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Analysis of Primary Coating Thickness Effects on Adhesion Strength in S355J2+N Steel Material

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Abstract

Steel is a metal alloy primarily composed of iron, with carbon as its main alloying material along with several other components according to specific requirements. Low carbon steel has a carbon content of 0.05-0.3% and is easily manufacturable. This type of steel is commonly used for vehicle frames and other applications. The material used in this study is Carbon Steel S355J2, classified as low carbon steel with 0.15% carbon and 1.46% manganese. Carbon Steel S355J2 is used for the underframe of freight trains by PT Industri Kereta Api Indonesia. Coating and protection are crucial due to its susceptibility to corrosion, which can damage its structure in operational railway environments. As additional data for the company and learning for the researcher, a pull-off test was conducted varying the thickness of the primer coat. The results showed that sample A (110 µm), B (150 µm), and C (200 µm) achieved adhesion strengths of 2.5 MPa, 4.5 MPa, and 5 MPa respectively. The surface roughness level of the samples was 90 - 120 µm. Based on the test results, the most suitable coating system for the UGL underframe painting project for PT Industri Kereta Api (INKA) is a primer with a thickness of 150 µm (Sample B). This thickness is not too high, yet it significantly exceeds PT INKA's minimum criteria and avoids overcoating.

Keywords: Adhesion; Carbon Steel; Coating; Corrosion; Pull off Test

Introduction

Steel is an alloy metal with iron as the base element and carbon as the main alloying element. The carbon content in steel ranges from 0.2% to 2.1% by weight, depending on its grade. The function of carbon in steel is as a hardening element (Setiawan, A., &

Pamungkas 2022). Low carbon steel is typically used for automobile and bus frames, among other applications (G. Brady 2002). The material used for this test is Carbon Steel S355J2. This material falls into the low carbon steel category with a carbon content of 0.15% and manganese content of 1.46% (Fajrin, A., & Butar 2023).

S355J2 steel is often used in the manufacture of underframes for railway vehicles as implemented by PT Industri Kereta Api Indonesia . This steel has high tensile strength and resistance to deformation, making it ideal for applications that require structural strength and durability. Underframes distribute the weight and loads evenly across the vehicle to prevent structural failure (Callister, W. D., & Rethwisch, 2018). Underframes also help to dampen and reduce vibrations and shocks from the track, enhancing passenger comfort and protecting the vehicle's components (Smith, W. F., & Hashemi, 2018). Therefore, the underframe is one of the core components of the entire train, necessitating an appropriate coating layer to protect and extend its lifespan. Coatings provide a barrier that protects the substrate from environmental elements that can cause corrosion, such as moisture, chemicals, and salts. This is especially important for metal surfaces exposed to harsh environments (ISO 2020)

Corrosion is the damage or degradation of metal due to a redox reaction between the metal and various substances in its environment, resulting in unwanted compounds. The corrosion process cannot be stopped but can only be controlled or slowed down (Nugroho et. al. 2017). Metal corrosion occurs due to the deterioration or destruction of the metal surface in aggressive environments such as liquids, gases, or soil. According to Rini Riastuti, a Professor in Corrosion at the Faculty of Engineering, University of Indonesia (FTUI), corrosion negatively affects the visual appearance of objects and causes plant downtime in industries because corroded equipment must be replaced. Corrosion also leads to product loss due to container, tank, or pipeline leaks, and loss of efficiency due to high costs incurred by the industry (Riastuti 2023).

In the railway industry, the corrosion rate is a crucial factor to consider because trains are exposed to outdoor environments, automatically subjected to rain and sunlight during operation. To prevent corrosion, protect the underframe from UV exposure, and shield it from scratches (Sonali 2023), a good and suitable coating layer is required to protect the metal effectively and extend the operational life of the train. Coating is the

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process of covering a substrate to protect the material from corrosion and provide protection (Jones 1996).

