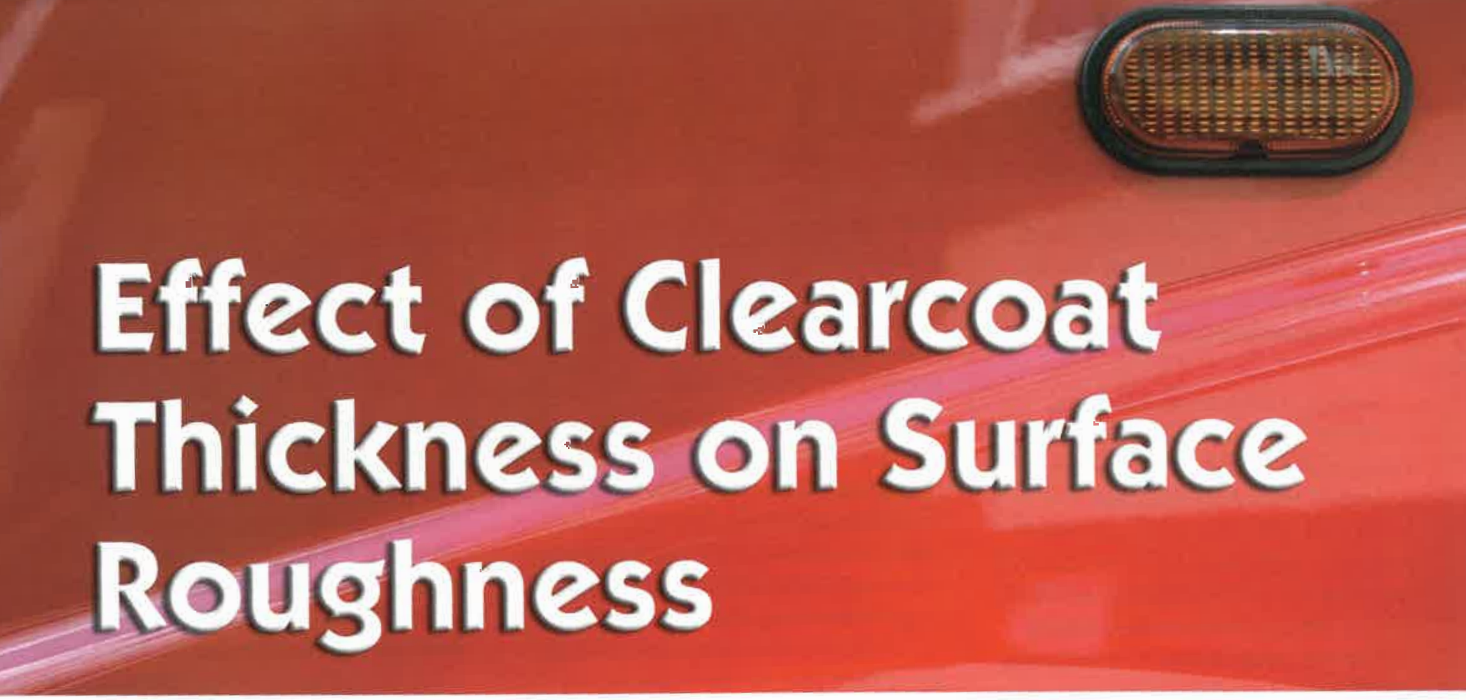

Effect of Clearcoat Thickness on Surface Roughness

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At most automotive assembly plants, five coating layers are applied to the assembled body panels: pre-treatment, electrocoat, primer, basecoat, and clearcoat. Two technologies are used in-plant to measure finish appearance. The second of these measures the "orange peel" roughness of a surface, divided into five wavelength increments: Wa, Wb, Wc, Wd, and We, which have undulation wavelengths ranging from 0.1 to 30 mm. The surface roughness less than 0.1 micrometer is also measured by the wave-scan instrument and is termed dullness (du). This study looked at the effect of clearcoat thickness on the six structure sizes.

Approximately 80 coil-coated aluminum panels were sprayed in either vertical or horizontal orientation with a solventborne clearcoat using different ambient flash times. Coating dry thicknesses (filmbuilds) varied from 20 to 60 micrometers.

