Optimisation of Undercoat Reflectance for Maximum Hiding

P. L. McGinley
Dulux Australia, P.O. Box 60,
Clayton, Victoria, Australia 3168

ABSTRACT

The use of grey undercoats to reduce the colour non-uniformity of poor-hiding topcoats is well established. Several methods are available for identifying the optimum grey level. The method whereby the colour difference to the full hiding topcoat colour is minimised, links well to the establishment of an opacity acceptance threshold level, related to product quality. A simple set of criteria leads to a paint application specification that produces acceptable performance.

1. INTRODUCTION

Poor opacity in a paint topcoat often leads to a customer complaint of non-uniformity of the applied colour of the painted surface rather than poor opacity of the paint itself. The non-uniformity arises from the difficulty in applying the paint at a uniform thickness. Where adjacent painted regions are overlapped, the thickness of the lapped area may be twice that of the surrounding areas. The substrate colour and the topcoat colour and thickness contribute to the final colour, so the thickness variation will produce a colour variation and customer complaint. If the paint could be applied at a uniform thickness then the colour would be uniform and customer complaint would be less likely.

In some paint systems such as automotive topcoats, there would be some opportunity to improve the opacity by varying the pigment loading or changing pigmentation to higher opacity grades. This is not the case with decorative paints where there is a fixed range of 12 to 16 colorants to choose from and there is very little choice on pigmentation or loading levels with chromatic colours especially. The only options for dealing with low opacity decorative paint colours are to (i) specify extra coats to be applied; (ii) select and specify an undercoat colour; (iii) reformulate the colour on to a higher opacity tint base ; or (iv) remove the colour from the range.

The problem can be alleviated by using an undercoat tinted to a shade as close as possible to the topcoat colour. However the high tint strength of most undercoats will allow the matching of only a small range of pastel shades which generally do not have opacity problems. Also, it is impractical to specify a different undercoat colour for every topcoat shade.

For some time the approach has been to provide a series of grey undercoats produced by tinting a white undercoat with black colorant at various concentrations. The greys so produced can have reflectance values at 540nm ranging from 30 to 90%. Several methods have been proposed for the selection of the optimum grey for a given colour. One technique has been to match the reflectance values of the undercoat to the complete hiding topcoat colour at the long wavelength region (640~700nm)[1] whilst another is to match the reflectances at the wavelength of maximum absorption[2]. The method proposed here is to select the undercoat that minimises the colour difference between the standard two-coat topcoat application over a tinted undercoat and the full hiding colour of the topcoat.

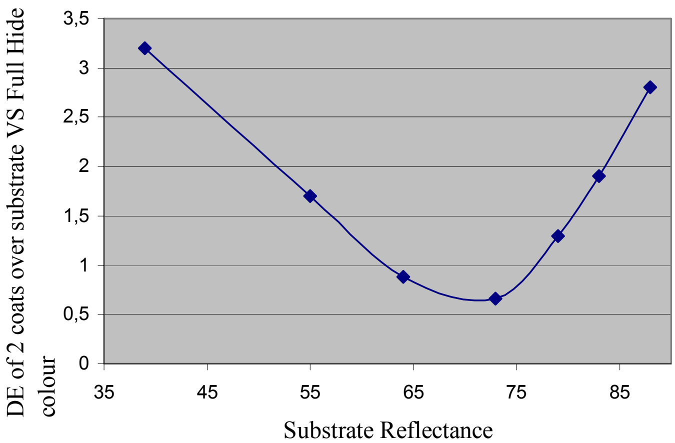


Figure 1. Effect of Substrate Reflectance upon colour difference to full hiding colour for colour "Aztec Glimmer"

Figure 1 shows for the colour "Aztec Glimmer" the colour difference between panels of 2 coats of topcoat applied over a range of grey tinted undercoats and a panel of full hiding topcoat (multiple coats). Clearly the choice of substrate reflectance has a strong influence upon the apparent opacity of the topcoat and hence the number of coats required to achieve opacity. For this example, 5 coats would be required to achieve DE=0.6 (CIE 1976) over the 85% near-white substrate, whereas the same DE can be achieved with just two coats over the 73% reflectance substrate.

