



Research Article

Effect of Temperature and Hardener Variations on Result of Painting Layers with Nitrocellulose (NC) Paint

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ABSTRACT

The finishing work using paint had almost been found on all products. Besides achieving an aesthetic appearance, the paint layer had also served to protect a product from sun exposure and even scratches. However, the paint layer had also had weaknesses, one of which was exposure to high temperatures. Temperature had been an external factor that significantly affected the surface layer of the paint. Excessive heat could have caused the paint layer to crack, fade, or even peel off. The aim of this research is to determine the impact of variations in temperature and hardener on the results of the painting layer, namely adhesion, gloss, hardness, and gasoline resistance on the results of painting using NC paint. The variations in this research were oven temperatures of 100°C and 120°C with a heating time of 20 minutes. The results on adhesion testing are classified as 5B or 0% (no surface peeling) in all variations. The best gloss power test results were 28.8GU at a temperature of 100°C using 10ml hardener. The hardness test results showed that there were no scratches on the paint surface for all variations. The results of the gasoline resistance test showed that there was no paint fading or fading when exposed to fuel in all variations by rubbing with a cloth repeatedly 50 times.

1. INTRODUCTION

Extreme temperatures that had recently struck Indonesia, particularly in Semarang City, had reached around 39°C. This heat had placed Semarang as the second hottest city after Surabaya, which had recorded the highest temperature in Indonesia (BMKG, 2024). The intense heat had become an external factor that could have affected the paint surface layer, such as surface cracking and fading. The result of checking the paint surface temperature on a car during midday using a thermometer gun had shown a temperature of 44°C. The internal factor resulting from the paint coating had been the quality of the paint. High-quality paint had influenced good adhesion, excellent gloss, and durability. However, using high-quality paint

had also impacted material costs, which had been significantly higher (Sopiyan et al., 2022).

Problems that had often arisen with paint involved small pinholes, textures resembling orange peel, excessive layer thickness causing the paint to run, the tendency of the paint surface to peel off, a lack of the desired gloss, mismatched color differences, the presence of scratches or sanding marks, and damage or discoloration of the paint when exposed to fuel (F. Z. Bahtiar et al., 2023). The deficiencies or weaknesses of paint had been improved by adding additives such as hardeners, retarders, and other additives to enhance the paint's quality. Nitrocellulose (NC) paint had a drawback, namely its less-than-perfect gloss and adhesion (Halim et al., 2021).

The hardener had functioned as a hardener, bonding molecules together so that different substances could



adhere properly. The resin contained in the hardener had the ability to enhance gloss, as the resin was liquid and transparent, while also accelerating the drying process (Dwiyati, 2015).

The coating process in this study was carried out using either liquid atomization techniques or powder application methods, depending on the type of coating material applied to the substrate surface. In the liquid atomization process, the paint material was sprayed evenly onto the panel surface to produce a uniform coating layer, while powder application involved the deposition of dry coating particles before the curing stage. After the application process was completed, the coated panels were subjected to a drying stage to ensure proper film formation and adhesion. The drying process could occur naturally at room temperature or be accelerated through the use of a heating device such as an oven. Natural drying generally required a longer time because the solvent evaporation and curing reactions occurred gradually under ambient conditions (Pratama et al., 2024; Ye & Pulli, 2017).

To improve efficiency and achieve more controlled curing conditions, an oven or drying chamber was utilized as the heating medium for the coated panels under investigation. The oven used in this study had a maximum operating temperature of 200°C and was capable of maintaining the heating process for up to 60 minutes. By using controlled heating temperatures and durations, the drying and curing process of the paint coating could be optimized to produce a stronger and more durable paint film. The oven treatment also allowed the evaluation of the coating's resistance to elevated temperatures, since exposure to heat can influence important coating properties such as adhesion, hardness, gloss, and chemical resistance. Therefore, the use of the oven not only accelerated the drying process but also served as an important parameter in determining the thermal durability and overall performance of the paint coating system (Blandin et al., 1987).

