以干涉颜料对彩色与灰色底漆进行测试对比的研究（上）

Coloured versus Grey Undercoats – Trials with Interference Colours (Part 1)

现代汽车涂料通常由两层结构组成：底漆包含带来颜色和效果的颜料，而透明面漆起到保护底漆免受机械和化学影响。除了彩色颜料，现代汽车涂料还使用铝颜料或干涉颜料，产生不同的效果。彩色颜料吸收一部分入射光并在所有方向上散射其余部分。

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铝颜料反射光线并产生类似于高光泽的高反射效果。自从上世纪八十年代中期以来，干涉颜料已被用于汽车涂料。顾名思义，其颜色不是通过吸收和反射产生的，而是通过光波的相互作用产生。这个原理也在自然界中被发现，例如在甲虫和蝴蝶的翅膀上。

开始时是单独使用干涉颜料；随后，将其与有色颜料混合以扩大颜色和效果范围。现在，在大多数情况下，所有三种颜料都一起使用以制备涂料。例如，使用细铝粉颜料增加涂料的不透明度。使用干涉颜料产生不寻常的颜色和效果；然而，这可能会降低遮盖力。

在许多情况下，当遮盖力不足时需应用有色或灰色填料。填料的颜色应当补偿底漆涂层的透明度，即不完全不透明的底涂层的颜色被底层填料所吸收。我

Modern car paint usually consists of a 2-layer structure: the base coat contains pigments for colours and effects, whilst the clear top coat protects the base coat from mechanical and chemical influences. In addition to coloured pigments, modern car paints contain aluminium or interference pigments which create different effects. Coloured pigments absorb part of the incoming light and scatter the rest in all directions. Aluminium pigments reflect the light and create high reflective effects similar to gloss. And since the middle of the eighties, interference pigments have been used in car paints. As the name implies, their colours are not created by absorption and reflection, but through the interaction of light waves. This principle is also found in nature, for example in beetles and butterfly wings.

Interference pigments were first used alone; before they were mixed with coloured pigments to expand the range of colours and effects. Nowadays, in most cases, all three pigment types are used together to create the paint. For example, a fine aluminium pigment increases the opacity of the paint. The use of interference pigments also allows

图1：车前盖板：先用白色涂布，然后表面用黑色涂布。从下到上，条纹已经被涂以不同的干涉色。根据视角，可以在白色底涂上识别出反射颜色或透射颜色。在黑色底涂上只有反射颜色可见。相应的透射颜色被黑色底涂吸收。
Figure 1: This bonnet has first been painted in white (Uni), From below to above, the stripes have been painted with different interference colours. Depending on the viewing angle, the reflection colours or transmission colours can be identified over the white undercoat. Over a black undercoat only the reflection colours are visible. The corresponding transmission colours are absorbed by the black undercoat.

