

Effectiveness of Epoxy Coating on Metal Surfaces of NEW773CAT Heavy Equipment Units

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Abstract

This study investigates the effectiveness of the epoxy coating system on NEW773CAT heavy equipment unit operating in a mining environment. The research primarily focuses on the influence of surface preparation methods, dry film thickness (DFT), and coating type on corrosion resistance and adhesion strength. Field case studies, thickness measurements, and visual inspections were employed to assess the performance of coating system. The results reveal that average coating thickness of 396 μm significantly exceeds the minimum ISO 12944 category C5-I standard, which specifies a DFT of 320-400 μm for high corrosivity environments. The surface preparation process using high-pressure cleaning and power tool cleaning (ST 3.0) was found to produce an ideal substrate for epoxy coating application. The use of high-built epoxy mastic as the primer and Aliphatic Polyurethane as the top coat demonstrated excellent corrosion protection and optimal interlayer adhesion. The spray application technique resulted in a uniform coating with no visible defects. This study emphasizes the importance of combining effective surface preparation and precise coating specifications to ensure long-term protection of metal surfaces in harsh environments. The findings suggest that epoxy coating systems, when correctly applied and prepared, can provide robust protection against corrosion, extending the service life of heavy equipment exposed to aggressive conditions like those found in mining operations.

Keywords: epoxy coating, NEW773CAT, coating thickness, adhesion strength, corrosion.

1. Introduction

Steel is one of the main materials used in various industrial sectors due to its excellent mechanical properties, widespread availability, and relatively economical cost. In automotive sector, steel used as a component of vehicle frames requires strength and impact resistance [1], [2]. Protection of metal surfaces from material degradation due to chemical or electrochemical reactions with the environment, such as corrosion, is a major challenge in various industrial applications [3], [4], particularly in the mining, maritime, and offshore construction sectors [5].

Corrosion of steel, particularly when exposed to humid atmospheres or marine environments [6], results in a reduction in thickness, formation of holes, and a decrease in mechanical strength, ultimately leading to component failure [7]. The consequences of corrosion do not only cause economic losses due to material replacement and regular maintenance but also endanger human safety if critical structural failures occur [8].

The process of coating metal surfaces has long been relied upon as the primary method of protection against damage caused by exposure to aggressive environments [9]. The effectiveness of this coating system is determined not only by type of coating material used but also by surface preparation method, application technique, coating thickness, and quality control during and after application [10].

Epoxy is a specialized protective paint used for coating steel surfaces [11], [12]. The purpose of this coating is to form a physical barrier between the steel and the environment, thereby preventing corrosive reactions [13], [14]. Epoxy paint is widely chosen because it has good adhesion [15], high chemical resistance, and ability to withstand aggressive environmental conditions [16], [17]. In contrast, alkyd coatings exhibit limited resistance to

moisture and chemical exposure. Chemical resistance refers to exposure to contaminants commonly found in mining environments, such as diesel fuel, hydraulic oil, lubricants, mild acids, and alkaline dust. Epoxy coatings offer stronger adhesion and a longer service life in humid environments. Zinc-rich coatings provide cathodic protection; however, they require a very high level of surface cleanliness and are sensitive to application errors. Meanwhile, polyurethane coatings exhibit excellent ultraviolet (UV) resistance but generally require an epoxy primer to achieve effective corrosion protection. Therefore, epoxy coatings—particularly high-built epoxy mastic systems—are preferred for heavy-duty applications due to their high surface tolerance, ability to achieve high dry film thickness (DFT), and strong bonding to mechanically prepared substrates [18].

