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SHADES OF DIFFERENCE

Visual and instrumental methods of colour assessment analysed. By Werner Rudolf Cramer, Consultant.

Methods of assessing colour and colour differences visually and instrumentally are discussed and compared. Preferred methods of carrying out visual colour assessment are described and explanations are offered for why visual and instrumental assessments may sometimes seem to give conflicting results.

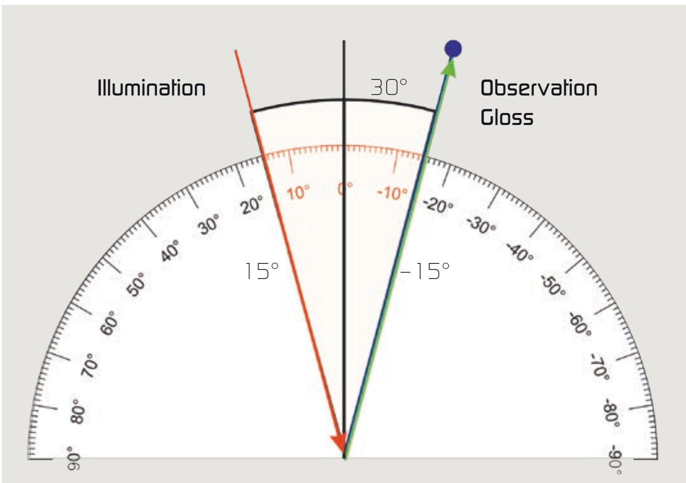
As with other coatings properties, colour is nowadays assessed both visually and with instruments. This assessment serves to determine both the colour in itself and also the comparison between a standard and an adjustment. The traditional method of visual appraisal has been complemented by using instruments, which should be more objective, simpler and safer than the visual one.

Colour pigments in the coatings, which partially absorb incoming light and partially scatter it in all directions, can be judged relatively easily both visually and instrumentally. Measuring instruments are available with a directional illumination at 45° or with spherical geometry.

The increased use of metallic coatings with aluminium pigments promoted the development of new methods in visual and instrumental assessment: the visual assessments were and are made at the window or in a light booth to obtain comparable and reproducible results. The development of instrumental assessment has resulted in portable devices with multiple measurement geometries. Here again illumination was introduced at 45°; with measurement at 15°, 45° and 110° from the corresponding gloss angle. These angles should correspond to visual aspects but have been chosen arbitrarily, like the additional measurement angles defined at 25° and 75°.

Today, portable measuring instruments still work with these geometries complemented by the -15° geometry. Originally, these geometries were intended for measuring metallic coatings. In the late eighties, the emerging use of interference pigments in coatings was measured with the same devices and geometries, without taking into account the physical and optical properties of these pigments.

Figure 1: In this example of visual observation, the starting position at the window is +15° for illumination and -15° for observation, i.e. the difference angle between illumination and observation is 30°.



RESULTS AT A GLANCE

→ Methods of assessing colour and colour differences visually and instrumentally are discussed. It is noted that the choice of measurement geometries offered by portable instruments is to a degree arbitrary, and was designed to take account of the characteristics of metallic pigments rather than the more complex behaviour of interference effect pigments.

→ Preferred methods of carrying out visual colour assessment are described. It is noted that the human eye observes a much larger area of colour than an instrument, including a significant range of Illumination and viewing angles. This may lead to the perception that instrumental and observed colour values conflict, especially in the case of interference pigments.

→ It is important to measure the appearance of effect coatings across a range of aspecular angles to identify their behaviour, which can include a marked change from reflection to transmission colour.

MEASUREMENT ANGLES AND CORRELATION PROBLEMS

The colour and effect of aluminium and interference pigments are highly dependent on measurement geometry, i.e. the combination of illumination and observation, both in visual and instrumental assessment. Ideally, both methods should yield the same result. Finally, assessment by instruments is derived from the visual: the physical reflection value, that is, the measurements by instruments are translated into physiological colour values that reflect the visual impression.

