull-Off Test (ASTM D4541), Cross-Cut Test (ASTM D3359), and electrochemical corrosion testing. Results indicated that specimens with primer (A1 and B1) had higher adhesion (15.60 MPa and 15.89 MPa) compared to those without primer (A2: 14.11 MPa; B2: 13.36 MPa). Corrosion Rate showed B2 despite its higher thickness (175–220 μm). The lowest corrosion rate occurred in B1 (0.000012431 mm/year, excellent category) and the highest in B2 (0.00128 mm/year, good category).

Keywords: Adhesion, Primer Coating, Coating Thickness, Corrosion Rate

1. Introduction

Carbon steel ASTM A36 is categorized as low-carbon steel, containing 0.05–0.30% C, and is preferred due to its good mechanical properties for various structural applications [1]. Despite these advantages, carbon steel is highly susceptible to corrosion, which significantly affects the long-term performance and durability of structures.

One of the most effective methods to enhance the service life of steel is through protective coating application. Coating functions as a barrier layer applied on the steel surface to provide decorative, functional, or combined purposes [2]. Typically, the coating system consists of three stages: primer, secondary, and top coat. Primer serves as the first layer to improve adhesion and corrosion protection [3], while the secondary and top coats provide additional protection and improve appearance [4].

Previous studies have shown that the rate of corrosion is strongly influenced by the quality and thickness of the coating. Pambudi [2] demonstrated that a combination of primer and secondary coatings significantly reduced corrosion on API 5L Grade B steel pipes. Similarly, Mulyono [5] emphasized that thicker coatings are more effective in reducing corrosive penetration. Surface preparation also plays a critical role in adhesion strength. Pratiknoa et al. [6] reported

that proper application methods improve bonding, while Nabilla [7] highlighted that surface roughness enhances adhesion due to mechanical interlocking.

However, in industrial practice, deviations from standard procedures are often made to save time and production costs. For example, primer is sometimes applied only before fabrication as a temporary protective layer, while the welding area remains unprimed and directly coated with secondary and finishing layers without additional surface preparation [8]. This practice leads to inconsistencies in coating adhesion, particularly in weld zones where the surface tends to be smoother compared to the blasted base metal.

Research by Dwiningsih [8] also showed that residual primer significantly affects adhesion strength, with the best results observed in specimens without residual primer. Nevertheless, the role of secondary coating thickness, especially on unprimed surfaces, remains less studied, leaving a gap in empirical data regarding its effect on adhesion and corrosion resistance.

The selected secondary coating thickness in this research ranges were determined based on the coating specification commonly applied in industrial protective coating systems and the requirements outlined in the relevant coating standards. The lower thickness range represents the minimum acceptable dry film thickness (DFT), while the higher thickness range represents the upper practical application limit that can be achieved without introducing coating defects such as sagging or excessive residual stress.

Only two thickness variations were investigated in this study to establish a clear comparison between relatively thin and thick coating conditions while maintaining a manageable experimental design. This approach enables the evaluation of coating thickness effects on corrosion performance while minimizing the influence of additional variables. The selected thickness ranges are representative of coating thicknesses commonly encountered in industrial applications and therefore provide practical relevance to the study.

Based on these issues, this research investigates the influence of primer application and variations in secondary coating thickness on adhesion strength and corrosion rate of ASTM A36 carbon steel. The results are expected to provide empirical evidence to support improvements in coating practices for structural steel fabrication.

2. Material and Method

This study used ASTM A36 standart for carbon steel plate specimens with dimensions of 300 × 300 × 6 mm. The specimens were divided into two groups: primer-coated (A1, B1) and non-primer (A2, B2), with two variations of secondary coating thickness: 100–150 μm (A series) and 175–220 μm (B series). Corosion Rate specimens with dimensions of 50 × 20 × 6 mm were prepared for electrochemical corrosion testing. These smaller specimens were coated using the same procedures and coating variations as the larger adhesion specimens, ensuring consistency in experimental conditions.

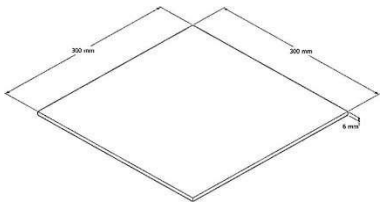


Fig. 1. Dimension of Coating Specimen

Prior to coating, all specimens underwent steel grit sandblasting to achieve a cleanliness level of Sa 2½ according to ISO 8501-1. The resulting surface roughness ranged from 100–119 μm, which meets the requirements for ensuring good coating adhesion [9].



