COLOUR SCALES AND RELATED COLOUR DIFFERENCE SCALES: CIEL*a*b* VERSUS CIEL*C*h° VERSUS CMC

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An industrial reference, A, was used as a standard for the estimate of the colorimetric coordinates, and compared with other references (B, C and D), considered by the company as variations of tonality with relation to the standard. Three samplings of reference A were then made for the verification of tonality differences.

A HunterLab (model ColorQuest 45/0) spectrophotometer was used for the determination of the colorimetric coordinates. The adopted measurement procedure is the constant of ISO Standard (ISO 10545/16 - Small Colour Differences), which uses the L*a*b* rectangular coordinate system defined in 1976 by CIE (Commission Internationale de l'Eclairage - International Commission of Illumination). The CMC coordinate system was subsequently used, developed by the Colour Measurement Committee of the Society of Dyers and Colourists of England.

The measurements of colour differences DL*, Da* and the Db* (CIE 1976) were made according to the CIEL*a*b* colour space, where coordinate L* is an indication of light and dark, the coordinate a* is an identification of tonality in the direction from green to red and coordinate b* is an identification of tonality in the direction from blue to yellow. Each difference (D) corresponds to the reading of the standard minus the reading of the sample being studied, for the three-colour coordinates,

$$DL^* = L^*_{sample} - L^*_{standard}\,;\ Da^* = a^*_{sample} - a^*_{standard}\,;\ Db^* = b^*_{sample} - b^*_{standard}$$

DE gives the value of the absolute difference of the three coordinates,

$$DE^* = \sqrt{DL^{*2} + Da^{*2} + Db^{*2}}$$

The colorimetric coordinates a* and the b* can also be represented according to a system of polar coordinates, defined as the CIEL*C*h° colour space. In this system, DC* is the difference between the saturation of the sample and the standard, and DH* is the difference of tonality angle (h°) between the sample and the standard,

$$DC^* = C^*_{sample} - C^*_{standard} \text{ where } C^* = \sqrt{a^{*2} + b^{*2}} \quad \text{and} \quad DH^* = \sqrt{DE^{*2} - DL^{*2} - DC^{*2}}$$

System CMC, in turn, is a set of equations of colour differences that use the values CIEL*C*h° of a colour standard to determine the sizes of the half-axes of an ellipse containing all the visually acceptable colours when compared with the standard. The acceptability ellipse contains 3 half-axes that are defined in three directions: L*, C* and h°.

When the calculation of colour differences CMC is used, it is necessary to decide if the ratio between luminosity and saturation determined for equations CMC is acceptable for each particular application. This ratio (l:c) can be modified; the ratio 1:1 between luminosity and saturation is recommended for the evaluation of the perception of colour differences; the ratio 2:1 is recommended for the assessment of colour acceptance, since greater differences in luminosity are more tolerable than in saturation and colour.

There is also the commercial factor (cf), which is a tolerance (the values of the D's) defined by the user for the acceptance of the total colour difference, DE_{CMC}, for a particular application. Depending on the type of material being evaluated, its surface texture, brightness and other features, the magnitude of colour differences acceptance will not always be the same. Tested British methods of standardization for some materials determine that for shining ceramic materials one cf of 0.75 is adjusted; for opaque ceramics, one cf equal to 1.0 is acceptable.

The equation for DE_{CMC} describes an ellipsoidal volume with the axes in the direction of luminosity and saturation, where tonality is centred on a standard, as follows:

$$DE_{CMC} = \sqrt{\left(\frac{DL^*}{lSL}\right)^2 + \left(\frac{DC^*}{cSC}\right)^2 + \left(\frac{DH^*}{SH}\right)^2}, \text{ where } DL_{CMC} = \frac{DL^*}{lSL}, DC_{CMC} = \frac{DC^*}{cSC} \text{ and } DH_{CMC} = \frac{DH^*}{SH}$$

and lSL, cSC and SH are functions of coordinates L*, C* and h°.