Nevertheless, the criticism is often heard from coating laboratories that observation at the window or in the light cabin does not correlate with the measurement results, particularly in the case of effect coatings. The contradiction is not due to inaccuracy in the measuring methods or errors or with conversions of the colour values, but to the different measuring geometries used in visual and instrumental assessment.

The selection of measuring geometries plays a decisive role for both assessment methods. In addition, the optical properties of interference pigments call for an appropriate choice of measurement geometries.

In summary, three areas that are presented individually and interpreted together need to be considered: the first area comprises visual assessment at the window and in a light cabin. The current portable measuring instruments provide only a small selection of measurement geometries. They supply the second area of investigation; the third area deals with the optical properties of interference pigments.

It may be mentioned in passing that the "GK311/M" spectrometer by Zeiss was developed at the end of the 1980s by Dr Hermann Gerlinger's team and used to measure the different areas and the associated measurement geometries. The basic concept comprises an adjustable illumination head and an adjustable measuring head. Both heads are arranged on a steel half rail, and software allows their position to be changed in 5° increments.

It is possible to adjust the illumination down to 65° and up to -45°. The detector is adjustable between 45° and -65°. This allows almost 250 measurable geometries to be made. Only a few copies of this device were built; one is still fully functional.

AN ORGANISED APPROACH TO VISUAL MATCHING

When making a visual assessment at the window, the sample panel(s) are first positioned so that the observer is looking at the gloss. In this initial position, the gloss angle (= angle of reflection) is the same as the angle of the illumination, and the normal sits between them perpendicular to the

Figure 2: Tilting the panel up, the angle of illumination increases and the aspecular (difference angle between observation and gloss) also increases.

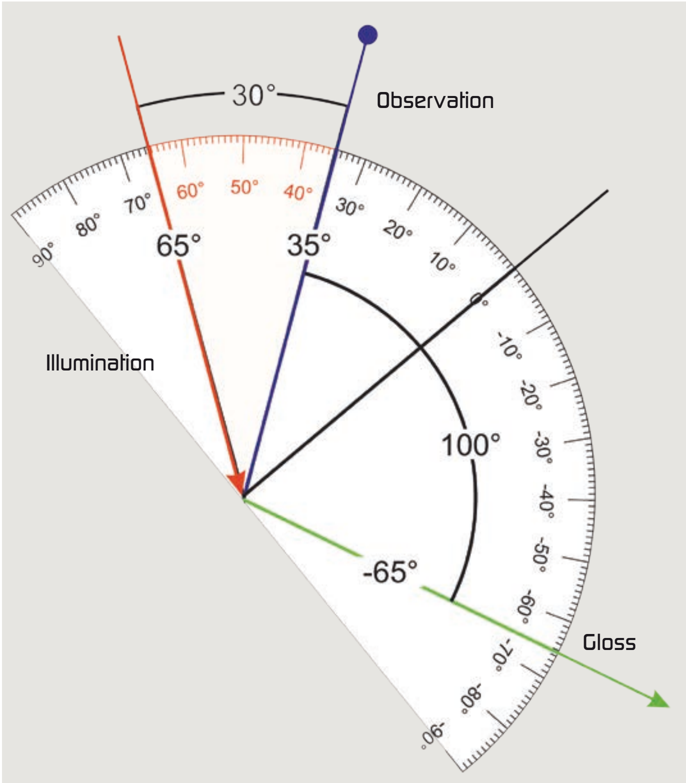


Figure 3: The observation angle increases when tilting the panel down. In the first steps the aspecular angle is negative, i.e. the observation angle is opposite to the gloss angle.