(a)



(b)

Fig. 2. a) Surface Roughness Testing, b) Surface Cleanliness Sa 2½

The surface roughness inspection reading was corrected by subtracting 50 μm. The average surface roughness value obtained in this test was in accordance with the target and the research scope, which was set in the range of 100–110 μm. After completing the inspection process, the test results were found to meet the expected criteria.

In the primer coating process, variations were applied between specimens with primer (coded A1–B1) and without primer (coded A2–B2). These were further combined with variations in secondary coating thickness, where the thickness distribution between primer-coated and non-primer specimens differed, but the total range remained the same. The primer coating applied was Hempadur 15570/15571, followed by Hempadur Mastic 45880 as the secondary layer. Coatings were applied with an airless spray method. Wet film thickness (WFT) was measured during application, and dry film thickness (DFT) was controlled according to product data sheet specifications [10].

Adhesion strength was evaluated using the Pull-Off Adhesion Test based on ASTM D4541, while qualitative adhesion assessment was carried out through the Cross-Cut Test following ASTM D3359 [11].

The corrosion rate test was carried out using a three-electrode cell connected to a Potentiostat Autolab PGSTAT128N, which was operated through NOVA software to record the current response to applied potential.

3. Results and Discussion

Surface roughness was measured using an Elcometer Tape Thickness Gauge with Press-O-Film. The readings represent the sum of film thickness and surface profile, and since the Press-O-Film has a base thickness of 50 μm, this value was subtracted to obtain the corrected roughness profile.

Table 1. Result Of Roughness Test

Code Specimen	Roughness **(μm)**
A1	111
B1	101
A2	117
B2	100
Average	107

The results show that all specimens achieved roughness values within the 100–119 μm target range, confirming that the blasting process (Sa 2½) was properly executed and produced the desired anchor profile. These findings are consistent with Nabilla (2017), who reported that increased surface roughness enhances coating adhesion by creating more active bonding sites [7]. Similarly, Hudson (2020) highlighted that surface preparation is a critical determinant of coating performance, since inadequate roughness can lead to poor adhesion and premature coating failure [9]. Therefore, the achieved surface profile in this study can be considered optimal for supporting strong adhesion between the coating layers and the carbon steel substrate.

The coating thickness measurement was conducted using a wet film thickness (WFT) gauge during application and confirmed by dry film thickness (DFT) readings after curing. The specimens were divided into two groups: specimens with primer (A1, B1) and without primer (A2, B2), each with variations in secondary coating thickness.

DOI:10.4186/ijeise.upnjatim.ac.id/E-ISSN: 2721-8775

Table 2. Result Of Dry Film Thickness

Specimen	*Primer Aplication (µm)*	*Scondary Aplication(µm)*
A1	70	140
	50	136
	70	112
A2	-	106
	-	102
	-	137
B1	50	201
	70	193
	70	202
B2	-	176
	-	203
	-	180

The coating thickness test showed variations between specimens in accordance with the research design. Specimens B1 and B2 exhibited higher final thickness compared to A1 and A2, as expected from the experimental setup where specimens in group B were targeted at a dry film thickness (DFT) of 175–220 µm, while specimens in group A were targeted at 100–150 µm.

In this study, adhesion measurements were taken at three points on each specimen using a 20 mm dolly and an Elcometer 51.



Fig. 3. Pull Off Testing

Table 3. Result Of Pull Off Adhesion Test

Code Specimen	*Adhesion strenght* (Mpa)			Average (Mpa)
	Point 1 (Mpa)	Point 2 (Mpa)	Point 3 (Mpa)	
A1	15,65	15,46	15,69	15.60
B1	16,17	15,93	15,56	15,89
A2	14,46	13,93	13,93	14.11
B2	13,66	13,36	13,36	13.46

All adhesion values exceeded the minimum requirement of BS EN ISO 12944-6 (>2.5 MPa), indicating that the applied coating systems met international standards for protective coatings. To better illustrate the differences between specimens, the quantitative results were also presented in the form of a bar chart, which facilitates comparative analysis of adhesion performance across the coating variations.

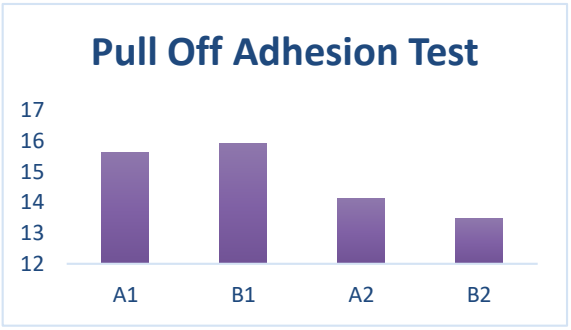


Fig. 4. Bar Chart of Pull Off Test

Specimens with primer (A1 and B1) showed higher adhesion than those without primer (A2 and B2). The highest value was obtained by B1 (15.89 MPa), while the lowest was B2 (13.46 MPa). This indicates that primer acts as a transitional layer that strengthens interfacial bonding [12]. Although A2 (14.11 MPa) still exhibited adequate adhesion, its value was lower than A1, confirming that primer contributes significantly to adhesion strength. Adhesion performance is also affected by the chemical

DOI:10.4186/ijeise.upnjatim.ac.id/E-ISSN: 2721-8775

interaction between resin and curing agents, which reinforces bonding with the substrate [13].

