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ISO 105-J03

Second edition
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Textiles — Tests for colour fastness —

Part J03:
Calculation of colour differences

Textiles — Essais de solidité des teintures —

Partie J03: Calcul des écarts de couleur

Reference number
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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 105-J03 was prepared by Technical Committee ISO/TC 38, *Textiles*, Subcommittee SC 1, *Tests for coloured textiles and colorants*.

This second edition cancels and replaces the first edition (ISO 105-J03:1995), of which it constitutes a technical revision and incorporates ISO 105-J03:1995/Cor.1:1996 and ISO 105-J03:1995/Cor.2:2006. Subclause 3.1 has been replaced with the current CIE recommended form. The equations produce identical results, but the decimal numbers are replaced by fractions, so as not to limit precision.

ISO 105 was previously published in thirteen “parts”, each designated by a letter (e.g. “Part A”), with publication dates between 1978 and 1985. Each part contained a series of “sections”, each designated by the respective part letter and by a two-digit serial number (e.g. “Section A01”). These sections are now being republished as separate documents, themselves designated “parts” but retaining their earlier alphanumeric designations. A complete list of these parts is given in ISO 105-A01.

Textiles — Tests for colour fastness —

Part J03: **Calculation of colour differences**

1 Scope

This part of ISO 105 provides a method of calculating the colour difference between two specimens of the same material, measured under the same conditions, such that the numerical value $\Delta E_{\text{cmc}}(l{:}c)$ for the total colour difference quantifies the extent to which the two specimens do not match. It permits the specification of a maximum value (tolerance) which depends only on the closeness of match required for a given end-use and not on the colour involved, nor on the nature of the colour difference. The method also provides a means for establishing the ratio of differences in lightness to chroma and to hue.

NOTE Annex A gives guidance on the interpretation of results. Annex B provides sample test data for use in checking computer programs. Annex C contains a sample computer program for calculating colour difference.

2 Principle

The CIE[1] 1976 $L^*a^*b^*$ (CIELAB) colour space has been modified to enhance its visual uniformity when calculating the colour difference between two specimens. The modifications to CIELAB by the CMC equation provide a numerical value, ΔE_{cmc}, which describes the colour difference between a sample and a reference in a more nearly uniform colour space. This permits the use of a single-number tolerance ("acceptability tolerance" or "pass/fail tolerance") for judging the acceptability of a colour match in which the tolerance is independent of the colour of the reference. The ellipsoid semi-axes (lS_{L}, cS_{c} and S_{H}) used to derive ΔE_{cmc} provide a means to interpret the three separate components of colour difference (lightness, chroma and hue) in manners suitable for a wide range of uses.

The equation for ΔE_{cmc} describes an ellipsoidal boundary (with axes in the directions of lightness, chroma and hue) centred about a reference. The agreed-upon ΔE_{cmc} acceptability tolerance describes a volume within which all specimens are acceptable matches to the reference.

The colour difference is composed of three components that comprise the differences between the reference and the specimen. These are as follows.

a) A **lightness** component that is weighted by a lightness tolerance ($\Delta L^*/lS_{\text{L}}$). This is represented as ΔL_{cmc}.

If the ΔL_{cmc} is positive, the specimen is lighter than the reference. If the ΔL_{cmc} is negative, the specimen is darker than the reference;

b) A **chroma** component that is weighted by the chroma tolerance ($\Delta C^*_{\text{ab}}/cS_{\text{c}}$). This is represented as ΔC_{cmc}.

If the ΔC_{cmc} is positive, the specimen is more chromatic than the reference. If the ΔC_{cmc} is negative, the specimen is less chromatic than the reference;

1) Commission Internationale de l'Éclairage, Central Bureau, Kegelgasse 27, A-1030 Vienna, Austria.

c) A **hue** component that is weighted by the hue tolerance ($\Delta H^*_{ab}/S_H$). This is represented as ΔH_{cmc}.