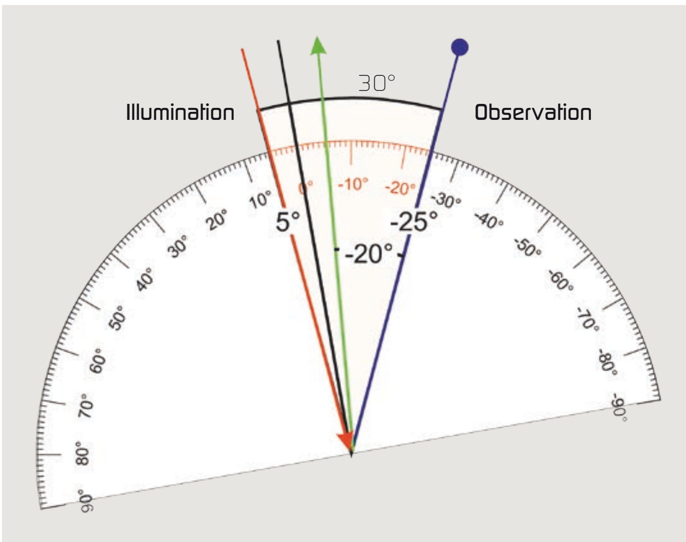


Figure 4: Tilting the panel further down, the aspecular angle increases. The difference angle between illumination and observation remains the same.

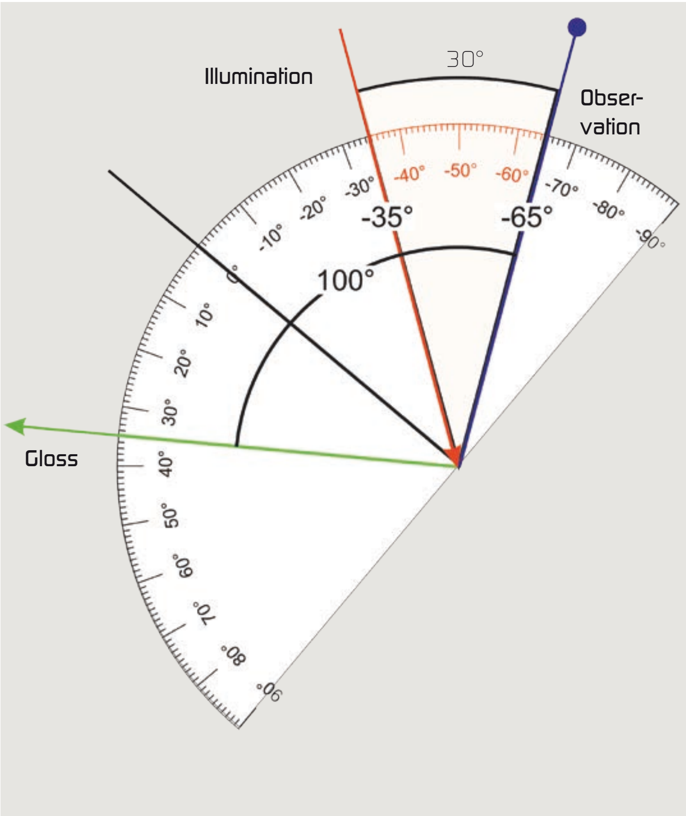


Figure 5: Tilting a panel up and down at a window produces the same colour travel.

