Enhancing Productivity in Coil Coatings

by Carlo Testa
Eastman Chemical UK Ltd.*

Sophisticated analytical instruments are vital for pursuing research in many areas of modern science and technology. Confocal imaging techniques provide detailed images of coating surfaces while multi-angled spectrophotometers are ideal for measuring color differences at various angles. In conjunction with each other, these techniques have provided the ability to differentiate between coating additives and understand the effect that the molecular weight of cellulose esters has on the level of metallic flake alignment in coil coatings. This understanding should enable coil producers to increase production through fewer rejects and reduce the need for re-coating while substantially improving metallic flake alignment.

TYPES OF COIL COATINGS

Coil coatings must exhibit excellent application characteristics to ensure uniform appearance and defect-free films on production lines, often at speeds greater than 200 m/min. During a short curing schedule at high temperature, the paint must be formulated so that solvents are released at the correct rate and the chemical reactions formed should ensure enough flexibility to enable the coated metal to be bent without cracking or loss of adhesion of the paint film.

Each type of coating has its own specific advantages, be it thickness, gloss, hardness, flexibility, durability in extreme weather, or resistance to chemical attack. The

Presented at the PRA "Innovative in Formulation" Additives for Coatings Conference, May 20-21, 2008, Frankfurt, Germany.
*European Technical Center, Acornfield Rd., Knowsley Industrial Park, Liverpool, L33 7UF, United Kingdom.

choice of the most suitable system must be based on its usage and expected performance, and should always be agreed upon between the manufacturer and the client. Some coatings are applied in a single layer, to either one or both sides, while others are used with a primer in multi-layered systems. There are two types of paint used for coil, based on either thermosetting or thermoplastic resins. The resins can be subdivided into eight general categories: alkyds, acrylics, epoxies, polyesters, polyurethane, silicone-modified resins, polyvinyl chlorides (PVC), and polyvinyl fluorides (PVDF).

The choice of paint system depends on the final requirements in terms of performance, life expectancy, and cost. A two-coat paint system is often used. The first coat is the primer, which is applied in most cases directly on to the pretreated metal surface. The primer usually contains anti corrosive pigments to protect the metal substrate from corrosion. The second coat is the finishing paint, which provides the color and appearance of the coated system, and plays a large part in the system's weathering and mechanical performance. The dry film thickness of the coatings is usually between 5–35 microns for a primer and 15–200 microns for top coats; thickness is determined by the resin technology used and the paint performance required.

MEETING THE AESTHETICS OF THE DESIGNER AND CONSUMER

In recent years there has been a move to meet style trends in terms of color and other visual parameters. The influence of color is becoming an increasingly important element during the development of new buildings, with designers choosing more lively colors and different textures. Metallic shades are often associated with modern technology. As a result, coil coating manufacturers have broadened their portfolios to include finishes which alter aesthetics and allow designers to create modern, vivid impressions that are used for interior and exterior uses. The use of metallic and pearlescent pigments has made it possible to create different appearances of color and gloss under various light conditions and viewing angles.

Metallic pigments incorporated into coatings can be regarded as metallic mirrors which produce specular reflect (light shone at one angle bounces back at the same angle). Pearlescent pigments are used to achieve vivid interactions of color and luster with the added dimension of variation depending on the angle of illumination and observation. These pigments also play an important role in the creation of many new and unique effects when used in plastics, printing inks, cosmetic formulations, and paints for automotive and industrial application. The unique pearlescent effect is produced by light interference rather than absorption. Pearlescent pigments on their own produce only a small amount of hiding and most pearlescent pigments are used with metallic flakes to increase the hiding power of the coating system.

CONFOCAL MICROSCOPY AND SPECTROPHOTOMETER

Confocal Microscopy

The coated substrate is scanned to build a 3-D profile of the surface. The roughness (RMS) of the surface is then calculated from the scanning measurements. Poor metallic or pearlescent flake alignment produces high surface roughness values while good alignment produces low surface roughness values.