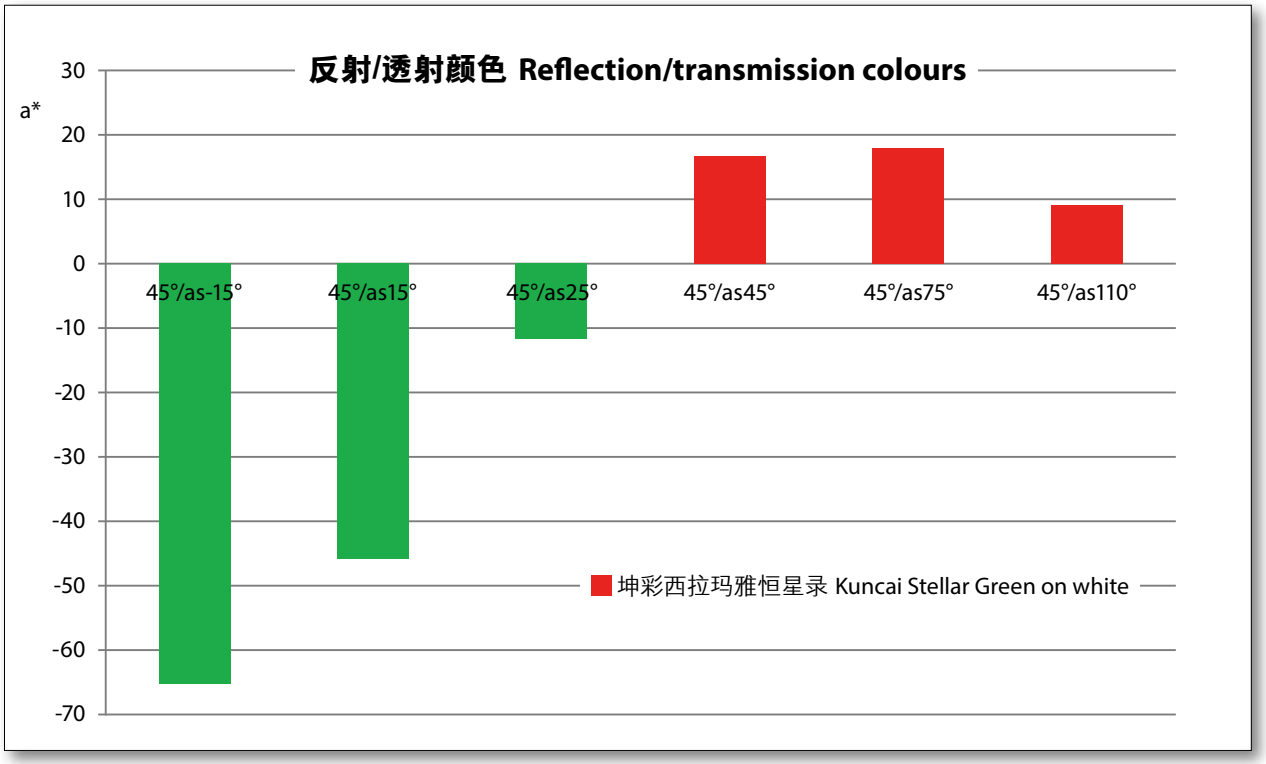

图2：光泽度为20°和30°之间的过渡区域。在此范围，干涉颜料变为透射颜色。当从光泽度的一定距离处观察时，坤彩星绿色从绿色变为红色的变化在白色底色下是可识别的。
Figure 2: The transition area is between 20° and 30° from gloss. Here, the interference pigments change to the transmission colour. The change of Kuncai Stellar Green from green to red is identifiable over a white undercoat when viewed at a distance from gloss.

们用眼睛可以像仪器区分一样小的组份如涂层及颜料。总体色彩印象就是所呈现的效果。不同的方面将在两个不同的试验系列中说明。一个将处理单个干涉颜料，另一个是处理实际的系列颜色。

许多干涉颜料是透明的，显示两种颜色或颜色效果。干涉颜料由涂覆有金属氧化物（例如氧化钛）的强衍射层的载体材料组成。颜料的表面反射部分光线并落在其上，这也发生在与载体材料的边界层上。两个光的部分彼此干涉并且产生典型的反射颜色。颜色效果特别取决于金属氧化物的层厚度和光的角度。类似的过程发生在颜料的背面，尽管由于缺少相移，得到的透射颜色与反射颜色互补。例如，珍珠绿在绿色光谱范围内反射强烈。当仔细查看时，相应的互补色会出现在红色光谱范围内。

这些类型的干涉颜料的透明度导致整个颜色效果对底色颜色的强依赖性。如果在底漆体系中使用透明干涉颜料并将其施加到黑色和白色底漆 / 填料上，结果显示出两个极端：黑色底漆吸收几乎所有落在其上的光线，白色反射几乎所有光线。干涉颜料的补充透射颜色也从后者反映出来。这种相同的效果在视觉色彩匹配和仪器测量中都存在：反射色可以被识别为接近于辐射。在光泽度的 20° 和 30° 之间的区域中，存在过渡区域，其中发生对互补透射色的改变。将相应的颜

unusual colours and effects; however, this may reduce the hiding power.

In many cases, a coloured or grey filler is applied when the hiding power is inadequate. The filler colour here should compensate for the transparency of the overlying base coat, i.e. the colour of the not-quite-opaque base coat is invigorated by the underlying filler. We can differentiate the individual components – paint layers and pigments – from one another as little with our eyes as with colour measurement instruments. The overall colour impression is what is always presented. The different aspects are to be illustrated in two different trial series. One will deal with an individual interference pigment and the other with a real series colour.