2. CHARACTERISATION OF THE TOPCOAT

It is not necessary to make such a series of these panels to characterise the behaviour of each colour of interest. If the Kubelka-Munk[3] scatter S and absorption K coefficients the film thickness T and the reflectance values of the substrate $R_{G=U}$ are known, then equations 1 to 3 will calculate the reflectance R of the combined topcoat/undercoat colour.

$$R = \frac{1 - R_{G=U}\left(a - b.ctgh\left(bST\right)\right)}{a - R_{G=U} + b.cgth\left(bST\right)} \tag{1}$$

$$a = (K/S) + 1 \tag{2}$$

$$b = (a^2 - 1)^{0.5} \tag{3}$$

Repeating the calculation for each grey undercoat and comparing the colour for each against the full hiding topcoat allows the optimum tinted undercoat to be identified as in Figure 1.

The scatter and absorption coefficients of the topcoat can be established in either of two ways well known to users of computer colour match systems. The easier method is to use the topcoat tint formula and a colour matching database. If the components of the topcoat colour (e.g. tint base and tinters for a decorative paint system) have already been characterised in terms of their *Si* and *Ki* values for

$$K = \sum C_i K_i \tag{4}$$

$$S = \sum C_i S_i \tag{5}$$

computer colour matching, then the scatter and absorption coefficients of the topcoat can be calculated from the tint formula and equations 4 and 5.

The second method applies if the database does not exist or if the colour components of the topcoat are unknown. Then the K and S values can be calculated from reflectance (R_B, R_W) and film thickness (T) measurements of a partially hiding topcoat film (e.g. 1 coat) applied over black and white substrates of reflectance $R_{G=B}$ and $R_{G=W}$. The laboratory techniques and the errors involved for this measurement are well described by Patton[4]. Equations 2, 3, 6 and 7 enable calculation of the S and K values for the topcoat.

$$a = \frac{\left(R_B - R_{G=B}\right)\left(1 + R_W R_{G=W}\right) - \left(R_W - R_{G=W}\right)\left(1 + R_B R_{G=B}\right)}{2\left(R_B R_{G=W} - R_W R_{G=B}\right)} \tag{6}$$

$$S = \frac{1}{bT}\left(Arctgh\left(\frac{a - R_B}{b}\right) - Arctgh\left(\frac{a - R_{G=B}}{b}\right)\right) \tag{7}$$

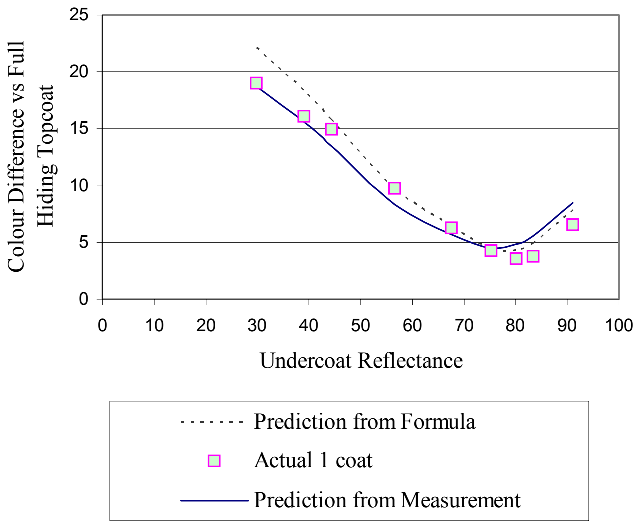
Once the combined topcoat/undercoat reflectance can be calculated for a nominated film build, this can be extended to a range of undercoats and the colour difference of each to the full hiding topcoat colour calculated. Figure 2 shows for the colour "Pink Fire" such a calculation of combined topcoat/undercoat colour using data derived from both methods and experimental data of topcoat applied to every tinted undercoat. As shown by the square dot points in Figure 2, the measured reflectance values indicate a minimum in the colour difference when an undercoat with reflectance in the region of 80% is used. This is in satisfactory agreement with the predicted data (full and dashed lines) which indicate a minimum with an undercoat of 75 to 80%.

3. OPACITY SPECIFICATION

A definition of opacity must include some performance criteria such as a minimum contrast ratio or maximum Delta-E. The process described here uses the Delta-E value between the topcoat/undercoat combination and the full hiding topcoat (DE_U). The allowed tolerance figure is determined by market expectations as to the performance of the topcoat. To meet higher market expectations of topcoat opacity, a lower colour difference value is required. For example, the tolerance value based on 2 coats of topcoat typically falls within a range from 1 to 3 and a value of 2 is used in these examples.

