Changes in Thickness and Gloss of Dry Films According to Spray Methods of Water-Soluble Metallic Base Coat

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***Abstract*—The distance between the object and the spray gun and the degree of coating overlap due to the spray distance must be optimized for achieving a uniform coating using a spray gun. Moreover, the paint sprayed from a spray gun is thicker at the center of the object to be painted and thinner toward the edges due to the difference in density. Therefore, the thickness of the paint according to the spray distance should be considered. In this study, a Three-Dimensional (3D) painting robot specially designed to spray paint under certain conditions was used to investigate the spray characteristics of the spray gun and the thickness and glossiness of dry films according to the spray distance and moving speed. Under the standard coating conditions for automotive refinishing, the optimum distance between the object to be coated and the spray gun is approximately 12–15 cm, and the speed of the spray gun is about 0.4–0.5 m/s. If the spray distance is small, the coating film will be thick, and the resin ratio will be high, with metallic particles embedded in the resin, resulting in low glossiness. The metallic particles are exposed on the coated surface at a larger distance, increasing the glossiness.**

***Keywords*—coating thickness, spray pattern width, spray distance, paintwork, spray gun, moving speed, 3D robot, gross**

I. Introduction

During automotive manufacturing, paintwork for new vehicles involves spraying paint on the car body with no accessory attached and then drying at a high temperature (110–160 ℃). However, during automotive refinishing [1], as the paint is sprayed and dried with fixtures (e.g., door trims and seats) attached to the car body, high-temperature drying is impossible; instead, drying is performed at a lower temperature (60–70 ℃) compared to the painting process for new vehicles, requiring caution not to damage the fixtures. Moreover, the paint used for refinishing generates many Volatile Organic Compounds (VOCs). Considering that workers perform refinishing rather than robots, the amount or quality of the paint is determined by worker experience. Thus, workers not being fully aware of the work characteristics or specifications of the spray gun entails considerable fatigue and low-quality refinishing.

Considering the termination of conventional oil paints [2] and mandatory usage of water-soluble paint [3] as part of the emission reduction policy, paintwork must be performed considering the characteristics of water-soluble paint. Compared with oil paint, which is easy to handle, water-soluble paint has limitations in color expression and covering of existing colors. As a result, various surfacers have been used to overcome such limitations. With multiple colors being applied to automobiles, along with increased usage of metallic- and pearl-based paint, workers need to clearly understand the moving speed of the spray gun, the distance between the object to be painted and the spray gun, and the overlap of spray [4] to facilitate tricky paintworks, such as color reproduction [5] and concealment of dichroism.

In this study, experimental research was conducted using a Three-Dimensional (3D) painting robot specially designed to spray paint under certain conditions to investigate the spray characteristics of the spray gun (essentially used for refinishing), as well as the thickness and glossiness of dry films according to the spray distance and moving speed.

II. Experimental Setup and Method

In this study, paint was sprayed onto cold-rolled steel specimens made of automotive steel plate material with dimensions of 150 (W) × 100 (L) × 0.8 mm (T) using a 3D robot. Next, the coating thickness was measured to investigate the spray characteristics of the spray gun and the variation of coating thickness according to the moving speed of the spray gun, spray distance, and overlap.

A. Experimental Setup

The experiment was performed inside a spray booth that can reproduce a constant spray environment without being affected by the external environment.

A gravity-type spray gun from SATA was attached to the 3D robot. High-Volume Low-Pressure (HVLP) technology was applied to the spray gun with a nozzle size of Φ1.3 mm [6]. The spray gun pressure was also kept constant using a digital pressure gauge and regulator.

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Water-soluble paint (NOROO company) was used for refinishing. Experimental reliability was secured using the 3D painting robot (Fig. 1) to control and check the moving speed of the spray gun and the spray distance between the spray gun and the object. Table I shows the specifications of the robot.

Figure 1. 3D painting robot.

A high-precision digital electronic scale (GF-603A) was used to measure the weight of the coated paint after the spraying. Table II shows the specifications of the electronic scale. The coating thickness was measured using a Dry Film Thickness (DFT) gauge (Elcometer 456), with its specifications in Table III. A metallurgical microscope (HNM005, 2,400 magnification) was used to examine the shape of the metallic particles of the paint as well as paint formation on the panel surface.

