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Analysis of the Effect of Paint Adhesion and Hardness on the Car Body Painting Process by Varying the Percentage of Paint Mixture

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Abstract

This study aims to analyze the effect of varying paint and thinner mixtures and the number of coats applied on the adhesion and hardness of car paint. The research method used was experimental, varying the paint:thinner ratio (100:110, 100:120, 100:130, and 100:140) and the number of coats applied (2 and 3). Adhesion testing was performed using a Cross-Cut Adhesion Tester, while hardness testing was performed using a Shore D Durometer.
The results showed that a paint:thinner ratio of 100:130 provided optimal results for both tested parameters. In the adhesion test, the 100:130 ratio achieved level 5B (best) with no paint peeling, while in the hardness test, it reached the highest value of 88.77 HD. Excessive addition of thinner (ratio 100:140) resulted in a decrease in quality, with adhesion decreasing to level 3B and hardness dropping to 83.3 HD.
Variations in the number of coats showed that using two coats provided more consistent results than three coats, especially in terms of adhesion. This study concluded that an optimal balance between paint and thinner is crucial for achieving good paint quality, with a 100:130 ratio providing the best results for automotive body painting applications.

Keywords: *Automotive Body Painting, Paint Adhesion, Paint Hardness, Paint-Thinner Mixture Variations, Paint Coating*

Abstrak

Penelitian ini bertujuan untuk menganalisis pengaruh variasi campuran cat dengan thinner serta jumlah lapisan pengecatan terhadap daya rekat dan kekerasan cat pada body mobil
Metode penelitian yang digunakan adalah eksperimental dengan memvariasikan rasio campuran cat : thinner (100:110, 100:120, 100:130, dan 100:140) serta jumlah lapisan pengecatan (2 dan 3 lapis). Pengujian daya rekat dilakukan menggunakan Cross Cut Adhesion Tester, sedangkan pengujian kekerasan menggunakan Durometer dengan skala Shore D.
Hasil penelitian menunjukkan bahwa rasio campuran cat:thinner 100:130 memberikan hasil optimal untuk kedua parameter yang diuji. Pada pengujian daya rekat, rasio 100:130 mencapai level 5B (terbaik) dengan tidak adanya pengelupasan cat, sementara pada pengujian kekerasan mencapai nilai tertinggi 88,77 HD. Penambahan thinner yang berlebihan (rasio 100:140) menyebabkan penurunan kualitas dengan daya rekat menurun ke level 3B dan kekerasan turun menjadi 83,3 HD.
Variasi jumlah lapisan menunjukkan bahwa penggunaan 2 lapisan memberikan hasil yang lebih konsisten dibandingkan 3 lapisan, terutama dalam hal daya rekat. Penelitian ini menyimpulkan bahwa keseimbangan optimal antara cat dan thinner sangat penting untuk mencapai kualitas pengecatan yang baik, dengan rasio 100:130 memberikan hasil terbaik untuk aplikasi pengecatan body mobil.

Kata kunci: pengecatan body mobil, daya rekat cat, kekerasan cat, variasi campuran cat-thinner, lapisan pengecatan

Introduction

In the automotive industry, the quality of car body paint is a crucial aspect affecting the durability, aesthetics, and resale value of a vehicle. The growth of the automotive industry in Indonesia, particularly in major cities, has increased the need for high-quality paint that provides optimal protection against corrosion, extreme weather, and mechanical abrasion (Fariz Rachman 2021). Paint quality is significantly influenced by the composition of the materials and the painting process, including variations in the percentage of paint and thinner used in the application process (Sopiyan 2022). These variations directly affect the paint's physical properties, such as adhesion and coating hardness, both of which determine the durability and longevity of the final paint finish (Ahmad Regal Saputra 2023).