The opacity specification on the need for additional coats and/or a tinted undercoat is determined by the answers to the following questions:

Figure2 "Pink Fire" Optimum Undercoat



Question 1: *"Is the topcoat opacity within acceptable limits when 2 coats are applied over a typical substrate?"*
The typical substrate is a light colour of about 85% reflectance. If the colour difference, calculated for an undercoat of 85% reflectance, DE_W , is less than the tolerance value, then the

Table 1: Colour difference for two colours applied on typical light coloured substrate

Number of Topcoats	DE_W of "Pink Fire"	DE_W of "Scarlet Ribbons"
1	5.58	13.6
2	2.43	8.1
3	1.37	4.7
4	0.84	2.8

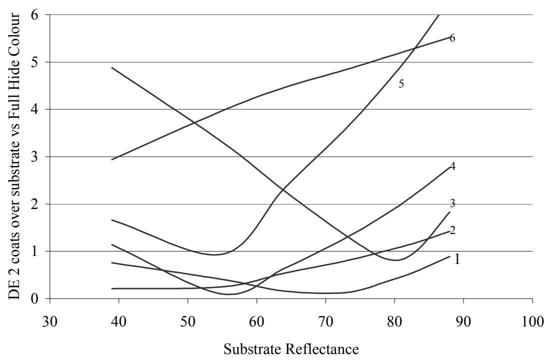
colour has acceptable opacity without any additional specification. Table 1 shows the variation in DE_W for two colours for the standard 2 coats and an extra 1 and 2 coats. Neither of these colours meets the tolerance ($DE_W < 2.0$) with the standard two coats.

Question 2: *"If the tolerance specification is not met for the standard 2 coats, will an additional 1 or 2 coats be sufficient without nomination of a specific undercoat?"*
In Table 1 the colour "Pink Fire" gives acceptable performance (DE_W =1.37) with one extra coat. The colour "Scarlet Ribbons" does not achieve tolerance even with two extra coats

Question 3: *"If a tinted undercoat is required, what is the optimum reflectance of the undercoat?"*
Calculations of the type used for Figure 2 can be employed for any colour. Figure 3 shows the effect of undercoat reflectance for several colours and the optimum undercoat can be read from the minimum for each colour. Colours 1, 2 and 3 all have a DE_W < 2.0 for 2 topcoats over the white substrate (85% reflectance) which means they are within standard tolerance. Colours 4, 5, and 6 have

a DE_W in the range 2.8 to 6.0 and in practical application tests were confirmed to have unacceptable opacity for that substrate. The reduction in the DE to that of the minimum for each colour by use of the optimum undercoat is sufficient for Colours 4 and 5 to achieve specification, but Colour 6 remains at DE_U =3.0 for the optimum (39%) undercoat and was withdrawn from the colour range.

Figure 3 Selection of Optimum Undercoat



Question 4: *"Is the topcoat opacity within acceptable limits when 2 coats are applied over the optimum tinted undercoat or will and extra coat or two be required?"*

Table 2 shows the variation in DE_U for the two colours Pink Fire and Royal Cruise applied over their respective optimum undercoats. Pink Fire achieves the tolerance value (DE_U < 2.0) with the standard two coats over its optimum undercoat whilst Royal Cruise requires three coats for the correct colour.

Table 2: Colour difference to the full hiding colour of two colours applied to their optimum undercoat

Number of Topcoats	***DE_U* of "Pink Fire"**	***DE_U* of "Royal Cruise"**
1	4.50	9.81
2	1.10	2.78
3	0.53	0.76
4	0.38	0.21

4. CONCLUSIONS

If the opacity is below standard, then the process[5] described will provide guidance on which of the following graded responses is required:

1: Recommend the application of one or two additional topcoats.
2: Recommend the preparation of the surface with the application of a high opacity grey undercoat of nominated lightness followed by 2 topcoats.
3: Recommend the preparation of the surface with the application of a high opacity grey undercoat of nominated lightness followed by three or four topcoats.
4: Reformulate the colour onto a higher opacity tint base if possible.
5: No treatment can produce a system of acceptable opacity so the colour should be withdrawn.

References

1. Y. Abe et al "Multi-Layer Coating Method Based on Spectral Reflectance of White or Gray colours", US Patent No: 4,546,007 Oct 8, 1985
2. A.B.J. Rodrigues "Optimising Gray Primer in Multilayer Coatings", US Patent No: 5,700,515 Dec 23, 1997
3. D.B. Judd and G. Wyszecki, "Color in Business, Science and Industry", 3rd ed., Wiley, New York, 1975.
4. P.B. Mitton, "Easy, Quantitative Hiding Power Measurements", J Paint Technology, 42(542), 159-183 (March 1970)
5. Patent applied for.