Many interference pigments are transparent and show two colours or colour effects. They consist of a carrier material that is coated with a strongly diffractive layer of a metal oxide – for example titanium oxide. The surface of the pigment reflects part of the light falling on it and this also happens on the border layer with the carrier material. Both light parts interfere with each other and typical reflection colours are generated. These are particularly dependent on the layer thickness of the metal oxide and on the angle of the light. Similar processes take place on the rear side of the pigment, although the resulting transmission colour is complimentary to the reflection colour because of the missing phase shift. For example, a pearl green reflects strongly in the green spectral range. When examined, the corresponding complementary colour appears in the red spectral range.

色值与对应的测量几何参数进行绘图时，可以示出该变化。使用绿色干涉颜料，当选择颜色值 a* 时，绿色反射颜色和红色反射颜色之间的变化变得可见（**图 2**）。

黑色底漆上的反射低于白色。使用绿色干涉颜料，红色透射颜色被白色底漆反射。当光线被分离成反射和透射时，两个部分一起再次产生白色。虽然白色底涂层上的色度首先随著角度差异 (aspecular) 的增加而减小，然后在过渡区域之后再次上升，其在黑色底漆上连续下降。对于亮度也可以看到类似的结果：其在白色底涂层上比在黑色上更高。这也首先随著角度差异的增加而减小然后再次上升。在黑色底漆上也会连续下降（**图 3**）。

使用最新的设备——X-Rite MA98 和 BYK-mac I 进行了测量。这里需要注意的是，测量角度的距离不相等。测量位置之间的差异以不等的步长增加；在这方面，这些陈述一般与测量几何参数相关。干涉颜料可以用两种装置以有限的方式测量。颜料或涂料的干涉由光的入射角的变化表示。BYK-mac 设备只提供一种照明几何形状，MA98 提供两种。干涉有时可以通过技巧显示；但必须注意的是，结果强烈依赖于应用程式的类型（**图 4**）。

试验显示透明颜料对底漆颜色的依赖性。白色和黑色代表两个极端。中间是刻度或灰色或彩色底漆。这两种可能性都应用于汽车 OEM 和修补涂料（修补

The transparency of these types of interference pigments leads to a strong dependence of the overall colour impression on the undercoat colour. If a transparent interference pigment is used in a base coat system and this is applied to a black and a white base coat/filler, the results show two extremes: the black undercoat absorbs nearly all light rays that fall on it, and the white reflects nearly all. And the complementary transmission colour of the interference pigment is also reflected from this latter. This same effect presents itself in both visual colour matching and with instrumental measurement: the reflection colour can be identified close to the radiance. In the region between 20° and 30° from the gloss, there is a transition area in which the change to complementary transmission colour takes place. This change can be illustrated when the corresponding colour values are plotted against the measurement geometries. With a green interference pigment, the change between the green reflection colour and the red reflection colour becomes visible when colour value a* is selected (**Figure 2**).

The reflection over a black undercoat is lower than over the white. With a green interference pigment, the red transmission colour is reflected by the white undercoat. As the light is separated into reflections and transmissions, both parts together produce white again. While the chroma over the white undercoat first decreases with the increasing differential angle (aspecular) and then rises again after the transition area, it lowers continuously over the black undercoat. A similar result can also be seen for the brightness: it is higher over the white undercoat than over the black. This