Spectrophotometry

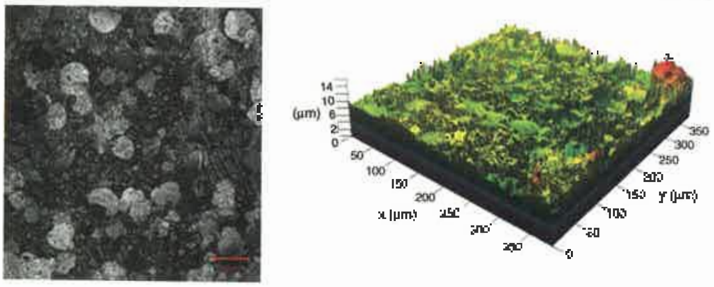
Spectrophotometry enables color measurement at various angles. A coating's reflectivity is maximized when viewed from the perpendicular and reduced when viewed from a shallower angle. This reflectivity change is a highly desirable property in the coil coating industry and is called "flop." Flop can be measured using a multi-angled spectrophotometer. High flop values indicate that the metallic and pearlescent flakes are aligning in an even and flatter manner. High flop values produce coatings that are visually brighter and more aesthetically pleasing. In the Eastman investigations, an X-Rite MA68II multi-angle spectrophotometer was used and the flop index value was calculated using the following equation:

$$\text{Flop} = \frac{2.69(L^*_{15} - L^*_{110})^{1.11}}{(L^*_{45})^{0.86}}$$

Table 1—Formulations

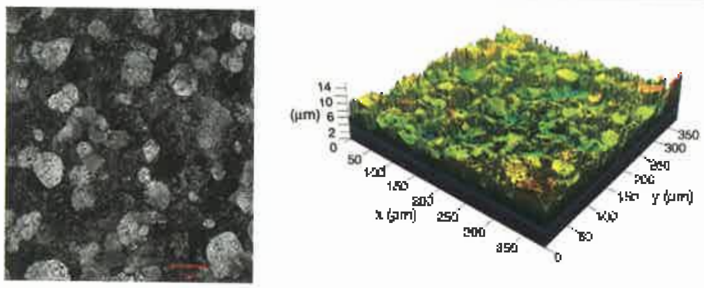
System	Molecular Weight of CAB	Amount (%) (By weight of coating)
Standard	—	—
Commercial Additive (unsaturated poly carboxylic acid polymer)	Unknown	0.2
Formulation 1	Low	1
Formulation 2	Medium	1
Formulation 2	Medium	3
Formulation 3	High	1
Formulation 3	High	3

Figure 1—Confocal image of standard formulation.



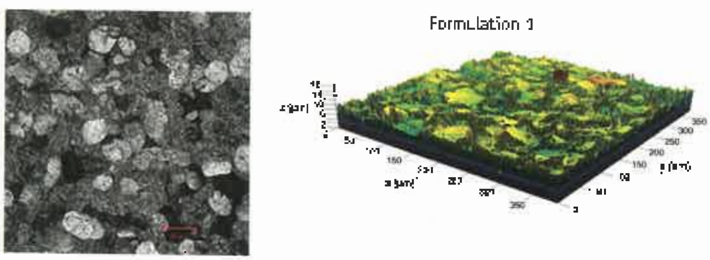
Average confocal surface roughness = 2.15 microns
Flop Index = 12.20

Figure 2—Confocal image of commercial additive formulation.



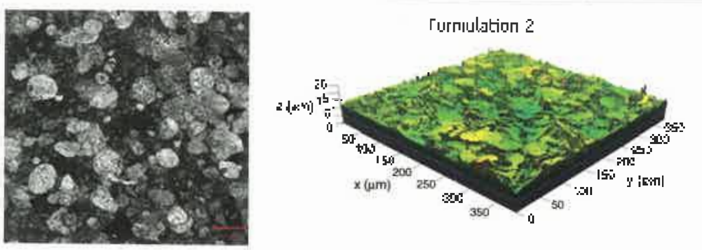
Average confocal surface roughness = 2.26 microns
Flop Index = 11.98

Figure 3—Confocal image of low molecular weight formulation (1%).



Average confocal surface roughness = 1.18 microns
Flop Index = 15.01

Figure 4—Confocal image of medium molecular weight formulation (1%).