If the ΔH_{cmc} is positive, the hue difference of the specimen is anti-clockwise from the reference in the CIELAB a^*, b^* diagram. If the ΔH_{cmc} is negative, the hue difference of the specimen is clockwise from the reference in the CIELAB a^*, b^* diagram.

3 Procedure

3.1 Calculation of CIELAB values

Calculate the CIELAB L^*, a^*, b^*, C^*_{ab}, h_{ab} values from the X, Y, Z tristimulus values for both the reference and specimen as follows:

$$L^* = 116\left[f\left(Q_y\right)\right] - 16$$

$$a^* = 500\left[f\left(Q_x\right) - f\left(Q_y\right)\right]$$

$$b^* = 200\left[f\left(Q_y\right) - f\left(Q_z\right)\right]$$

where

$$Q_x = \left(X/X_n\right);\ Q_y = \left(Y/Y_n\right);\ Q_z = \left(Z/Z_n\right)$$

and

$$f\left(Q_i\right) = (Q_i)^{1/3} \text{ if } Q_i > (6/29)^3$$

else

$$f\left(Q_i\right) = (841/108)\,Q_i + 4/29 \text{ if } Q_i \leqslant (6/29)^3$$

where

i varies as X, Y, and Z

$$C^*_{ab} = \left(a^{*2} + b^{*2}\right)^{1/2}$$

$h_{ab} = \arctan\left(b^*/a^*\right)$ expressed on a 0° to 360° scale with the a^* positive axis being 0° and the b^* positive axis at 90°.

For these equations, X_n, Y_n and Z_n are the tristimulus values of the illuminant/observer combination in which it is desired to calculate CMC(l:c) colour differences. The preferred illuminant/observer combination is D65/10°. Table 1 gives the values for this and five other combinations.

Table 1 — Tristimulus values for six illuminant/observer combinations

Illuminant/observer combinations	Tristimulus values		
	X_n	Y_n	Z_n
D65/10°	94,811	100,00	107,304
D65/2°	95,047	100,00	108,883
C/10°	97,285	100,00	116,145
C/2°	98,074	100,00	118,232
A/10°	111,144	100,00	35,200
A/2°	109,850	100,00	35,585

3.2 Calculation of CIELAB colour differences values

Calculate the CIELAB colour differences ΔL^*, Δa^*, Δb^*, ΔC^*_{ab}, ΔE^*_{ab}, ΔH^*_{ab}, using the following equations, in which the subscripts R and S refer respectively to the reference and specimen CIELAB values:

$$\Delta L^* = L^*_{\text{S}} - L^*_{\text{R}};$$

$$\Delta a^* = a^*_{\text{S}} - a^*_{\text{R}};$$

$$\Delta b^* = b^*_{\text{S}} - b^*_{\text{R}};$$

$$\Delta C^*_{\text{ab}} = C^*_{\text{ab,S}} - C^*_{\text{ab,R}};$$

$$\Delta E^*_{\text{ab}} = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{1/2};$$

$$\Delta H^*_{\text{ab}} = pq\left[(\Delta E^*_{\text{ab}})^2 - (\Delta L^*)^2 - (\Delta C^*_{\text{ab}})^2 \right]^{1/2}$$

where

$p = 1$ if $m \geqslant 0$

or

$p = -1$ if $m < 0$

and $q = 1$ if $|m| \leqslant 180$

or

$q = -1$ if $|m| > 180$

where $m = h_{\text{ab,S}} - h_{\text{ab,R}}$

in which $|...|$ indicates that the *positive* value is to be used regardless of the sign of the expression between the two lines.

