Method of grading carpet stains

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Abstract

The visual judgement on stains of fibrous products may considerably differ among inspectors because of subjective evaluations. Accordingly, the development of their evaluation methods based on physical measurement is strongly demanded by users. This paper deals with a carpet staining grader designed to enable the determination of absorption factors of stains in the near-infrared range to meet the stain gray scale. The method is based on the fact that the stains of almost all fibrous products absorb the near-infrared radiation, irrespective of their high reflection factor of the products in this range.

1. Introduction

The visual judgements on stains of fibrous products being generally employed at present may considerably differ among inspectors because of subjective evaluations. Under these circumstances, the development of their evaluation methods based on physical measurement has been strongly demanded by users.

Two methods were recently proposed in ISO/TC38/SC1. One is a proposition by Stoodley¹⁾, ²⁾ in 1981, while the other is a proposition by Emmenegger^{3), 4)} in 1984. Also, as Ns method was proposed by Teraji in 1980. However, these propositions do not always satisfy the adaptability with the visual sense. Since stains are visually judged not only by colors but also by the appearances including gloss, it is a matter of course that the judgement from the concentration and color difference do not match the visual sense.

It is found in this paper that stains absorb the near-infrared radiation, so that stains are emphasized and their degrees can be evaluated very easily. Thus, this paper deals with the relation between the reflection factor of stains in the near-infrared range and the visual judgement of stain.

2. Current methods of stain evaluation

Stoodley proposed a method of evaluating stains by statistically analyzing the CIELAB color difference values on more than 12000 samples whose stains had been visually judged.^{1), 2)}

In the Emmenegger's method,^{3), 4)} the CIELAB color difference values were converted into achromatic color difference values for the purpose of comparing them with the gray scale.

In the Teraji's method,^{5), 6)} the stain grade values can be obtained by using C* (color concentration values) in the HC*B* color system developed by Teraji.

The gray scale method by the visual judgement which has been standardized by JIS L0805⁷⁾ is available as one of the stain evaluation methods. Since this method has been originally intended to compare the stains of white cloth, it is not applicable to colored substances. However, the judgement using a color difference meter is variously attempted to enable a color difference scale which agrees with the gray scale. Stains of a dyed carpet are judged by using the gray scale, for example. The stain degrees can be represented by the color chip numbers (grade values) in any way. Table 1 and Fig. 1 show the relation between the color differences of this gray scale and grade values. The curve which fits with these value series cannot be represented by one equation easily. Such a curve is expressed by jointing two equations at grade value 3, as is shown in Fig. 1. Accordingly, the color difference value series are represented by equations (1) and (2) which are divided by using grade value 3, or, color difference 8 as the base point.

$$\Delta E \leq 8 \quad N = (20 - \Delta E)/4, \dots\dots\dots (1)$$

$$\Delta E > 8 \quad N = [2(\log(\Delta E/2)/\log 2) - 10]/2, \dots\dots\dots (2)$$

where ΔE is Color difference, N is Grade value.

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Table 1 Prescribe for staining scale by color difference values

Order of staining	Color difference	Values of increase
5	0 + 0.2	
4 - 5	2.0 ± 0.3	+ 2.0
4	4.0 ± 0.3	+ 2.0
3 - 4	6.0 ± 0.4	+ 2.0
3	8.0 ± 0.5	+ 2.0
2 - 3	11.3 ± 0.7	× 1.4125
2	16.0 ± 1.0	× 1.4129
1 - 2	22.6 ± 1.5	× 1.4125
1	32.0 ± 2.0	× 1.4159

Fig. 1 Relation of color difference and order of staining scale

The color difference ΔE in equations (1) and (2) is given by the Adams Nickerson's color difference formula generally called AN40 as

$$\Delta E = 40[(0.23 V_y)^2 + (\Delta(V_x - V_y))^2 + (0.4\Delta(V_z - V_y))^2]^{1/2} \dots (3)$$

where V_x , V_y and V_z are Values obtained by converting CIE tri-stimulus values into the Munsell value function.