Testing paint adhesion and hardness is a key parameter in assessing the quality of protective coatings on car bodies. Good adhesion ensures the paint adheres firmly to the surface, preventing peeling and damage from external factors (Jones & Smite 2019). The hardness of the paint layer plays a role in resisting scratches, impacts, and exposure to harsh environments, thereby extending the life of the paint and the vehicle as a whole (Rimbawati 2019).

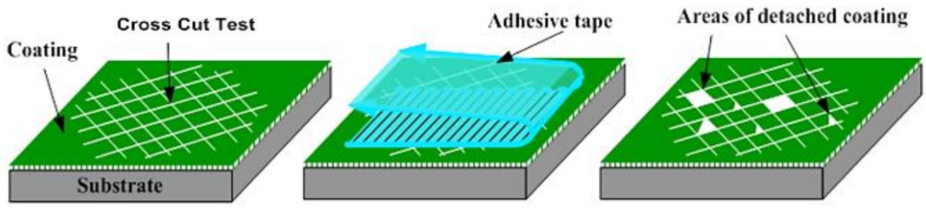


Figure 1. Relationship Between Paint Mixture Percentage and Paint Layer Hardness

The main objective of this study was to determine the effect of varying paint mixture percentages on the adhesion and hardness of the paint on car bodies. By understanding this relationship, it is hoped that an optimal paint mixture formulation can be obtained to produce a strong, durable, and high-quality protective layer. This study also aims to provide a scientific basis for the proper mixing of paint materials to improve the efficiency and effectiveness of the painting process in the automotive industry (Zahra Sativa 2024). Furthermore, the research results are expected to serve as a reference in the development of environmentally friendly paint formulations that meet international quality standards.

Heating to a temperature of approximately 140°C. A chemical reaction in the resin causes drying and the formation of dense cross-links, resulting in a hard and durable coating (Zulfahri 2022). This type is commonly used in automotive production processes in factories due to its resistance to extreme weather. Urethane is a two-component paint containing alcohol and isocyanate, which react to form a urethane cross-linking structure. Urethane paint is known for its excellent coating properties, including resistance to gloss, weather, and solvents. Although the drying process is slow, the use of drying equipment is necessary to ensure optimal hardness (Sopiyan 2022). Temperature and the mixing ratio of the ingredients significantly affect the hardness and adhesion of urethane paint.

Lacquer is a paint that dries quickly through solvent evaporation, but its strength is relatively lower than heat polymerization and urethane. This type of paint is suitable for fast application and finishing, but is less resistant to weather and chemicals (Rimbawati 2019). The application process, such as drying temperature and layer thickness, significantly determines the final hardness of the paint layer.

Factors affecting the physical properties of paint include drying temperature, material composition (ratio of resin, thinner, and pigment), application process, and the number of layers applied. Variations in the mixture ratio significantly affect the adhesion and hardness of the paint layer. For example, too high a thinner ratio can result in a thin layer and reduced hardness, while too high a resin ratio can cause the layer to be too thick and difficult to dry evenly (Fariz Rachman 2021). Hardness testing is typically performed using a Shore D durometer, while adhesion is tested using the cross-cut test method according to ASTM D-3359 standards.

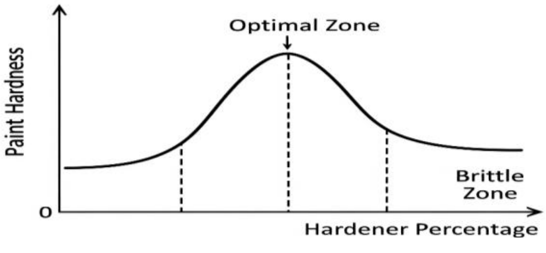


Figure 2. Comparison diagram of heat polymerization, urethane, and lacquer characteristics.

Test results indicate that the optimal mixture ratio of thinner to resin is approximately 100:130, resulting in the highest hardness and best adhesion (Latumerissa 2023). Variations in the application process, such as drying temperature, also significantly impact the final quality of the paint layer.