Trials with different flash time and spray orientation were analyzed separately. Correlations between the magnitude of the wave-scan structure sizes and the filmbuild were calculated. The R-squared values for du and We relationships were less than 0.64. However, strong relationships between Wa, Wb, Wc, and Wd against film thickness were found. For most structure sizes, the roughness decreased as additional clearcoat was added. However, for Wb and Wc, the application of additional clearcoat either increased the roughness of the surface, or furnished no additional benefit.

INTRODUCTION

The paint finish of a vehicle plays a major role in how customers perceive a vehicle's quality. For most, the ideal look is mirror-like: highly glossy and perfectly smooth. Most vehicle manufacturers apply five coating layers; each layer in the coating process has a unique function. Beginning at the surface of the vehicle body, the zinc-coated steel is treated with phosphate. The purpose of the phosphate layer is to clean and chemically treat the vehicle body. The zinc phosphate coating promotes adhesion of electrocoat primer, the

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second layer, to the steel and enhances corrosion protection. The electrocoat layer, or e-coat layer, also aids in corrosion resistance of the steel body. The third layer, the full body anti-chip primer, is employed to improve resistance to chipping. Above this layer lies the basecoat layer, which is added for color and provides protection from UV light. Finally, the top layer, clearcoat, is applied to the vehicle to enhance durability and shine.

There are many process variables involved in coating a vehicle, such as paint flow rate, atomization, applicator-to-target distance, dehydration, spray booth conditions, and applicator type. In-plant, the coating thickness is usually controlled by paint flow rate and applicator speed. This investigation examines the relationship between clearcoat film thickness and appearance.

BACKGROUND

In general, coating appearance can be defined with two characteristics: waviness and brilliance. Focusing on the surface, one acquires information about the waviness characteristic. Specifically, information is obtained about the size, depth, and shape of surface structures[1] formed through the deposition of paint particles on the surface of the vehicle. As the particles are sprayed, they align themselves relative to each other in groups or structures. Focusing on the reflected image of an object allows one to obtain information about the image forming qualities, also called brilliance or distinctness of image (DOI).[1] The lines of the image will either appear distinct or blurred. If the outline of the image appears distinct, a reflected light source will look brilliant. However, if the outline of the image is blurred, a reflected light source will look diffused.

The wave-scan DOI is an appearance-measuring instrument developed by BYK-Gardner (Geretsried, Germany). It uses a laser point source to illuminate the surface of a sample at a 60° angle. The instrument is rolled along the painted surface and takes a reading every 0.08 mm for a total of 1250 measurement points over a distance of 10 cm. A detector measures the reflected light intensity at an angle of 60°. In this way, the optical profile of the surface is detected.

Mathematical filter functions are used to divide the optical profile into five wavelength ranges or "structure sizes": Wa (0.1–0.3 mm), Wb (0.3–1.0 mm), Wc (1.0–3.0 mm), Wd (3.0–10.0 mm), and We (10.0–30.0 mm). Within each structure size, the light intensity profiles are standardized by assigning a value of 1000 to the average. The absolute values of the deviations of each individual reading to the standard line are averaged to obtain a "contrast" value. Ultimately, the profile data is simplified to a single contrast value for each structure size. The contrast values for each of these elements range from 0 to 100, with zero representing a perfectly smooth surface. In addition, the wave-scan DOI instrument is equipped with a reflectometer, which measures reflected light intensity and characterizes brilliance. A white-light emitting diode (LED) illuminates the surface of a sample at a 20° angle. The reflection is captured by the lens of a charge-coupled device (CCD) chip, also positioned at 20°. The intensity of the scattered light at the edges of the image of the LED in relation to the intensity at the center produces a value called dullness. Giroux[2] found that the wave-scan DOI's measurements correlated well with human perception.

Lex[3] has presented some theories for optimizing the paint process. He showed that increasing clearcoat from 16 to 50 μm decreases the Wc and Wd undulations, but does not affect the other wave-scan elements. This contrasts with the "tsunami" theory, based on the physics of surface tension leveling, which states that it is possible to level a wave with a wavelength that is at most 10 times the depth of the liquid under it.[4] For example, a 50 μm (2.0 mil) thickness of clearcoat can level waves with a maximum wavelength of 0.5 mm of basecoat. Therefore, according to this theory, du, Wa, and small Wb elements can be leveled by clearcoat, but not structures Wc or higher. Lex[3] also suggests reasons why an appearance element may be too high in a process. For example, the very fine textures which contribute to dullness may be caused by dry spray which results when there is an excessive loss of solvent from the paint before it reaches its target, and it cannot be leveled during cure. He further states that vertically sprayed and cured surfaces, which are impacted to a greater extent by gravitational forces, tend to have higher Wc and Wd values than horizontal surfaces. Kigle-Böckler[5] proposes that increasing clearcoat film thickness improves flow and leveling characteristics and ultimately improves Wc and Wd values. "The peel or longer waves (Wc–We) are a measure of the flow/leveling properties and can be influenced by the clear coat film thickness, material properties, and process variables".[6]