Based on a study titled *The Effect of Drying Temperature Variations on the Gloss of Paint on Motor Vehicle Components*, it had been shown that the highest gloss value at temperature variations of 40°C, 60°C, and 80°C with a heating duration of 25 minutes had been at 40°C, achieving 98.9 GU, and producing good adhesion quality (Sopiyan et al., 2022). The results of the study conducted by Bahtiar & Bahar had shown that the best gloss was achieved with a mixing ratio of 1:1.3, reaching a value of 79.7 GU (F. Bahtiar & Bahar, 2022). Another study conducted by Syaiful and Suwahyo had shown the best results in minimizing the corrosion rate by using epoxy primer paint. The lowest corrosion rate was 8.4 mpy at an oven temperature of 40°C, while at an oven temperature of 60°C, the corrosion rate could be reduced to 7.8 mpy (Rifai & Suwahyo, 2021).

To determine the results of the paint coating, several testing methods had been required. The adhesion test had been used to measure the strength of the paint layer in resisting peeling from the surface. The gloss test had evaluated the level of glossiness achieved by the paint coating on the surface. The hardness test had assessed the paint layer's resistance to scratches, while the gasoline resistance test had determined the durability of the paint layer against fuel exposure, particularly in preventing fading.

From the description above, the researcher had concluded that several factors could support this study: the nitrocellulose (NC) paint, which had weaknesses in adhesion and gloss that were not optimal; excessively high midday temperatures; and the hardener's ability to bond molecules or substances. Based on this background, the researcher had chosen study *Effect of Temperature and Hardener Variations on Result of Painting Layers with Nitrocellulose (NC) Paint*.

The contribution of this study lies in providing insights and solutions to improve the quality and durability of nitrocellulose (NC) paint. This includes addressing its limitations in adhesion and gloss through the integration of hardeners and optimizing the drying process under controlled temperatures.

2. METHOD

In this study, the method applied was an experiment with a pre-experimental design using a one-shot case study approach, where there were no control variables, and the sample selection was carried out without randomization (Sugiyono, 2020). The objective of this study was to evaluate the impact of temperature variations (100°C and 120°C) and hardener content (5ml and 10ml) on certain properties of NC paint, including adhesion, gloss, hardness, and fuel resistance (fading). Testing was conducted using ASTM D 3359 standards for adhesion, a gloss meter for gloss measurement, a pencil hardness tester PH-3363 to measure surface hardness, and a fuel resistance test to assess the paint surface's response to fuel. The object of this research was NC Semi Black Gloss paint. Some specifications of this paint shown at Table 1.

Table 1. Paint specification

Brand	Steel Gloss
Code	NC Semi black Gloss
Ratio	1 : 1 (Paint : Thinner)
Air pressure	4~5 bar
Drying time	1 hour at 28~30°C 30 min. at 60°C
Space between layers	1.3 ~ 1.5mm

The design of the experiment (DoE) of this study is clearly shown in Table 2. A total of four treatment schemes were applied to evaluate the effect of temperature and hardener concentration on the coating properties. Each treatment consisted of a combination between two levels of oven-drying temperature (100°C and 120°C) and two levels of hardener concentration (5 ml and 10 ml). For each treatment, three specimens per scheme were prepared. Thus, the overall number of specimens used in this study was 12.

Table 2. Design of Experiment

Scheme	Oven Temperature (°C)	Hardener concentration (%)	Specimens (pcs)
1	100	5	3
2	100	10	3
3	120	5	3
4	120	10	3

Research Limitation

The study only examined two variations of oven drying temperatures (100°C and 120°C) and two hardener concentrations (5 ml and 10 ml). Variations outside these ranges were not tested; therefore, the results cannot be generalized to other temperature and concentration conditions. The research used a particular NC (Nitrocellulose) paint without comparing it to other types of paint, so the conclusions apply only to the paint used in this study. Each test was conducted with three repetitions per treatment. This number may limit statistical accuracy for broader industrial-scale production variations.

The testing was performed on a single type of substrate (with no variation in base materials mentioned), making it non-generalizable to all surface types. Adhesion (ASTM D-3359), hardness (ASTM D-3363), and fuel resistance tests were conducted according to these standards. Results may differ if other testing standards are used. Durability testing was conducted only against gasoline (RON 90) with a rubbing method of 50 cycles. Other environmental conditions, such as UV exposure, extreme humidity, or different chemicals, were not tested. The study focused on results after drying and immediate testing without including long-term durability tests (aging tests) or prolonged environmental exposure. Gloss testing was conducted only at a 60° light angle with a maximum limit of 90 GU. Results may vary at other measurement angles or under different gloss standards.