In this study, the cross-cut test was performed at three points on each specimen. The results at each point were then classified according to ASTM D3359 standards.

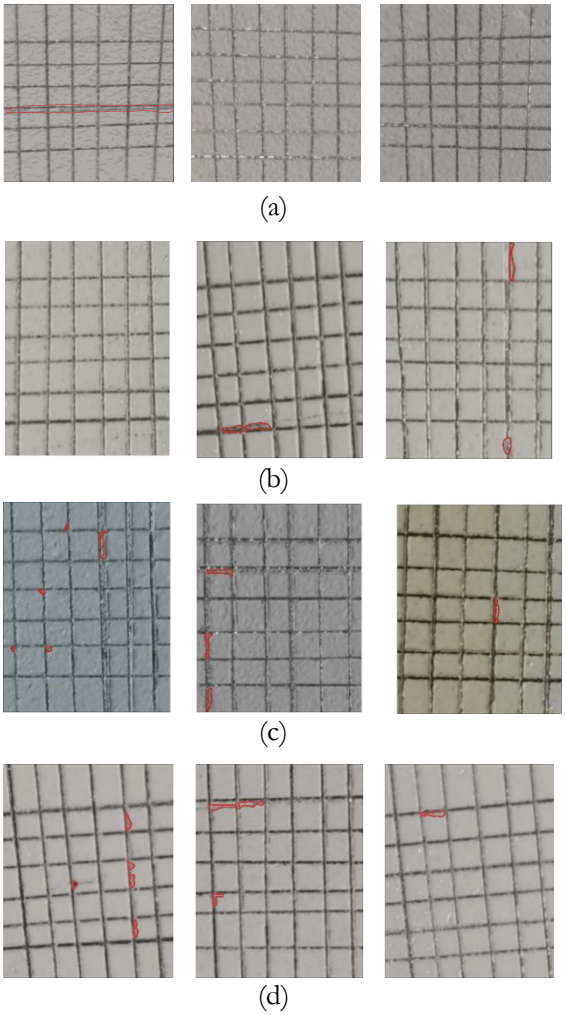
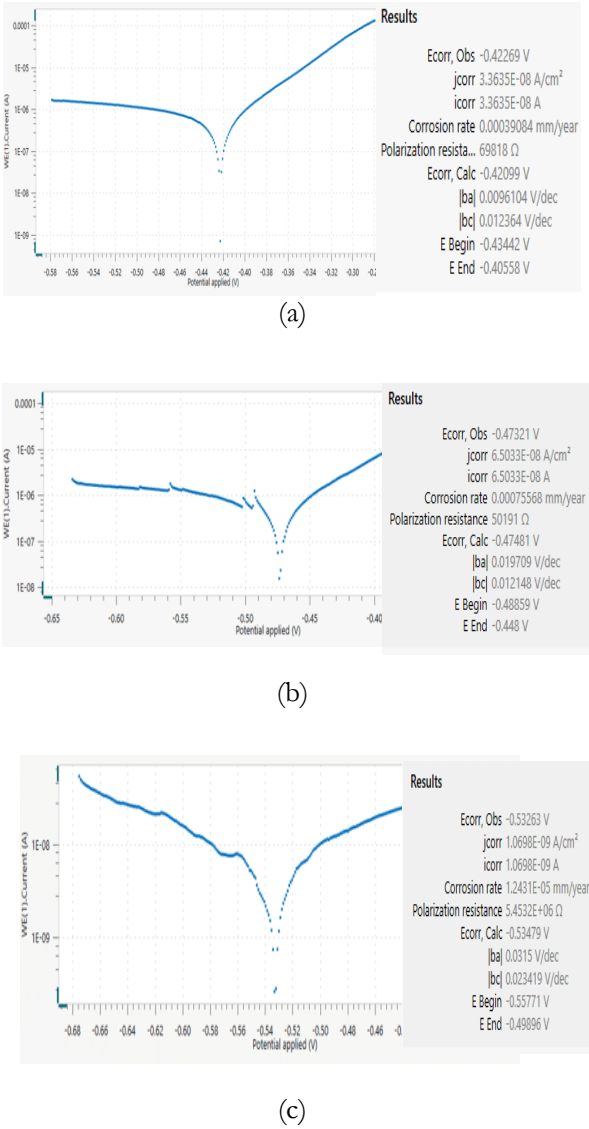
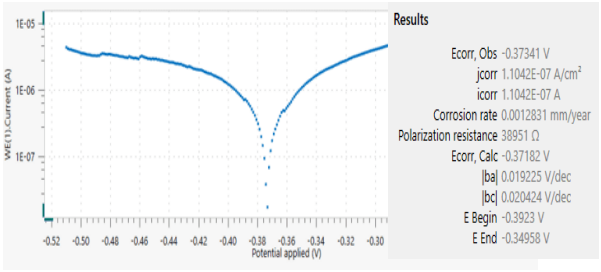