or the equivalent

$$\Delta H^*_{\text{ab}} = t\left[2\left(C^*_{\text{ab,S}}\,C^*_{\text{ab,R}} - a^*_{\text{S}}\ a^*_{\text{R}} - b^*_{\text{S}}\ b^*_{\text{R}}\right)\right]^{1/2}$$

where

$t = 1$ if $a^*_{\text{S}}\,b^*_{\text{R}} \leqslant a^*_{\text{R}}\,b^*_{\text{S}}$

or

$t = -1$ if $a^*_{\text{S}}\,b^*_{\text{R}} > a^*_{\text{R}}\,b^*_{\text{S}}$

3.3 Calculation of the CMC colour difference, $\Delta E_{\text{cmc}}(l{:}c)$

3.3.1 The CMC colour difference is obtained from the following equation:

$$\Delta E_{\text{cmc}}(l:c) = \left[\left(\Delta L^*/lS_{\text{L}}\right)^2 + \left(\Delta C^*_{\text{ab}}/cS_{\text{c}}\right)^2 + \left(\Delta H^*_{\text{ab}}/S_{\text{H}}\right)^2\right]^{1/2}$$

Calculate the ellipsoid semi-axes from the L^*_{R}, $C^*_{\text{ab,R}}$ and the $h_{\text{ab,R}}$ of the reference as follows:

$S_{\text{L}} = 0{,}040\,975 L^*_{\text{R}} / \left(1 + 0{,}017\,65\, L^*_{\text{R}}\right)$ if $L^*_{\text{R}} \geqslant 16$

or

$S_{\text{L}} = 0{,}511$ if $L^*_{\text{R}} < 16$;

$S_{\text{c}} = \left[0{,}063\,8\, C^*_{\text{ab,R}} / \left(1 + 0{,}013\,1\, C^*_{\text{ab,R}}\right)\right] + 0{,}638$;

$S_{\text{H}} = \left(FT + 1 - F\right) S_{\text{c}}$

where

$F = \left\{\left(C^*_{\text{ab,R}}\right)^4 / \left[\left(C^*_{\text{ab,R}}\right)^4 + 1\,900\right]\right\}^{1/2}$;

$T = 0{,}36 + \left|0{,}4\cos\left(35 + h_{\text{ab,R}}\right)\right|$ if $h_{\text{ab,R}} \geqslant 345^\circ$ or $h_{\text{ab,R}} \leqslant 164^\circ$

or

$T = 0{,}56 + \left|0{,}2\cos\left(168 + h_{\text{ab,R}}\right)\right|$ if $164^\circ < h_{\text{ab,R}} < 345^\circ$.

3.3.2 The value of l is usually set to 2,0. The value of c shall always remain at 1,0. This fixes the ratio of the three semi-axes to best correlate with visual assessment of typical textile samples. Other values of l may be required in cases where the surface characteristics significantly differ from those of flat textiles.

4 Test report

The test report shall include the following information:

a) the number and year of publication of this part of ISO 105, i.e. ISO 105-J03:2009;

b) all details necessary for complete identification of the sample and reference specimen(s) tested;

c) identification of the spectrophotometer or colorimeter, including the CIE geometry type, with which the input data was obtained;

d) the $\Delta E_{\mathrm{cmc}}(l:c)$ value(s) of the test specimen(s);

e) the values of l and c [e.g. CMC(2:1)];

f) the illuminant and observer conditions used in the calculations (e.g. D65/10°);

g) if applicable, the acceptability tolerance used in making pass/fail judgements (see Annex A);

h) if required, the CMC component colour differences, ΔL_{cmc}, ΔC_{cmc} and ΔH_{cmc};

i) if required, the CIELAB L^*, a^*, b^*, C^*_{ab}, and h_{ab} values for references and test specimen(s) and the associated ΔL^*, Δa^*, Δb^*, ΔC^*_{ab} and ΔH^*_{ab} values;

j) the date of the test report.

Annex A
(informative)

Interpretation of results

For purposes of determining acceptability of colour match for some specific purpose, the user should determine a “tolerance” which is agreeable to all parties involved. The ΔE_{cmc} value calculated between a specimen and a reference, when compared to this agreed-upon tolerance, provides a means of determining if a specimen is an acceptable match to the reference. Specimens which are compared to a reference will fall into two categories: those for which the ΔE_{cmc} values are less than or equal to the agreed-upon tolerance are acceptable (pass), while those for which the ΔE_{cmc} values are greater than the agreed-upon tolerance are unacceptable (fail).

