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Thermosetting powder coatings: Finish appearance and durability at cure window corner points

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ABSTRACT

This project investigated the finish quality of automotive powder coatings in terms of appearance, adhesion and chip resistance. Two powder basecoats (red and black), of three particle sizes, and a colorkey primer (red) were studied in relation to the process temperature and time pairs based on the cure window provided by the paint manufacturer. The appearance was quantified using the contrast values of the wave-scan structure spectrum elements (Wa, Wb, Wc, Wd, and We). Gravel and scratch tests were used to quantify adhesion and chip resistance properties.

It was found that long-waves (Wc, Wd and We) were less affected by the curing time and temperature variation. The contrast values of short-waves (Wa and Wb) increased with increasing process temperature and time. The most dramatic increase was observed at high process time and temperature. High process temperatures (193 °C) resulted in good long-wave coverage. Small contrast values of the long-waves were obtained for all cure conditions, for both red and black basecoats. The results for short-waves were not as consistent. This work suggests that powder basecoats and colorkey primers can yield appearance qualities comparable to water-borne counterparts.

1. Introduction

The automotive manufacturing industry is one of the largest industrial sectors in North America, producing millions of vehicles annually for North American and International export markets [1,2]. As new vehicles are being developed to be more fuel-efficient and less emitting during their operation, the environmental burden of the manufacturing phase becomes proportionately more significant. Stricter environmental legislation, increasing costs of petroleum-based solvents, and competitive pressure to decrease the cost of application, are driving the automotive industry toward using innovative coatings and application technologies, while at the same time maintaining the durability and appearance of their products [1]. One of the technologies which could assist in achieving these goals is the use of powder coatings. A distinctive characteristic of powder coatings is minimal or zero volatile organic compound (VOC) emissions. This is important in regulatory aspects. In addition, the reuse of overspray can result in high overall material utilization. The reported increase in use of powder coatings is attributed to their durability, low cost and low VOC emissions [3,4]. In addition, powder coatings achieve a glossy finish similar to water-borne or solvent-borne paints.

The types of coating selected for painting a vehicle greatly depend on the desired appearance of the final finish, as well as its resistance to weathering, corrosion and chipping. The typical layering that is applied to a vehicle is summarized in Table 1. Finish quality is one of the most important aspects of automotive coatings. Anecdotal evidence suggests that customers perceive vehicle quality based on the finish appearance. As a result, it is important to achieve a finish that has high gloss and a smooth surface (mirror-like). While this is true for the outer part of the vehicle, it is not necessary for inner surfaces of a car (for example, areas under the hood). Recently, an important innovation has been the use of colorkey primers for areas of the car that do not require a high gloss appearance. Colorkey primers, if properly formulated and applied, could potentially eliminate the basecoat stage in these areas. This would result in significant reductions in material use and process effort. Also the use of powder coatings in basecoat applications, instead of solvent-borne and water-borne coatings, could potentially eliminate the energy used for dehydration of water-borne basecoats (although cure temperatures may be slightly higher), and at the same time reduce air emissions and wastewater generation through powdercoat reclamation and recycling. Alternatively, the

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Table 1
Paint processes in a typical automotive application.

Order of application	Name	Purpose	Application method	Dry film thickness (μm)
1	Pre-treatment	• Remove pressing oil • Pacify surface	Dip	~0.1 [19]
2	Electrocoat (e-coat)	• Seal metal from environment	Dip	20–30 [20]
3	Primer (anti-chip)	• UV protection of e-coat • Stone chip resistance	Spray	30–35 [20]
4	Basecoat	• Imparts uniform color	Spray	15–18 [20]
5	Clearcoat	• Creates gloss • UV protection for basecoat • Chemical resistance	Spray	38–40 [20]

use of powder basecoats could potentially eliminate the powder primer stage.