Fig. 5. a) classification 5B of Crosscut Adhesion Test, b) classification 4B of Crosscut Adhesion Test, c) classification 4B of Crosscut Adhesion Test, d) classification 4B of Crosscut Adhesion

Based on the cross-cut test results (Figures (a)-(b), the best adhesion performance was observed in specimens A1 and B1 (with primer), classified as 4B–5B, indicating very minimal or no peeling. In contrast, non-primer specimens (A2 and B2) consistently showed 4B, with slight detachment along the cut lines. The superior performance of the primer system can be attributed to its ability to distribute stresses more evenly across coating layers, reducing the risk of failure under external deformation [12]. Since the minimum acceptable rating in ASTM D3359 is 3B, all specimens in this study met the required standard.

This test, conducted using a three-electrode electrochemical cell, automatically provided data on corrosion rate, corrosion potential, and corrosion current for each specimen, along with the corresponding Tafel plots.





(d)

Fig. 6. a) Corrosion Rate Test Result A1, b) Corrosion Rate Test Result B1, c) Corrosion Rate Test Result A2 d) Corrosion Rate Test Result B2

The corrosion rate results were also represented in the form of a bar chart to facilitate clearer comparison and analysis among the specimens.

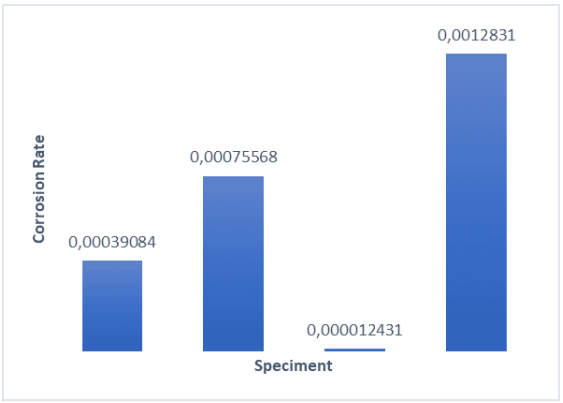


Fig. 7. Bar Chart of Corrosion Rate Test

Specimen B1 recorded the lowest corrosion rate (1.24×10^{-5} mm/year), confirming that the combined primer and secondary coating system was highly effective in limiting corrosive ion penetration. This aligns with Afshar et al. (2023), who reported that primer layers, particularly zinc-rich or epoxy-based, can reduce steel corrosion rates by several orders of magnitude compared to unprotected steel [14]. Specimen A1, although coated with primer, exhibited a higher rate (3.9×10^{-4} mm/year) than B1, likely due to its lower overall thickness (100–150 µm) or the presence of micro-defects such as pores or fine cracks that compromised the barrier performance. In contrast, the non-primer specimens (A2 and B2) showed the highest corrosion rates (7.6×10^{-4}–1.28×10^{-3} mm/year), indicating that secondary coating alone provided insufficient protection. the absence of primer increases electrolyte penetration, making the coating system more vulnerable to localized corrosion.

4. Conclusions

Primer application significantly improved adhesion strength. Specimens with primer (A1 and B1) consistently demonstrated higher pull-off values compared to those without primer, confirming the role of primer as a bonding transition layer between substrate and topcoat.

Coating thickness variation affected performance only when supported by primer. Specimen B1, with both primer and higher secondary coating thickness (175–220 µm), achieved the best adhesion (15.60 MPa) and the lowest corrosion rate (1.24×10^{-5} mm/year).

Non-primer specimens exhibited reduced performance. Despite thicker secondary coatings, specimens A2 and B2 showed weaker adhesion and higher corrosion rates (up to 1.28×10^{-3} mm/year), highlighting that secondary layers alone were insufficient to provide long-term protection.

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