TABLE I. 3D PAINTING ROBOT SPECIFICATIONS

3D Robot		
X-axis	Model	RBC-21HSA
	Stroke	1100 mm
	Motor	HC-KFS43 KFS/AC 400 W
	Encoder	INC/5CLD/131072
	Gear ratio	20
	Max. rpm	1350
	Moving speed	0.1~0.7 m/s
Y-axis	Stroke	900 mm
	Motor	HC-KFS23
	Input	3 phase AC 118 V 1.1 A
	Output	200 W
	Moving speed	0.1~07 m/s
Z-axis	Stroke	500 mm
	Moving speed	0.1~0.5 m/s

TABLE II. SPECIFICATIONS OF ELECTRONIC SCALE

Digital Electronic Scale	
Model	GF-603 A
Weight	620 g
Minimum weight	0.001 g
Straightness	±0.002 g
Stable time	1.2 s

TABLE III. SPECIFICATIONS OF DIGITAL DRY FILM THICKNESS GAUGE

Digital DFT Gauge	
Model	Elcometer A456C
Range	0~1500 μm
Accuracy	±1~3% or ±2.5 μm
Resolution (0~100 μm)	0.1 μm
Resolution (100~1500 μm)	1 μm

B. Experimental Method

The spray gun was mounted on the 3D painting robot specially designed to automatically control the moving speed of the spray gun, spray distance, and coating overlap. The experiment was performed considering the width, pattern, and arrival rate of spray according to the moving speed of the spray gun in compliance with the standards in the manuals from the paint and automotive manufacturers [7, 8]. Table IV shows the experimental conditions.

In this study, a 3D painting robot was used to analyze the coating quality according to the change in the transfer speed of the spray gun and the coating overlap, and all experiments were conducted under the same nozzle and air pressure conditions, as shown in Table IV.

TABLE IV. EXPERIMENTAL CONDITION

Temperature	25 ℃
Humidity	67%
Velocity of wind	0.7 m/s
Paint	1K Water Base coat
Spray gun type	Gravity-type HVLP
Nozzle size	1.3 mm
Baking	Air blowing
Panel (Width × Length × Thickness)	150 × 100 × 0.8 mm
Air pressure	2.0 bar
Gun speed	0.2~0.7 m/s

(1) The experiment was conducted in a spray booth dedicated to water-soluble paint to maintain a constant temperature, humidity, and wind speed.

(2) The spray gun and the object remained parallel, while the spray angle was perpendicular to the thing.

(3) Cold-rolled panels of sizes 150 × 100 mm were used for spray.

(4) The moving speed of the spray gun was increased by 0.1 m/s from 0.2 to 0.7 m/s, with the thickness of dry

films measured at different spray distances (80, 100, 120, 140, 160, and 180 mm). For the reciprocating spraying in the horizontal direction, the coating overlap in the vertical direction was set to 50 mm.

(5) After the water-soluble base coat was applied once, it was forced dried with Dry-Jet, followed by subsequent coating twice. Table V shows the base coat application guide.

(6) The thickness of the paint coating on the panel was measured at five positions by the test methods of KS M ISO 19840 [9], KS M ISO 2808 [10], and SSPC-PA2, with the average of the measurements applied.

(7) The gloss was measured at angles of 20°, 60°, and 85° for each specimen after applying and drying only the water-soluble base coat. Table VI shows the gloss-meter specifications.

