



FORMULATING EXCELLENT AUTOMOTIVE EFFECTS

Eight golden rules for creating automotive coatings using effect pigments. By Werner Rudolf Cramer.

Modern automotive surfaces shine through the use of interference and aluminium effect pigments. Effective use of these pigments in formulating automotive coatings depends on deep knowledge on their properties and features in application.

Exciting colours and effects make modern automotive finishes shine. Interference pigments, introduced in the mid-80s for automotive OEM coatings, are the stars in providing great visual effects. The first series of automotive colours containing white interference pigments were applied in a three-layer system, using a white basecoat, a white interference coat and a clear coat. After that, the trend turned to coloured coatings, using mixtures of colour pigments, together with white and colour interference pigments. At the end of the 90s, these coloured coating systems were again enhanced by the introduction of aluminium pigments, which had been used for some time for effect finishing. With the development of new effect pigments also came the development of new measurement methods. This included the multi-angle measurement of aluminium and interference pigments and the use of these measurements in characterising visual surface effects. The multitude of innovations with regard to pigments – and also to coatings and application technologies – has influenced how a new colour standard is created and what aspects are to be considered in its creation. Here are eight golden rules for the effective creation of automotive colours.

MINDING THE GEOMETRIES

In most cases, modern automotive coatings have visual effects that involve differences – either in the lightness of the coating, or in both the lightness and the colour of the coating – which depend on the location of the illumination and the location of the observer with respect to the coating surface, and the geometries that arise from the path of light from one to the other.

The light source – let's take the sun, as an example – illuminates each point on the vehicle with a quantifiable angle of incidence from the "normal" (which is the perpendicular to the car body surface at the point of incidence) and is reflected from it at the same angle to the normal. Together with the illumination, the normal and the "gloss" (or reflected light) all lie in the same plane, as shown in *Figure 1*. Within this plane, the positions of the illumination and the observer are defined by their angles of difference from the normal: an illumination of 15° means that the light source (the sun) illuminates the surface (our vehicle) at an angle of 15° from the normal.

The "specular angle" (the angle of reflected light, or gloss) corresponds to the illumination angle (for practical reasons, the angle notation for this is preceded by a minus sign, which is physically incorrect), while the "aspecular angle" is the angle of difference between the reflected light and the observer. If one would be observing the gloss of the vehicle (i.e. if the observer were to be at the same angle as the reflected light, as in *Figure 1*), the aspecular angle between gloss and observer

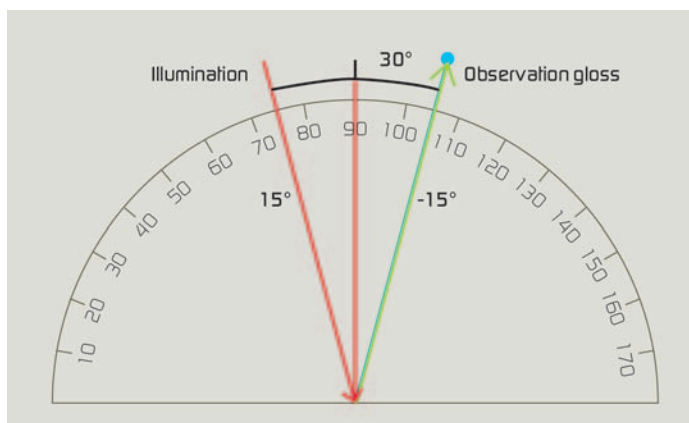
RESULTS AT A GLANCE

- Angle-dependent visual effects have arisen since the 80s and can be characterised by multi-angle measurements.
- Interference pigments create angle-dependent colour effects and can be used additively.
- Aluminium pigments can be used to create metallic effects.
- Mixing colour pigments with the effects of interference pigments and aluminium pigments creates dazzling new coatings.

would be 0° . However, if the observer's eye moves away from the gloss direction, the aspecular angle starts to grow. In the example in *Figure 2*, the car body panel has been tilted and the illumination and the gloss/specular angle are now both at 5° from the new normal, but, as a result of the tilt, the gloss has moved 20° away from the observer. The ASTM E2539 Standard Test Method for Multiangle Color Measurement of Interference Pigments proposes characterising the colour reflection effects of effect pigments in a coated surface by collecting measurements at multiple angles in the plane formed by the illumination, the normal and the gloss, including on the "opposite" side of the gloss.