The success of the coating process greatly depends on several key factors that ensure the coating performs effectively and provides the intended protection and enhancement to the substrate. These factors include proper surface preparation (Campbell Jr 2011), selection of appropriate coating materials, coating system, and correct application techniques (ASM International 2015). A good coating should indeed have strong adhesion to ensure its effectiveness and longevity. Adhesion refers to the ability of the coating to firmly stick to the substrate surface. Strong adhesion is crucial for the coating to provide the intended protection and performance characteristics (ISO 2020). Some factors that can affect the adhesion of a coating is surface preparation and coating thickness (Teng 2023). Surface preparation is a crucial step in ensuring the effective adhesion and performance of coatings. One common and effective method for surface preparation on S355J2 steel, is grit blasting . Grit blasting involves propelling abrasive particles such as steel grit, blasted against a surface at high velocity to clean and roughen it, providing an optimal substrate for coating application (Davis 2001).

This analysis aims to determine the appropriate primer paint thickness to achieve maximum corrosion protection, minimize painting defects, and optimally slow down the corrosion rate while providing the company with an overview of the costs associated with the performance of each paint thickness. Primer coating, is the initial layer of coating applied to a substrate before the application of the main or topcoat . The primary purpose of a primer is to prepare the surface for subsequent coatings, ensuring better adhesion, enhancing corrosion resistance, and providing a smooth base for the topcoat (Brockenbrough, R. L., & Merritt 1999). Primer coating is key to the adhesion of the entire coating system. It must adhere strongly to the metal and to the coating system applied over it (Atmaji, 2016). The primer coating used in this scientific research is an epoxy resin. Epoxy is a type of resin with excellent water resistance, solvent resistance, acid resistance, and corrosion prevention (Le Huy, C. H., & Thanh 2023)

Research Methode

In this study, the author varied three primer paint thicknesses to determine their

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effect on the overall paint adhesion (primer coat and top coat). Testing was conducted using a pull-off test on the outermost paint layer, which is the top coat. Flow diagram on this research can be seen on figure 1 below.