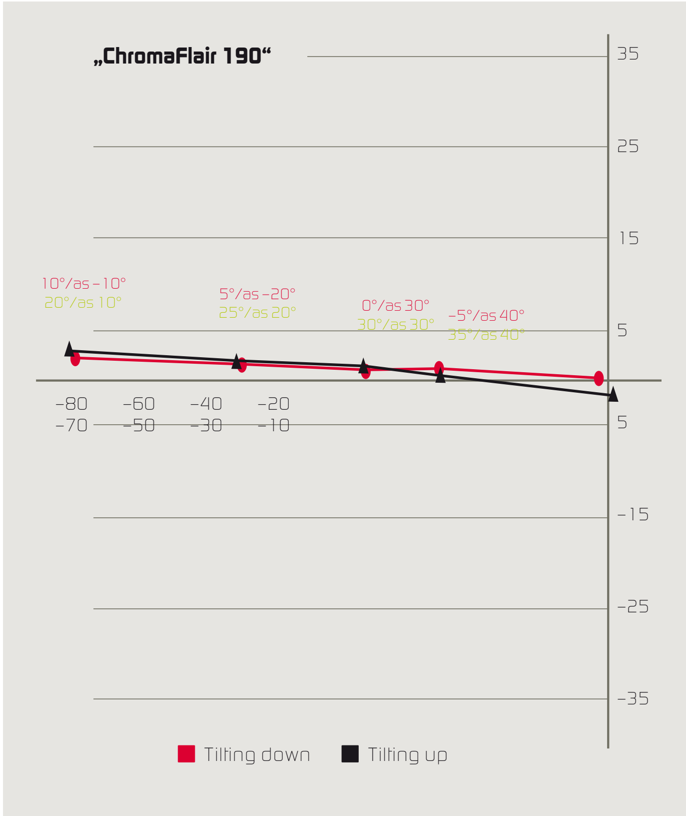
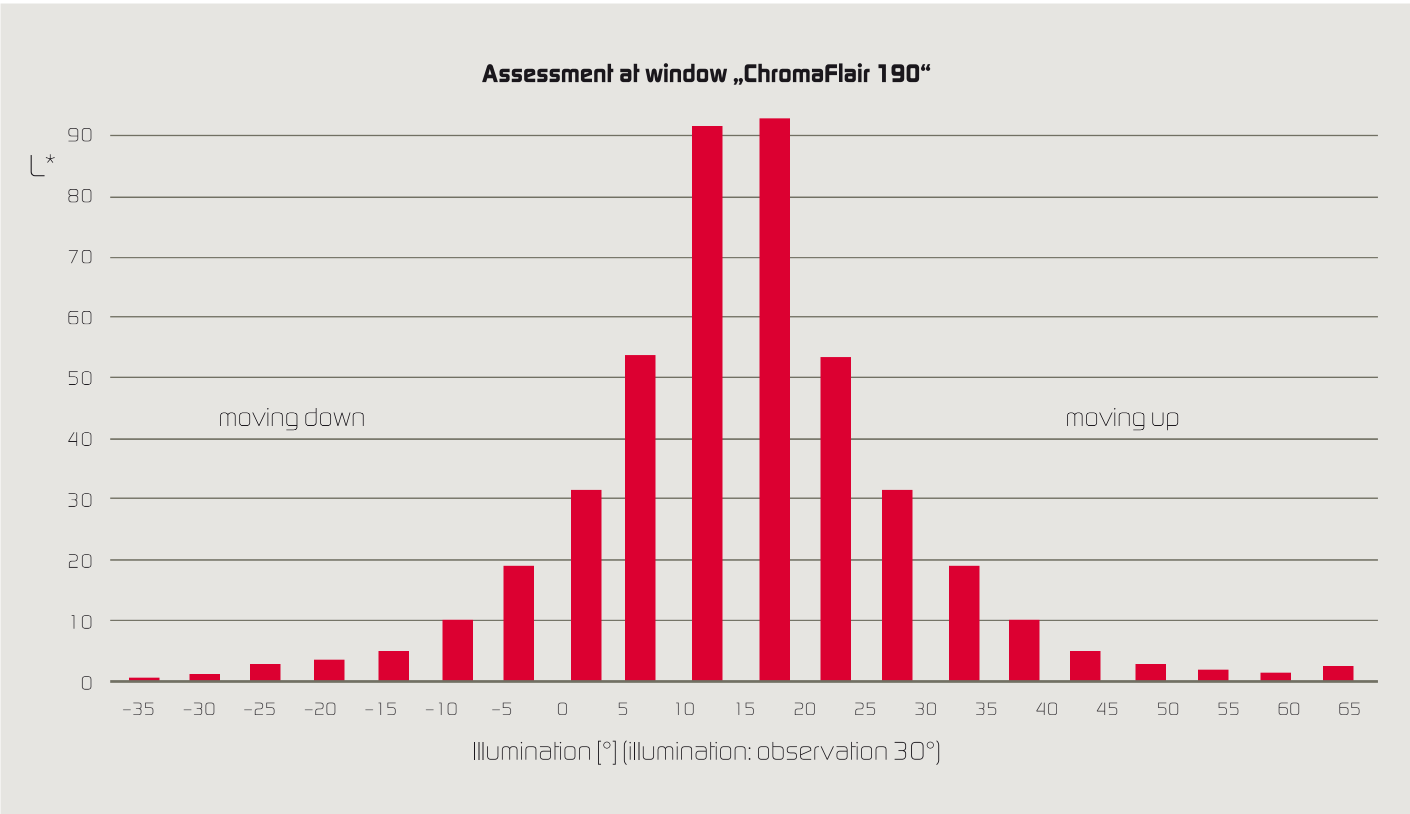