These values are represented by

$$Y = 1.2219V_y - 0.23111V_y^2 + 0.23951V_y^3 - 0.0021009V_y^4$$

$$+ 0.0008404V_y^5, \\ 1.01998X = 1.2219V_x - 0.23111V_x^2 + 0.23951V_x^3 - 0.0021009V_x^4 + 0.0008404V_x^5, \dots (4)$$

$$0.84672Z = 1.2219V_z - 0.23111V_z^2 + 0.23951V_z^3 - 0.0021009V_z^4 + 0.0008404V_z^5$$

It is inconvenient to obtain value V from equation (4). Accordingly, the author employed AN 40's modified color difference formulas (5) and (6)⁸⁾ which can yield a value closely approximated to AN40.

$$\left. \begin{aligned} (L \uparrow / 10 \text{ is suited to } V) \\ L \uparrow = L \uparrow_y = 25Y^{1/3} - 16.53 \quad Y \geq 1\% \\ L \uparrow = L \uparrow_y = 8.470Y \quad Y \leq 1\% \\ L \uparrow_x = 25X_c^{1/3} - 16.53 \quad X_c \geq 1\% \\ L \uparrow_x = 8.470X_c \quad X_c \leq 1\% \\ \dots \dots \dots (5) \\ L \uparrow_z = 25Z_c^{1/3} - 16.53 \quad Z_c \geq 1\% \\ L \uparrow_z = 8.470Z_c \quad Z_c < 1\% \\ s = 4.0 (L \uparrow_x - L \uparrow_y) \\ t = 1.6 (L \uparrow_y - L \uparrow_z) \\ \Delta E = [(\Delta L \uparrow_y)^2 + (\Delta_s)^2 + (\Delta_t)^2]^{1/2}, \\ \dots \dots \dots (6) \end{aligned} \right\}$$

(for CIE standard source C, $X_c=Y_c=Z_c=100.00$)

where $\Delta L \uparrow_y$ is Metric lightness difference, Δ_s is Redness-greenness chroma difference, Δ_t is Yellowness-blueness chroma difference, ΔE is Color difference.

This standard using the gray scale is employed as a criterion to judge the stain degrees on white cloth by means of the visual evaluation. It is also employed for dyed cloth materials in general. The author also employed this gray scale for visual judgement of stains on various dyed carpets in this experiment. However, this gray scale method requires skill more or less. The author employed 216 samples including stainless samples as the reference samples in the experiment. Hue value and chroma values of stain itself were obtained to be about 7.5Y 2.5/2.0 by plotting the lightness difference and color difference from those of stainless reference samples on the chromaticity diagram. The carpets employed for the experiment were graded with stain values by a stepping test according to the petitioned date and time.

Stains are presumable to have been caused by the loamy soil attached to shoes. Fig. 2 and 3 show the chromaticity diagram and lightness diagram by AN40.

As is understood from Fig. 2 "Chromaticity diagram of stain", the stain itself not gray, but colored with low saturation. This stain is sometimes bright unexpectedly. It means that the stain is brighter than a carpet according to carpet colors. As the stain becomes more noticeable, the lightness becomes higher in certain samples as shown in Fig. 3. This fact means that the judgement is difficult if it is based on lightness of stain it self as a boundary.

Fig. 2 Chromaticity behavior of carpet staining

Since the color difference is represented by an absolute value, this problem may be settled. Due to these causes, the stain grade values obtained by a color difference meter and the visual evaluation are often reversed.

3. stain evaluation based on near-infrared absorption measurement

Fig. 4 shows a spectral reflectance curves for a carpet of darker colors than stain colors. The curve of stainless carpets (0) is plotted at the bottom level in the wavelength range from 400nm to 500nm or so. From this fact, the visual judgement requires a technique to check stains only, and the measurement using a color difference meter is presumably difficult.