The equation for $\Delta E_{\mathrm{cmc}} = 1,0$ describes an ellipsoidal boundary (with axes in the directions of lightness, chroma and hue) centred around a reference. The ellipsoid semi-axes lengths are defined by lS_{L}, cS_{c} and S_{H}, and when multiplied by the agreed-upon tolerance describe a volume within which all specimens are acceptable matches to the reference.

In some applications, the acceptable specimens need to be sorted into groups such that the specimens within any one group are very close colour matches to each other and could be used, for example, to manufacture a single garment. In such applications (e.g. rectangular “555” sorting), it becomes necessary to define subvolumes of acceptability. The dimensions of each subvolume may be developed by using the ratio of the three semi-axes of the CMC volume and dividing the total acceptance volume by the number of such subvolumes. For “555” sorting, this is illustrated in Figure A.1.

Although the total colour difference ΔE_{cmc} is valid for achromatic specimens, the method of partitioning this difference is not valid when $C^*_{\mathrm{ab,R}} \leqslant 4,0$ except for lightness differences. When $C^*_{\mathrm{ab,R}} \leqslant 4,0$, the chroma and hue difference components often do not correspond with visual assessments. The use of the individual components for determining the size of the individual sort boxes for sorting purposes is still valid.

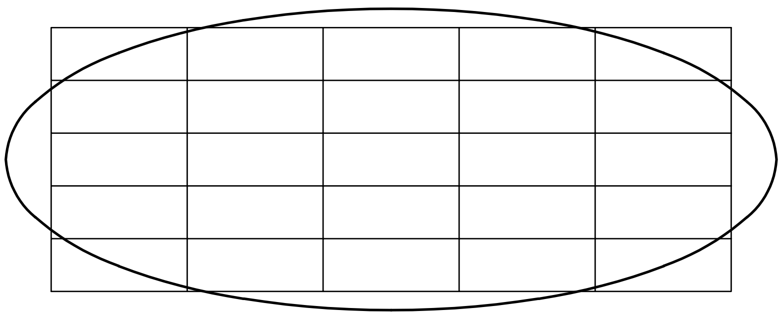

Figure A.1 — “555” sort blocks within acceptance volume (2-dimensional view)

Annex B
(informative)

Representative test data

To help check computer programs giving ΔE_{cmc} values from the CMC equation, some representative test data are given in Table B.1. The data are for illuminant D65 and the 10º observer using X_n = 94,811, Y_n = 100,00, and Z_n = 107,304 (from Table 1). The six reference pair colours shown are red, blue, yellow, green, grey and another red. The l:c ratio used is 2:1.

Table B.1 — Test data for the CMC(2:1) formula (D65/10)

Pair	Tristimulus values			CIELAB values			ΔE_{cmc}
	X	Y	Z	L^*	a^*	b^*	
1	69,556	70,797	67,146	87,39	5,32	7,19	
	68,614	69,698	65,942	86,85	5,59	7,29	0,42
2	53,180	57,467	66,036	80,44	–3,35	–3,84	
	54,385	58,760	67,111	81,16	–3,35	–3,52	0,45
3	63,089	67,667	23,126	85,84	–2,45	55,67	
	61,950	66,366	22,565	85,18	–2,26	55,52	0,27
4	23,178	28,245	21,074	60,11	–15,42	14,97	
	21,896	27,060	20,137	59,03	–16,64	14,86	0,97
5	12,938	13,590	16,071	43,64	0,35	–3,39	
	12,168	12,737	15,221	42,36	0,64	–3,68	0,81
6	14,640	11,100	11,060	39,75	27,95	2,35	
	14,520	11,190	12,220	39,90	26,57	–0,57	2,33