Figure 6: When tilting a panel by the window, the highest lightness is observed near the gloss and will decrease when the panel is tilted away from this. The same or similar values occur due to the principle of the reversibility of light; deviations reveal the orientation of the effect pigments.

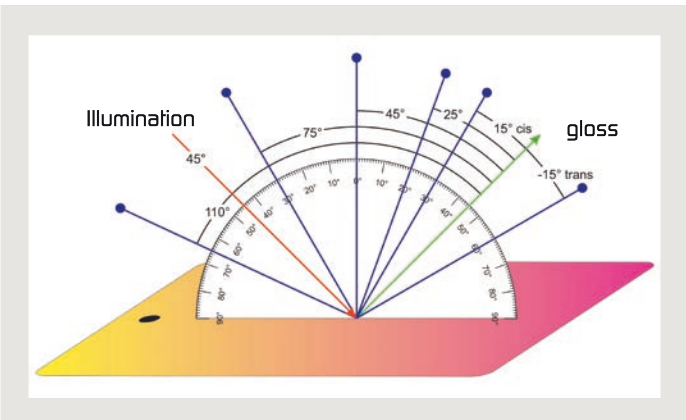


sample panel(s). As an example, suppose that the angle of the illumination is +15° to the normal. Accordingly, the gloss angle is -15°. Here the angle convention is used, according to which the angles on the illumination side are designated positive and those on the observer side negative values, although according to optical principles the angle of incidence equals the angle of reflection.
The observer now tilts the sheet or sheets upwards to themselves or down away from them. In all cases, the angle between them and the light source always remains the same, in this example always 30°. In the case of portable measuring instruments, on the other hand, the difference angle (aspecular) between illumination and observer changes with each measurement geometry (*Figure 1*).
If the observer tilts the sample sheet toward themselves, the angle of illumination increases. At the same time, the difference angle (aspecular) between the observer and the gloss angle increases. For example, if the illumination angle changes from +15° to +45°, the gloss angle changes from -15° to -45°. The angle of the observer is then +15°, which corresponds to a difference to the illumination of 30°. This results in a difference angle (aspecular) between observer and gloss of 60° (*Figure 2*).
If the panel is moved away from the observer and tilted down, then initially the illumination angle moves towards the normal, for example, from +15° to +5°. The corresponding gloss angle is then -5° and the observation angle -25° (*Figure 3*). This corresponds to a difference angle (aspecular) between observer and gloss of -20°. If the observer tilts the sheet down further, the angle of illumination moves to the normal and then changes sides, for example to -10°. The gloss angle then lies on the other side at +10°. The observation angle changes to -40° and the difference angle (aspecular) between observer and gloss is now 50° (*Figure 4*).

THE PRINCIPLE OF REVERSIBILITY – AND SOME EXCEPTIONS

An important issue must be taken into consideration when tilting up and down: due to the principle of light reversal, the colour values are almost identical. For example, measurements at +10° illumination and -20° observation theoretically correspond to measurements at +20° illumination and -10° observation. If measurement values are taken when tilting downwards, it will be seen that the results are almost the same as when tilting upwards. Differences are so slight to the eye that one perceives practically the same colours or the same colour gradients. Ultimately, it does not matter whether the sample panel is tilted up or down; the same colour impressions are obtained (*Figure 5*). The differences are, however, greater with drawdowns. This results in a preferred orientation, which becomes noticeable in measurements. The difference is small in sprayouts, though it may depend on the quality of the spray application.