Operating a spray gun involves several important factors that need to be considered to make sure all of the specimens are given the same treatment. There are four factors that should be considered:

1. Distance of Painting

The distance between the spray gun and the material being painted varies depending on the process and the object itself. If the distance is too close, it may cause the paint layer to run and result in an orange peel texture. On the other hand, if the spraying distance is too far, the paint will appear transparent on the material, with reduced gloss, sanding marks (scratches), and uneven color (streaks).

2. Spraying Angle

When spraying, the body position should be aligned with the material being painted and follow the shape of the workpiece, whether curved or flat. The spray direction should form a 90° angle and be from top to bottom to avoid fatigue.

3. Swing Speed

The swing speed should remain stable. If the speed is inconsistent, it will result in uneven thickness between different surfaces. The ideal swing speed is approximately 12 feet per second.

4. Overlapping

Overlapping is a painting method where each subsequent spray pass overlaps the previous one on the object's surface. This technique aims to prevent thin spots, color discrepancies, maintain consistent thickness, and ensure there are no areas without paint between the first and subsequent layers. Table 3 clearly shows the Oven specification that was used for this study.

Table 3. Oven specification

Brand	Kirin
Model	KBO-190LW
Voltage	AC-220V 50/60Hz
Power consumption	570W
Net weight	6,24kg
Automatic timer settings	10,20,30,40,50,60min.
Dimension	506x372x347
Temperature settings	100 ~ 250°C


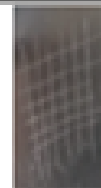

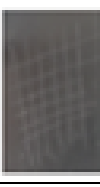
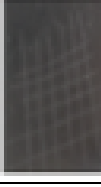
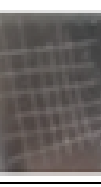
Data Analysis

The data analysis in this study adopted a descriptive statistical approach. The analysis process focused on evaluating the painting results influenced by variations in temperature and hardener content. The data were then presented in tables and graphs, accompanied by a discussion of the research findings. Testing was conducted according to ASTM D 3359 standards for adhesion tests, gloss meter standards for gloss testing, pencil hardness tester PH-3363 for measuring hardness, and fuel resistance testing standards.

3. RESULT AND DISCUSSION

Based on the findings of the research conducted, which align with the research focus on the effects of temperature and hardener usage on adhesion strength, gloss level, hardness, and resistance to fuel substances, will be presented in Tables and Figures. Each sample was tested three times to obtain consistent data.

Table 4. Result of adhesion test at temperature 100°C


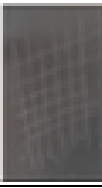
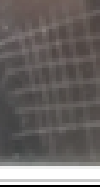
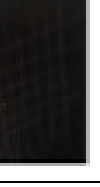
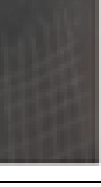
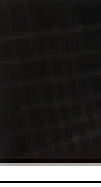
HC	Temperature var. (100°C)		
5ml			
10ml			

Based on the results presented in Tables 4 and 5, the variations in oven-drying temperature (100°C and 120°C) and hardener composition (5 ml and 10 ml) produced excellent adhesion performance according to the ASTM D-3359 standard. The adhesion test showed no peeling or coating detachment on the painted surface, resulting in a peeling percentage of 0%. Based on the ASTM classification system, all samples were categorized as 5B, which indicates that the paint film remained completely intact without any visible flaking or separation after the test. These findings demonstrate that the coating system had a very strong bond with the substrate surface. The excellent adhesion performance is closely related to the role of the hardener in the coating formulation. Hardener materials function by binding previously loose molecules into a denser and more compact structure, thereby improving the cohesion and stability of the paint layer (Dwiyati, 2015).

The application of an appropriate hardener composition significantly influences the overall quality of the paint coating, particularly in terms of adhesion strength. In this study, the addition of 5 ml and 10 ml hardener provided suitable mixing proportions that enabled stronger intermolecular bonding within the coating layer. A proper balance between resin and hardener allows the curing process to occur more effectively, resulting in improved mechanical properties and coating durability. Consequently, the paint layer becomes more resistant to peeling, cracking, and mechanical stress during adhesion testing.

In addition, the oven-drying temperatures of 100°C and 120°C contributed positively to the curing process by accelerating solvent evaporation and promoting faster molecular cross-linking within the coating film. Higher drying temperatures help optimize the formation of chemical bonds between coating particles, producing a more uniform and stable paint surface. This accelerated curing process enhances the interaction between molecules, which ultimately increases the adhesion strength of the coating on the substrate surface. The combination of suitable hardener composition and controlled oven temperature therefore, plays an important role in achieving high-quality coating performance with excellent adhesion characteristics (Noor & Tarmed, 2013).