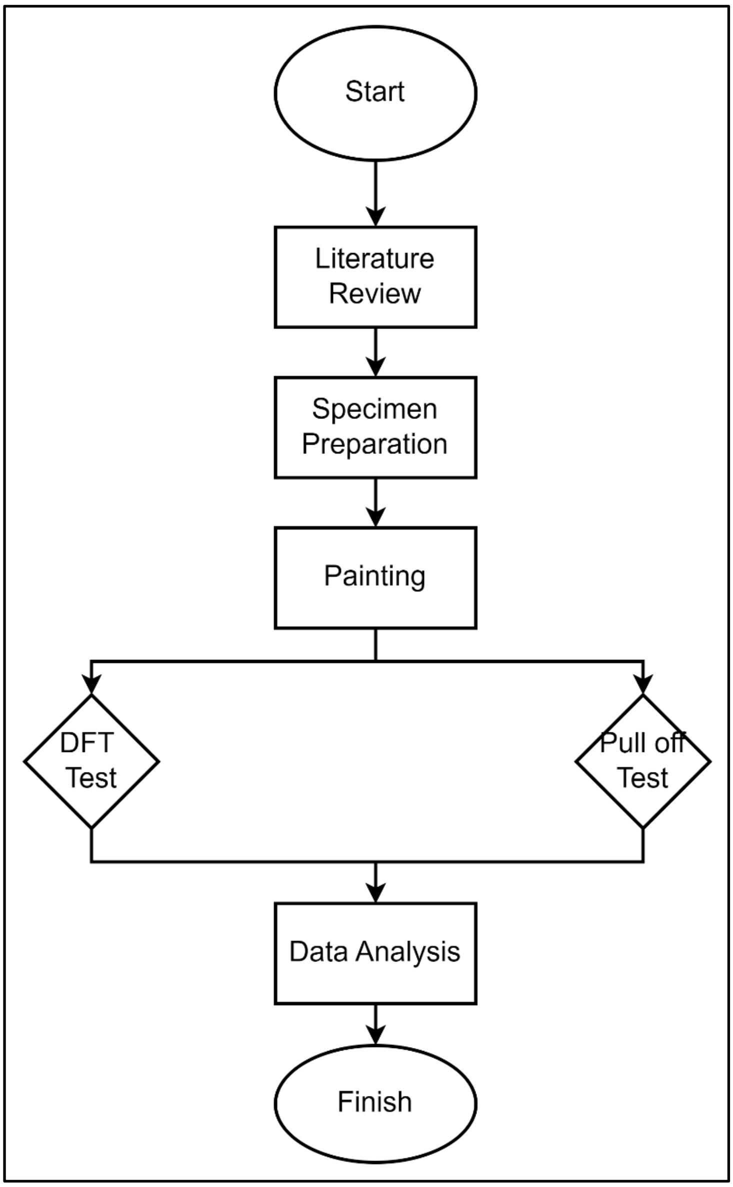

Figure 1 Research Flow Diagram

The samples were laser-cut to dimensions of 150 mm x 100 mm x 2.5 mm. Afterward, the samples underwent a grit blasting process with iron sand as the blasting medium, achieving a cleanliness level of Sa 2.5 (SSPC SP-10) and a profile of 90-120 µm. The process of measuring surface roughness can be seen on figure 2 below.

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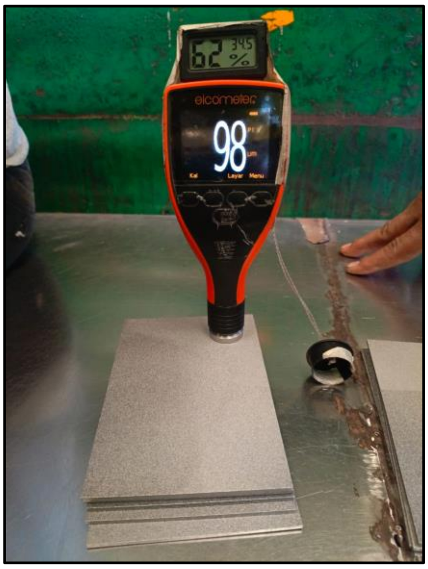

Figure 2 measuring surface roughness

After blasting, the samples were primed with a two-component epoxy paint. Two-component paint is a type of coating system that consists of two separate components, a resin (base) and a hardener (curing agent), which must be mixed together before application in a specific mixing ratio, as detailed below (Brock, T., Groteklaes, M., & Mischk 2000). The primary coating process and its parameters can be seen in Figure 3 and Table 1 below.

Figure 3 Primary Coating Application

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Table 1 Primary Coating Parameter

Parameter	Keterangan
Base	PRIMER SURFACER EP PLUS GREY
Hardner	HARDENER PSEP
Thinner	DANA PAINT THINNER PU (15-20%)
Mixing Ratio	Base:Hardener = (2 : 1) By Volume
Method	Air Spray
Tool	Spray Gun
Pressure	4 – 5 bar
Temperature	30℃
Dry to Touch	10 menit pada temperature 30°C
Hard dry	12 jam pada temperature 30°C

Source: obtained from primary data, (2024)

After the samples dried, a Dry Film Thickness (DFT) test was conducted to determine their thickness. The process of measuring Dry Film Thickness (DFT) can be seen in Figure 4 below.

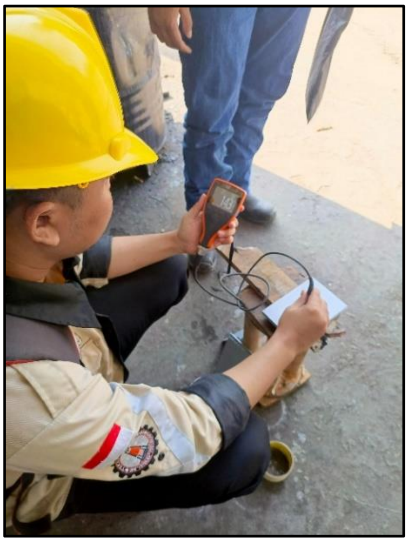

Figure 4 Measuring Dry Film Thickness (DFT)

Subsequently, the samples were coated with a top coat of polyurethane paint. As the outermost protective and decorative layer, the top coat serves as the final layer applied to a surface (Dössel 2008). The top coat was applied following the specified parameters

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in table 2 below.