Materials and Methods

The materials used in the painting process were Suzuka S315 metallic blue 200cc paint, Nippe 2000 Primer Epoxy Survacer, and Nippon Super A high-gloss thinner. The paint was sprayed onto a 20 cm x 20 cm plate with a thickness of 0.8 mm. The spraying distance was 20 cm, the spray gun nozzle was 2 mm, and the compressor pressure was 25 psi. The experimental approach was used to assess the effect of varying paint mixture percentages on the adhesion and hardness of the paint on the car body.

The paint and thinner ratios varied from 100:110, 100:120, 100:130, and 100:140, with two and three coats applied. Adhesion testing was performed using the cross-cut test method according to ASTM D-3359 standards, which involves creating parallel and intersecting lines on the paint surface, followed by peeling off the adhesive tape to assess the adhesion level. The results showed that a 100:130 ratio provided the highest adhesion level at level 5B, with few defects in the test area, indicating excellent adhesion. Conversely, a 100:140 ratio showed a decrease in adhesion to level 3B, with more extensive peeling defects.

The first independent variable was the paint and thinner mixture ratio, which included four levels: 100:110, 100:120, 100:130, and 100:140. This variation was chosen based on previous studies showing that the mixture ratio affects the physical properties of paint (Herdians 2023). The second independent variable was the number of paint layers, consisting of two levels: two and three layers, which aimed to assess the effect of layer thickness on the paint's physical properties. The main dependent variables included paint adhesion and hardness. Adhesion was measured using the cross-cut test method according to ASTM D-3359 standard, which assesses the adhesion of paint layers to substrate surfaces (ASTM 2017).

Paint hardness was measured using a Shore D durometer, which measures a surface's resistance to mechanical scratches (Sopiyan 2022). Measurements were made directly on samples that had undergone the painting process with varying mix ratios and number of coats.

Results and Discussions

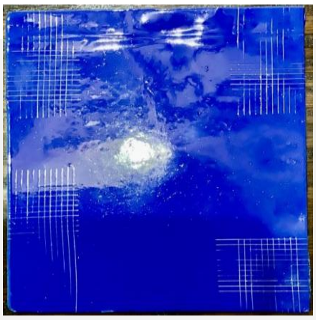
Paint Adhesion

Adhesion testing was conducted using the cross-cut test method according to ASTM D-3359 standard to assess the adhesion strength of paint layers to car body surfaces. Test data showed that the paint to thinner ratio significantly affected the paint adhesion. Test results showed that a ratio of 100:130 produced the highest adhesion at level 5B, indicating excellent adhesion without peeling defects. At this ratio, the paint layer adhered optimally to the plate surface, with a balance of hardness and adhesion (Herdians 2023).

Conversely, increasing the thinner ratio to 140:100 resulted in a decrease in adhesion to level 3B, with peeling defects of around 10-15%. This was due to the decreased resin concentration in the mixture, resulting in a thinner and less durable paint layer (Herdians 2023). A ratio of 100:110 demonstrated adhesion at level 4B, with minor defects of around 3-5%, indicating that the higher viscosity hindered paint penetration into the surface.

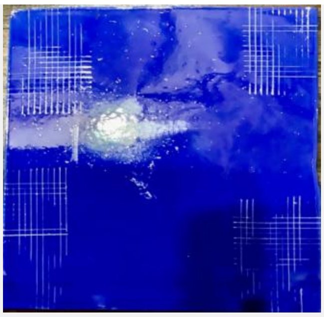
The number of coats also plays a role in adhesive stability. Tests show that using two coats provides more consistent and stronger adhesion than using three coats, especially at the optimal ratio of 100:130. In three-coat tests, the risk of peeling increases due to excessive coat thickness and uneven thinner distribution (Herdians 2023). This mechanism is related to the viscosity and thickness of the coats, which affect penetration and adhesion.