Surface preparation is a critical prerequisite for the successful application of epoxy coatings. The effectiveness of coating system depends heavily on the surface preparation performed before application. Without proper preparation, the coating will not adhere adequately, resulting in a shortened coating service life, adhesion failure, blister formation, and an increased risk of premature corrosion [18]-[22]. Good surface preparation includes cleaning contaminants such as oil, dust, and rust, as well as creating a roughness profile that allows the paint to adhere both mechanically and chemically [23], [24]. Various methods have been developed for this purpose, including cleaning with solvents, manual cleaning with brushes and sandpaper, mechanical cleaning with tools such as grinders, and abrasive blasting methods that produce a rough metal surface [25]. Although abrasive blasting is considered the most effective surface preparation method, it is often impractical for field maintenance of large-scale heavy equipment. Therefore, mechanical surface preparation methods such as power tool cleaning (SSPC-SP 2 and SSPC-SP 3) are widely applied under field conditions and can deliver acceptable performance when combined with surface-tolerant epoxy coating systems. Each method has its advantages and disadvantages depending on the substrate condition, type of paint used [26], and the operational environment of the protected steel structure [27].

Momber et al. [8] conducted a study on the effectiveness of corrosion protection, which is strongly influenced by surface preparation methods and the type of coating system. Through statistical approaches such as Design of Experiment (DoE) and ANOVA, it was found that the combination of blast-cleaning with a lower coating thickness provided the best performance in terms of pull-off strength and rust creep compared to brushing or grinding methods. In their research, You et al. [28] emphasized the importance of surface microstructure on the effectiveness of coating system. In the context of tight sandstone gas reservoirs, changes in permeability and porosity due to salt precipitation showed that surfaces with micropores and microfractures could accelerate the degradation of the coating system if not thoroughly prepared before application. This supports the urgency of applying comprehensive surface preparation methods to prevent adhesion failure. Idora et al. [1] study used the blasting method with a cleanliness standard of SA 2.5, which provides an ideal surface for coating. The combination of blasting and the use of epoxy paint proved to give the best adhesion strength and lower corrosion rates compared to application methods using brushes or rollers. The quality control aspect in Ibrahim and Abidin's [10] research applied the Six Sigma DMAIC approach and Kaizen to coating and auto detailing services. As a result, the identification of critical quality (CTQ) issues such as low coating durability, gloss quality, and application detail was successfully addressed through continuous improvements based on human-centered design and SOP checklists. Nogoro and Golwa [16] conducted an experimental study using the induction cleaning method for removing epoxy and plastic coatings from concrete surfaces, with optimal temperature analysis based on the inverse square law. This shows that thermal physics also plays a significant role in the efficiency of surface cleaning as part of the recoating cycle.

This study is motivated by the need for an optimal and durable coating system to protect heavy equipment units such as NEW773CAT, which are used in mining environments. Extreme environmental conditions, high humidity exposure and presence of abrasive particles make the metal surfaces highly susceptible to corrosion. Therefore, the painting process is not just an aesthetic aspect, but also a structural function that maintains the reliability of the equipment. Literature and empirical data then served as the primary foundation for developing an analytical framework to assess the effectiveness of coating system used in painting projects for NEW773CAT and generator set shelters. The analysis focuses on parameters such as DFT, application methods (brush, roll,

spray), surface conditions (surface preparation) before coating, as well as adhesion quality, impact resistance, and corrosion rate predictions.

2. Experimental Methods

The method used in this study is based on a field case study and experimental testing to evaluate the performance of coating system on metal surfaces in the painting project of NEW773CAT heavy equipment unit, as shown in [Figure 1](#). Primary focus of this study is on the influence of surface preparation methods, the coating thickness (DFT), and the type of coating system on corrosion protection and adhesion quality.



Figure 1. NEW773CAT heavy equipment unit

The research flowchart in [Figure 2](#) is designed to illustrate systematic stages of study conducted to analyze the effectiveness of epoxy coating system on the metal surface of NEW773CAT heavy equipment unit. This flowchart illustrates the sequence of research activities, beginning with the initial study and specification determination, followed by surface inspection and preparation, testing of application and coating thickness, culminating in the visual evaluation and result analysis stages, and providing a clear and structured overview of the entire research process.

