

Effect of Surface Cleanliness on Powder Coating Quality

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Abstract

Due to environmental and usage conditions, it is inevitable for metal parts to be exposed to harmful effects such as rusting, oxidation, and corrosion. One method of protection against these effects is the surface coating processes. Processes such as electrostatic powder coating, which are preferred in industry due to their environmental impact and ease of use, can help protect metal parts from corrosion. However, in some surface coating processes, oil, dirt, rust, or residues remaining between the material surface and the paint can reduce the quality of the coating. Proper surface cleaning prior to processes such as electrostatic powder coating is important for the adhesion quality and protective ability of the paint on the material.

In this study, the effect of surface cleaning performed before electrostatic powder coating on the paint applied to the part will be examined. Additionally, the effect of cleaning processes performed with different chemicals on the quality of the paint will be discussed. Results will be obtained by examining the samples under a microscope after cleaning and conducting hardness tests. Subsequently, the surface and cross-sections of the painted samples will be examined, and hardness and cross-cut tests will be applied. This study aims to investigate the effect of different surface preparation processes on the quality of the paint after electrostatic powder coating application.

Keywords: Electrostatic powder coating, corrosion resistance, surface cleaning, paint quality

Introduction

Parts made of metal material are exposed to many harmful effects such as rusting, oxidation, and corrosion throughout their service life. One method of protection against these effects is surface coating processes as pointed out by Wardan (2018) is powder coating, a commonly used surface coating process, is preferred due to its lack of solvents, its relatively even distribution on the part surface, its ability to coat the part in very thin layers, and its high application speed in industrial facilities as noted by Prasad (2016). The powder coating process is divided into two types based on the type of paint and application method: thermoplastic paints, which consist of thermoplastic resin, pigment, filler materials, and stabilizers—usually made of substances like polyethylene and polyamide—are generally applied by dipping into fluidized powder. A study by Du (2016) explains that thermoset paints, which consist of epoxy resin, polyester resin, various hardeners, and contain different pigments and filler materials, are more commonly applied electrostatically using spray guns.

For the paint to fully cure and adhere permanently to the part, it must pass through a system called a curing oven or baking oven. This system varies depending on different part sizes and the duration the part remains inside. As explained by Nergiz (2021), the main components of baking ovens consist of a thermoblock—heat exchanger and fans—an opening through which the part passes, doors for entry and exit of the part, insulation panels, and the conveyor line above the oven. The painted parts are kept in the curing oven at specific temperatures (149–232°C) and for predetermined durations depending on the thickness of the parts as explained by Lv (2023). When the curing process is complete, a highly durable and homogeneous coating is expected to form. Wardan (2018) highlighted that the main factor determining the quality of the paint is the surface preparation carried out before the part enters the painting process.

Materials and Methods

Materials

The main materials to be used in the project are a sheet metal part made from cold-rolled ST-37 steel and electrostatic powder coating. ST-37 steel is a low-carbon structural steel cold-rolled for general

use, designated by material number 1.0037 according to DIN 1623/2. According to the tests conducted, the dimensions of the materials used vary. The table below lists the tests in which the materials are used and the approximate dimensions of the parts.

Sheet Metal Size	Tests Performed
180mmx120mm & 2mm thickness	Impact test, cross-cut test, paint thickness test
120mmx18mm & 2mm thickness	Vickers microhardness test
A cross-section 18 mm × 2 mm thickness embedded in bakelite	Analysis under microscope

Methods

The project began with the cutting of sheet materials made of ST-37 steel into dimensions of 180 mm × 120 mm at the Sistem Teknik Makina factory. Subsequently, the sheet metal parts cut to the required dimensions underwent three different types of cleaning processes. These are:

Washed part: Samples that were cleaned with acid by passing through the washing line at the Sistem Teknik Makina factory, then rinsed with water and dried,

Part wiped with thinner: Samples that did not go through the washing line, but whose surfaces were wiped with thinner by personnel after cutting and then sent for painting, and

Untreated part: Samples that were cut in the condition in which they were stored under factory conditions, and were sent for painting without undergoing any surface cleaning process.

All these parts, which were cleaned in three different ways, were consecutively placed together into the powder coating booth and coated with electrostatic powder paint. Then, with the help of the conveyor, they continued into the paint curing oven and were held for the duration of the curing process. After the curing process was completed, the parts were removed from the oven and let cool. Afterwards, they were cut into 18mm sheets and marked, as seen in the Figure 6.



