Evaluation on the Stability of Light Faded Images of Color Xerography According to Color Difference in CIELAB

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The light fading of 4 kinds of color xerographic copies was tested by exposure to the 3 kinds of light sources. Color patches having M, C or Y image were prepared from a full size copy of Macbeth Color Checker used as test pieces. The fading was evaluated according to color difference (ΔE^*) in $L^*a^*b^*$ color space. The value of ΔE^* greatly depended upon the kinds of copy and toner. On the character of the fading, discoloration was strong in C image and the discoloration was equal to the fading of color in M image. In case of Y image, the fading of color showed a definite effect.

1. Introduction

The need of color xerographic copy was comparatively little up to now, because of the expensive copy machine, a high running cost and the low image quality with poor color reproducibility. In recent years, however, there is a growing need for it on account of the progress of the xerographic technics accompanied with the improvement of image quality and through the rapid increase of computers and color printers equipped in the offices. In general, it was considered that the unconventional copies such as electrophotographic copy were prepared in large quantities and were thrown away after use. However, accompanied with the improvement of image quality and the popularization of color copy machine, the color xerographic copy has come to use for the commercial advertisement and the manuscript or original image which is necessary to file in the field of art and science. In these cases, image stability and preservation of the copy became a serious subject. Color xerographic image is formed by fixing the fused color toners on paper base. As the degradation phenomenon of the image formed with the toners on paper was considered as follows: (a) exfoliation of the toner image from based paper by external mechanical force, (b) softening of the toner image and its adhesion to paper by heat and presure, (c) adhesion of plasticized toner image to paper by plasticizer included into vinyl chloride sheet, (d) fading of color toner by chemical reaction with acid materials included into based paper, (e) fading of color toner by air, heart, light and humidity. The important subjects effected to the stability and preservation of the image are (d) and (e). On the studies of these effects, the degradation of paper for storage (1) and the stability of color toners before use (2) were previously reported. But the study on the stability of color xerographic image is scarecely reported.

In our studies on the image stability and its evaluation, color xerographic images were adopted. The methods for testing and evaluation of the faded images are similar to those of the processed photographic color print.

In this presentation, we describe the experimental result of the accelerated light fading test to the color xerographic images.

2. Experimental

2.1. Preparation of color patches for fading test

Color xerographic images for fading were prepared from a full size copy of Macbeth Color Checker made by color xerographic process. Four kinds of copies were prepared by use of 4 different types of copy machines. Ten copies were prepared at a time in every kind of copy. The copies were supplied from copy service stores in town without any special request. Four kinds of copies and copy machines shows in Table 1.

Table 1 Kinds of Color Xerographic Copies and Copy Machines

Kind of Copy (Symbol)	Trade Name of Copy Machine		Color toner (in order of fixing)
F X	Fuji Xerox	Type 6800	Yellow, Magenta, Cyan
R X	Ricoh	COLOR 5000	Yellow, Cyan, Magenta
CXT	Canon	COLOR-T	Yellow, Magenta, Cyan
CXL	Canon	COLOR LASER COPIER-1	Yellow, Cyan, Magenta(Black)

A color patch was used as a test piece for fading test. The patch having a color image of Cyan (C), Magenta (M) or Yellow (Y) was prepared by cutting out and separate from a copy. Red (R), Green (G), Blue (B) and an achromatic color patches were prepared when they were needed.

2.2. Method and condition for fading test

Light fading test was carried out by use of 3 different light sources; white fluorescence lamp, mercury lamp and sunlight.

1) White fluorescence lamp: The patches were illuminated by 4 fluorescence lamps (Toshiba FL20SW). Illuminance on the surface of the patches were 17.5–18.0 Klx and UV radiation of 0.53 mW·min/cm^2. A maximum illumination time was 16 days.

The patches were illuminated continuously and the fading was measured for every time. When 4 anti-fading type fluorescence lamps (Toshiba FL20S·N–EDL·NU; trial manufacture) were used as a light source, the patches were illuminated with illumination of 11.0–11.8 Klx and UV radiation of 0.03 mW·min/cm^2.

2) Mercury lamp: The patches were irradiated by UV radiation of 4.2 ± 0.3 mJ/cm^2 by use of a mercury lamp (Toshiba type H-400P). The maximum irradiation time was 10 hours and the total radiation energy was 15.7 J/cm^2.