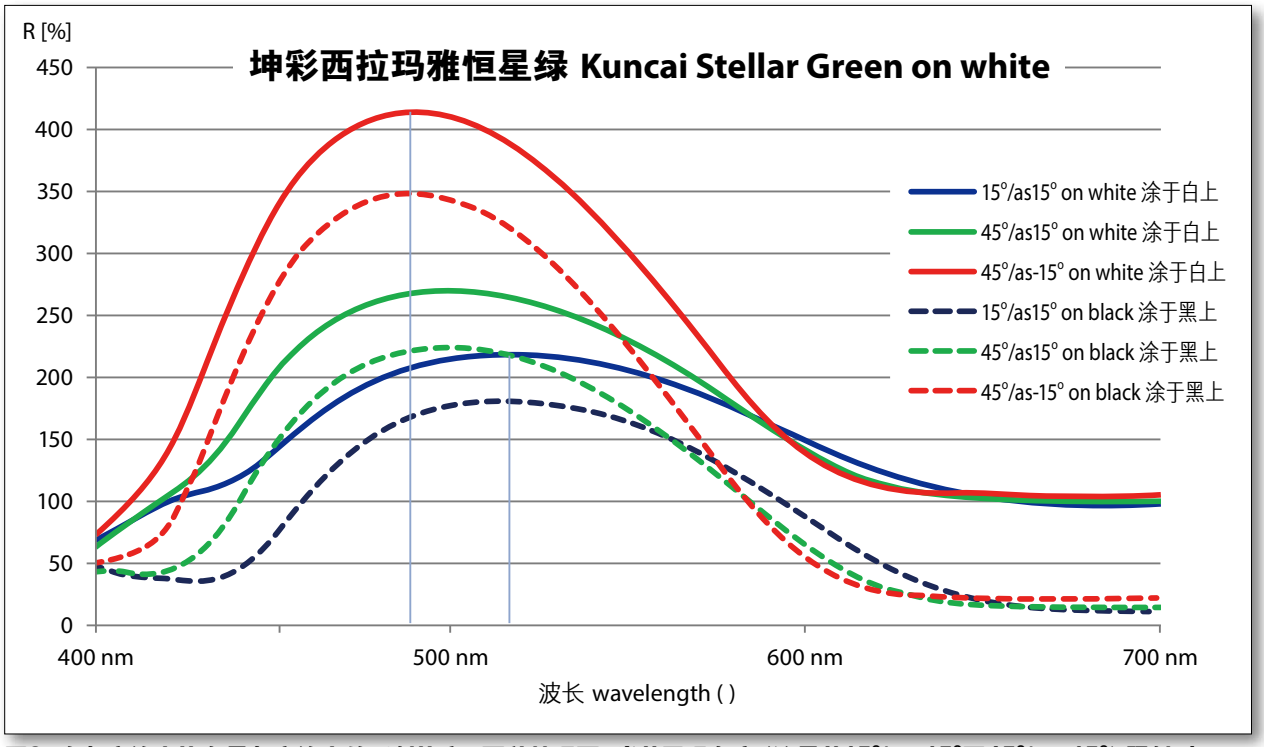

图3：白色底涂上比在黑色底涂上的反射比高。两种情况下，当从平坦角度（这里从15°/ as15°至45°/as-15°）照射时，反射偏移至较短的波。
Figure 3: The reflections are higher over a white undercoat than over a black undercoat. In both cases, the reflections shift to shorter waves when irradiated from a flatter angle (here from 15°/as15° to 45°/as-15°).

漆）中。寻找更好的方法——无论有无颜色——往往达到哲学的维度，虽然事实情况是清楚的：整体的颜色印象决定结果，无论是在视觉评估和仪器测量。并且整体色彩印象由不同的元件组成。首先，大部分光从底涂层反射。该反射可以由反射性的铝颜料反射和由干涉颜料和干涉颜料内部反射组成。吸收彩色颜料在所有方向上传播光，甚至是来自上述颜料类型的反射光。底涂层中的过程非常复杂，因为在这里不同类型的颜料和它们不同的光学性能在一起。根据底涂层的透明度，剩余比例的光穿透该底涂层并通过下侧逸出。这种比例的光也在底涂层中经受复杂的光学过程，然后撞击底涂层。

透明底涂层的作用就像白光照在透明的彩色膜上一样。部分光被反射，一部分被吸收，另一部分通过另一侧离开膜。这部分光然后碰到底漆。根据颜色不同，在这里接受不同的处理。当用绿光照射时，红色底漆

also first decreases with the increasing differential angle and then rises again. Over a black undercoat, it falls continuously (**Figure 3**).

The measurements have been carried out using the most up-to-date devices – X-Rite MA98 and BYK-mac I. It is important to note here that the measurement angles are not at equal distances. The difference between measurement positions increases in unequal steps; in this respect, the statements relate generally to these measurement geometries. Interference pigments can be measured in a limited way with both devices. The interference of a pigment or a paint is shown by changes in the incidence angle of the light. The BYK-mac device offers just one illumination geometry and the MA98 offers two. The interference can sometimes be shown by a trick; it must be noted, however, that the results depend strongly on the type of application (**Figure 4**).