The stain measuring method proposed in this paper utilizes that the stained portions absorb more near-infrared radiation than stainless

Fig. 3 Lightness behavior of carpet staining

Fig. 4 Spectral reflectance curve of carpets

portions do. It is true for carpets, fibrous products, paper, or the like. Fig. 5, 6, 7 and 8 show changes of spectral reflectance due to stains for several carpets with different colors. Number 0 corresponds to a new carpet and numbers 1 and 2 corresponds to that after conducting stepping test for 12 days and 24 days, respectively. As shown in these figures, the carpets have high reflection factors in the near-infrared range, independently of colors of

Fig. 5 Spectral reflectance curve of carpets

Fig. 8 Spectral reflectance curve of carpets

Fig. 6 Spectral reflectance curve of carpets

Fig. 7 Spectral reflectance curve of carpets

materials. The absorption in the near-infrared region always increases with the stain degrees. As a result, the stain is graded using near-infrared absorption factor, irrespective of colors and brightness in the visible range, although the judgement of stain depends upon the colors and brightness in the visible zone. It is not sure whether grade is proportional to the stain degrees or not, because it is not experimented yet. However, it is sure that the stain is graded according to its order. In order to obtain the grade values of stain by substituting the reflection factors in the near-infrared range into Eqs. (1) and (2), the reflection factors are converted into Munsell values, assuming that the value of stainless carpets is 10. A N value close to the visual judgement value was obtained by multiplying the value difference by coefficient, and then, by substituting the multiplied value into ΔE in Eqs. (1) and (2).

We obtained the color difference and metric lightness by using the Adams Nickerson's color difference formula, or AN40 from the spectral reflectance of carpets obtained by Hitachi Model 307 spectrophotometer and specified the color difference and value difference from those of the stainless reference samples as ΔE and ΔV , respectively. Assuming that the Munsell value of the stainless reference samples is 10 from the reference factor at 780nm, Eq. (5) for obtaining the metric lightness was modified as shown in Eqs. (7) and (8) for the purpose of obtaining the difference of the Munsell value V_i as compared with the reference value.

$$V = (25R^{1/3} - 16.53) / 10 \dots\dots\dots (7)$$

$$\Delta V_i = 10 - [25((RS/RB) \times 100)^{1/3} - 16.53] / 10 \dots\dots\dots (8)$$

where RB is Reflection factor of stainless sample, RS is Reflection factor of stained sample.

Value difference is obtainable to be $9.2\Delta V$ after obtaining ΔE from the AN40 color difference equation according to JIS. Since the magnification, which is regarded to be the closet to the visual judgement, was about 6.0 as a result of experiments about ΔV_i , the value corresponding to ΔE in Eqs. (1) and (2) is $6.0 \Delta V_i$. Table 2 shows the comparison of grade values with the visual judgement after obtaining the grade values by substituting ΔE , ΔV and ΔV_i into Eqs. (1) and (2). The correlation coefficients of ΔE , ΔV and ΔV_i with the visual judgement are as shown below.

$$\Delta E : r = 0.8555$$

$$\Delta V : r = 0.7409$$

$$\Delta V_i : r = 0.9369$$

Thus, ΔV_i shows excellent correlation.

4. Instrumentation and results

Next, the author measured samples after tentatively manufacturing a reflectance meter as shown in Fig. 9 This optical system is designed to irradiate the sample at 60° and to receive reflected light at 0° . The filters are sharp cut-off filter R-68 and heat ray absorbing filter HA-50 made by Hoya Glass Co. The photo detector is a silicon photodiode (S-1226-5BQ manufactured by Hamamatsu Photonix Co.), the output from which is amplified, and then, converted to a Munsell value by a transducer. After setting the value to 10 using the reference sample carpet, a test carpet is measured, and a difference from the reference value is multiplied by 6.0. Its grade value is indicated by applying the multi-