Figure 6. Sheet metal parts cut and marked for testing

For microscopic examination, one sample from each type was prepared, resulting in a total of three pieces each. These pieces were then embedded in hot bakelite. To remove residual materials from the cross-sectional surface of the bakelited samples, they were sanded and polished. The Nikon ECLIPSE LV150N Industrial Microscope in the laboratory of Manisa Celal Bayar University is used to examine them.

For the impact test, a custom testing setup designed by Sistem Teknik Makina, which drops a 1 kg steel cylinder vertically onto the painted sheet metal from a height of 1 meter, is used. Since this apparatus applies the same force each time, the results observed on the surfaces of the parts are

comparable. The setup includes a locking mechanism that ensures the 1 kg weight is released equally each time. When the lock is opened, the weight drops from the same height to the painted part placed at the bottom of the apparatus.

The equipment used for the cross-cut test consists of a blade that creates six parallel cuts spaced 8–10 mm apart, followed by six perpendicular cuts in accordance with ISO 2409 standard. After the cuts are made on the surface of the part, the tape included in the test kit is applied to the surface and then pulled off to observe the amount of paint removed from the surface. The observed results are graded on a scale from 0 to 5, as specified in the standard, based on the amount of paint detachment.

For the Vickers microhardness test, Future-tech FM-700 Microhardness Tester device in the laboratory of Manisa Celal Bayar University is used. 120 mm × 18 mm samples were placed in the specimen holder of the device, and all three samples were tested under loads of 300 gf, 100 gf, and 10 gf, each with a dwell time of 10 seconds. For each sample and each load level, 10 tests were conducted. Depending on the load, the lens that allowed the best view of the indentation was used. With the help of the device, the two diagonals of the indentation left on the surface were measured, and the Vickers hardness value was determined. The calculations were carried out automatically by the device, and the formula used is provided below in Eq. (1).

$$HV = 1.854 \times \frac{F}{d^2} \quad (1)$$

During the microscopic examination of the bakelited samples, each sample was first placed under the microscope lens, and the section between the sheet metal surface and the paint layer was located. Measurements were taken on the captured images. For each image, 10 measurements were conducted, and although the average values of the measured paint thickness will be presented, the standard deviation of the measurements will also be reported to illustrate the cases where the coating is not uniform (especially considering the poor paint adhesion observed on the surfaces of unwashed parts). Images were taken at 500x magnification for measurement purposes; however, 1000x or 1500x magnifications were also used in some cases to better illustrate anomalies between the metal and the paint.

Results and Discussion

Impact Test

The results for the impact test can be analyzed visually. In the sample cleaned in the washing line, a small amount of deformation is observed on the paint surface. This deformation can be interpreted as resulting from the sheet metal itself being deformed, causing the paint on the surface to be compressed and damaged. However, no visible paint detachment or blistering is present after the impact, as seen in Figure 7.



Figure 7. Sample cleaned in washing line, after the impact test

In the sample wiped with thinner, a minimal yet more noticeable amount of paint deformation is observed compared to the sample that passed through the washing line. This can be interpreted as a result of the paint's adhesion quality to the material being slightly lower in this sample compared to the washed sample as it can be seen in Figure 8.



Figure 8. Sample wiped with paint thinner, after the impact test

In the untreated sample, areas of paint detachment and the marks left by the impact are clearly visible. Compared to the other two samples, this one shows the highest amount of paint detachment and the most visible marking. This is thought to be due to the paint not adhering properly to the sheet metal, resulting in the paint peeling off after the impact as it can be seen in Figure 9.



Figure 8. Untreated sample, after the impact test

After the impact test, it was generally observed that as the surface cleaning quality of the parts decreased, the rate of paint peeling due to impact increased. Although the sample wiped with thinner showed less peeling compared to the untreated sample, the paint on the surface of the sample that passed through the washing line showed the best overall performance. Based on this result, it has been demonstrated that wiping with thinner before electrostatic powder coating provides better impact resistance than coating without any cleaning process, while cleaning through a washing line results in the highest resistance.

Cross-Cut Test

As a result of the cross-cut test, every sample yielded a level 0 result in accordance with ISO 2409 standard, which means that there was no paint removal from any of them. Following this test, it was observed that all three samples successfully passed. Therefore, no suitable data could be obtained to compare the effect of surface cleaning prior to painting on paint quality based on this test. The results can be seen in Figure 9.