Annex C
(informative)

Computer program for calculating colour difference

This is a simple test program written in BASIC for calculating ΔE_{cmc}. Specific forms of the program may require modification for use on some computer systems.

```
10 'CMC (L:C) COLOUR DIFFERENCE FORMULA

20 '##############################################

30 'Input data and print results

40 '##############################################

50 INPUT "Input CMC (l:c) weighting factors 'l', 'c' ";L,C

60 INPUT "Input X,Y,Z of reference";X(1),X(2),X(3)

65    LPRINT "X,Y,Z of reference";X(1),X(2),X(3) :GOSUB 160 :L1=CL :A1=CA :B1=CB

70 INPUT "Input X,Y,Z of specimen";X(1),X(2),X(3)

75    LPRINT "X,Y,Z OF specimen ";X(1),X(2),X(3) :GOSUB 160 :L2=CL :A2=CA :B2=CB

80 GOSUB 230

90 LPRINT "L*,a*,b*, Hue angle of reference ";L1,A1,B1,H1

100 LPRINT "L*,a*,b*, Hue angle of specimen ";L2,A2,B2,H2

110 LPRINT "DL/ISI  DC/cSc  DH/Sh  DEcmc(";L;":"C")"

120 LPRINT DL;DC;DH;DE : LPRINT : GOTO 60

130 '##############################################

140 'Calculate L*, a*, b* values (D65/10)

150 '##############################################

160 X(1)=X(1)/94.811:X(2)=X(2)/100:X(3)=X(3)/107.304

170 FOR I=1 TO 3:IF X(I)<(6/29)^3 THEN FX(I)=841/108*X(I)+4/29 ELSE FX(I)=X(I)^(1/3)

 180 NEXT

190 CL=116*FX(2)-16:CA=500*(FX(1)-FX(2)):CB=200*(FX(2)-FX(3)):RETURN

200 '##############################################

210 'Calculate CMC colour difference

220 '##############################################
```

```
230 DL=L2-L1:C1=SQR(B1*B1+A1*A1):C2=SQR(B2*B2+A2*A2):DC=C2-C1

240 S1=DL*DL+(A2-A1)*(A2-A1)+(B2-B1)*(B2-B1)

250 DH=0:AA=S1-DL*DL-DC*DC:IF AA<=0 THEN 260 ELSE DH=SQR(AA)

260 IF (A2*B2)=0 THEN 280 ELSE H2=180-SGN(B2)*90-ATN(A2/B2)*57.3

270 GOTO 300

280 BB2=SGN(ABS(B2)):AA2=SGN(A2+B2)

290 H2=90*(BB2-AA2+1)

300 IF (A1*B1)=0 THEN 320 ELSE H1=180-SGN(B1)*90-ATN(A1/B1)*57.3

310 GOTO 340

320 BB1=SGN(ABS(B1)):AA1=SGN(A1+B1)

330 H1=90*(BB1-AA1+1)

340 IF H1<=164 OR H1>=345 THEN 350 ELSE GOTO 360

350 T=.36+ABS(.4*COS((H1+35)/57.3)):GOTO 370

360 T=.56+ABS(.2*COS((H1+168)/57.3))

370 SL=.040975*L1/(1+.01765*L1):IF L1<=16 THEN LET SL=.511

380 SC=.0638*C1/(1+0.0131*C1)+.638:F=SQR(C1^4/(C1^4+1900)):SH=SC*
  (T*F+1-F):DL=DL/(L*SL):DC=DC/(C*SC):DH=DH/SH

385  DA=H2-H1:IF ABS(DA)>180 THEN Y1=-1 ELSE Y1=1

386  Y2=Y1*DA:IF Y2<=0 THEN DH=-DH

390 DE=SQR(DL*DL+DC*DC+DH*DH)

400 RETURN
```

Bibliography

[1] CIE Publication 15:2004, *Colorimetry*, 3rd Edition

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