A visualization of the relationship between the mix ratio and adhesion is presented in Figure 4.1, which shows that the 100:130 ratio achieved the highest adhesion value, while the 100:140 ratio experienced a significant decrease. This data confirms that the paint mixture formulation must be optimized to achieve the best adhesion, which is influenced by the balance between resin and thinner (Herdians 2023).



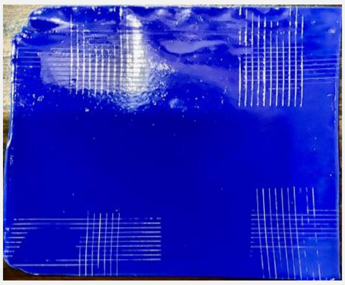
100 % : 110 %

Testing was conducted on the first plate with a paint:thinner mixture ratio of 100:110 referring to the classification of adhesion test results resulting in an adhesion level of 4B. In this test, there were slight defects in the coating, where in the cut area around 3-5% of the area was defective. The damage was mainly visible at the intersection of the scratches, with a small peeling pattern distributed around the area where the test lines intersect.



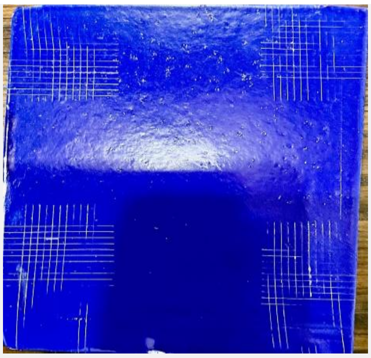
100 % : 120 %

Tests conducted on the second plate with a paint:thinner mixture ratio of 100:120 refer to the classification of adhesion test results showing a level of adhesion at level 5B. The test results show very clean cut edges, no peeling areas in the entire test box. The cross section of the scratch remains intact and shows no signs of peeling, indicating excellent adhesion between the paint layer and the substrate.



100 % : 130 %

Tests conducted on the third plate with a paint:thinner mixture ratio of 100:130 refer to the classification of adhesion test results showing an optimal adhesion level at level 5B. In this test, the cut edges showed very clean and precise results, with no peeling areas (<1%). The entire test area, including the scratch intersection point, showed perfect adhesion without any defects or peeling.



100 % : 140 %

Testing on the fourth plate with a paint:thinner ratio of 100:140, based on the adhesion test result classification, resulted in a decreased adhesion level to level 3B. Observations revealed significant defects, with the coating peeling off approximately 10-15% of the total test area. The damage was primarily seen at intersections and along the test lines, with a broader peeling pattern than at other mix ratios. Some areas showed peeling extending beyond the cut line.

Figure 1. Graph of the relationship between paint mixture ratio and adhesion, showing a peak at a ratio of 100:130.