Average confocal surface roughness = 1.22 microns
Flop Index = 14.9

Note: Formulation 2 at 3% showed no improvement over the 1%

CELLULOSE ACETATE BUTYRATE

The ability to control metal-flake and pearlescent orientation is critical in producing high quality finishes. Many industries, especially the automotive industry, utilizes the comprehensive portfolio of cellulose acetate butyrate (CAB) grades to improve the aesthetics of the paint used on automobiles. The CAB functions by acting as a viscosity control agent that "locks" the metallic and pearlescent flakes in the proper orientation. Better flake alignment means formulators require fewer flakes to achieve the same or better desired aesthetic impact. This also results in beneficial cost savings. The information on the effect of CAB on the orientation of the metallic and pearlescent pigments used in the coil industry was limited and a research project was set up to investigate the performance of CAB.

SELECTING THE CORRECT GRADE OF CAB

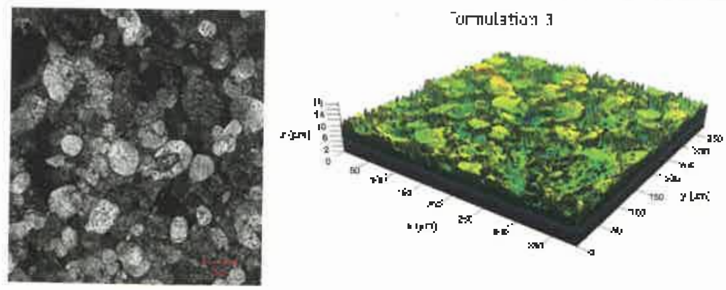
The ability to manipulate the composition of cellulose esters during their manufacture makes them very versatile and flexible materials for coatings applications. The starting material for cellulose esters is natural anhydroglucose polymer from renewable sources that is esterified using mixtures of acetic, propionic, or butyric anhydrides to form a product with controlled ester content, hydroxyl content, and molecular weight. Grades of cellulose acetate butyrate, for example, can vary by the ratio of acetic to butyric ester groups, hydroxyl number, and molecular weight. Changes in the composition of the product affect the solubility, compatibility reactivity, viscosity, melting point, glass transition temperature, and hardness. For example, the hydroxyl group on the CAB can be crosslinked into the coating resin "back bone" via reaction with melamines and isocyantes. For the coatings formulator, this ability to manipulate the properties of cellulose esters means that there are grades of CAB with specific characteristics available for many types of applications. The selection of a specific grade of CAB depends on the requirements of the application.

In terms of coil coatings, it was not known what the optimum molecular weight would be in terms of metallic/pearlescent flake alignment. In order to assess the effect of molecular weight on the metallic flake alignment, a range of molecular weight grades of commercial CAB formulations were evaluated in a commercial metallic polyester/melamine coil formulation. This formulation was known to produce poor metallic flake alignment even with a commercial additive that was designed to improve flake alignment based on an unsaturated polycarboxylic ester. The CAB formulations were run on a coil coating pilot plant line and cured under standard conditions. It is to be noted that application via a draw down bar at low shear in the laboratory does not replicate the shear applied on a main coil coating application line. CABs have been shown by Eastman to lower rheology at high shear rate, allowing better flow and improved metallic flake alignment. Therefore, it is best to evaluate CABs under the shear conditions that occur in the actual coating plant.

The various molecular weight grades were pre-dissolved in coil coating solvent, 1 of CAB to 5 of solvent (mixture of dimethyl esters of glutaric, succinic, and adipic acid) and added to a standard metallic polyester coil coating at a level of five percent by weight of the finished coil coating. The formulations were then applied on a coil coating pilot plant line.

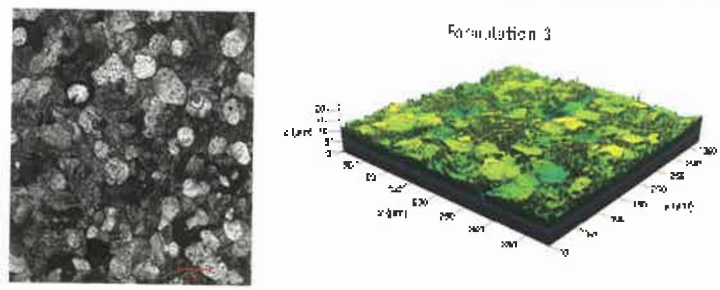
In order to assess metallic flake alignment, confocal microscopy was used to measure the surface roughness and a multi-angled spectrophotometer was used to measure the flop values.