Figure 9. From left to right: Washing line sample, paint thinner sample, and untreated sample cross-cut test results

Vickers Microhardness Test

In the microhardness test, 10 measurements were conducted for each of the three different loads: 300gf, 100gf, and 10gf. The average hardness results for each of the three samples at these different load levels are presented in Table 2, Table 3, and Table 4 below.

Table 2. Microhardness test results for the washing line sample

Number of tests	Load	Average hardness (HV)
10	300gf	18.06
10	100gf	16.93
10	10gf	18.53

Table 3. Microhardness test results for the paint thinner sample

Number of tests	Load	Average hardness (HV)
10	300gf	19.75
10	100gf	16.75
10	10gf	18.54

Table 4. Microhardness test results for the untreated sample

Number of tests	Load	Average hardness (HV)
10	300gf	17.46
10	100gf	15.85
10	10gf	18.57

The resulting data indicate that the samples subjected to surface cleaning processes exhibited higher hardness values under both 300gf and 100gf loads. This has been interpreted as a result of better paint adhesion to the surface and fewer residual materials between the paint and the metal surface after curing. Under the 10gf load, all three samples showed very similar results. This may be due to the 10gf load being insufficient to significantly deform the paint layer. Another possible explanation is the presence of errors during the testing process.

Surface thickness measurement

The SaluTron D4-Fe coating thickness gauge was used to measure the paint thickness of the coated sheet metal parts from the outside. These measurements were taken from different sections of the samples, and the average values are presented in the table. The obtained thickness values will later be

compared with the paint thickness measurements performed on the cross-sections of the parts under a microscope.

Table 5. External paint thickness measurement results

Sample	Average paint thickness (μm)
Washing line sample	81.37
Paint thinner sample	61.6
Untreated sample	54.2

Cross-section

For each sample’s cross-sectional image examined under the microscope, images were taken from random areas of the three sections embedded in bakelite. In each captured image, 10 measurements were taken to determine the average paint thickness. All images are captured in 500x magnification unless stated otherwise. Some of the captured images with the measurements are presented in Figure 10 to Figure 15.