Water-borne and solvent-borne topcoats have been used for decades in the automotive industry. The knowledge gained through experience combined with the extensive research findings in relation to these coatings, has resulted in a pool of knowledge explaining their performance qualities. However, there is a gap in research when the appearance qualities of powder basecoats and colorkey primers are concerned. The studies reported in the literature review section have focused more on grouped appearance parameters such as long-wave, short-wave, glossiness and orange peel (OP). However, a detailed investigation of specific wavelength ranges has not been reported for powder coatings. This is important because knowing the process adjustments which affect specific features of surface quality provides a means to optimize the process for best overall appearance. This becomes more significant if a specific layer is completely removed (*i.e.* apply colorkey primer and eliminate basecoat application). In addition, studies reported in the literature mostly have focused in the rheological properties of powder coatings as an important factor affecting leveling and consequently appearance. However, for day-to-day in-plant applications, viscosity is difficult to measure, so there is a need to use more practical predictors to optimize appearance.

The objective of this study was to investigate the effect of the cure window (time/temperature pairs) on the finish quality of one red colorkey primer (RCP) and two powder basecoats – red (RBC) and black (BBC) of 30 μm particle size. Different curing scenarios were investigated using times and temperatures corresponding to the corners of the manufacturer's cure window. Other factors such as viscosity, degree of conversion (dry) film build and process heating rate were studied as well, and findings will be reported in future articles since the experiments were extended beyond the cure window corners to include isothermal conditions.

2. Literature review

Powder coating technology and production methods have improved significantly over the years. The global market for powder coatings is expected to increase at about 6% a year from 2010 to 2015. This is considered a higher growth than the general coatings market [5].

Even with the improvement in powder formulations and application technologies, powder coatings are generally used as anti-chip primers. Their use as topcoats has not yet become a standard process. One reason is that it is not clear whether the substitution of liquid paint with powder is sufficiently superior to justify modifications required in manufacturing plants necessary to accommodate the new powder technology. For the topcoat stages, solvent borne and water-borne basecoats, and solvent borne clearcoats are more common [4]. In contrast, suppliers of smaller, non-glossy parts to the automotive industry such as brake calipers, door handles and interior trim, have been applying powder coatings to their products for many years.

The appearance quality of powder coatings, and other decorative coatings in general, is characterized by orange peel, which is influenced by the leveling of paints, and by the reflective characteristic known as distinctness of image (DOI). The size range of the surface structures that cause the orange peel effect is between 0.1 and 100 μm [6]. Orange peel (OP) may be quantified using a contrast value between 0 and 100 (unitless). High values of the orange peel rating indicate that the paint film has a smooth finish [7]. The wave-scan instrument was developed by BYK-Gardner (Geretsried, Germany) and simulates the visual impression obtained from optical inspection of surface structures. Structures are analyzed based on their size. Mathematical filtering is used to separate the data collected from the optical profile of the surface into different surface undulation wavelengths ranging from less than 0.1 to 30 mm (Table 2). The lower the contrast values of the wave-scan elements, the smoother the appearance [8]. Analyzing the values of each component of the wave-scan structure spectrum makes it possible to determine factors that affect the finish quality.

Several research studies have investigated factors that affect the finish quality of powder paints. Included are factors such as powder application techniques, particle size and particle size distribution (PSD), rheological properties, film thickness, relative humidity (RH), formulation, orientation of surfaces, substrate roughness, and cure conditions. Mazumder et al. reported that fine particles are more likely to appear in the overspray than on the work piece, due to their lower inertia [9]. Biris et al. also reported that the OP and gloss of powder coatings was improved by controlling electrostatic spray application (*i.e.* corona voltage) [6]. This literature review will focus on reported findings related to the effect of cure time, temperature and film thickness on the appearance quality, since these are the factors considered on this research.

Kenny et al. investigated the appearance of acrylic clear powders by analyzing the stages that powdercoat undergoes, until a final film was formed. Panels were treated with primer and basecoat before the powder clearcoat was electrostatically sprayed. Panels were then baked at 150 °C for 25 min. Film thickness was 80 μm and the particle size of powders ranged from averages of 10–40 μm. A Nippon Paint-Suga Test Instrument responding to "long-waves" (100s–1000s μm) and "short-waves" (10s–100s μm) was used to determine the image clarity [10]. It should be noted that the range for "short-waves" and "long-waves" reported in the literature differs between authors (Table 2 shows BYK definitions).

Table 2
Wave-scan elements and their wavelength range.

Wave-scan element	Wavelength range (mm)	
Dullness (du)	<0.1	
Wa	0.1–0.3	Short-waves
Wb	0.3–1	
Wc	1–3	
Wd	3–10	Long-waves
We	10–30	