Table 5. Result of adhesion test at temperature 120°C

HC	Temperature var. (120°C)		
5ml			
10ml			

The crosscut test was conducted using a tool such as a cutter or knife and tape, following ASTM D 3359 standards. The overall adhesion test classification results are provided in Table 5. Several modifications have been made to improve the surface quality in order to enhance the adhesion of the coating material to the substrate. However, based on several studies conducted, achieving a 5B classification has become the goal for adhesion testing between the paint and the substrate. This classification means that there is no peeling of the coating layer from the surface (Magdaleno-López & de Jesús Pérez-Bueno, 2020).

Table 6. Adhesion test Classification

Temp. (°C)	Hardener concentration	
	5 ml	10 ml
	Classification	Classification
100	5B	5B
120	5B	5B

The results presented in Table 6 indicate that variations in oven-drying temperature and hardener composition did not significantly affect the adhesion strength of the paint

coating. All tested samples demonstrated excellent adhesion performance, as evidenced by the absence of peeling or detachment on the paint surface after testing. These findings suggest that the coating system was able to maintain a strong bond with the substrate under all treatment conditions. The absence of peeled areas indicates that both temperature variations (100°C and 120°C) and hardener additions (5 ml and 10 ml) were still within the optimal range for achieving good coating adhesion. (Argana, 2013).

In addition, the characteristics of nitrocellulose (NC) paint contribute to the faster drying behavior observed during the oven process. NC paint is known for its quick-drying properties due to the rapid evaporation of solvents. When exposed to high temperatures, the drying process becomes even faster, which may limit the ability of the paint film to form a perfectly even and glossy surface. Consequently, although adhesion performance remained excellent, excessive drying speed at higher temperatures can reduce the aesthetic quality of the coating, particularly its gloss appearance (Cao et al., 2024; Fallah et al., 2018).

The variation of 10 ml hardener or an increase in hardener volume causes the gloss level to also increase. This is because the hardener contains resin with transparent color characteristics, making the surface layer appear shinier. When observed, the use of 10 ml hardener results in a more pronounced and glossier gloss level. The gloss level test was conducted using an instrument with a 60° light angle and a maximum gloss limit of 90 GU. Detailed information on the test results can be found in Table 7.

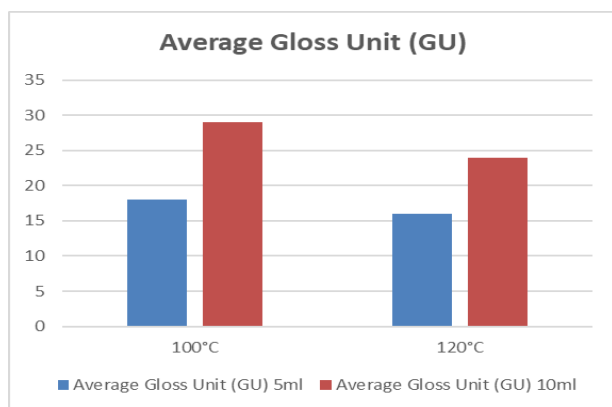


Fig. 1. Results of Gloss Level Testing

Table 7 clearly demonstrates that the best gloss level result was obtained using 10 ml of hardener at an oven-drying temperature of 100°C, with an average gloss value of 28.8 GU. In contrast, the lowest gloss level was recorded in the treatment using 5 ml of hardener at 120°C, which produced a gloss value of 16.1 GU. These findings indicate that both the amount of hardener and the drying temperature significantly influence the surface appearance of the coating. A higher hardener concentration contributes to

better film formation, resulting in a smoother and shinier paint surface. The results also suggest that the combination of a low hardener concentration and high drying temperature negatively affects the gloss performance of the coating. The use of only 5 ml of hardener may have reduced the effectiveness of the curing process, causing the paint layer to dry unevenly and produce a duller surface appearance. Furthermore, excessive drying speed at 120°C can limit the leveling process of the coating film, preventing the surface from achieving optimal smoothness and light reflection.

As a result, the gloss value decreases significantly under these conditions. On the other hand, lower drying temperatures combined with a higher hardener concentration provide sufficient time for the coating film to level properly and form a more uniform surface. This condition enhances the reflection of light on the substrate surface, producing a shinier and smoother finish. Therefore, the interaction between drying temperature and hardener composition plays an important role in determining the final gloss characteristics of the paint coating. Proper control of these parameters is essential to achieve optimal aesthetic quality and coating performance (Atilgan & Sofuoglu, 2023).