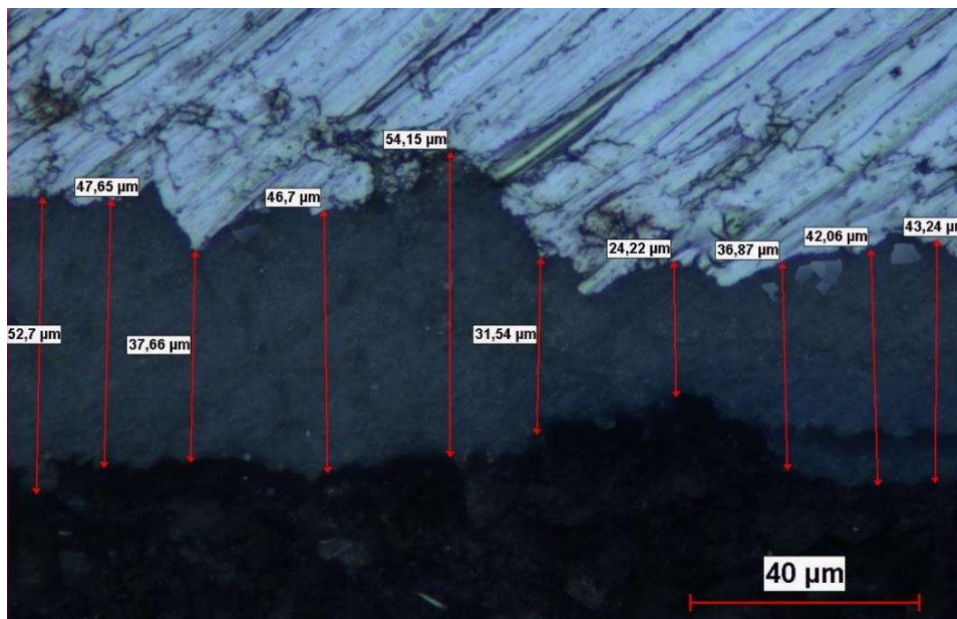


Figure 10. Washing line sample, measurement 1

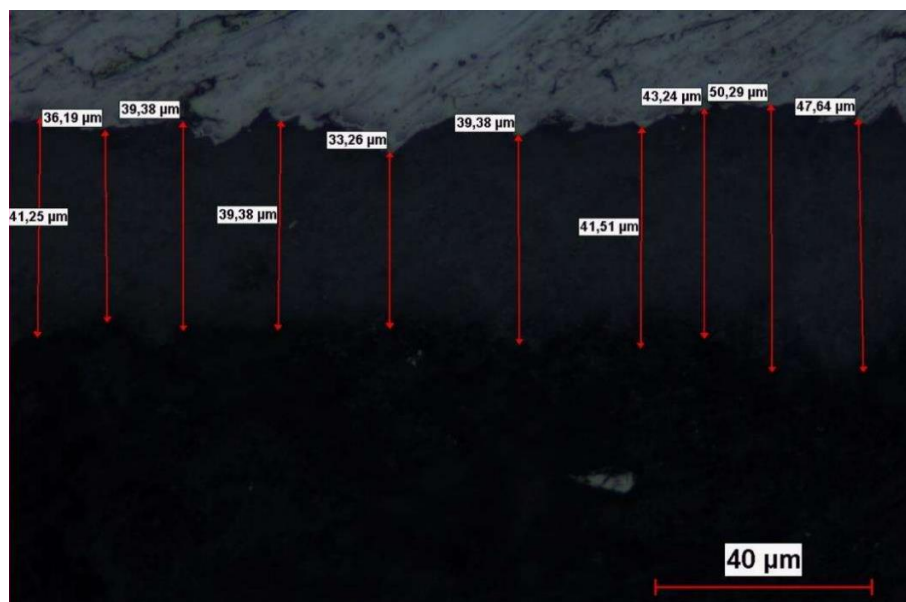


Figure 11. Washing line sample measurement 2

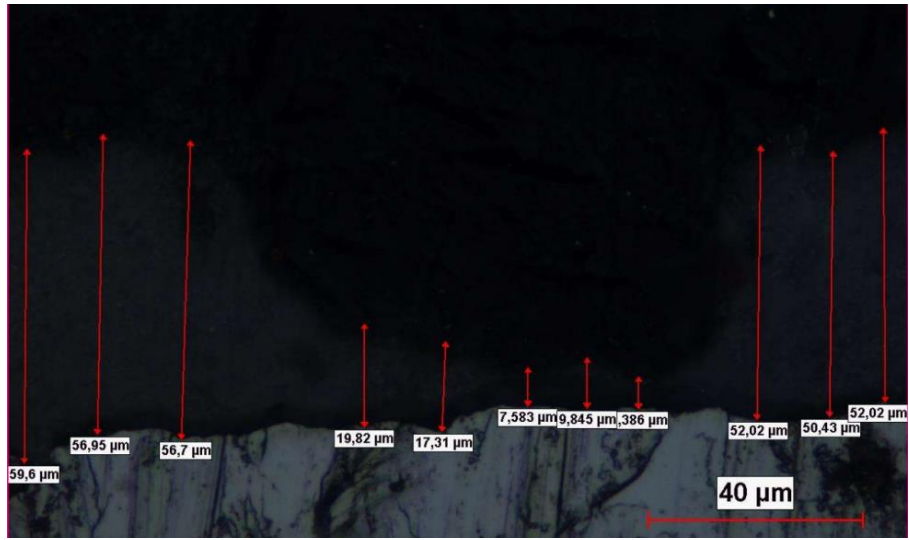


Figure 12. Paint thinner sample, measurement 1

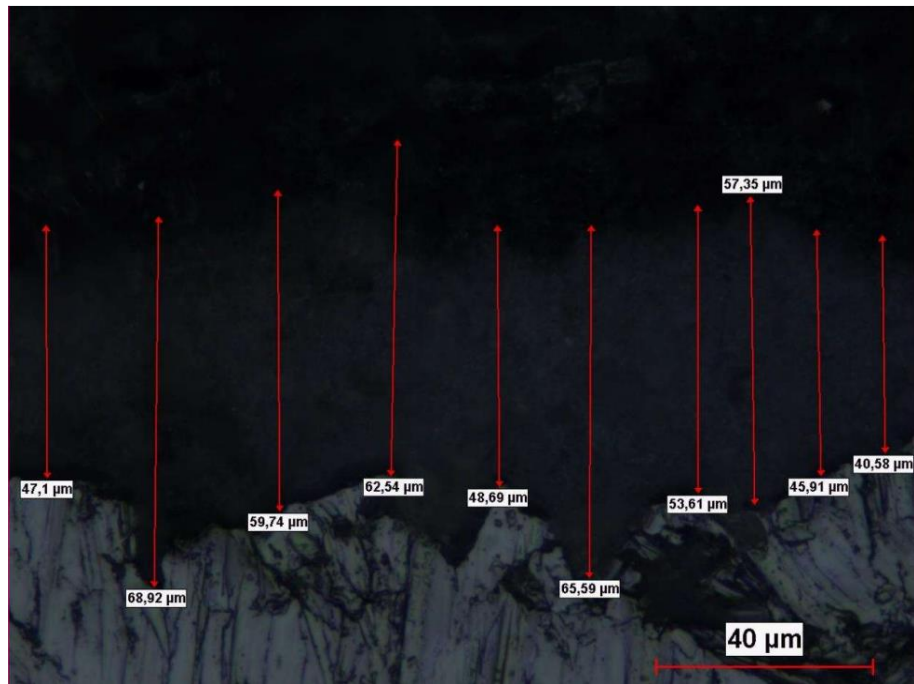


Figure 13. Paint thinner sample, measurement 2

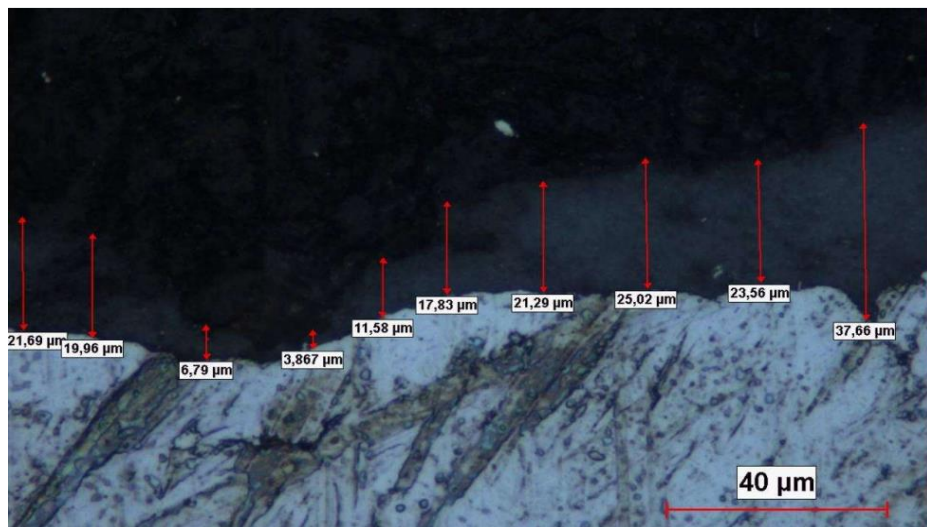


Figure 14. Untreated sample, measurement 1

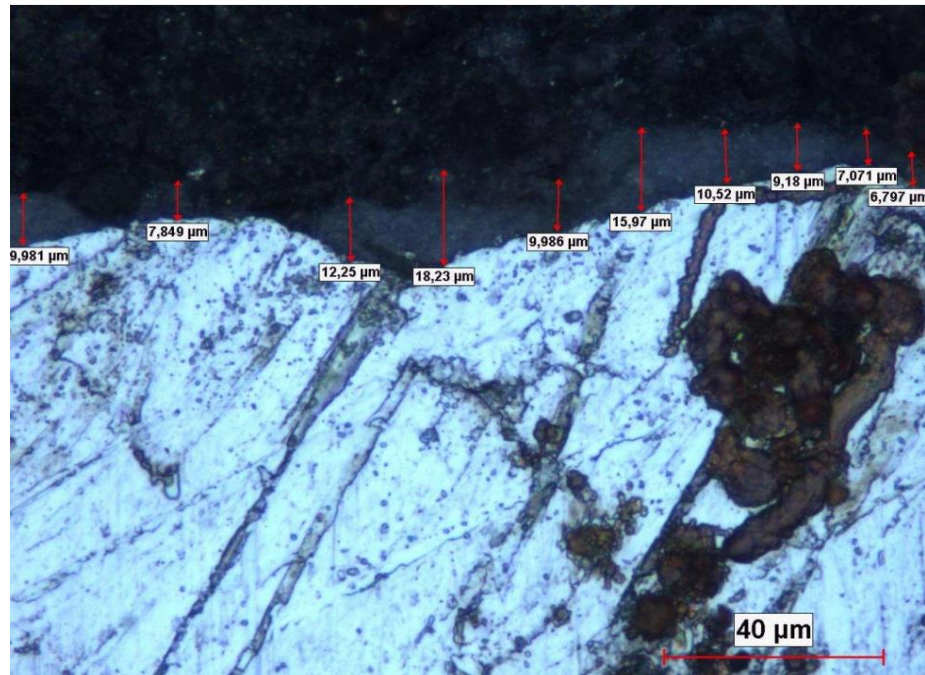


Figure 15. Untreated sample, measurement 2

Residual substances are observed between the material and the paint in the untreated samples. Such residues both reduce the adhesion quality of the paint, as seen in the impact test, and lead to a decrease in paint thickness and a non-uniform coating causing extremely thick or extremely thin coating layers. This can be seen in Figure 16 and Figure 17 below.



Figure 16. Residual substances between the metal surface and the paint for the untreated sample



Figure 17. Residual substances between the metal surface and the paint for the untreated sample

The average values and standard deviation of the 10 paint-thickness measurements taken under the microscope are given in Table 6, Table 7 and Table 8 below for each sample.

Table 6. Paint thickness measurement results for the washing line sample

Measurement no.	Average paint thickness	Standard deviation of measurements
1-10	41.68	8.87
10-20	41.15	4.76
20-30	44.68	2.78
30-40	43.97	3.16

As seen in Table 1, the average paint thickness remains consistent across all the measurements, with moderate standard deviation. This suggests that the samples that went through a washing line have a relatively consistent thickness in the paint layer.

Table 7. Paint thickness measurement results for the paint thinner sample