For formal reasons, these aspecular angles are given a negative sign. Thus, the aspecular angle of -15° corresponds to an observation angle at -60° when illuminated at 45° . To distinguish between the positions, the prefixes "cis" and "trans" may be cited. "Cis" angles are located on the illuminated side, while "trans" angles are on the opposite side of the gloss. Manufacturers of measurement instruments refer to these

Figure 1: The geometries of the illumination, the surface and its normal, the observer and the gloss (= reflection). In this example, the observer is observing from the same angle from the normal as the gloss/reflection.



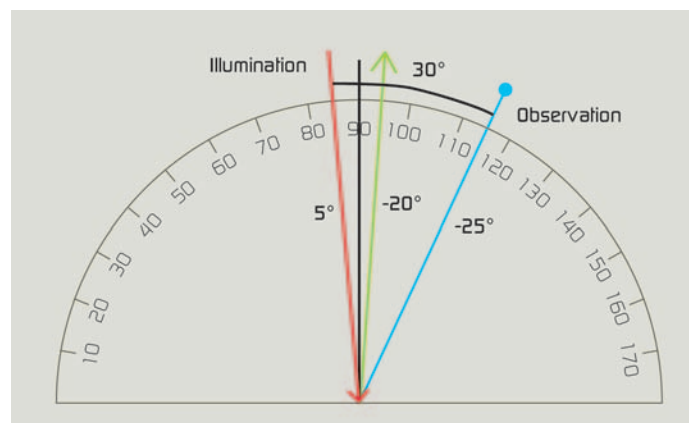
standard aspecular angles, usually -15° , 15° , 25° , 45° , 75° and 110° , which correspond to absolute observation angles of -50° , -30° , -20° , 0° , 30° and 65° (see *Figure 3*). The measurement results at $45^\circ/\text{as}-15^\circ$ are similar to those at $65^\circ/\text{as}15^\circ$: if the connecting line between the two geometries $45^\circ/\text{as}15^\circ$ and $45^\circ/\text{as}-15^\circ$ in the extension of the two geometries $45^\circ/\text{as}25^\circ$ und $45^\circ/\text{as}15^\circ$, then the coating mix does not contain a colour interference pigment. With a colour interference pigment, the curve bends counterclockwise. Coatings with aluminium pigments do not have this kink; the connecting line for these occurs between the measured values at $45^\circ/\text{as}25^\circ$, $45^\circ/\text{as}15^\circ$ and $45^\circ/\text{as}-15^\circ$ and is nearly straight (see *Figure 4*).

GETTING TO KNOW EFFECT PIGMENTS

While colour pigments partially absorb incoming light and partially scatter it undirected in all directions, interference pigments additionally partially transmit the light. Particularly, in the case of transparent interference pigment types, one can recognise the intense reflection colour and the transmission colour, which are complementary to each other. Transparent interference pigments consist of a substrate particle (of e.g. mica, aluminium oxide, or silicon oxide) covered with a highly-refractive metal oxide layer. When light strikes the surface, a part of this light is reflected, while the other part travels through the metal oxide layer until it arrives at the boundary layer to the substrate, where it is, again, partially reflected. This reflected portion of the light exits the pigment particle parallel to the first reflection component, and both component light waves then interfere with each other constructively or destructively, depending on the path length difference (the "phase shift") taken by the passage through the metal oxide layer. The degree of constructive or destructive interference differs by wavelength of light, and the thickness of the metal oxide layer can be tailored to interference of certain wavelengths. Light of certain wavelengths is therefore seen to be selectively reflected, depending on the thickness of the highly refractive layer (or layers), their refractive indexes and the angle of the incoming light.

The rays of light that pass all the way through transparent interference pigments experience something similar on the reverse side of the pigment and also interfere. Since the rays of light are moving from optically denser to optically thinner media, the phase shift is absent. For this reason, the transmission colour complements the reflection colour: if the interference pigment reflects blue, then its transmission colour is yellow. This can be observed when the pigment on a transparent film or a white substrate is applied: the colour perceived on

Figure 2: If a test panel is tilted by the observer, the angle between the light source and the observer does not change: it remains at 30° , but there is now an aspecular angle between the observer and the gloss/reflection.



- the surface appears to be blue while the transmission colour is yellow. *Figure 5* shows how there can be a viewing angle transition from the reflection colour to the transmission colour.

There are different types of interference pigments, which can roughly be distinguished by how they were produced: transparent, or semi-transparent ones are made in wet-chemical processes for which the carrier materials consist of natural mica, aluminium oxide or silicon oxide. These carrier particles can be coated with metal oxides such as titanium dioxide, iron oxide or chromium oxide.