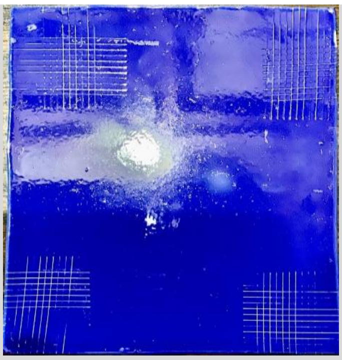
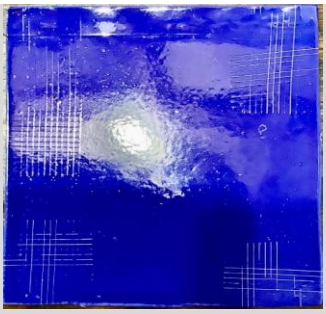
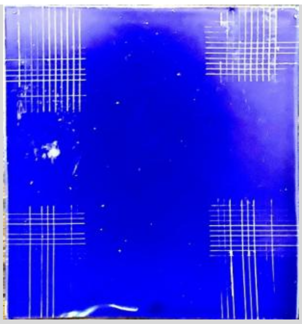
 100 % : 110 %	This test used a mixture of paint and thinner with a ratio of 100:110. The test results showed that the coating adhesion was at level 4B, which means there were minor defects in the coating layer. Based on observations, approximately 3-5% of the cut area had defects, especially at the intersection of scratches. These defects were in the form of small peeling distributed around the area where the test lines intersected, but were still within reasonable limits. The level of adhesion at this ratio was considered quite good, although it had begun to show signs of minor damage to the paint layer.
 100 % : 120 %	Testing on the second plate with a paint mix ratio of 100:120 resulted in a decreased adhesion level to level 3B. Observations revealed more significant defects, with peeling coating areas reaching 5-10% of the total test area. The damage was particularly visible at intersections and along the test lines, with a broader peeling pattern compared to the 100:110 ratio. This indicates that increasing the thinner in the mix is beginning to deteriorate the coating adhesion.
 100 % : 130 %	On the third plate with a paint mix ratio of 100:130, the test yielded a 2B adhesion level. Observations indicated that the coating damage was more severe, with peeling areas covering approximately 10-15% of the total test area. The peeling pattern was more widespread across the cut line, with some areas of damage extending beyond the test line. The adhesion of the paint layer at this ratio indicated significantly lower quality.
 100 % : 140 %	Testing on the fourth plate with a paint mix ratio of 100:140 showed that the adhesion level decreased to level 1B. Observations showed significant damage, with the peeling coating area reaching 15-20% of the total test area. The peeling pattern was very clear and spread across almost the entire scratch area. This damage extended to areas outside the test line intersection, indicating that this ratio produces very weak adhesion and is inadequate for applications requiring good coating durability.

Figure 2. The results of the adhesion test at various mixture ratios and number of layers show an increasing and decreasing trend according to the ratio.

Paint Hardness

Testing on the fourth plate with a paint mix ratio of 100:140 showed that the adhesion level decreased to level 1B. Observations showed significant damage, with the peeling coating area reaching 15-20% of the total test area. The peeling pattern was very clear and spread across almost the entire scratch area. This damage extended to areas outside the test line intersection, indicating that this ratio produces very weak adhesion and is inadequate for applications requiring good coating durability.

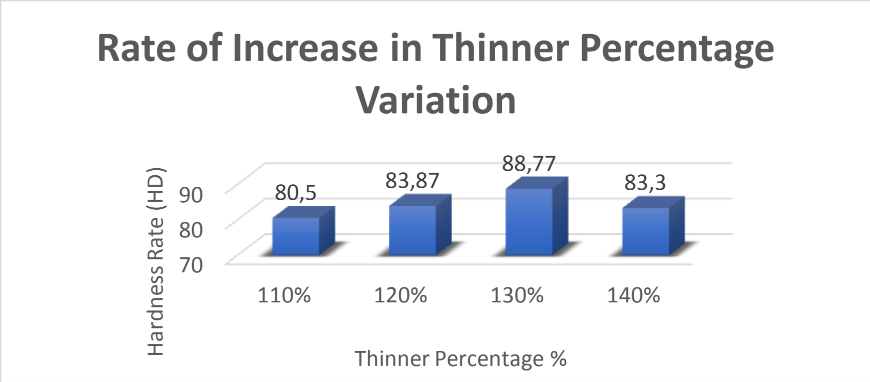


Figure 3. Average Hardness Rate for Each Thinner Mixture Variation

Conversely, a decrease in hardness occurred at a ratio of 100:140, with a hardness value of 83.3 HD. Increasing the amount of thinner in the mixture caused the paint layer to become too thin and less dense, resulting in a decrease in hardness. This was due to the reduced concentration of resin, which plays a key role in forming the layer's hardness. Furthermore, testing also showed that the number of layers affected the final hardness of the paint layer. Using three layers tended to increase hardness slightly more than using two layers, but the difference was not significant. This indicates that the primary factor influencing hardness is the material ratio in the mixture, not the number of layers.