Figure 7: A portable instrument illuminates at 45° (red line). Measurement is made at -15°, +15°, 25°, 45°, 75° and 110° off gloss (blue lines).

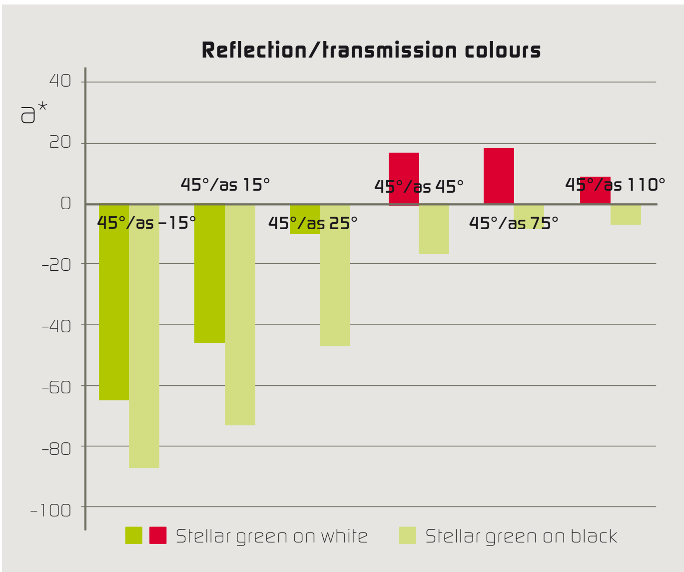


Other methods of observation yield the same results: if the sample sheet is held upside down and then tested with its back to the window, then the same conditions result when tilting forwards and backwards. Even in a walk-in light cabin these conditions will be found; other light cabins are designed according to the customer's specifications. Here, the sample panel is often illuminated from above vertically or under 45° and then tilted forwards and backwards. The sequence of geometries is comparable (*Figure 6*).
One aspect of the visual checks should not be forgotten: the area of a sample sheet seen by the human eye is significantly larger in relation to the measuring spot of an instrument. At a normal distance from the viewer and with a normal size, the viewing angle between the top and bottom edges is approximately 20°.
The visual examination starts close up to the gloss; when tilting forwards and backwards, the observer continues to move away from the gloss, as their position to the window and lighting remains constant. The portable measuring instruments maintain the position of the illumination, and the angle to the observation changes with each geometry. In the case of interference pigments, which have a more or less pronounced colour travel, a different process is observed than the one that results from instrumental measurement.

INSTRUMENTAL ASSESSMENT: GEOMETRICAL CONSIDERATIONS

Colour effects and gradients, especially of interference pigments, are highly dependent on the geometries by which they are illuminated and observed. The fact that the portable devices use geometries that are different from those used in visual matching does not say anything about their quality.
The choice of fewer geometries also limits the amount of data that comes with each additional measurement. Even the introduction of an additional geometry at -15° from gloss angle (aspecular), as defined in the ASTM standard test method, has required a great deal of work from many users. What occurs in a measuring device and what the angle designations mean remains incomprehensible to many users even today (*Figure 7*).

Figure 8: If coloured transparent interference pigments are applied to a white background, the colour change from the reflection to the transmission colour is shown when measuring the gloss line. The transition range is between 20° and 30° from the gloss angle.



A coating with colour pigments shows little or no colour travel; an aluminium-pigmented coating in particular has a glossiness because of changes in lightness when the measurement geometries change. Its gloss is at its brightest close up and decreases as the observer moves further away. This behaviour can be described using portable devices. The detector moves away in greater and greater steps from the gloss angle at a constant illumination angle. In this way, special phenomena can be recorded that are visually described with other geometries.
An example of this is blends with carbon black pigments: as fine-particle pigments they are bluish, as coarse ones, they are brownish. When mixed with the same aluminium pigment, the mixture of bluish carbon black is much darker than the mixture with the brownish when looked at close up to the gloss. The lightness ratio changes depending on the distance from the gloss: the mixture with the bluish carbon black becomes lighter than the mixture with the brownish. This behaviour can also be detected in mixtures with interference pigments. The change in lightness can be described both visually and using instruments.

