magical mixtures

By Werner Rudolf Cramer / Münster, Germany

Transparent mica pigments are some of the most appealing pigments used in automotive and industrial coatings. Their optical characteristics are determined by interference phenomena arising through their chemical makeup. One of these characteristics is their "magical" behavior when mixed with other mica pigments as well as with color pigments.

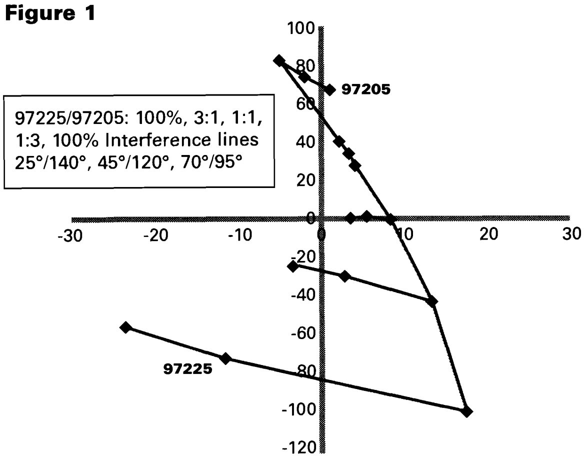
Paint mixing is a physical process that should be distinguished from the theory of color vision. Unfortunately, in paint mixing, this fact is often forgotten when surprising results are obtained.

Until recently, most standard automotive finishes were produced with absorbing color pigments. In the meantime, special-effect pigments have taken a significant share of the standard finish market and enjoy great popularity with car owners due to, for instance, their lustrous effect. What is little known, however, is that the rules of mixing that apply to these special finishes are different from those applied to absorbing color pigments.

Mica Pigments

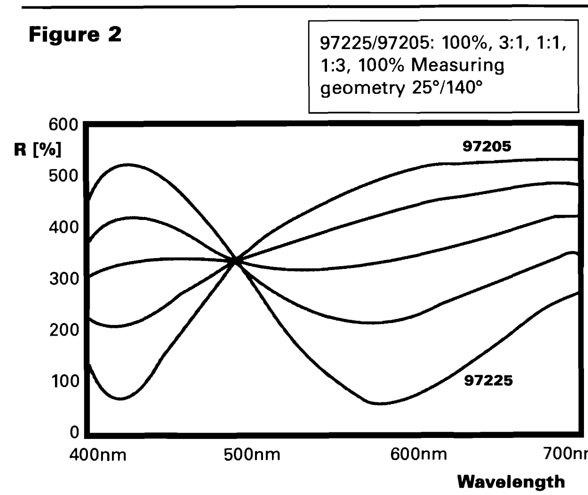
Transparent mica pigments are a new breed of pigments that acquire their color effects through interference. They consist of flakes of mica as the centerpiece, covered with a highly refractive layer of titanium dioxide (TiO_2). White light impinging on this type of pigment is partially reflected at its TiO_2 surface. The remainder passes (is refracted) through the TiO_2 layer until it encounters the surface of the mica, where it is again par-

Figure 1



a*b* values for interferences at 25°/140° (illumination/observation angle), 45°/120°, and 75°/95° for mica yellow, mica blue and mixtures thereof. The connecting line for 25°/140° measuring geometry shows the change of color direction being dependent on the angle of illumination.

Figure 2



The reflection curves for mica yellow (Afflair 97205), mica blue (Afflair 97225) and mixtures thereof oscillating through a node. The maxima and minima of the base colors are opposed.

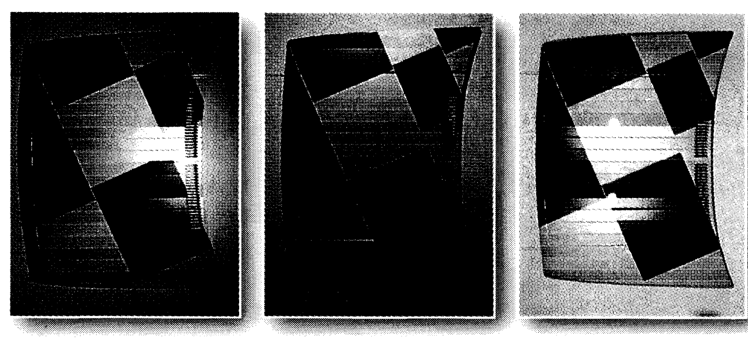
tially reflected, leaving the pigment parallel to the first reflected light component.

The waves of the latter component will have undergone a shift relative to the first component, corresponding to the relative difference in the paths taken. This difference is calculated as the additional path traveled through the TiO_2 layer minus the path traveled in the meantime by the first reflected component. A wave peak coinciding with another wave peak will produce a magnified wave, while a wave trough on another wave trough will give a flatter wave. In the simplified interference formula, the resultant reflection color is a function of the layer thickness of the TiO_2, of its refractive index and of the angle from which light impinges.