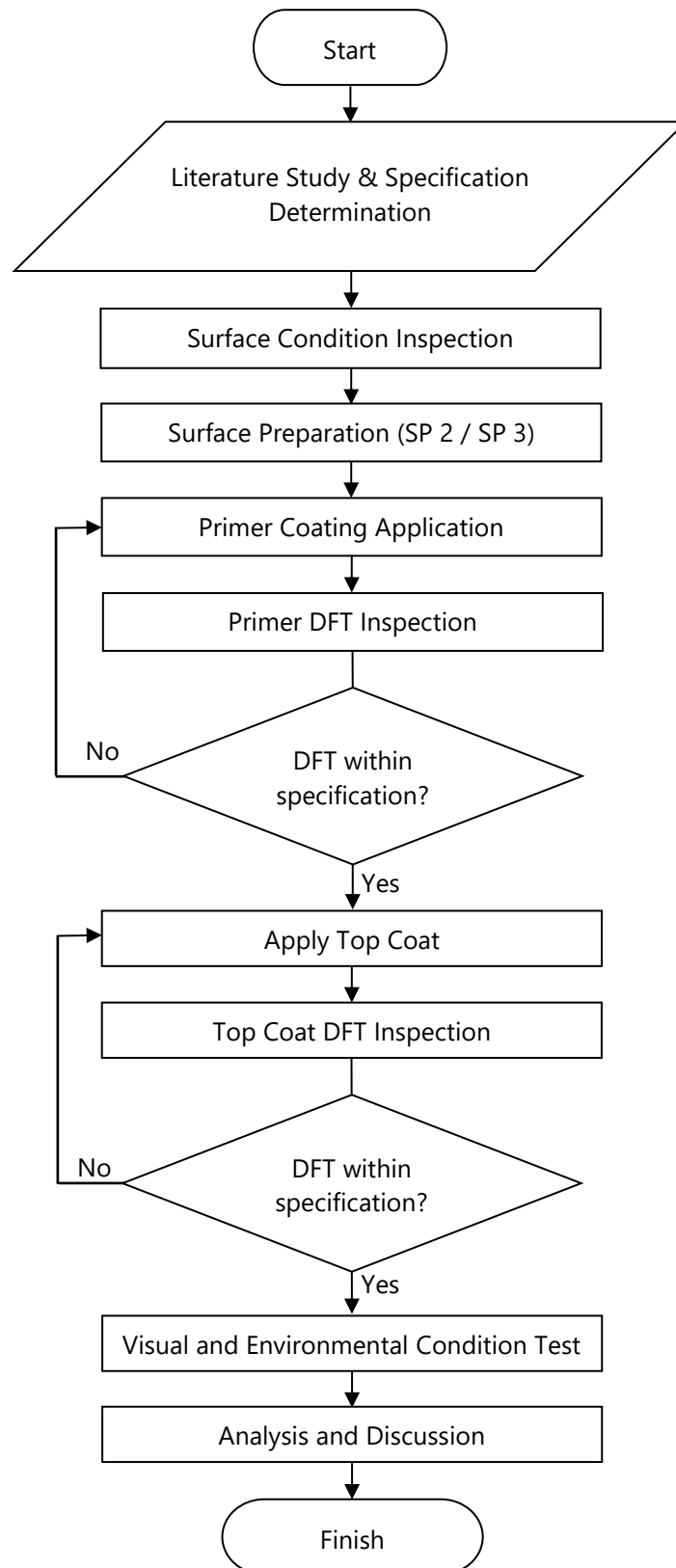


Figure 2. Research flowchart

Figure 2 is the Research Flowchart. This study begins with initial study and specification determination stages to establish a coating system that suits metal protection needed in a mining environment. The selection of the coating system, including type of paint, application methods, and quality standards, is based on extreme conditions, such as high humidity, fluctuating temperatures, and exposure to abrasive particles that accelerate the corrosion process. Based on the review, a two-layer coating system is used, consisting of high-built epoxy mastic as the primer and Aliphatic Polyurethane as the top coat, referring to internal standards and industry standards such as SSPC.