ANGLE-DEPENDENT BEHAVIOUR OF EFFECT PIGMENTS

An advantage of instrumental assessment over the visual can be seen in the colour properties of coloured, transparent interference pigments: if a coating of this type is applied to a white background, the change from the reflection to the transmission colour is recognisable.
These pigments have a typical reflection colour on their surface; light rays that penetrate the pigments generate a complementary transmission colour on the back due to the missing phase shift. The constant illumination angle of the measuring instruments as well as their change from the difference angle (aspecular) to the gloss ensure the correct description of this optical property: between the difference angles (aspecular) of 20° and 30° there is an intermediate area in which change takes place, depending on the type of pigment (*Figure 8*).
Portable devices display part of the colour properties of a coatings and its pigments with their selection of geometries. Visual matching shows a different part of the colour properties and can therefore give different results. Therefore, it is important to combine both outcomes to make an optimal assessment.

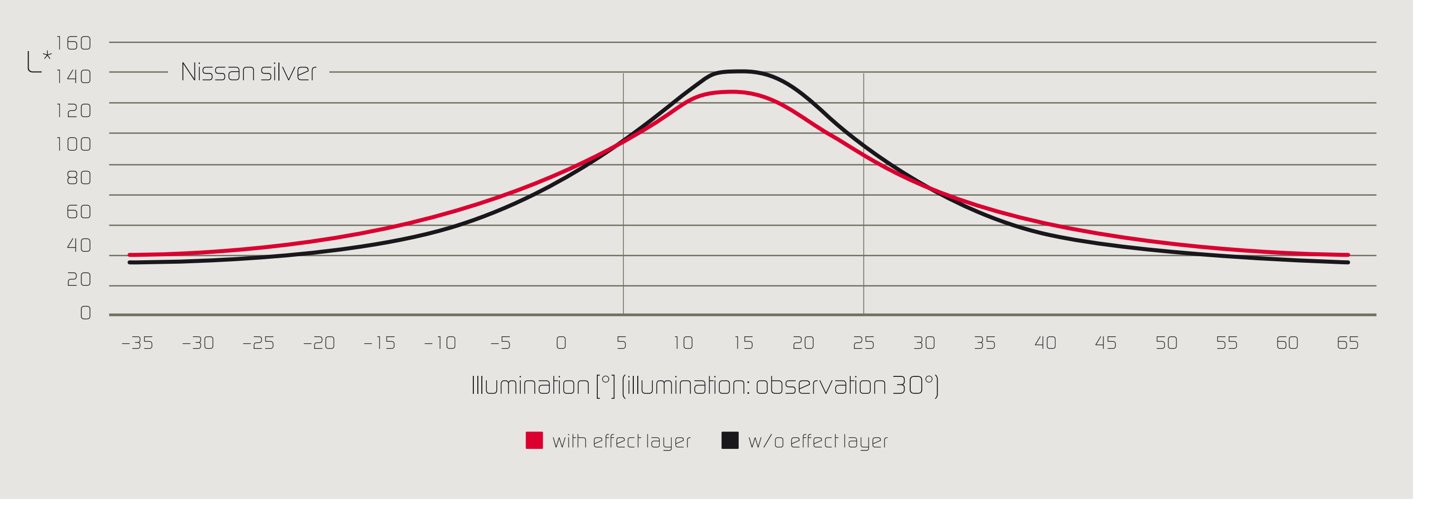
APPEARANCE OF METALLIC AND EFFECT PIGMENTS COMPARED