Measurement no.	Average paint thickness	Standard deviation of measurements
1-10	63.36	4.4
10-20	66.37	8.05
20-30	35.42	21.34
30-40	55.00	8.86

Table 2 shows that the average paint thickness is generally higher than the values from Table 1, the variation is more noticeable, with standard deviation values up to 21.34. This implies that wiping the samples with paint thinner may lead to a less consistent coat compared to the washing line samples, due to the possibility of missing certain spots in the cleaning process by hand. The greater overall thickness values may be due to residue between the surface and the metal.

Table 8. Paint thickness measurement results for the washing line sample

Measurement no.	Average paint thickness	Standard deviation of measurements
1-10	52.73	6.6
10-20	18.93	9.24
20-30	10.78	3.56
30-40	13.29	3.46

According to Table 3, the average paint thickness significantly less than the other two samples in most measurements, and the standard deviation is moderate to high. These results show that the untreated samples have a much thinner paint layer that can lead to less resistance to corrosion and impact.

As seen in the visuals and tables, the main difference between the washing process and wiping with paint thinner is that the coat thickness is less variable, which means that while very high thickness may be observed in some areas, other areas may be covered with an excessively thin layer of paint. The washing line process provides both a consistent thickness compared to the other methods as well as an acceptable average thickness value.

Conclusions