Test data showed that varying the mixture ratio directly affected the layer's hardness, with a ratio of 100:130 producing the best results with a hardness value of 88.77 HD. Increasing or decreasing this ratio resulted in a decrease in hardness, which has implications for the layer's resistance to scratches and impacts.

Data visualizations show that hardness increases with the optimization of the material ratio, and a decrease in hardness occurs when the material is too thin or too thick. Therefore, controlling the material ratio in paint mixing is crucial for achieving the desired physical properties in automotive paint layers.

Discussion

The introduction to this study emphasizes the importance of understanding the effect of varying paint mix percentages on the physical properties of the paint layer on a car body, particularly adhesion and hardness. Variations in the paint mix ratio, such as resin and thinner, are empirically known to affect the final quality of the applied paint layer. Previous studies have shown that an optimal mix ratio can improve adhesion strength and scratch resistance.

The effect of the mix ratio on adhesion is strongly influenced by the mix viscosity. A ratio of 100:130 represents an optimal balance, where the viscosity allows for maximum surface penetration and a strong chemical bond between the paint layer and the substrate (Herdians 2023). Excessive thinner addition, such as a ratio of 100:140, causes a decrease in resin concentration, resulting in a thinner coating that is less able to adhere effectively, reducing adhesion to level 3B (Tyagit et al. 2019). Conversely, a ratio of 100:110 with a high viscosity tends to inhibit penetration into the surface pores, reducing adhesion to level 4B.

Empirical data from cross-cut adhesion testing shows that a 100:130 ratio achieves the highest adhesion level (5B) with minimal defects (<1%), while a 100:140 ratio decreases to 3B with peeling defects of around 10-15%. This indicates that excess thinner weakens the physical and chemical bonds of the paint layer (ISO 2018). Furthermore, the number of coats also plays a role; using two coats tends to provide more stable adhesion than three coats, which can lead to excessive thickness and uneven thinner distribution.

This effect is supported by the adhesion mechanism, which involves physical penetration and chemical reaction between the resin and the substrate. The optimal viscosity at a 100:130 ratio facilitates both mechanisms in a balanced manner, resulting in a strong and durable coating (Sopiyan 2022). When the viscosity is too high or too low, this process is disrupted, resulting in reduced adhesion.

In addition to affecting adhesion, variations in the paint mixture also affect the hardness of the paint layer. Test data shows that a 100:130 ratio produces the highest hardness (88.77 HD), while a 100:140 ratio decreases it to approximately 83.3 HD. Excessive thinner addition causes the coating to become too thin and structurally less dense, resulting in decreased hardness (Herdians 2023). Conversely, too low a ratio results in high viscosity, which hinders the drying process and the formation of a solid structure.

The conclusion of this analysis indicates that the optimal paint mix ratio is 100:130, as it achieves a balance between adhesion and hardness. Variations outside this ratio tend to degrade the physical quality of the paint layer, which directly impacts the durability and aesthetics of the vehicle finish (Latumerissa et al. 2023). Therefore, controlling the proportions of ingredients in paint mixing is crucial to ensure high-quality paint results.

Conclusions

This study shows that varying the paint and thinner ratio significantly affects the physical properties of the car body paint layer, particularly adhesion and hardness. A ratio of 100:130 proved to be the optimal formulation, producing the highest adhesion at level 5B and a hardness of 88.77 HD, indicating excellent adhesion and coating strength. The number of coats also impacts the stability of the paint's physical properties; using two coats provides more consistent and stronger results than three coats, which can potentially increase the risk of peeling due to excessive thickness.

Controlling the mixing variables and the number of coats is crucial to ensuring the final quality of the car body paint. This study's contribution to automotive industry science and practice is that it emphasizes the importance of proper material formulation and paint process management to achieve optimal results, and supports the development of industry standards for environmentally friendly and high-quality paint mixing.

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