Assessing colour differences for automobile coatings using CRT colours Part I: Evaluating Colour Difference of Solid Colours

B. Han*, M. R. Luo* and E. J. J. Kirchner**
Department of Colour and Polymer Chemistry, University of Leeds, LS2 9JT, UK
*** Akzo Nobel Coatings, The Netherlands*
Corresponding author: M. Ronnier Luo (m.r.luo@leeds.ac.uk)

ABSTRACT

This paper describes a study to simulate the colour appearance and colour difference of metallic coatings on a CRT display. The performance of the methodology developed was evaluated by assessing colour differences on CRT comparing with those using physical panels. It was found a good agreement between two sets of visual results. This suggests a promising way to conduct quality control by assessing colour differences using the simulated images of metallic samples.

1. INTRODUCTION

Colour difference research has been carried out for over three decades and many colour difference formulae, such as CIELAB, CMC, CIE94, BFD, LCD and CIEDE2000, were developed to fit a given experimental data set accumulated under similar viewing conditions for which samples are illuminated at a high luminance level under a daylight simulator with a mid-grey background using a fixed viewing and illumination geometry say 0/45. In automotive industry, colour difference control is a challenging task due to the change of colour appearance when they are viewed from different aspecular angles. These colours are so called effective colours. By taking into account the specific geometric effects inherited in metallic coatings, a numerical colorimetric control method was developed by Chou *et al*[1] based on the proper weights at different aspecular angles of existing colour difference formulae. Since the preparation for the desired surface colour samples is tedious and costly, the aim of the present study is to investigate the feasibility of using a CRT display to simulate the colour difference and colour appearance of metallic coatings. The study was divided into two parts: colour difference assessment of metallic coatings using solid CRT colours (colours without texture) and textured CRT colours. This paper describes the first part of the study. The metallic data set in Chou *et al*'s study[1] was applied. The colour differences of metallic sample pairs were reproduced on a CRT display according to their measured instrumental data at four aspecular angles. The colour differences based on the CRT solid colours were assessed and the results were compared with those in Chou *et al*'s study using physical samples.

2. GENERATING CRT STIMULI

In order to compare the visual results of metallic pairs based on physical samples with those simulated on a CRT colours, it is essential for CRT colours having very similar colour differences as their corresponding physical pairs. The CRT display used was a Barco Reference Calibrator. Since the gamut of CRT display is somewhat limited, there were colours outside the range of CRT gamut. Thus, for some colours of physical samples beyond gamut of CRT display, their chroma values were reduced while the lightness and hue were kept unchanged. The colour differences of each metallic pair at 20^o, 45^o, 75^o and 110^o aspecular angles were reproduced on CRT. The reproduction accuracy for these colour difference pairs was examined using the following equation:

$$\Delta E = \sqrt{(\Delta L^*_{crt} - \Delta L_{sur}{}^*)^2 + (\Delta a^*_{crt} - \Delta a_{sur}{}^*)^2 + (\Delta b^*_{crt} - \Delta b_{sur}{}^*)^2} \quad (1)$$

where ΔE is represented by colour difference and is calculated between the difference of a pair of CRT colours and that of the corresponding pair of the surface colours; the ΔL^*, Δa^* and Δb^* are the lightness, redness-greenness, yellowness-blueness differences between a pair of colours under a particular aspecular angle. The subscripts, *crt* and *sur*, denote CRT and surface colours, respectively. A ΔE of zero means a perfect colour reproduction of colour differences between the CRT and surface colours. All CRT colours were measured using a Minolta CS1000 tele-spectroradiometer (TSR). The mean and maximum reproduction errors were 0.56 and 1.89 ΔE^*_{ab} units respectively. Finally, there were only 6 out of 50 pairs having their reproduction errors larger than 1 ΔE^*_{ab}. In general, this performance is considered to be sufficiently accurate for the current experiment. Note that the typical repeatability performance of CRT colours is in similar degree, about 0.5 ΔE^*_{ab}.

3. VISUAL ASSESSMENT

The grey scale method[2] was applied in this study for assessing colour differences of metallic coatings on a CRT. The experimental arrangement for grey scale represented on the CRT together with the colour difference pairs of metallic coatings is shown in Figure 1 under a grey background with an L^* value of 50. The grey scale used in this experiment consists of 6 grades marked from 0 to 5 and a 'standard', the same colour as Grade '5' in the grey scale. The relationship between grades (G) and visual difference (ΔV) is given in Eq. (2), which was obtained by fitting the grades and CIELAB ΔE^*_{ab} of the grey scale.

$$\Delta V = 0.0634G^4 - 0.9525G^3 + 5.3382G^2 - 16.041G + 26.178 \qquad (2)$$

where visual difference ΔV is in ΔE^*_{ab} units.

Figure 1 illustrates the experimental situation, where a black separation line with 1-pixel size was used to divide between two samples in each pair. In pair on the right is formed by the 'standard' and one of the grey scale samples chosen by observer. During the experiment, the left or right position of the grey pair and the test pair was interchanged automatically. Meanwhile, the left or right location of two samples in the test pair and grey pair was arranged randomly. The order to present fifty metallic pairs was also randomised in each observing session.