APPLYING SPECIFIC INTERFERENCE PIGMENTS

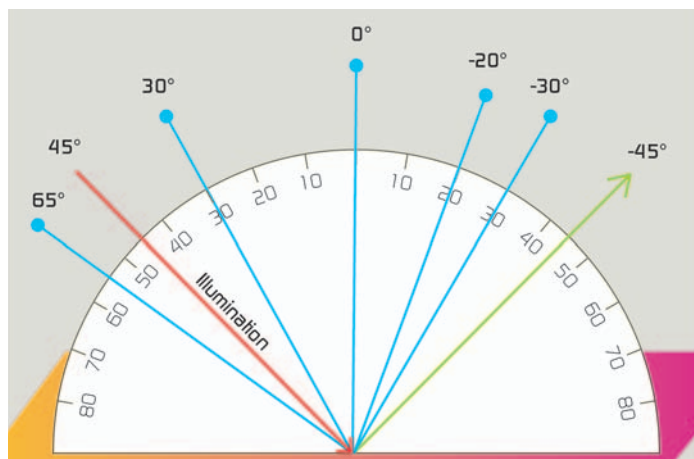
Since interference pigments are mostly transparent, appropriate pigments need to be added to the coating formulation to increase hiding power. By mixing transparent interference pigments with blue, or green colour pigments, the transparency of the mixture decreases. Simultaneously, the chroma (colour intensity) of the mixture initially increases, only to decrease again after a certain point. This phenomenon is also common in white colour mixtures: a blue pigment or its corresponding paste is usually bluish black. When more white is added, the mixture becomes more colourful and chromatic (bluer) – up until a certain point. Beyond this point of the highest chroma, further addition of white makes the mixture start to become paler and more achromatic again.

These days, aluminium pigments are also added to finishing mixtures to achieve an optimum colour mix with maximum chroma of the interference pigment and also a high degree of hiding power. However, it should be noted that both coloured and aluminium pigments can strongly influence the interference effect, or even prevent it. When mixing a new colour, it is crucial to make sure that using an interference pigment only makes sense when it emphasises or enhances the colour.

USING ALUMINIUM PIGMENTS WISELY

Similarly to the interference pigments, this type of pigment comes in different sizes: fine aluminium pigments have a lower gloss (a “satin” gloss), whereas coarse pigments have a much stronger one. However, increasing coarseness decreases the hiding power. Different pigment sizes are offered by manufacturers. In addition to classifications by size, aluminium pigments are also distinguished by how they were produced – which results in different optical characteristics. Normal aluminium pigments are formed by pulverising aluminium into tiny particles, after which small particles that resemble potato tubers are

Figure 3: Modern portable measurement instruments illuminate at 45° and measure at -15°, 15°, 25°, 45°, 75° and 110° aspecular.



formed. When these are flattened, they become aluminium pigment “flakes” (so named because of their irregular appearance, similar to “cornflakes”). When the pulverisation is carried out with an inert gas process, then the result is small beads, that, when flattened, lead to flat, round pigments called “silver dollars”. Aluminium pigments vary in sizes ranging from 11 µm to 24 µm for the cornflakes and 14 µm to 34 µm for the silver dollars (the numbers quoted are median diameter, or D50).

In a visual assessment, for example, when tilting the test panel at the window, the illumination and observation angles change. However, as can be seen in *Figure 2*, during this process, the positions of the illumination (sun) and the observer – and thus the angle between them – remain the same. The geometries for visual observation do not correspond to those of measuring instruments. This would require that the light source would always have to shine at the same angle.

Aluminium pigments and pastes react to colour pigments in the same way that white or colour interference pigments do: the chroma increases to a maximum, and then falls again, while the lightness increases continues to increase.

SELECTING THE DESIRED COLOUR RANGE

To create a new colour with visual effects, start with a special effect pigment and observe its behaviour. If, for example, one takes a colourful interference pigment, then the first step is to mix it with black to

Figure 4: Coloured interference pigments show significant colour changes depending on the illumination and aspecular angle.

Tilting a panel in the light booth or at the window, the geometries are different to those of portable instruments.