Spectral distribution curves of two different types of fluorescence lamps shows in Figure 1, and the curve of a mercury lamp shows in Figure 2. The fading test was carried out at a temperature of 22 ± 5°C and a relative humidity of $60 \pm 10\%$.

3) Sunlight: The patches were exposed to sunlight by use

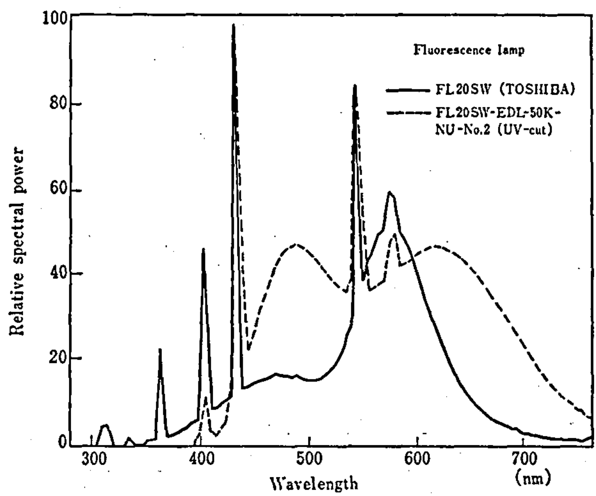

Figure 1 Relative spectral distribution of fluorescence lamps

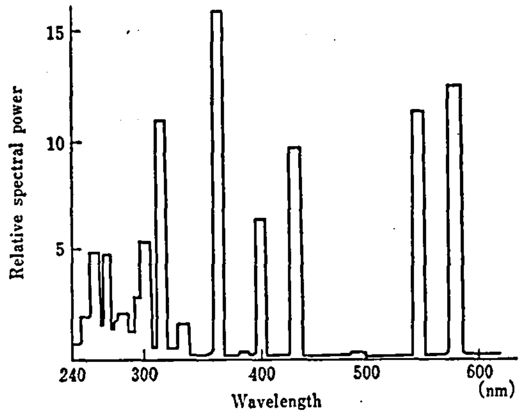

Figure 2 Relative spectral distribution of a mercury lamp (H 400-P)

of the under glass exposure rack (Suga Test Instruments Type IS-1) for 20 days (20 April-19 May, '87 at Tsukuba Research Center). Total radiation energy of UV (300–400 nm) and visual (400–700 nm) were 16.9 and 171.1 W·min/cm^2 respectively.

2.3. Measurement of fading and evaluation method for image stability

As we described in a previous report (3), the method of stability evaluation by specification with the color difference in L*a*b* color space (CIELAB) can be expressed the degree of fading in numerical and the character of fading in quantitative. In this report, therefore, the image stability was evaluated with color difference. For obtaining the color difference (ΔE^*), tri-stimulus values (X, Y, Z) of the patches were measured using photoelectric colorimeter by the direct reading method (JIS Z8722-1982). The formular for calculation of color difference shows in Figure 3, and a schematic diagram of ΔE^* in L*a*b* color space shows in Figure 4. The value of ΔE^* expresses the amount of fading in numerical. Moreover, ΔE^* was analysed with three contents as follows: ΔH^* (hue difference), ΔC^* (saturation difference) and ΔL^* (lightness difference). From the ratio of the

CIELAB : CIE 1976 ($L^* a^* b^*$) color space

L^* : lightness index $\quad$ a^*, b^* : chromaticness index

$L^* = 116(Y/Y_n)^{1/3} - 16 \qquad a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \qquad b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$

$\because X/X_n > 0.008856,\ Y/Y_n\ \&\ Z/Z_n > 0.00856$

X_n, Y_n, Z_n : tristimulus value at perfect reflecting diffuser

$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ (JIS Z 8730 - 1980)

ΔE^* : color difference at $L^* a^* b^*$ color specification

$C^* = (a^{*2} + b^{*2})^{1/2}$ $\quad$ C^* : saturation

$\angle H^0 = \tan^{-1}(b^*/a^*)$ $\quad$ $\angle H^0$: hue angle

$\Delta L^* = L_2^* - L_1^* \qquad \Delta C^* = C_2^* - C_1^* \qquad \Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{1/2}$

analytical specification of ΔE^*

$$\Delta S = \Delta L^* + \Delta C^* + \Delta H^* \qquad \Delta L^*\% = \frac{\Delta L^*}{\Delta S} \times 100 \qquad \Delta C^*\% = \frac{\Delta C^*}{\Delta S} \times 100 \qquad \Delta H^*\% = \frac{\Delta H^*}{\Delta S} \times 100$$