Table 2 Comparison of visual judgement and each measurement data

Sample No.	Delta E	Gray scale	Delta V	Gray scale (9.2 ΔV)	Visual judgement	Delta Vi	Gray scale (6.0 ΔV_i)
2 - 0	1.19	4.7	0.1	4.7	4.6	0.56	4.16
2 - 1							
2 - 0	3.43	4.1	0.05	4.9	3.3	1.46	2.81
2 - 2							
3 - 0	4.51	3.9	0.10	4.8	3.9	0.48	4.28
3 - 1							
3 - 0	12.55	2.4	0.44	4.0	2.8	1.48	2.78
3 - 2							
7 - 0	3.51	4.1	0.14	4.7	4.2	0.57	4.15
7 - 1							
7 - 0	4.92	3.77	0.26	4.4	3.3	1.07	3.40
7 - 2							
26 - 0	1.94	4.5	0.15	4.7	4.3	0.52	4.22
26 - 1							
26 - 0	7.65	3.1	0.39	4.1	2.4	2.11	1.84
26 - 2							

Gray scale: Eqs. (1) and (2)

ΔE : Value of color difference meter

ΔV : Value difference in Eq. (7)

ΔV_i : Value difference in Eq. (8)

plied value into the grade value is indicated by applying the multiplied value into the grade value computing circuit. Table 3 and 4 show measured results of 216 samples including reference samples. In Table 3, two commercial color difference meters were compared with this system meter. The visually judged results and measured results were reversed from each other in 4 samples in cases of two color difference meters, respectively, but no reverse judgement was occurred in this system. (All the other method utilizing the visible range show similar reversed results.)

Table 3 *Number of contrary judgement with visual judgement*

Color difference meter		New model of judgement device
A	B	
4	4	0

Table 4 shows the distribution of difference from the visual judgement for all samples. Measured results by this system show a small dispersion as compared with those by the two commercial color difference meter.

Table 4 *Distribution of measurement difference with visual judgement*

	Color difference meter		New model of judgement device
	A	B	
+2.0	2	2	
+1.5	18	9	1
+1.0	45	34	9
+0.5	45	47	35
0	38	53	61
-0.5	18	15	54
-1.0	7	8	12
-1.5	1	6	2
-2.0			

We also measured by the gray scale by the experimental device for the purpose of verifying this system. The spectral reflectance of the gray scale was almost flat up to about 800nm. White cloth was spread below the gray scale for this measurement. Table 5 shows measured results. From these results, it can not be determined yet whether coefficient 6.0 is acceptable or not. However, we will be able to find an optimum point between 5.0 and 6.0 at least.

5. Considerations

The author employed the spectrophotometer and prototype experimental instrument for verifying this measuring method. The optical condition of the experimental instrument is as specified below.

Irradiation : 60° Light receiving : 0°

This experiment was also made to check the directivity. In order to prevent a practical instrument from being affected by the directivity, the practical instrument is recommendable to be designed as follows.

Circumferential irradiation at 60°

Light receiving at 0°

or

Irradiation at 0°

Circumferential light receiving at 60°

According to the study of Gunji et al⁹⁾, however, the following specifications are recommended.

Irradiation at 45° and light receiving at 0° for cut pile carpets.

Irradiation at 0° and light receiving at 45° for loop pile carpets.

6. Conclusions

This system is effective for evaluation of the stain of such carpets and other fibrous products as the reflectance is high in the near-infrared range, but it is not applicable to products whose reflectance are not so high in the near-infrared range, of course. However, the stains on elastic floor materials were fully measurable. A simpler

Table 5 *Measurement of gray scale*

Grey scale order	5	4 - 5	4	3 - 4	3	2 - 3	2	1 - 2	1
Measure value	5.0	4.4	3.8	3.4	2.9	2.4	2.0	1.5	1.0

Fig. 9 Schema of staining grader

inspection instrument may be designed, if it is not always necessary that the inspection instrument conforms to the grade values of JIS.

Acknowledgement

In closing this paper, the author wishes to express hearty thanks to Mr. Takashi Sato and Kunio Tsuchimoto of Toyo Linoleum Co., Ltd. for their appropriate advices about the visual judgement and maintenance and also to Prof. Mitsuo Ikeda of Tokyo Institute of Technology for his various suggestions about this paper.

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Received December 1, 1986; accepted March 15, 1988