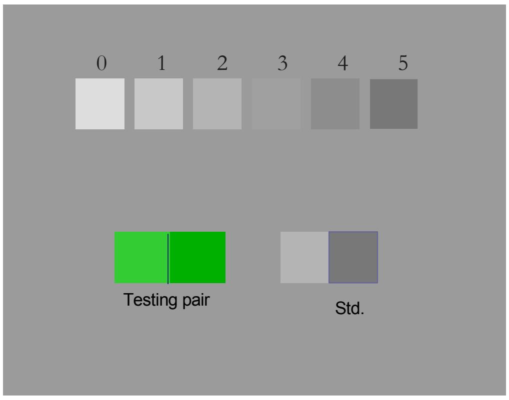

Figure 1: Experiment arrangement for colour difference assessment on a CRT display.

4. RESULTS AND DISCUSSIONS

4.1 OBSERVER ACCURACY AND REPEATABILITY

Nine observers took part in the experiment and six of them did visual assessments twice. Observer repeatability and accuracy were investigated in terms of PF/3, which was derived by Luo and Rigg[3]. For example, a PF/3 of 30 represents a 30% disagreement between the two sets of data investigated. Each observer's raw data in grades were first transformed to ΔV values using Eq. (2). The PF/3 was first calculated between each observer's two repeated sessions. These values for all observers were then averaged to indicate observer repeatability. For observer accuracy, PF/3 measure was calculated between each individual observer's visual results and the mean visual results without any adjustment of their scales. It was found that the mean PF/3 value was 54 units for observer accuracy and 57 for observer repeatability. These variations are larger than those found in the previous studies[4,5] using typical samples such as paint and textile with uniform surfaces but agreed well with those in Chou *et al.*'s study based on physical metallic coatings.

4.2 COMPARING VISUAL RESULTS BETWEEN SURFACE AND CRT SOLID COLOURS

The visual results from colour difference assessments using CRT colours were compared with those using surface colours in Chou *et al*'s study. Note that Chou *et al* data only have one set of visual data corresponding to one aspecular angle. In their experiment, each observer was asked to fist select a particular angle showing the greatest colour difference between a pair. Subsequently, grey scale was used to scale the colour difference at that particular angle. Four methods were used to compare between the CRT and physical visual results as described in Table 1. The comparison results in PF/3 units are also reported in Table 1. Method 1 (M1) shows that the perceived colour differences on CRT metallic pairs at 45^{o} aspecular angle fit best to those on the surface colours. The results indicate that the colour difference under 45^{o} aspecular angle is the most suitable data for representing the colour difference of metallic coatings on the CRT, when data from an individual angle is required. **M2** applies the averaged ΔV from the four aspecular angles assuming that equal weight to the four ΔV values in each metallic pair displayed on CRT. It can be seen that a large improvement was made comparing M2 with **M1**, i.e. the agreement between the visual assessments on both surface and CRT colours improved by over 200% in PF/3 units. **M3** applies the maximum ΔV from the four angles and it is not surprising that further improvement occurred because observers were instructed to scale difference of surface sample pairs at the angle showing the largest colour difference in Chou *et al*'s study. With **M4**, because the weights on the perceived colour differences of metallic pairs under four aspecular angles were optimised, the results clearly gave the best agreement with those of physical samples (having a very low PF/3 value of 20).

The above results are quite promising because the visual results based on CRT (M2, M3 and M4 methods) gave excellent agreement with those from physical samples. The degree of disagreement ranged from 20 to 28 PF/3 units is much smaller than typical observer variation about 55 PF/3 units. This demonstrates that the simulation methodology used here was quite satisfactory.

Table 1 Comparison between visual assessments on surface colours and CRT colours in terms of PF/3

		PF/3
Method 1 (M1): to *compare ΔV data from each of the four aspecular angles in this study with the visual results from Chou et al's study, respectively.*	20^{o}	50
	45^{o}	42
	75^{o}	51
	110^{o}	58
Method 2 (M2): to *compare average ΔV values of four aspecular angles in this study with those from Chou et al's study.*		28
M3 (M3): to *compare the maximum ΔV values from four aspecular angles in this study with those from Chou et al's study.*		25
M4 (M4): to *compare ΔV values obtained from four aspecular angles with those from Chou et al's study by optimising weighting factors assigned to the ΔV values of each aspecular angle. ($W_{20} + W_{45} + W_{75} + W_{110} = 1$, where W_i indicates the optimised coefficient.)*		20

5. CONCLUSIONS

By reproducing the colour differences of metallic coatings on CRT, the feasibility of using CRT for colour difference evaluation for metallic coatings was investigated and approved. A good agreement between the colour difference assessment on CRT solid colours and surface colours can be achieved as accurate as 20 PF/3 units using the method which the colour differences of metallic panels were calculated using the optimum weights for different aspecular angles. Although the similar methods such as M2, M3 performed slightly worse than M4, they can still be used to estimate the simulated colour differences on CRT.

References

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