Table 2 TOP COAT Parameter

Parameter	Keterangan
Base	DANAGLOSS PU 2K RAL 7048
Hardner	HARDENER 741-0000
Thinner	15-20%
Mixing Ratio	Base:Hardener = (3 : 1) By Volume
Method	Air Spray
Tool	Spray Gun
Pressure	4 – 5 bar
Temperature	30°C
Dry to Touch	10 menit pada temperature 30°C
Hard dry	12 jam pada temperature 30°C

Source: obtained from primary data, (2024)

After the samples dried, a Dry Film Thickness (DFT) test was conducted to determine their thickness. The process of measuring Dry Film Thickness (DFT) can be seen in Figure 5 below.

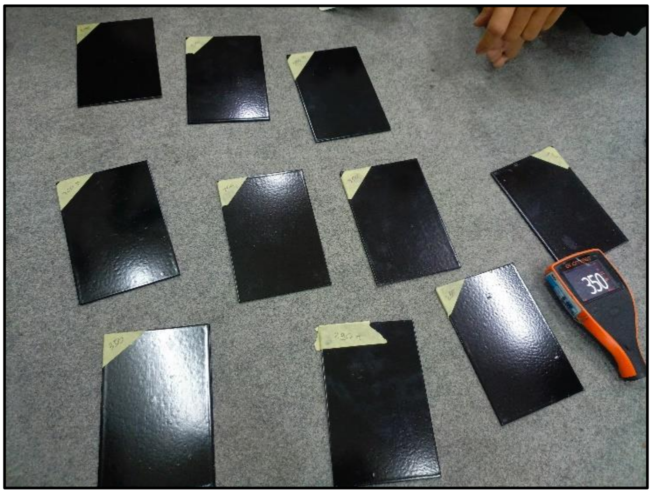

Figure 5 Measuring DFT Thickness

After 7 days of drying, a pull-off test was conducted using a Portable Adhesive Tester to determine the adhesion strength of the coating layer to the plate, based on ASTM

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D4541 standards. A pull-off test is a method used to measure the adhesion strength of coatings to a substrate. This test determines the force required to detach the coating from the substrate, providing valuable information about the durability and quality of the coating (Sward, G., & Koleske, 2012). The process of gluing the dolly to the specimen and the pull-off testing can be seen in Figures 6 and 7 below.

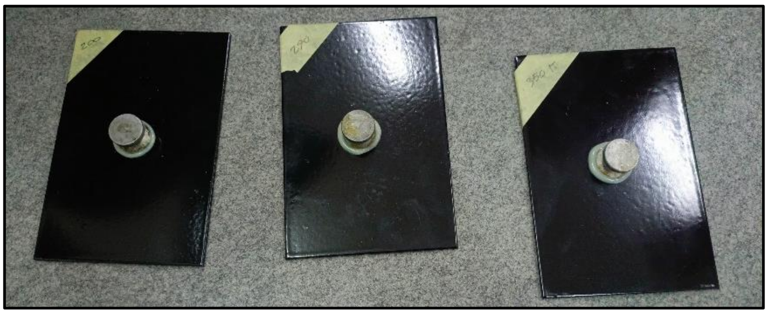

Figure 6 Attaching the dolly process

Source: Personal documentation

Figure 7 Pull of test

Source: Personal documentation

All data were collected through direct testing, followed by discussion and analysis to determine which paint thickness had the best adhesion performance.

Result and Discussion

The results of the DFT and pull-off tests can be seen in the following Table 3 and

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Figure 8.