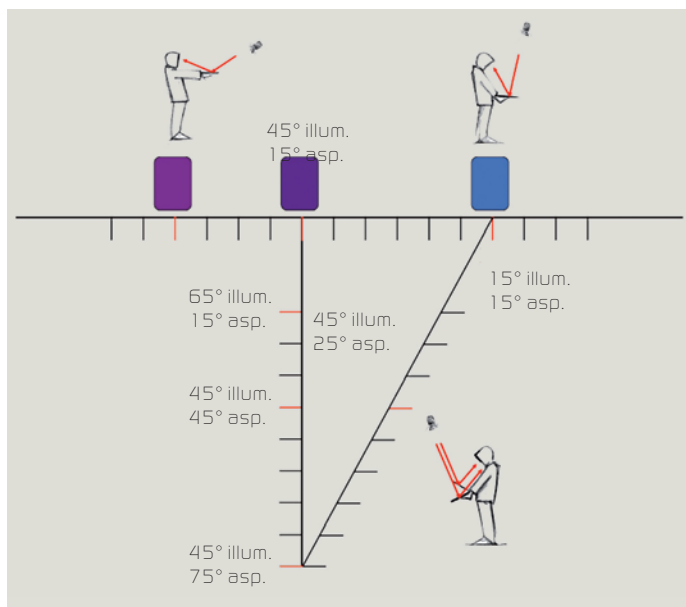
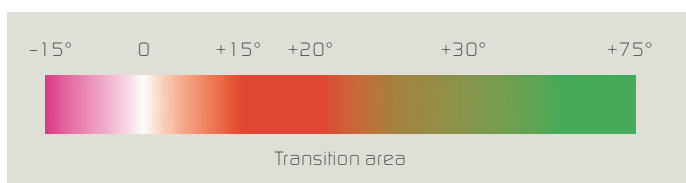


Figure 5: Transparent interference pigments change their colour due to the aspecular angle. Near gloss – between 20° and 30° from gloss – there is a transition area where the reflection colour changes to the complementary transmission colour.



determine the effect. The next step is to repeat the experiment with a blue or green colour pigment (or their corresponding pastes). The actual colour and effect possibilities of such interference pigments can be very quickly recognised in experimenting with these combinations. From these trials, a number of ideas will arise for new colours, which can be prepared in OEM applications.

On the other hand, one can also control the desired colour range in a targeted manner by adjusting the combination of different pigment types: if the formulation is dominated by a colour pigment, then this will determine the overall colour. The addition of an aluminium pigment will determine the shine effect of the mixture; here one can choose from a spectrum, between fine to coarse aluminium pigments, as well as between “cornflakes” and “silver dollars”. Additional interference pigments allow one to determine the visual effect behaviour of the complete mixture. Here again, there is a large range of options that opens the door to many possibilities.

If, for example, one starts with a blue pigment, then white and colour interference pigments may be added. White interference pigments give a silvery effect, while colour interference pigments create more colour effect. Even gold or red copper interference pigments can be added to the original blue pigment: since they have absorbent elements, subtractive mixing behaviour also occurs in such mixtures, and therefore blue colour pigments combined with gold interference pigments can also produce beautiful green hues. If one wanted to mix bright metallics or silver, as in the coating seen in *Figure 6*, then one

could conveniently choose an aluminium pigment from the beginning. Since different types and sizes are offered, the decision for the level of shine and the coarseness of the complete mixture is made at this point. Afterwards, colour pigments can be added to provide a general, directional tint to the colour. Interference pigments can also be added, depending on the type and proportions of the overall mixture, to give a more, or less pronounced colour effect – as in the bright red in *Figure 7*.

THINKING IN COLOUR SYSTEMS

The portfolio of colour and effect pigments offered is so expansive that it is possible to create virtually any colour, nowadays. Nevertheless, it is always important to remember that these pigments are real and not theoretical. It is not possible to produce an “ideal” (neutral) yellow. Yellow colour pigments have either a red, or a green component. Furthermore, a red colour pigment, can produce many red colour effects. The reason for this is, firstly, the same as for the yellow, and, secondly, the reaction of red pigments with white or in mixtures is not ideal, and instead can turn to, for example, violet, or more bluish hues in mixtures with white. Adding a colour pigment to a mixture leads to a movement of its location in all three dimensions of colour space, changing chroma, colour and lightness.

Interference pigments with a strong colour effect are singular pigments, meaning that they do not constitute a colour system of many

Figure 6: Metallic colours show a powerful change in intensity depending on the observation angle.



Figure 7: The effect of a metallic red (left) is very clear.



Figure 8: Matte finishes are the latest trend, but are still not that popular. They can pose difficulties in OEM coatings and refinishing repair jobs.