The third aspect of colour assessment deals with optical properties. These are initially independent of the described methods of visual and instrumental colour inspection. The description of properties raises the question of whether and how they can be adapted to those methods.
Aluminium pigments change their lightness when illuminated at different angles with the same difference angle (aspecular). They also change their lightness when observed at fixed illumination angles with different aspecular angles. Looking at the corresponding reflection curves, a change in the level of reflection is noted, but no displacement (*Figure 9*).
According to the principles of interference, interference pigments react to the change in angle of the illumination. With the same aspecular angle, the reflection curves shift to shorter wavelengths when the pigment or the corresponding coating is illuminated more evenly, i.e. red interference pigments shift to yellowish, yellow interference pigments to greenish and green to bluish. Measurements with changed illumination angles clearly show this behaviour in both the reflection curves and the a*b* colour values (*Figure 10*).
The behaviour is typical for each interference pigment and can also be used for identification. The characteristic anchor shape formed by the interference line with the measurement geometries 15°/15° - 45°/15° - 65/15° and the aspecular line with 45°/15° - 45°/25° - 45°/45°, is specific for an interference pigment. In the connection of 45°/25° - 45°/15° - 65°/15°, the arm always points 45°/15° - 65°/15° counter-clockwise.
These geometries cannot be matched using portable devices; however, due to the principles of light reversal, the 45°/-15° geometry can be used instead of the 65°/15° geometry. It is illuminated at 45° and observed at -60° (corresponding to -15° aspecular) with this geometry. If the light path is reversed, it is illuminated at 60° and observed at -45° (corresponding to 15° aspecular); 45°/-15° corresponds to 60°/15°. The optical properties of an interference pigment can be partially captured using this “trick”.

VISUAL AND INSTRUMENTAL ASPECTS SUMMARISED

All three descriptions have their merits: visual assessment is more like the human behaviour of moving the sample sheet back and forth. In most cases, two sample sheets are compared to detect colour differences. Colour differences can also be detected with the portable measuring instruments as long as they occur with the available measurement geometries. Different measurement geometries are, however, required to characterise and differentiate interference pigments.
To make visual assessments, it is recommended that the measuring panel should be moved in a parallel fashion from top to bottom while

Figure 9: Application also influences behaviour with regard to lightness. The same coating was applied with and without an additional effect layer. Close to the gloss, the effect layer produces a brighter shade.



“The human eye is and remains the decisive tool for assessing colours and colour differences.“

3 questions to Werner Rudolf Cramer

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Why is a visual assessment of colour and colour differences still important? *The human eye is and remains the decisive tool for assessing colours and colour differences. Insofar it stands for the final judgement in any workflow that deals with colours. The instrumental assessment of a colour helps and supports the visual assessment. Both methods should be used together to get an optimal assessment.*

Are portable measuring instruments as reliable as stationary tools? *Portable instruments are no compromise concerning their instrumental characteristics and properties. They can be used as portable instruments as well as stationary instruments in a lab. There might be differences in the choice of geometries which are more or less useful to capture the colour travel of effect pigments.*

What are the most significant obstacles when assessing effect pigments (compared with other pigment classes)? *The colour travel of interference pigments is a big challenge. On the one hand you have to describe this colour travel, on the other hand you can use it to identify an interference pigment. It has a unique colour travel that makes it different from other interference pigments. This colour travel is also typical compared to other kinds of pigment.*

simultaneously changing the illumination angle. Holding the sample sheet up and looking over it, it should also be illuminated evenly. If the sheet is lowered, it is illuminated and observed at steeper and steeper angles. To achieve similar results with portable measuring instruments, the 45°/-15° is included in the assessment. Coloured interference pigments ‘bend’ the arm from 45°/15° - 45°/-15° counter clockwise, while aluminium pigments ‘run straight’ in relation to the arm 45°/25°- 45°/15°.

Figure 10: Tilting a sample panel at the window or in a light cabin shows the same colour gradient for both tilting down and tilting up. The colour gradient that current portable devices describe corresponds to the gradient when the gloss angle is changed. In all cases, different colour gradients arise from those of the interference.