Figure 3 Color difference formula at CIELAB calculated from XYZ tristimulus values

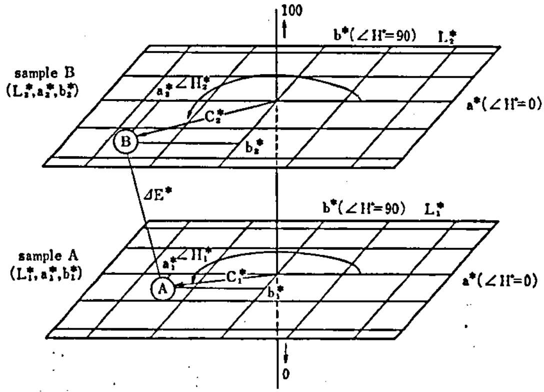

Figure 4 Schematic diagram of specification of ΔC^*, ΔL^*, ΔH^* and ΔE^* on coordinates with $L^*a^*b^*$ system

Table 2 Visual Sensory Specification of Color Difference

ΔE^* Value	Sensory specification
0 ~ 0.5	trace
0.5 ~ 1.5	slight
1.5 ~ 3.0	noticeable
3.0 ~ 6.0	appreciable
6.0 ~ 12.0	much
12.0	very much

contents, the character of fading can be evaluated as discoloration and/or fading of color. The relation between the value of ΔE^* and visual sensory shows in Table 2.

3. Experimental Results and Discussion

3.1 Color reproduction of color xerographic images

The color reproduction of color xerographic images to original images was not satisfied compared with that of the images of photographic print. The reproducibility of the images were considerably poor in tone and contrast. The faithful reproduction of

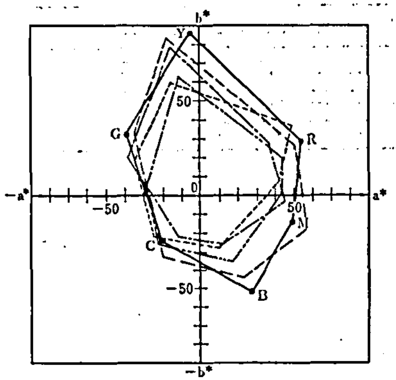

Figure 5 Color reproduction of xerographic images corresponded to original images

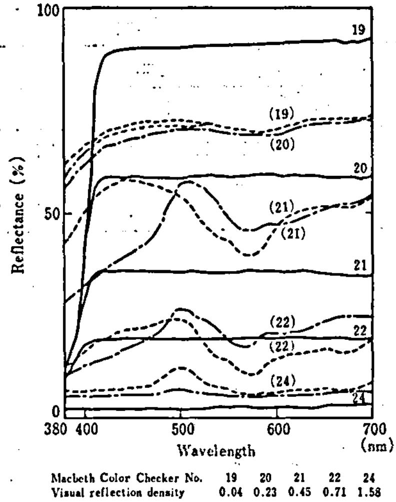

Figure 6 Spectral reflection curves of original and color xerographic copies in achromatic color

achromatic color image was especially difficult. Figure 5 shows the color reproduction of all kinds of the copies as diagrams plotted cn a*, b* coordinates in CIELAB. In this figure, CXL is the most resemble to original and the scatter of Y and M from the original were larger than C image. In the case of achromatic color, spectral reflection curves of original checker and the copies of FX and CXL are showed in Figure 6. From this figure, the character of achromatic color image in each copy and the difference of the shape of the curves between each copy and original were observed.

3.2. Relation between the values of color difference and fading time

Table 3 shows the change of ΔE^* values through the fading time by illumination with white fluorescence lamp, and the change of the values also shows as linear graphs in Figure 7(a) and 7(b).