The results from the experiments conducted on sheet metal parts that undergo electrostatic powder coating show that cleaning such parts before the painting process offers multiple benefits. Firstly, the cleaning process is necessary to ensure a homogeneous paint thickness and to prevent areas with thicknesses as low as 8–9 micrometers, which could impact parameters such as the corrosion resistance of the parts negatively. Furthermore, it has been determined that the peeling of the paint upon impact is significantly reduced when surface cleaning is performed prior to painting.

When it comes to the type of surface cleaning, the methods addressed in this study include cleaning the parts through a proper washing line and wiping them with paint thinner. When these cleaning methods are compared, while no major differences were observed in certain tests such as hardness and impact tests, examination of the paint cross-section under a microscope revealed that the parts that went through the washing line exhibited a more uniform paint thickness compared to those wiped with thinner. For this reason, the choice of surface cleaning method according to the usage are for the final parts and the resources available, can be discussed.

An important point not addressed in the study is the effect of the surface cleaning methods on the corrosion resistance in the coated parts. In future studies, to investigate this topic in depth, similarly prepared samples can be subjected to tests such as the salt spray test in accordance with the ASTM B117 standard to examine their corrosion resistance. Additionally, while examining the cross-section between the part and the paint, more detailed and close-up visual inspections—such as with a scanning electron microscope—can be conducted to closely observe the interface between the paint and the part, in order to observe the existence of residual substances and their effects on paint quality.

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