MATERIALS AND METHODS

The experimentation for this study was completed at the Chrysler Automotive Research and Development Centre (ARDC), in Windsor, Ontario, Canada. One of the components of the ARDC is the 4500 m², $50 million Automotive Coatings Research Facility (ACRF). The ACRF is solely dedicated to research that will reduce costs, improve quality, and/or reduce the environmental effects of coating Chrysler vehicles. It consists of a powdercoating booth, topcoating line, and curing

Figure 1—Wave-scan spectrum of panels before and after clearcoat.

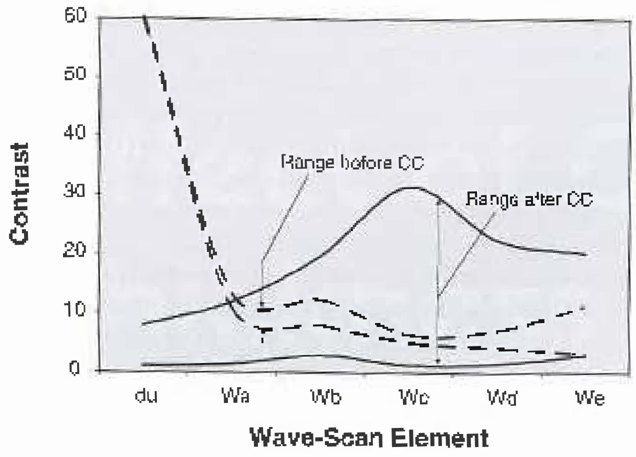


Figure 2—Dullness variability with filmbuild.

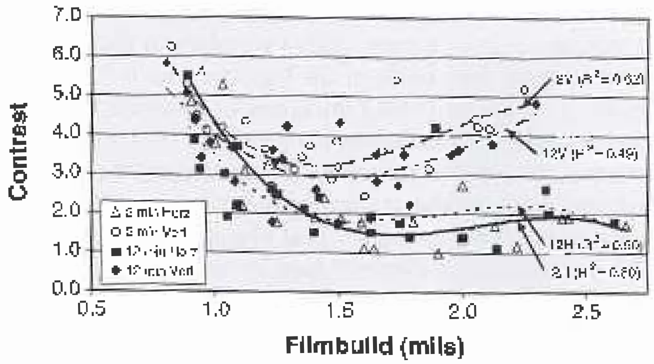


Figure 3—Wa variability with filmbuild.

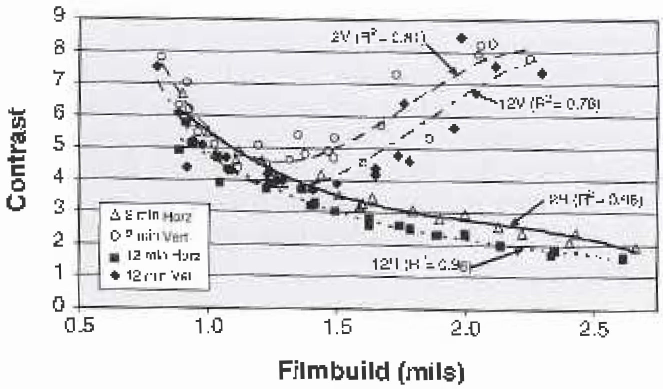


Table 1—Optimum Clearcoat Filmbuild (µm)

	Wa	Wb	Wc	Wd
Horizontal	>67[a]	41	43	>68
Vertical	33	36	38	>57

(a) > indicates optimum may be at filmbuild greater than those studied.

oven that can be utilized to apply any combination of primer, basecoat, and clearcoat to full-size pretreated, e-coated vehicle bodies. The ACRF has been used to test coatings in full-size settings, reduce plant down-time when launching a new product or process, compare the performance of coating materials from different suppliers, and field-try coatings application equipment and techniques.