The limits considered acceptable for coordinates L*, a* and b* had been initially defined as D=0,5 unit for the three coordinates; later this limit was magnified to D=1,0 unit. For the CMC system, the value cf=0,75 and ratio l:c of 2:1 were adopted. After the colour measurements using the spectrophotometer, a visual evaluation was performed using a colour matching booth and PEI procedures.

For each batch of samples, five pieces were randomly selected; each piece was divided into five parts (the four edges and the central part); each part was measured twice, the second measurement being made at 90° in relation to the first one (taking into consideration the metamerism). The light sources used were D65, corresponding to the average natural light (including the ultraviolet region), with a colour temperature of 6504K; the light source A, incandescent light, with colour temperature of 2856K; and the light source F02, cool white fluorescent light, with colour temperature of 4200K.

RESULTS

The results for the D's, the colour differences, are listed below for systems CIEL*a*b*, CIEL*C*h° and CMC, for light sources D65, A and F02.

References[1]	Illuminant D65/10°			Illuminant A/10°			Illuminant F02/10°		
	DE^*_{Lab}	DE^*_{LCh}	DE^*_{CMC}	DE^*_{Lab}	DE^*_{LCh}	DE^*_{CMC}	DE^*_{Lab}	DE^*_{LCh}	DE^*_{CMC}
B	0,76	0,80	1,24	0,91	0,94	1,42	0,88	0,90	1,39
C	0,35	0,35	0,34	0,40	0,39	0,41	0,37	0,36	0,34
D	0,92	0,91	1,00	1,00	0,99	1,16	0,94	0,95	1,10
A[2]	0,31	0,30	0,60	0,32	0,32	0,66	0,28	0,28	0,51
A[3]	0,37	0,37	0,16	0,39	0,39	0,20	0,37	0,37	0,16
A[4]	0,82	0,82	0,50	0,77	0,77	0,40	0,78	0,78	0,44

[1]Refers to standard - the values of standard A are L*=94,09, a*=-0,27 and b*=0,33 for D65.

[2, 3 and 4]Are samplings of the standard A; thus, the results should be under the limits - DE=0,5 for L*a*b*/L*C*h° and DE=0,75 for CMC.

Table 1. *Colour differences for samples A, B, C and D.*

CONCLUSION

The use of CIEL*a*b* and CIEL*C*h° coordinate systems can lead to errors because these systems use tolerances with fixed limits, independent of the colour space region in which the sample is being studied. As visual perception is dependent on the colour being analysed (the colour space region) and is variable, the fixed systems produce errors of evaluation. System CMC, using acceptability ellipses that vary in size and form depending on the region of the colour space where the standard is located, it presents results based on visual perception. It can be observed that for systems CIEL*a*b* and CIEL*C*h° some samples of reference A present tonality variations that would be perceivable to the human eye (DE>0,5), but for system CMC there is no tonality variation bigger than DE_{CMC} 0,75, i.e., the samples are inside the standards. These results match those of the visual analysis performed using the colour-matching booth.

REFERENCES

[1] AMERICAN ASSOCIATION OF TEXTILE CHEMISTS AND COLORISTS. *AATCC Technical Manual.* Research Triangle Park, NC: AATCC, 1997.

[2] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. *Determination of Small Colour Differences.* Genève, Switzerland: ISO 1995.

[3] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard Guide for Selection, Evaluation and Training of Observers.* West Conshohocken, PA: ASTM 1997.

[4] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard Practice for Visual Appraisal of Colours and Colour Differences of Diffusely Illuminated Opaque Materials.* West Conshohocken, PA: ASTM 1996.

[5] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard Terminology of Appearance.* West Conshohocken, PA: ASTM 1999.

[6] HUNTER, R. AND HAROLD, R. *The Measurement of Appearance.* 2nd Ed. New York: John Wiley, 1987.

[7] MCLAREN, K. *The Colour Science of Dyes and Pigments.* Bristol, UK: Adam Hilger Ltd., 1986.