After the specifications are determined, an initial inspection is conducted on the condition of metal substrate surface. This inspection includes a visual assessment of old paint, measurement of the existing DFT, and checking for contaminants such as salt and dust. The average thickness of existing coat was found to be 76 μm , and some areas exhibited surface damage that necessitated further cleaning actions.

The next step is surface preparation, which involves mechanical cleaning methods based on SSPC-SP 2 dan SP 3 standards. High-pressure cleaning was performed using a water-jet system to remove soluble salts, dust, oil, and loosely adhered contaminants. This was followed by mechanical cleaning using rotary wire brushes and needle scalers driven by electric grinders. These tools were employed to remove rust scales, degrade existing coatings, and irregular surface. This process combined manual cleaning with hand tools and mechanical cleaning with power tools to eliminate rust, flaking old paint, and other contaminants. Proper surface preparation is a crucial factor in ensuring optimal coating adhesion and preventing premature coating failure.

Once the surface is prepared, the primer is applied using high-built epoxy mastic. This paint is applied using airless spray method with a nozzle size of 0.019–0.021 inches and an operating pressure of 200–250 bar. The spray distance was maintained at 30–40 cm from substrate surface, with a 50% overlap pattern to ensure uniform coating distribution and to minimize defects such as sagging or pinholes. The target thickness is expected to be 150 μm . Afterward, primer DFT is checked using a measuring tool to ensure the thickness meets specified requirements.

If primer DFT inspection results do not meet the specifications (either too thin or too thick), corrective actions such as re-sanding or adding additional layers will be taken to meet the standards. However, if the primer thickness is correct, the process proceeds to top coat application stage using Aliphatic Polyurethane. The top coat is applied using the appropriate color (Yellow Caterpillar) with a target thickness of 75 μm .

Environmental conditions were continuously monitored throughout coating application process using a digital hygrometer–thermometer with an accuracy of ± 0.5 $^{\circ}\text{C}$ and a dew-point meter, in accordance with ISO 8502-4. The monitored environmental parameters included steel surface temperature (ST), dry bulb temperature (DBT), dew point temperature (DPT), and relative humidity (RH). During application process, ST ranged from 28 to 38 $^{\circ}\text{C}$, while DPT ranged from 26 to 32 $^{\circ}\text{C}$, ensuring a minimum temperature difference of ≥ 4 $^{\circ}\text{C}$ was consistently maintained. This value exceeds the critical threshold of 3 $^{\circ}\text{C}$ recommended to prevent condensation on the steel surface. In addition, RH remained below the maximum allowable limit of 85%. The coating application process was suspended whenever environmental conditions approached the condensation risk threshold to ensure optimal coating quality and adhesion performance.

The subsequent stage is top coat DFT inspection to ensure the outer layer meets the specifications. DFT measurements were performed using a magnetic–induction–based thickness gauge in accordance with ISO 19840. Measurements were taken at 30 points per coating layer, evenly distributed across structural areas considered critical for potential corrosion and mechanical degradation. Before recoating, the existing coating thickness was 76 μm , indicating insufficient protection for environments with high corrosivity (C5 category). Therefore, recoating with an appropriate coating system was required to enhance corrosion resistance and extend the service life of steel structural components. If the measured thickness did not meet the specified criteria, corrective actions (rework) or localized repairs (spot repairs) were performed using touch-up methods or partial recoating. Once the thickness is correct, the procedure continues to the final stage, which involves analysis and result discussion, covering the evaluation of all technical parameters (DFT, visual conditions, environment), and the conclusion.

3. Results and Discussion

3.1. Environmental Condition Analysis

The environmental conditions during the painting process must be carefully considered as they can significantly impact the painting results. To understand the dynamics of environmental conditions during coating work, several factors must be observed throughout the day, including temperature and humidity fluctuations. Four key parameters that are crucial for determining the feasibility of coating are steel temperature, air temperature, dew point, and humidity. These parameters are then used as references for making technical decisions in the field.