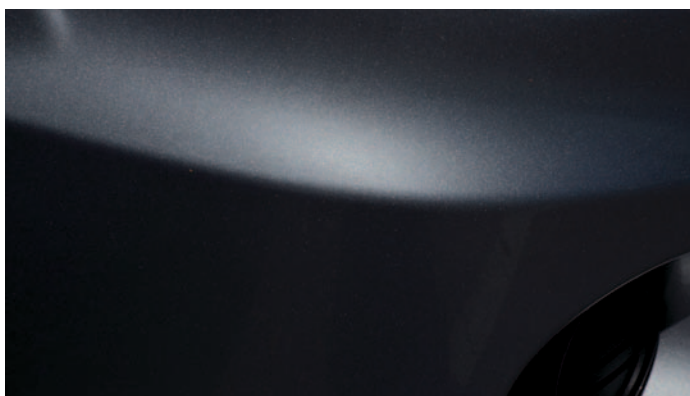


Figure 9: Black, white and silver are favourites around the world. Very few bold colours become an OEM finish.



“Currently, golden pigments are in the focus.”

3 questions to Werner Rudolf Cramer

What difficulties pose matte clearcoats for OEM coatings and refinish jobs? *The result of a painting with matte clearcoat depends on components such as the hardener and thinner as well of application conditions such as booth temperature and humidity. This applies to OEM coatings and refinishes. In refinishes, there are different grades of matte clearcoats which are caused by different car models and parts.*

How do colour and aluminum pigments influence the interference effect? *Colour pigments affect the overall colour impression. The interference effect is usually reached. Aluminum pigments have a direct influence on the interference effect because both have their strongest reflection near gloss. You obtain fairly “hard” colours with aluminum pigments and their blends with colour pigments, while interference pigments lead to more “soft” blends in ad-mixtures with colour pigments.*

In addition to metallic paints, what are other popular effects coatings? *Besides metallic colours, interference pigments are often used in combination with colour and aluminum pigments. Depending on the area of application, various popularities of interference pigments can be determined. Currently, golden pigments – aluminum as well as interference pigments – are in the focus. They are not only useful to create gold-yellow colours, but also helpful to create different colour compositions*



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- components. On the other hand, they can still also be mixed with other coloured and interference pigments. The latter is, however, less advisable since it is quite likely that the overall final effect is not predictable.

OBEYING THE MIXING LAWS

Automobile finishes and many industrial mixtures are typically blends of various pigments or pastes. These not only have different colours and effects, but also behave differently when mixed. When colour pigments such as yellow and blue are combined to make green, this is referred to as subtractive mixing. If, on the other hand, transparent interference pigments such as pearl yellow and pearl blue are blended together, the result is not green, but a white. They mix additively.

It is possible to imagine the different mixing characteristics by using two colour filters of yellow and blue as an example: in subtractive mixing these two filters are in sequence, light passes through one, then the other. The first filter – the yellow one, for example – first filters out all wavelength ranges from the white light except for the yellow range. After that, the blue filter filters out all rays of light except wavelengths in the blue range. The transmission profile of both filters overlaps in the green area of the spectrum so green remains as the resulting colour of light allowed through both filters.

For additive mixing, imagine the filters in parallel, alongside one another: in this case, again, the yellow filter allows all the light rays of the yellow spectral range to pass through and the blue filter allows all the light rays of the blue spectral range to pass through. Where the light from both filters converge, they add up to white again.

To shift the colour of absorbing pigments in a certain direction, one can conveniently use neighbouring pigments, or pigments with a similar tint: a blue does not become more reddish with a red, but with a violet. A yellow becomes more reddish when mixed with an orange. In

this case, a red would force the mixture too quickly into the red area; and one would not begin with a greenish yellow, but with a reddish yellow.

Transparent interference pigments blend more or less ideally to create intermediate colours. Semi-transparent or hiding interference pigments can also be mixed to achieve the desired effect. However, many attempts and a lot of experience are necessary for successful results.

FINDING AN EXTRAORDINARY COLOUR CREATION

The variety of colours and effects is so expansive that selecting or discovering a new colour is hard to do, at first glance. Here are three suggestions for modern colours relevant to today's taste:

- To create a radiant, plain white, avoid adding pigments in the yellow-red-brown area. A little blue does wonders to make a white turn into a bright white. To create a corresponding whiter-than-white effect, use a pure white interference pigment instead of an interference pigment based on natural mica. These do not appear yellowish at higher aspecular angles.
- A metallic colour may have a slightly glossy effect if fine aluminium pigments are used. By combining coarse “silver dollar” and fine “cornflake” pigments, a metallic effect can be “taken to extremes,” as one might say. Additional interference pigments can enhance this effect because this type of pigment reflects extremely close to the gloss.
- Colour effects that dazzle the onlooker can optimally be created using colour interference pigments. These pigments can more or less be mixed haphazardly together with colour pigments. Applying such pigments allows one to control not only the colour effects, but also their chroma. All in all, there are so many fascinating interference and aluminium pigments available that their full potential is still far from being exhausted.