The trials show the dependence of transparent pigments on the undercoat colour. White and black represent the two extremes. In between are graduations or grey or coloured undercoats. Both possibilities are applied in both automotive

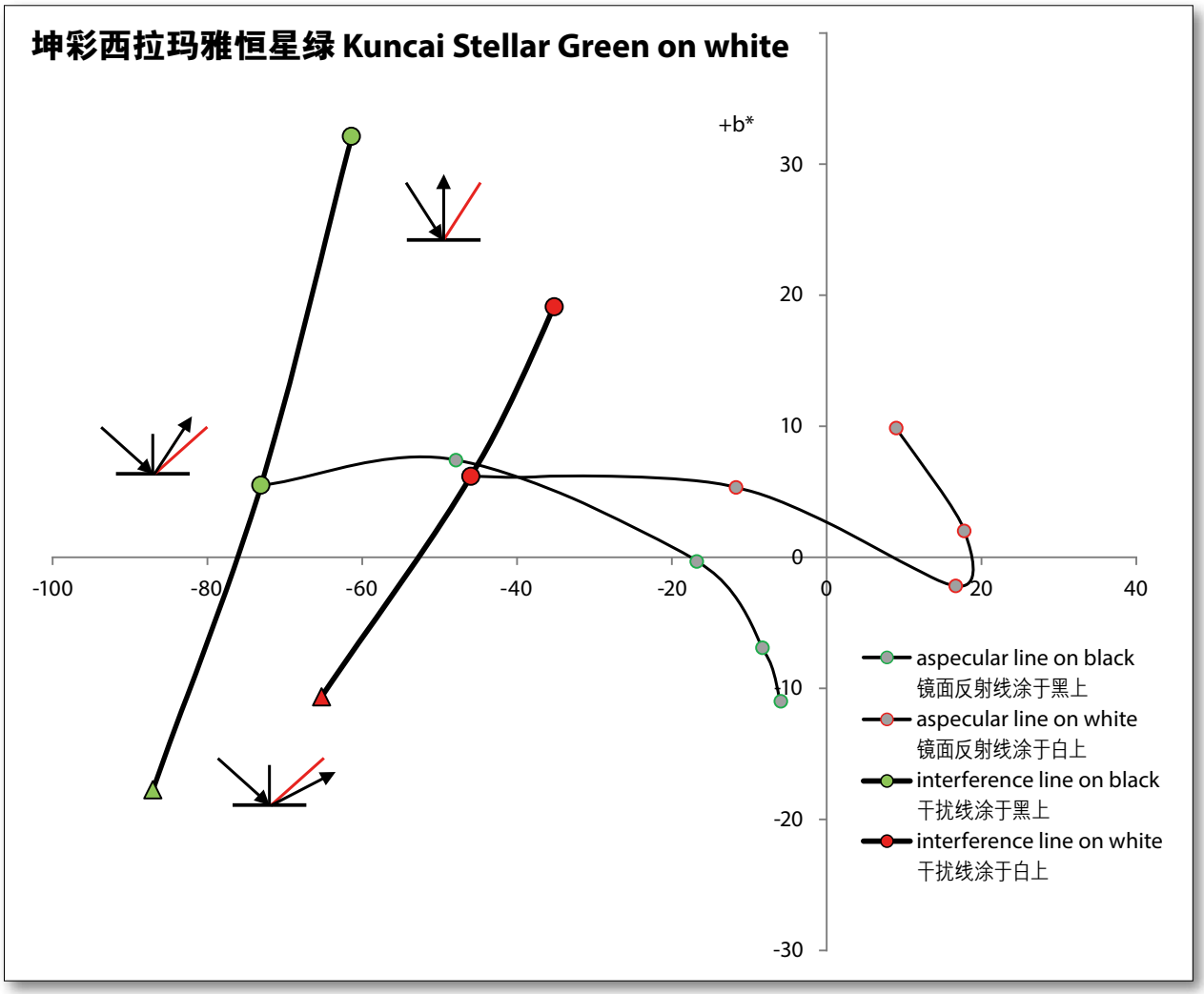

图4：干扰线由几何参数为15°/ as15°，45°，as15°和45 / as-15°组成。在白色底涂上，在光泽度上可以识别出互补的透射颜色。

Figure 4: The interference line consists of the geometrics 15°/as15°, 45°,as15° and 45/as-15°. Over a white undercoat, the complementary transmission colour is identifiable at geometrics from gloss.

图5：样板：使用白光，由白至黑的四个增量的颜色进行颜色区分。如果用红光照射相同的样板，则黄色和红色变为白色和/或浅灰色。绿色和蓝色不反射任何红色光，所以显示为黑色。红色底涂层在彩色底涂层上显示出相似的光学反应。

Figure 5: With white light, the four increments of white to black are identifiable along with the colours. If the same sample panel is irradiated with red light, yellow and red change into white and/or light grey. Green and blue do not reflect any red light, so they appear black. A red base coat shows similar optical reactions over coloured undercoats.