By encasing a flake of mica in various thicknesses of TiO_2, the color effect achieved ranges from silver-white through yellow, red, and blue, to green with increasing thickness. In physical terms, selective reflection of the incident light is taking place. Unlike with color pigments, there is little or no absorption. And, with mica pigments, since what is being manipulated is the incident light, they follow the light-mixing rules when more than one such pigment is used together. An example of this is mixing yellow and blue mica pigments, which produces white, not green.

Optical Properties of Mica Pigments

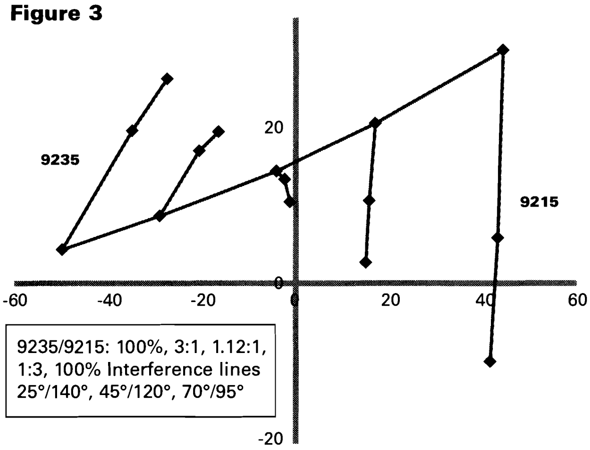
To understand the consequence of mixing transparent mica pigments, it is necessary first to describe their optical properties. Upon examination of a sample of sheet metal that has been sprayed with a mica-pigmented paint, what one sees is an extensive color interplay. Colorimetrics provide a more precise way of defining this interplay. The interference formula expresses the reflection color as a function of the angle of light incidence. If a paint is measured with a varying angle of light incidence while the difference between the angle of reflection and the observation angle is kept constant, the



readings will show the typical interference line of the pigment. Carrying out further measurements with a constant illumination angle (e.g., 45°) while the angular difference is changed will produce the gloss line typical for this illumination angle.

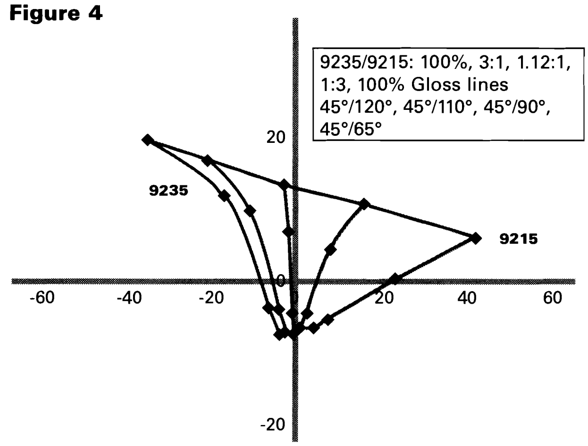
If the measurement is carried out with a sample in which the mica-containing paint has been sprayed onto a white background, then at above 30° from the angle of reflection

Figure 3



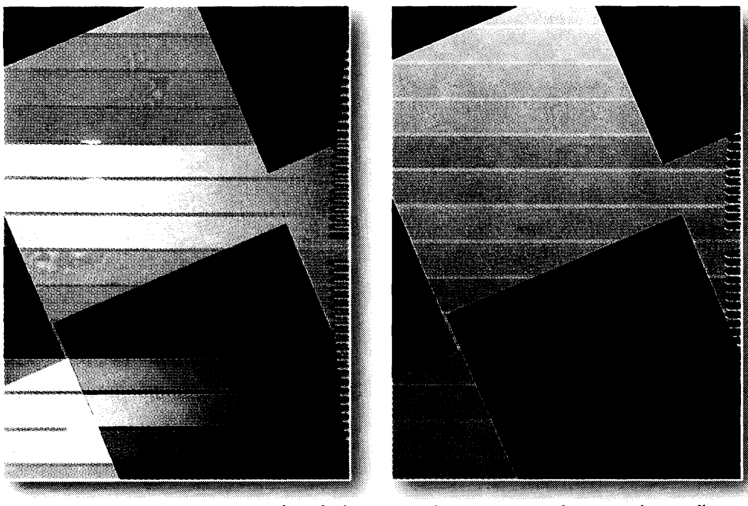
a*b* values for interferences at 25°/140° (illumination/observation angle), 45°/120°, and 75°/95° for mica green (Afflair 9235), mica red (Afflair 9215) and mixtures thereof. The connecting line for 25°/140° measuring geometry shows the color direction dependent on the angle of illumination as changing upon mixture of mica green and mica red.

Figure 4



While the direction of the interference lines rotates, the color lines remain angle-independent; they have a common focus as the angle of observation is moved further from the gloss angle, so enlarging the angular difference.

the transmission color of the pigment is perceived. The transmission color consists of those light components emerging on the side of the pigment opposite the reflected components. And what is perceived is this transmission color reflected from the white background.