Table 3 Result of DFT test

Sample	DFT Primary Coating (µm)	DFT Primary Coating + Top Coat (µm)	Daya Adhesi (Mpa)
A	110	200	2,5
B	150	230	4,5
C	200	350	5

Source: obtained from primary data, (2024)

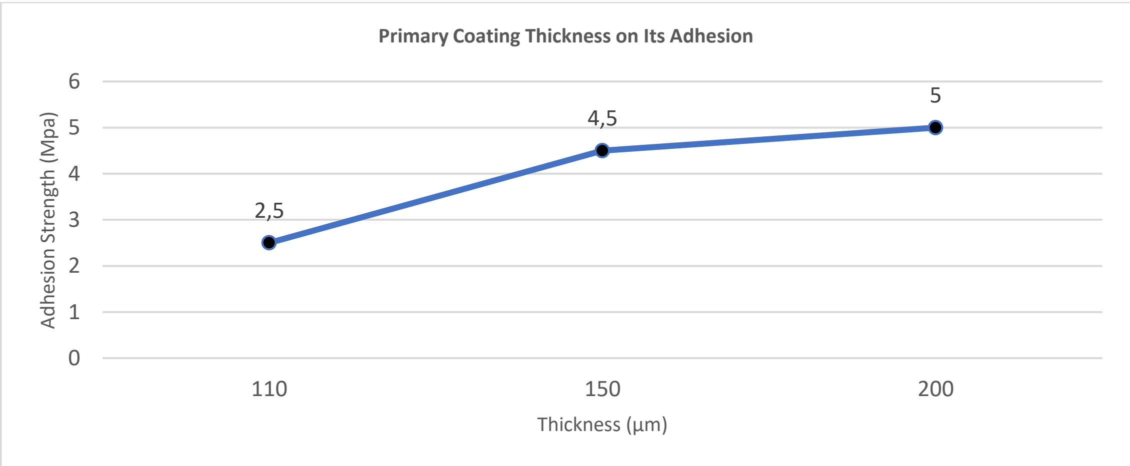

Figure 8. Graph of Effect Primary Coating Thickness on Its Adhesion

Source: obtained from primary data, (2024)

Based on the test results, sample A, with a primer thickness of 110 µm, achieved an adhesion strength of 2.5 MPa, which does not meet PT INKA's minimum adhesion requirement of 3 MPa. Subsequently, sample B, which used a 150µm primer layer, demonstrated good adhesion performance with a value of 4.5 MPa. Lastly, sample C exhibited the best adhesion performance with a value of 5 MPa, but it used a relatively thick primer layer of 200 µm. Based on these results, the most suitable coating system for the underframe painting project for PT INKA's UGL application is a primer with a thickness of 150 µm. This thickness is not too high, yet it significantly exceeds PT INKA's minimum criteria and avoids overcoating. The test data show that the trend of increasing

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adhesion strength by increasing primer thickness slows down in samples B and C. From the results, it can be predicted that if the primer thickness is further increased above 300 µm, there is a risk of cracking in the primer layer, which would decrease the adhesion strength.

This data can serve as a reference and additional consideration for PT INKA in determining a more economical and efficient primer usage strategy without sacrificing the established quality standards. This research provides important insights into the effect of primer thickness on adhesion performance and can assist the company in making better decisions regarding the use of materials and coating processes. Ultimately, this can contribute to increased efficiency and reduced production costs.

Conclussion

Based on the test results:

1. Sample A, with a thin coating of 110 µm, achieved an adhesion strength of 2.5 MPa, which is below PT INKA's adhesion criteria.
2. Sample C had the best adhesion performance at 5 MPa but used a relatively thick primer coating of 200 µm.
3. Sample B, with a thinner primer coating of 150 µm, also showed good adhesion performance at 4.5 MPa. With its thinner coating and strong adhesion results, the coating system of sample B is suitable for application on the underframe coating of PT INKA's UGL project.
4. This data can serve as a reference and additional information for the company.

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