TABLE V. WATER BASE, CLEAR COAT APPLICATION GUIDE

Base coat	Mixing ratio (vol)	100: 25~60%
	Number of coats	3 times
	Fresh time	Air blowing
	Setting time	10~20 min
	Dried film	10~20 μm

TABLE VI. GLOSS-METER SPECIFICATIONS

Range	20°	0–2000 GU
	60°	0–1000 GU
	85°	0–161.4 GU
Measurement Area	20°	10 × 10 mm
	60°	8 × 16 mm
	85°	4 × 55 mm
Repeatability	0~10 GU	±0.1 GU
	10~100 GU	±0.2 GU
	100~2000 GU	±0.2%
Reproducibility	0~10 GU	±0.2 GU
	10~100 GU	±0.5 GU
	100~2000 GU	±0.5%
Resolution	0~10 GU	±0.1 GU
	>100 GU	±1 GU

III. EXPERIMENTAL RESULTS AND DISCUSSION

The film formation of the water-soluble base coat and clear coat, as well as the spray characteristics of the spray gun, were identified using the 3D painting robot that can control the moving speed of the spray gun, spray distance, overlapping width, and pressure. It was possible to identify the optimal spray method to obtain a high-quality [12, 13] refinished surface with uniformly sprayed paint by identifying the spray characteristics of the spray gun [11] and deriving optimal conditions for the moving speed of the gun, distance from the object, and overlapping width. The summary of the analysis is as follows.

A. *Paint Spray Distribution of the Spray Gun*

The paint sprayed from a spray gun hits the object in the shape of a parabola. As shown in Fig. 2, the spray pattern width decreases with a decrease in spraying distance, and vice versa.

For paint sprayed from a spray gun using compressed air, the pressure decreases, and the atomization of the paint increases with an increase in the distance from the gun nozzle. As atomization in the form of fog increased, the arrival rate decreased because the amount of paint that could not reach the object also increased.

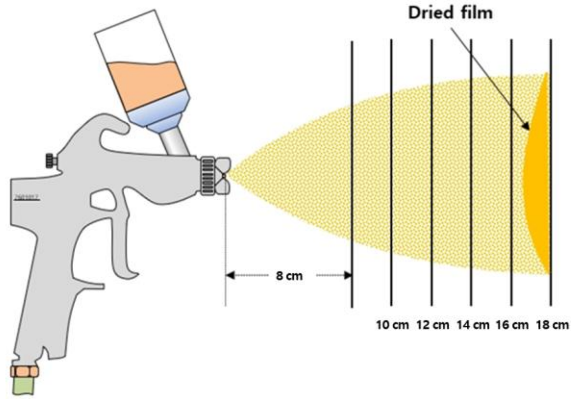

Figure 2. Spray gun spray width.

The paint was sprayed onto the object with a dimension of 300 × 300 mm with grids while the spray gun was moved at a speed of 0.4 m/s in the horizontal direction, as shown in Fig. 2. The weight of the paint in an area of 5 × 5 mm was measured after spray. The thickness of the paint was found to be high at the center of the object and low toward the edges regardless of the spray distance, as shown in Fig. 3. However, the thickness of the paint was the highest at a position downward from the center, which was horizontal with the spray gun nozzle position, because of the air circulation in the spray booth from top to bottom at a speed of approximately 0.7 m/s and gravity. When the spray distance was short, the sprayed paint showed the highest thickness in the form of a peak at about 45 mm downward from the object's center. When the spray distance increased, the same tendency was observed, but the shape of the peak became broader as the variation in the thickness of the dry films decreased.

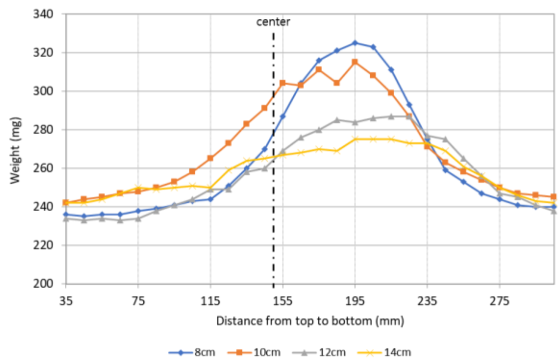

Figure 3. Weight of film according to spray distance.

B. Coating Thickness According to the Spray Gun Moving Speed and Spray Distance

After mixing the paint and ensuring its correct viscosity according to the base coat painting manual, the paint was sprayed twice using the Wet-on-Wet method, with the coating thickness measured after drying. At this instance, if the distance between the spray gun and the object was too close, the paint settled on the object became thick and flowed downward, making it difficult to use the paint. Therefore, the minimum distance between the spray gun and the object was 8 cm.