显示为黑色，反之亦然。为了测试出透明底涂层对有色或灰色填料的可能影响，已经使用来自标致的标准颜色路西法红的测试系列。

测试设置

材料从 PPG Refinish 公司获得，并且根据涂料配方混合标准颜色路西法红。填料颜色用混合涂料进行模拟：一种绿色，一种红色和一种红紫色混合涂料。根据制造商的说明书，将所有混合的涂料气动喷涂于样板上。并且所有混合涂料与白色混合涂料分别按比例为 80:20、60:40、40:60 和 20:80 制备，并相应地喷涂制板应用。在第二系列中，产生的灰色调也符合 PPG Refinish 所设定的配方，灰度等级分布为 SG01 到 SG06（光谱灰色）等级。然后在两个喷涂程式中均将路西法红气动喷涂在所有涂装的样板上作为底涂层。作为参考，应用底漆喷涂至另一块板上，直到完全不能表征出透明度 (SW Monitor)。然后用高固体分 (HS) 透明清漆密封所有样板。

使用 X-Rite MA98 和 BYK-mac I 测量样板的颜色。两个装置各自在绝对值为 -60°、-30°、-20°、0°、+30° 和 +65° 下进行测试。这些几何参数在 45° 光泽度照射下分别对应的角度为 -15°、15°、25°、45°、75° 和 110°。每次针对参考样品的值，对反射颜色和 a * b * 颜色值均进行评估。上述几何参数用于表示 a * b * 颜色值。反射值评估的重点是接近辐射光线的 15°——(镜面角度 15°) 和远离辐射光线的 45°（镜面角度 45°）的参数测定。这些几何参数包括在 45° 照明和在 -30° 和 / 或 0° 的观察 / 测量。

OEMs and repairs painting (refinishing). The search for better methods – whether with or without colour – often reaches philosophical dimensions, although the factual situation is clear: the overall colour impression determines the result, both in terms of visual assessment and also in instrumental measurement. And the overall colour impression consists of different components. Firstly, a large part of the light is reflected from the base coat. This reflection can consist of reflections from reflective aluminium pigments and reflections from and within interference pigments. Absorbing colour pigments spread the light – even the reflected light from the aforementioned pigment types – in all directions. The processes in the base coat are very complex, as here different types of pigment and their different optical properties come together. Depending on the transparency of the base coat, the remaining proportion of the light penetrates this base coat and escapes through the underside. This proportion of the light is also subject to complex optical processes in the base coat and this then hits the undercoat.

The transparent base coat acts like a transparent colour film with white light shining on it. Part of the light is reflected, another part is absorbed and a further part leaves the film through the other side. This part then hits the undercoat. And depending on the colour, it receives different treatment here. A red undercoat appears black when it is irradiated with green light, and vice versa. In order to report the possible effects of a transparent base coat on a coloured or grey filler, a test series has been initiated with the standard colour Lucifer Red from Peugeot.

Test set-up

Materials were acquired from PPG Refinish and the standard colour Lucifer Red was mixed according to paint formulation. The filler colours were simulated with mixed paints: one green, one red and one red-violet mixed paint. All mixed paints were applied pneumatically to sample panels according to the manufacturer's instructions. And all mixed paints were prepared with white mixed paint in the ratios 80:20, 60:40, 40:60 and 20:80 and correspondingly applied. In a second series, grey tones were created also in line with recipes stipulated by PPG Refinish as grey graduations from SG01 to SG06 (Spectral Grey). Then Lucifer Red was applied pneumatically as a base coat on all painted sample panels in two spray procedures. As a reference, a further panel was sprayed with the base coat until no transparency could be identified (SW Monitor). All sample panels were then sealed with a HS clear varnish (High Solid).

The sample panels were measured for colour using the X-Rite MA98 and the BYK-mac I. Both devices each measure at -60°, -30°, -20°, 0°, +30° and +65° in absolute values. These geometries correspond to -15°, 15°, 25°, 45°, 75° and 110° from gloss at an illumination under 45°. Both the reflection colour and the a*b* colour value were assessed, each time against the values of the reference sample. The aforementioned geometries were used in the presentation of the a*b* colour values. The focus of the reflection values assessment was the geometries of as15°- (aspecular 15°) close to the radiance and the as 45° (aspecular 45°) away from the radiance. These geometries are comprised of the illumination at 45° and the observation/measurement at -30° and/or 0°.