In this work, coil-coated flat aluminum panels were sprayed using electrostatic bells (ITW-Ransburg Aerobell Copes) mounted on linear-motion Alstom Model OH-001 and SM-001 actuators. PPG DCT 5555 clearcoat (acrylic acid/epoxy) was used at conveyor speeds ranging between 2.12 and 6.13 m/min (7 and 20 fpm) to achieve different film thicknesses. The panel rack was configured with three horizontal or three vertical panels. In each set of three, one 10.2 cm × 30.4 cm bare steel panel was coated and cured to measure the dry film thickness (filmbuild); one 10.2 cm × 15.2 cm coil-coated panel was allowed to flash for 2 min at ambient temperature; and the other 10.2 cm × 15.2 cm coil-coated panel was allowed to flash for 12 min at ambient temperature. The environmental set points and equipment specifications were: booth temperature/relative humidity = 80 F/50%; flowrate (V/H) = 225/245 mL/min; shaping air (V/H) = 220/235 mL/min; voltage = 90 kV; and bell speed = 40,000 rpm. Two passes were required with a target distance of 25.4 cm (10 in.). In total, 41 runs were performed at different line speeds, spraying vertical or horizontal panels in each run. Panels were then cured at 291°F for 25 min in a rack that holds the panels at 30° to the horizontal.

After curing, all 10.2 cm × 15.2 cm panels were scanned five times for surface waviness in the same direction using the wave-scan DOI, and the results averaged. The filmbuild reported here refers to the average of the measurements made with a model 355 Elcometer at six points along the filmbuild panel.

RESULTS AND DISCUSSION

Figure 1 shows that the clearcoat clearly improves the dullness of the coil-coated panels. For the Wa and Wb appearance elements, the clearcoat both improved and worsened the surface roughness. In the long wave range (Wc, Wd, and We), the clearcoat generally created a rougher surface. This figure also shows that the coil-coated panels, although not flat, are consistent in their characteristics, providing a good base for these experiments.

The 2 min flash and the 12 min flash film thickness and appearance element data were tested for statistical differences using a paired t-test. It was determined that

Figure 4—Wb variability with filmbuild.

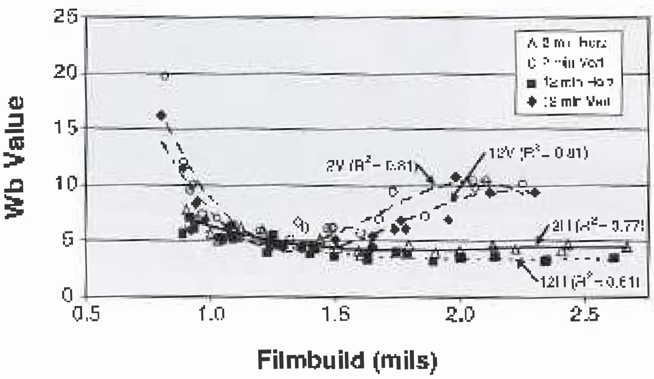


Figure 5—Wc variability with filmbuild.

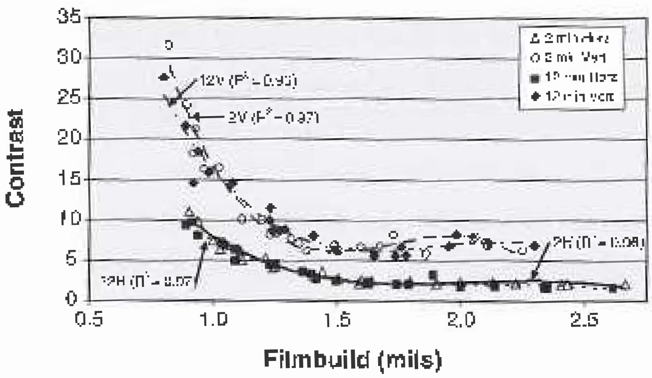


Figure 6—Wd variability with filmbuild.