Figure 5—Confocal image of high molecular weight formulation (1%).



Average confocal surface roughness = 1.45 microns
Flop Index = 13.7

Figure 6—Confocal image of high molecular weight formulation (3%).



Average confocal surface roughness = 1.32 microns
Flop Index = 14.55

Figure 7—RMS roughness plotted against flop index for each formulation.

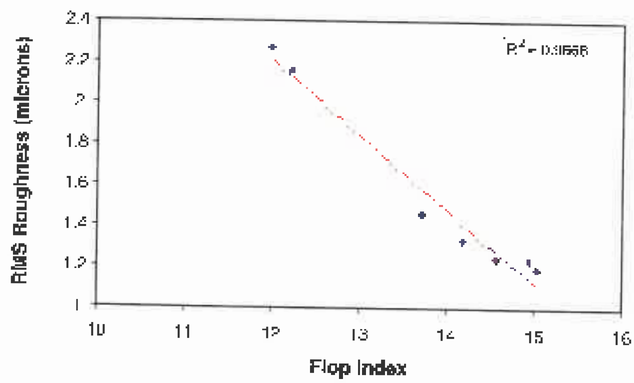


Table 2—Results

System	MWT	Amount (% by wt)	RMS	Average RMS	Flop Index
Standard	----	----	1.95, 2.29, 2.21	2.15	12.20
Formulation 1	Low	1	1.30, 1.25, 1.11	1.18	15.01
Formulation 2	Medium	1	1.21, 1.27, 1.17	1.22	14.92
Formulation 2	Medium	3	1.33, 1.29, 1.34	1.32	14.15
Formulation 3	High	1	1.44, 1.41, 1.49	1.45	13.7
Formulation 3	High	3	1.22, 1.29, 1.34	1.32	14.55
Commercial Additive	Unknown	0.2%	2.31, 2.10, 2.4	2.26	11.98

CORRELATION BETWEEN MOLECULAR WEIGHT AND METALLIC FLAKE ALIGNMENT

These confocal microscopy images of the metallic coil coating without cellulose acetate butyrate (*Figure* 1) show a multitude of high peaks, indicating a rough surface. This is also true for the system that contains the commercial additive (*Figure* 2) that is recommended for improving metallic flake alignment. The images (*Figures* 3–6) of the systems containing cellulose acetate butyrate show far fewer peaks and large domains of flat areas. The cellulose acetate butyrate containing system has aligned the metallic flakes such that they are flatter and more even.

The confocal images demonstrate that the high molecular weight grades are effective in improving metallic flake alignment. However, the lower molecular weight grades are more efficient and a much lower level is required to achieve the same effect such that 1% of a cellulose ester butyrate at the low-to-medium molecular weight range is as effective as 3% at the high molecular weight.

CORRELATION BETWEEN SURFACE ROUGHNESS AND FLOP INDEX

If we plot the average surface roughness against the flop index (*Figure* 7), we observe that the flop values are also in agreement with the surface roughness profiles. Low surface roughness produces higher flop values. The formulations without cellulose acetate butyrate produce far lower flop value and visually are darker with a more "grainy" appearance.

CONCLUSION

Confocal imaging techniques have provided detailed images of metallic coil-coated surfaces. The technique via 3D profiles has shown that the addition of CAB has a dramatic impact on the surface roughness and thereby on the overall appearance properties, in comparison to the control. Cellulose esters in the molecular weight range of low to medium were the most effective in aligning metallic flakes, such that they were flatter and more even. The appearance of such coatings are visually brighter and more aesthetically pleasing. It has also been demonstrated that there is correlation between surface roughness and flop index measured via multiangle spectrophotometry.

ACKNOWLEDGMENT

I would like to express my gratitude to Deep Bhattacharya and Lou Germinario at Eastman (Kingsport, TN) for providing the confocal imaging data. CT