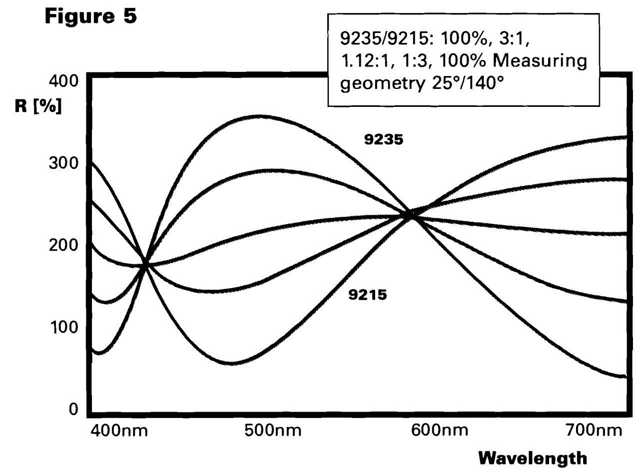
As a result of this interference condition, the reflection maximum for mica paint shifts to smaller wavelengths as the illumination angle becomes flatter. Steeper illumination angles cause a shift to larger wavelengths: mica red appears more yellowish at flatter angles and more bluish at steeper angles. And mica green turns more bluish as the angle flattens and more yellowish as it becomes steeper. Similarly, with mica blue, there is a shift to blue-violet or green, respectively, and with mica yellow a shift to greenish or reddish, respectively.

When mica pigments are mixed together, they behave in the same way as additive mixtures. Virtually ideal results are obtained with 1:1 mixtures whose a*b* values in the CIELAB system lie between those of the respective base colors. Conversely, the strength of color of a red color pigment means that a 1:1 mixture with yellow color pigment differs only very slightly from the red base pigment.

These facts can be merged. On the one hand is the additive mixing process. This can be verified based on readings taken for defined measuring geometries. On the other hand, there are additional phenomena resulting from the interference characteristics and producing "magical" results. For example, mica green 9235 changes color as outlined above from yellowish to bluish-green if the illumination angle is chosen flatter and the angular difference is left constant. For mica red 9215, exactly the opposite is true. The pigment appears yellower as the illumination angle becomes flatter. Mixing the two pigments minimizes the interferences. The effects achieved by keeping the illumination angle constant and varying the angle of observation are not lessened.

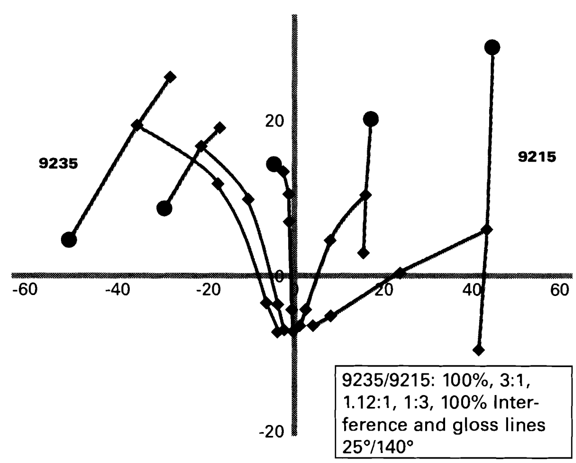
The rules of additive mixing do apply here, but the interferences are, so to speak, turned on their head.

Figure 5



The reflection curves for mica green, mica red and mixtures thereof form two nodes through which they oscillate. These nodes are reflection-identical sites at which, even with the mixtures, there are no changes to be seen. In the reflection curves for the base colors, the minima and maxima are opposed.

Figure 6



Interference and color lines describe the optical properties of mica green, mica red and mixtures thereof. With the 45°/120° measuring geometry, the gloss and interference lines collide. The 25°/140° geometries are identified with (green) dots.

Looking at the reflection curves of the starting colors and mixtures thereof, the characteristic oscillation nodes (at these wavelengths no changes occur) can be observed. Also, the maximum for mica green and the minimum for mica red lie between these two nodes. At the measuring geometries used to measure interference, the mixture exhibits only a slight shift in its reflection maximum.

When mica pigments are mixed together, they behave in the same way as additive mixtures.

This effect can also be observed in other mixtures such as mica yellow with mica blue. Here, too, the direction of the color shift changes between the two pigments. The reflection curves only oscillate through one node, but here, too, the reflection maxima and minima are opposed.

Conclusion

Transparent mica pigments are a fascinating example of unusual mixing effects. Here, a special role is played by their optical properties in particular, which are due to interference. Providing a more detailed account of the effects achieved, colorimetrics is a good way of defining the visual impressions. If new developments from pigment manufacturers are anything to go by, the number of interference pigments is set to grow in the near future. Although for production control (e.g., of paint and plastics containing these pigments), a reduction in measurements to an acceptable level will be crucial, it will also be important to explore all of the optical properties in order to appreciate the unusual and breathtaking behavioral patterns that are available.

For more information on color testing, e-mail wrcramer@aol.com