Table 7. Gloss level test results

Temperature	100°C		120°C	
	HC		HC	
Testing Repetition	5 ml	10 ml	5 ml	10 ml
1	17,3	27,9	16,2	24,7
2	19.5	29,7	14.3	21,7
3	18.3	28,8	18	22,8
Mean	18.4	28,8	16.1	22,6

The hardness test was conducted using a 2B pencil at a 45° angle. The testing method involved scratching the 2B pencil on the surface that had been painted and dried. Each scheme with variation of temperature and variation of hardener concentration was repeated three times. The overall test results can be seen in Table 8.

Table 8. Hardness test results







Temp	100°C		120°C	
	Hardener concentration		Hardener concentration	
Test	5 ml	10 ml	5 ml	10 ml
1	No scratches	No scratches	No scratches	No scratches
2	No scratches	No scratches	No scratches	No scratches
3	No scratches	No scratches	No scratches	No scratches

Tables 9 and 10 present the results of the ASTM D-3363 pencil hardness test conducted using a 2B pencil applied at a 45° angle to the coated surface. This testing method is commonly used to evaluate the hardness and scratch resistance of paint coatings by observing whether the pencil causes visible damage to the surface. The results obtained from all treatment variations demonstrated that the paint layer maintained its integrity during the testing process. No scratches, grooves, or visible defects were observed on the coating surface after the test was performed.

The findings indicate that the paint coating possessed good hardness characteristics under all treatment conditions, including oven-drying temperatures of 100°C and 120°C and hardener compositions of 5 ml and 10 ml. The absence of scratches suggests that the coating layer had sufficient resistance to mechanical pressure and surface abrasion. This condition reflects the successful curing process of the paint film, which allowed the coating to form a strong and stable structure on the substrate surface.

In addition, the performance of the coating in the hardness test is closely related to the function of the hardener and the curing temperature during the drying process. The hardener acts as a curing agent that strengthens intermolecular bonds within the paint layer, resulting in improved surface hardness and durability. Meanwhile, the oven-drying process accelerates solvent evaporation and enhances the formation of a denser coating structure. As a result, the combination of appropriate hardener composition and controlled drying temperature contributed to the formation of a hard, durable, and scratch-resistant paint surface (Demmatacco et al., 2024; Dwiwati, 2015).

Table 9. Hardness test results at 100°C







HC	Temperature var. (100°C)		
5ml			
10ml 1			

Tables 9 and 10 show that no scratches, cracks, or visible damage were found on the paint layer surface after the hardness testing process. These results indicate that the coating layer possesses good hardness characteristics while still maintaining sufficient flexibility, meaning that the surface is hard but not brittle. The absence of surface

defects demonstrates that the paint coating was able to withstand mechanical pressure without experiencing failure or deformation. This condition reflects the good quality of the coating film and indicates that the curing process occurred effectively under the applied treatment conditions.

These findings are consistent with the theory that hardener functions as a curing agent that strengthens intermolecular bonds within the paint layer, thereby improving the hardness properties of the coating. A proper hardener composition allows the coating structure to become denser and more stable, resulting in higher resistance to scratches and physical damage. Previous research conducted by Agarwal also reported that higher hardener concentrations produced greater hardness values in the coating layer. This suggests that increasing the hardener content can enhance the curing reaction and improve the mechanical performance of the paint film, particularly in terms of surface hardness and durability (Agarwal & Agarwal, 2019).

Table 10. Hardness test results at 120°C

HC	Temperature var. (120°C)		
5ml			
10ml 1			

Gasoline (such as Peralite) is evenly poured over the surface of the paint layer that has dried. Gasoline is used as a material to simulate environmental conditions that might affect the durability of the paint. After pouring the gasoline, the paint surface is repeatedly rubbed, usually 50 times, in a back-and-forth motion. This rubbing simulates the friction or physical contact that can occur on the paint surface during daily use.