When the distance between the spray gun and the object was 8 cm, an acceptable dry film thickness was obtained, as shown in Fig. 4. However, the spray pattern width from the spray gun was narrow. The pressure of the air accompanying the paint spray affected the paint settled on the object, causing agglomeration and flow of the paint immediately after spraying, resulting in critical defects in the painting quality.

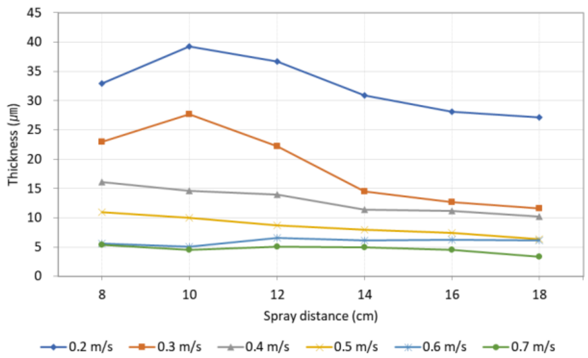

Figure 4. Film thickness by moving speed of the spray gun.

At spray distances of 16 and 18 cm, agglomeration and flow of the paint did not occur. Even though the same amount of paint was sprayed, the paint could not reach the object due to its atomization and a reduction in paint spray pressure, thereby decreasing the thickness of the formed film and increasing the loss of paint.

Following the paint manufacturer's manual, the optimal moving speed of the spray gun to obtain ideal dry films with a low defect rate is approximately 0.4–0.5 m/s. The painting quality was excellent when the distance between the spray gun and the object was about 12–14 cm.

Figs. 5 and 6 are the results of observing the painted surface and cross section magnified 600 times and 1800 times with a microscope. Looking at the cross section of Figure 5, it was confirmed that the coating thickness was thicker at 8cm than at the spray gun distance of 18cm.

In addition, the surface was uneven at a distance of 18 cm, whereas the surface was smooth at a distance of 8 cm. This is because the metallic particles could not enter into the paint and adhered to the surface. In addition, looking at the surface as shown in Figure 6, it can be seen that the metallic particles are distributed above the surface at 18 cm, whereas at 8 cm, they are evenly distributed above and below the surface. This is the reason why metallic particles have different distribution tendencies depending on the distance, which results in different colors.

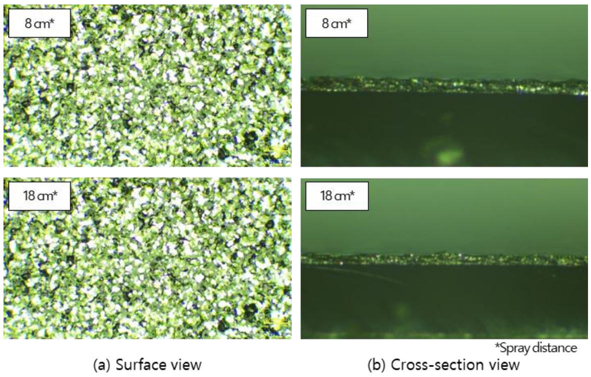

Figure 5. Dried condition of base coat (×600).

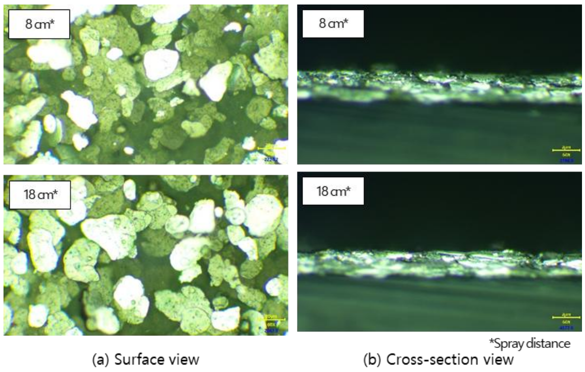

Figure 6. Dried condition of base coat (×1800).