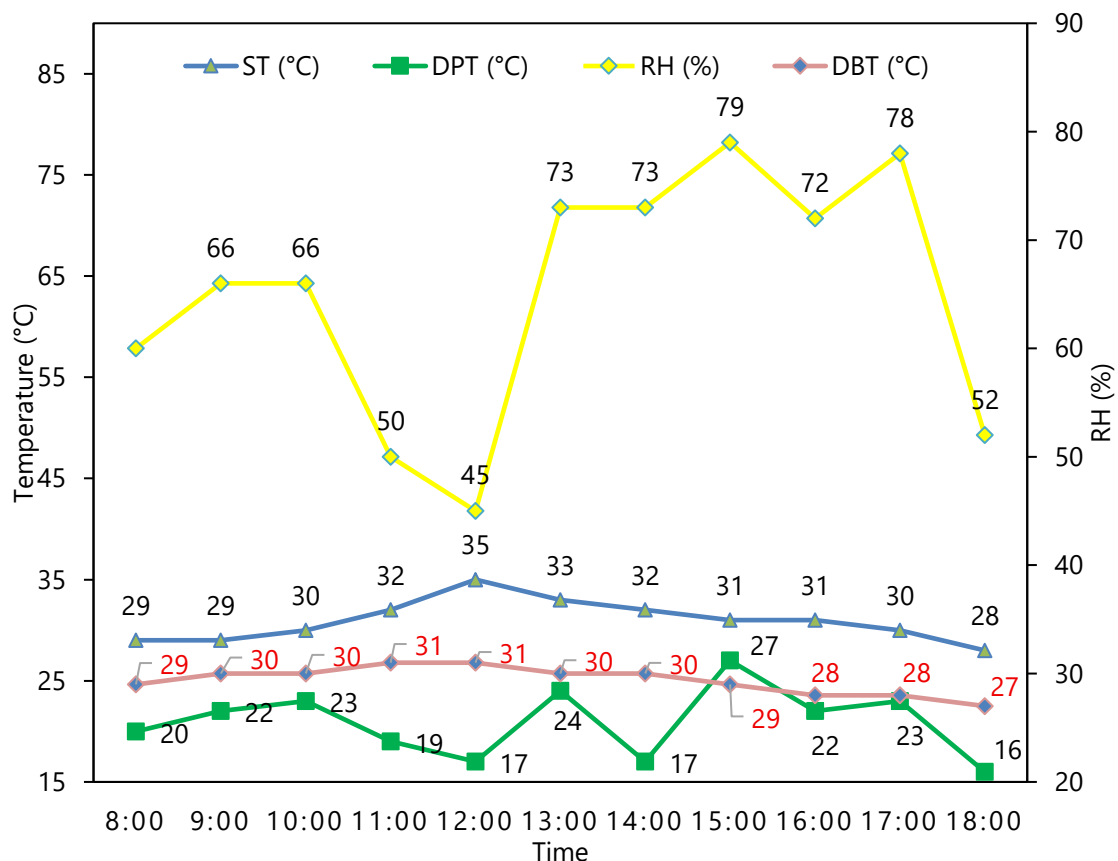


Figure 3. Environmental condition

Figure 3 illustrates the variation of environmental conditions during the coating application process from 08:00 to 18:00, including ST, represented by blue line, which was strictly controlled through direct surface. Temperature measurements using a contact-type infrared thermometer DBT, indicated by red line, representing the ambient air temperature measured using a calibrated digital thermo-hygrometer with an accuracy of ± 0.5 °C. DPT shown by green line measured using a digital dew point meter in accordance with ISO 8502-4; and RH, represented by the yellow line, measured using a digital thermo-hygrometer. The ST reached approximately 35 °C around midday and gradually decreased in the afternoon, following changes in ambient temperature. The DBT remained relatively stable within the range of 27–31 °C, while the DPT ranged from 16 to 27 °C. The temperature difference between ST and DP consistently exceeded 3 °C, with a minimum value of approximately 4 °C, thereby satisfying the technical requirements to prevent condensation on the steel surface. RH fluctuated throughout the day, ranging from approximately 45% to 80%, yet remained below the recommended maximum of 85%. The decrease in RH during midday correlated with an increase in steel surface temperature due to solar heating [29], [30]. In contrast, the rise of RH in the late afternoon coincided with a reduction in ambient

temperature [31]. Overall, the environmental conditions during coating application remained within safe standard-compliant ranges, supporting optimal formation of the protective coating without the risk of condensation-related failure.