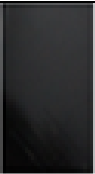
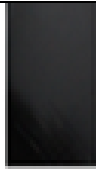



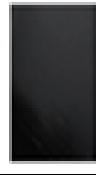
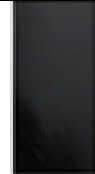



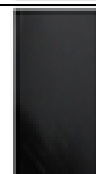



Fig. 2. Gasoline resistance testing

After the rubbing process, the paint layer was carefully inspected to identify any signs of damage, such as fading, peeling, discoloration, or loss of coating integrity. The inspection results showed that the paint surface remained unchanged after exposure to gasoline and the rubbing treatment. The absence of visible defects indicates that the coating possessed good resistance to fuel exposure. This demonstrates that the paint layer was able to maintain its physical and chemical stability even after direct contact with gasoline.

The evaluation of the test results was based on the ability of the coating to retain its original condition after the fuel resistance test. A paint layer that remains intact without peeling, softening, or color degradation is categorized as having good fuel resistance performance. These findings suggest that the coating formulation, including the hardener composition and curing process, contributed to the formation of a durable protective layer. Therefore, the paint system can be considered effective in protecting the substrate surface from chemical exposure, particularly from fuel substances such as gasoline (Rossi et al., 2021; Ryntz & Buzdon, 1997).

Table 11. Gasoline resistance test results

HC	Temperature var. (100°C)		
5ml			
10ml			
HC	Temperature var. (120°C)		
5ml			
10ml			

The fuel resistance test provides an indication of the coating's ability to withstand exposure to fuel or other chemical liquids that may potentially damage the paint layer. This test is important for evaluating the durability and protective performance of the coating under conditions that simulate actual usage environments. A paint coating

with good fuel resistance is expected to maintain its appearance, adhesion, and surface quality even after direct contact with gasoline or similar substances (Feng et al., 2018; Seubert et al., 2012). Therefore, the results of this test can be used to determine the effectiveness of the curing process and the stability of the coating formulation.

Based on the data presented in Table 11, no fading, discoloration, or visible damage was observed on the paint surface under all treatment conditions, including oven-drying temperatures of 100°C and 120°C and hardener compositions of 5 ml and 10 ml. These findings indicate that the coating layer had excellent resistance to fuel exposure. The absence of color changes occurred because the elevated temperature during the curing process accelerated the hardening and drying of the paint film, resulting in a more stable and durable coating structure. The curing process strengthened the intermolecular bonds within the paint layer, preventing deterioration or loss of brightness when exposed to fuel. Consequently, the paint coating was able to maintain its original appearance and protective properties after the fuel resistance test.

4. CONCLUSION

After conducting the series of coating performance tests, it can be concluded that all paint formulations demonstrated good adhesion properties under every temperature variation and hardener concentration applied in this study. No peeling or delamination of the paint layer was observed during the testing process, indicating that the coating system was able to bond effectively to the substrate surface. This result suggests that the curing process and the addition of hardener contributed significantly to the formation of a stable and durable coating film. Furthermore, the gloss level evaluation indicated that the best surface appearance was achieved at a curing temperature of 100°C with the addition of 10 ml of hardener, producing an average gloss value of 28.8 GU. This condition provided a smoother and more reflective coating surface compared to the other treatment variations. The hardness test also revealed that the coating achieved optimal mechanical performance at curing temperatures of 100°C and 120°C with the application of 5 ml and 10 ml of hardener. Under these conditions, no scratches were observed on the paint surface, indicating that the coating film possessed excellent resistance to mechanical deformation and surface damage. In addition, the fuel resistance test demonstrated highly satisfactory results at the same temperature and hardener combinations, where the paint layers showed no color fading or degradation after exposure to fuel. These findings indicate that the coating formulation was capable of maintaining its physical appearance and protective characteristics even under

chemical exposure conditions. Overall, the results confirm that the combination of appropriate curing temperature and hardener concentration plays an important role in improving the durability, hardness, gloss quality, and chemical resistance of the coating system.

Future studies should optimize curing parameters across a broader temperature and hardener range while investigating long-term durability under environmental and chemical exposures. Microstructural and chemical analyses are needed to clarify the hardener–paint interactions, and trials on various substrates will determine coating adaptability. Exploring eco-friendly hardeners and evaluating energy efficiency will further enhance industrial applicability.

Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

Conflicts of Interest: Declare conflicts of interest or state, “The authors declare no conflict of interest.”

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NOMENCLATUR

AC	Alternating current
°C	Celcius degrees
GU	Gloss unit
HC	Hardener concentration
Kg	Kilogram
ml	Mili-litres
mpy	mili-inch per year
NC	Nitrocellulose
W	Watt