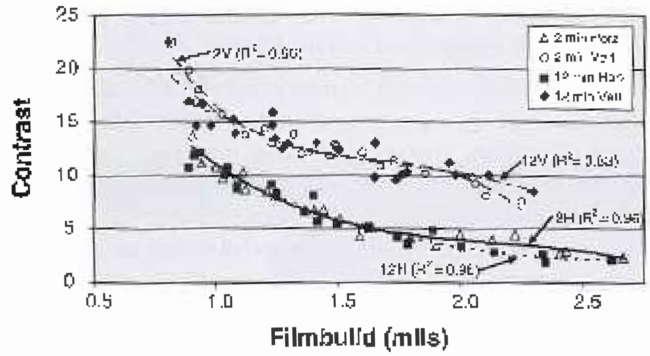
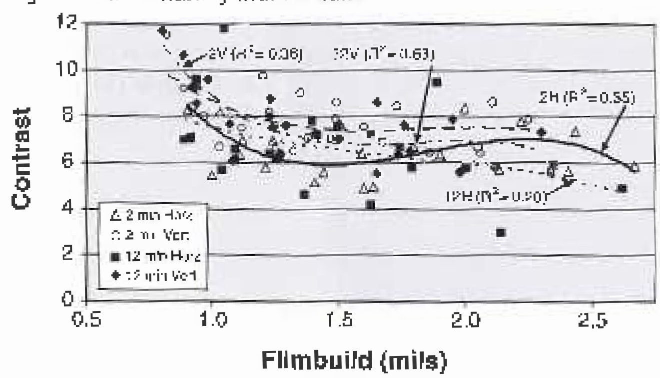


Figure 7—We variability with filmbuild.



the 2 min and 12 min flash time data must be analyzed separately since average values of Wa and Wb were significantly different at the $\alpha = 0.05$ level. Next, the paired t-test was used to determine if there were statistical differences in appearance elements and film thickness between horizontal and vertical panels for each of the flash time datasets. In both cases, it was found that the horizontal and vertical film thicknesses were statistically different for corresponding line speeds and flash times.

Plots of wave-scan appearance elements versus filmbuild are shown in *Figures* 2 to 7, with each plot having four data series: horizontal panels with 2 min flash, vertical panels with 2 min flash, horizontal panels with 12 min flash, and vertical panels with 12 min flash. In each case, third order polynomial trend lines were used to fit the data, and the R-squared value for the fit is indicated on the graphs. The R-squared values for three of four du and all We relationships were less than 0.64, the criteria used to determine whether there was a strong relationship.[7] However, strong relationships between Wa, Wb, Wc, and Wd versus film thickness were found. For these data sets, generalizations regarding the effect of filmbuild can be made. For vertical panels, there appear to be minima in the Wa and Wb plots, indicating that there is a optimal clearcoat filmbuild, after which further addition of clearcoat does not improve smoothness. The fact that these optima occur only in vertically sprayed and flashed panels leads one to conclude that this increase in roughness is probably an example of "microsagging," wherein the coating sags due to gravity. For Wa, this minimum occurs around 33 μm (1.3 mil) and for Wb the minimum is around 36 μm (1.4 mil). For horizontal panels, the Wa and Wd continue to decrease as filmbuild increases, as is true for Wd in vertically sprayed panels. These parameters do not have an optimum. For horizontally sprayed panels, the Wb does not decrease at a clearcoat thickness greater than 41 μm (1.6 mil). Although there is not a physical optimum in this case, there is an economic optimum since increasing the clearcoat uses more material, but does not result in a smoother finish. Likewise, the Wc parameter has economic optima of 38 μm (1.5 mil) for vertically sprayed panels and 43 μm (1.7 mil) for horizontal panels. These optima have been summarized in *Table* 1.

In addition, it can be seen from the figures that a longer flash time results in a smoother finish in terms of du, Wa, and Wb in vertically sprayed panels, but not horizontal. This would seem to contradict the earlier finding that flashing in the vertical position leads to sagging, hence more flash time should lead to more sagging and higher contrast numbers.

Horizontally sprayed panels generally have a smoother finish, especially at higher filmbuilds, because of leveling immediately after spraying. This leveling is significant at all filmbuilds for Wc and Wd, which agrees with Lex,[3] but contradicts the "tsunami" theory, which predicts that Wc undulations would not be leveled out by a wet film thickness less than 100 μm (4 mil).

CONCLUSION

There is a belief in paint shops that a thicker clearcoat can be used to hide surface undulations in the basecoat. This is generally not true since it was found that for surface undulations of 0.3 to 3.0 mm (Wb and Wc), increased clearcoat filmbuild does not improve the surface smoothness, and may even result in larger undulations or simply a waste of material.

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