3.2. Surface Preparation Analysis

The surface preparation methods applied are as follows:

- a) High-pressure cleaning with clean water.
- b) Cleaning using power tools with the ST 3.0 / SSPC-SP3 standard on rusty areas.

This method is considered a medium-level surface preparation, classified as mechanical cleaning, differing from abrasive blasting. The effectiveness of this method is relatively high when combined with a coating system that has surface-tolerant characteristics (surface-tolerant epoxy system).

Although it is not the most effective method, such as blast-cleaning, ST 3.0 standard still provides a sufficient surface profile to create both mechanical and chemical adhesion of the paint, if no active contaminants are left behind. The results of coating thickness measurements before surface preparation and after surface preparation are presented in Figure 4.

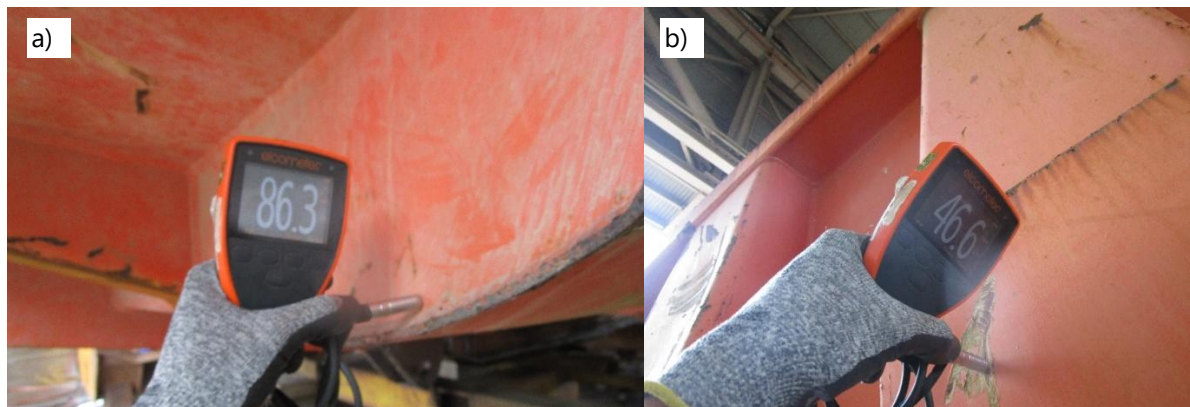


Figure 4. Surface condition of the NEW773CAT steel: (a) before surface preparation; (b) after surface preparation

3.3. Coating System Effectiveness

The performance of the coating system can be evaluated from the following aspects:

3.3.1 Adhesion Strength

The coating system, utilizing spray methods and epoxy-based materials such as Aliphatic Polyurethane and high-build epoxy mastic, provides higher adhesion strength than systems employing roll or brush methods. Spray application results in a more uniform layer distribution, optimal penetration into pores, and strong interlayer bonding. The adhesion strength in this method has been reported to reach up to 22.5 MPa.

3.3.2 Corrosion Protection

A thick and uniform coating prevents moisture and oxygen from penetrating the steel substrate. The actual DFT values indicate that this system can provide long-term protection, even in environments with C5 exposure, such as those found in mining. The thicker the protective coating (zinc, epoxy, or polyurethane), the lower the corrosion rate that occurs.