C. Distribution of Metallic Particles According to the Spray Distance

The adhesion of metallic particles in the coating film according to the spray distance of the base coat was observed from the front and side. The cross-section was observed after cutting the specimens using a precision cutter.

When the moving speed of the spray gun was constant, the coating thickness increased with a decrease in spraying distance and vice versa. Table VII shows the condition of dry films at magnifications of 600 and 1,800 times, when the spray distances were 8 and 18 cm, respectively, at a spray gun moving speed of 0.4 m/s. The resin ratio in the coating film increased as the spray distance decreased, and vice versa. When the resin ratio was high, the metallic particles in the resin were embedded at the bottom of the resin part. When it was low, the metallic powders were not embedded in the resin and were visible on the surface of the resin.

D. Glossiness According to the Spray Distance

When the dry specimens were visually inspected after applying only the base coat according to the spray distance, it was found that glossiness decreased as the spray distance decreased, and vice versa.

Fig. 7 shows glossiness at various projection angles measured according to the spray distance using a gloss meter. When the spray distance was short, the glossiness was low at 20° and 60° projection angles because the coating film was thick and metallic particles were embedded in the resin; however, the glossiness was relatively high at 85°. When the spray distance increased, the glossiness was high at 20° and 60° because metallic particles were exposed on the resin surface, while the glossiness was low at 85°.

When refinishing a car, the panel is exposed to the external environment and differs from when the vehicle was first shipped. Therefore, if the glossiness is somewhat lowered, spray at about 12cm, and when it is higher, spray at 14–15cm to prevent the heterochromatic phenomenon.

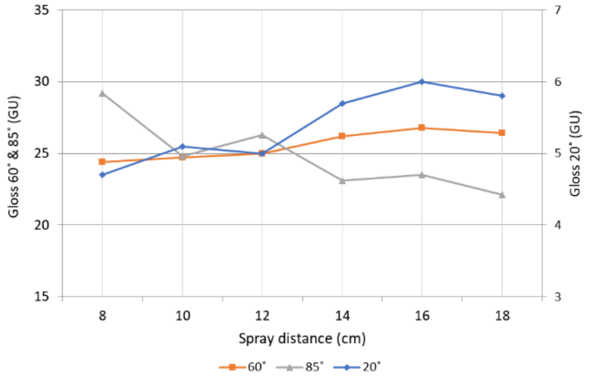

Figure 7. Glossiness by projection angle.

IV. Conclusion

An experiment was performed under different spray gun moving speeds and spray distance conditions using a 3D painting robot, maintaining constant painting conditions, such as the spray overlap width, injection pressure, and spray booth. The following conclusions were drawn.

(1) Under the same painting conditions, the ideal spray distance was approximately 12–14 cm, and the ideal moving speed of the spray gun was 0.4–0.5 m/s to meet specification standards and ensure quality painting.

(2) For the distribution of the paint sprayed from the spray gun, the coating thickness decreased toward the object edges due to a decrease in the arrival rate. Moreover, the coating thickness was higher at a position downward from the center of the object under the influences of the airflow in the spray booth and gravity.

(3) The coating thickness increased as the distance between the object and the spray gun decreased and decreased as it advanced. The resin ratio in the thick coating film increased as the distance decreased, and vice versa.

(4) When the resin ratio in the coating film was high, the glossiness was low at 20° and 60° because metallic particles were embedded in the resin; however, the glossiness was relatively high at 85°. When the resin ratio in the coating film was low due to the long spray distance, the glossiness was high at 20° and 60° because metallic particles were exposed on the resin surface, and the glossiness was relatively low at 85°.

Therefore, it was confirmed that the coating thickness and the distribution of resin and metallic particles changed according to the painting conditions of the water-soluble base coat. Changes in glossiness according to the condition of metallic particles could also be confirmed with the difference in color depending on the glossiness despite applying the same color paint.

In the future, further research will be conducted on the variation of dichroism according to the base coat film thickness in the same color and spray angle, as well as methods to reduce the difference in dichroism.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Woonsang Lee and HaengMuk Cho conducted the research and wrote the paper; Woongsang Lee analyzed the data. All authors had approved the final version.

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