3.3.3 Visual Quality

Visual inspections conducted during and after application reveal satisfactory coating results, with no surface defects, including sagging, cracking, or orange peel. This reflects the optimal control of the application procedure in accordance with principles of the quality control circle (QCC).

3.4. Coating Thickness (DFT)

The measurement results of the DFT show that the entire coating system application exceeds the minimum specification standards, with the following results:

Table 1. DFT coating results and average actual DFT specifications

Unit	Coating layer	DFT specification	Average actual DFT
NEW773CAT	Primer	150 μm	323 μm
	Top Coat	75 μm	396 μm

Table 1 shows that the actual thickness values are excellent in the coating application, with a total average thickness of 396 μm for NEW773CAT. This value exceeds the minimum requirements generally applied to standard protective coatings under ISO 12944 category C5-I, which requires a total DFT of 320–400 μm for very high protection in heavy industrial environments.



Figure 5. Primer coat thickness

Excessive thickness can significantly reduce rust creep and improve pull-off adhesion strength when combined with proper surface preparation [32]. This finding is consistent with the field results, which showed no indication of visual defects, such as blistering or flaking, during the final inspection process. Figures 5 and 6 show the coating inspection.

A thickness greater than the standard can enhance both corrosion resistance and abrasion resistance, provided the coating remains uniform and does not develop defects such as sagging or cracking. A thicker layer will extend the substrate's lifespan in aggressive environmental conditions, such as those found in open-pit mining, provided the curing process is flawless and defect-free [33].



Figure 6. Top coat thickness



Figure 7. Coated NEW773CAT

The application of this coating system is considered quite effective in creating a strong protective layer against direct sunlight exposure, water, and industrial contamination, given that Aliphatic Polyurethane has excellent resistance to UV, solvents, and abrasion, as stated in the technical datasheet from the paint manufacturer—the results of NEW773CAT after the coating process are shown in [Figure 7](#).

4. Conclusion

Based on results of the coating project on NEW773CAT heavy equipment unit in the mining area, it is concluded that the obtained DFT exceeds the required minimum standard. For the NEW773CAT unit, the average thickness of high-built epoxy mastic primer coat reached 323 μm , and the Aliphatic Polyurethane top coat thickness was 396 μm . ISO 12944 category C5-I requires a total DFT of around 320–400 μm for heavy industrial environments or high corrosivity. The achievement of specified coating thickness was primarily influenced by the application method employing spray techniques, which if operationally compared with brush application, resulted in a more uniform coating distribution, minimized visual defects, and enhanced interlayer adhesion.

The effectiveness of surface preparation method used, to wit ST 3.0 (power tool cleaning), was also proven to be adequate. Although this method does not remove all mill scale and heavy rust like the blasting method, the combination of high-pressure cleaning, mechanical cleaning, and visual inspection successfully created a clean substrate ready to accept the paint. The epoxy mastic coating system demonstrated good performance on steel surfaces cleaned of active rust by mechanical surface preparation. This performance cannot be attributed solely to the surface preparation method; rather, it results from the compatibility between the ST 3.0 level of surface cleanliness and the surface-tolerant characteristics of epoxy mastic coatings. Compared to alkyd coatings, which exhibit limited resistance to moisture and chemical exposure, epoxy-based coatings provide superior adhesion and barrier properties on mechanically prepared steel surfaces. Zinc-rich coatings, although effective in providing cathodic protection, generally require abrasive blasting to achieve optimal performance and are less tolerant of residual rust. Meanwhile, polyurethane coatings offer excellent ultraviolet resistance but typically require an epoxy primer to ensure adequate corrosion protection. Therefore, selecting a high-built epoxy mastic coating system combined with an aliphatic polyurethane topcoat is appropriate, as both materials are designed to provide high resistance to moisture, chemicals, and ultraviolet radiation, making them well-suited for extreme environments such as mining operations. Generally, the results of this project do not only meet applicable industry standards but also align with recent scientific findings on the effectiveness of protective coating systems for steel structures under field conditions.

5. Acknowledgments

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6. References

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