Table 3 ΔE^* Values of the Color Patches Faded by Illumination with White Fluorescence Lamp

Color patch	Cyan					Magenta					Yellow				
II* \ I*	48	96	192	288	380	48	96	192	288	380	48	96	192	288	380
F X	1.7	1.9	2.0	2.2	2.4	1.3	1.8	2.1	2.3	2.5	0.7	0.8	0.8	0.9	1.0
R X	1.8	1.8	1.9	1.9	1.9	1.3	1.8	3.1	4.5	6.0	0.9	0.9	1.2	1.4	1.9
CXT	1.1	2.6	5.0	7.0	8.3	1.5	3.0	5.6	8.2	10.0	3.6	8.0	15.4	22.3	27.9

I* = Fading time (h)
II* = Symbol of copy

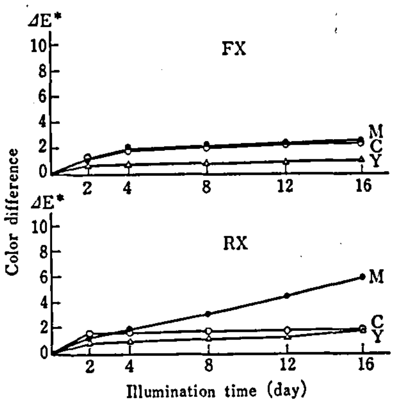

Figure 7 (a) Fading of color patches by illumination with fluorescence lamp (sample: FX and RX)

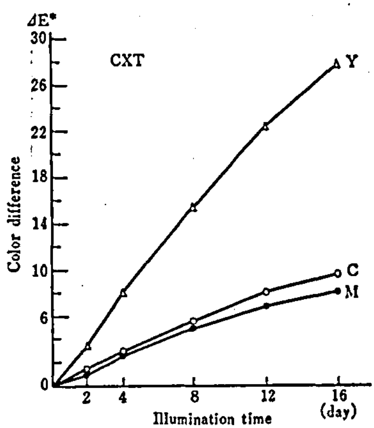

Figure 7 (b) Fading of color patches by illumination with fluorescence lamp (sample: CXT)

The values depended upon the kind of copy and upon the kind of toner in a copy. CXT showed much higher value than that of other copies. Especially, Y image showed remarkable high value and the value rapidly increased correlated with illumination.

For make it clear that the effect of UV radiation on fading, the fading test of the copy illuminated by different type of fluorescence lamp was examined. This result shows in Figure 8. The fading of the patches illuminated by UV-cut fluorescence lamp was retarded in low value. When the patches were irradiated by mercury lamp, the values of the copies were shown in Table 4.

Figure 9(a) and Figure 9(b) show the relation between ΔE^*

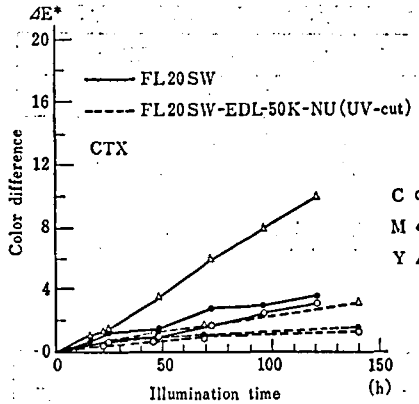

Figure 8 Effect of UV radiation on the fading by illumination with white fluorescence lamp

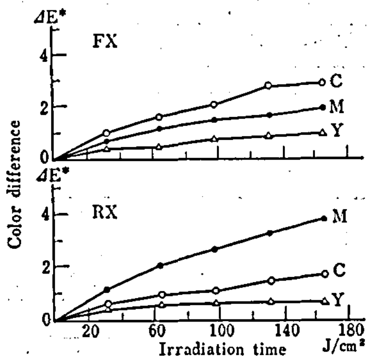

Figure 9 (a) Fading of color patches by irradiation with UV radiation (sample: FX and RX)

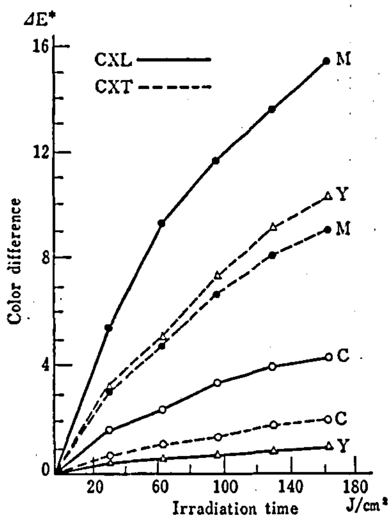

Figure 9 (b) Fading of color patches by irradiation with UV radiation (sample: CXT and CXL)

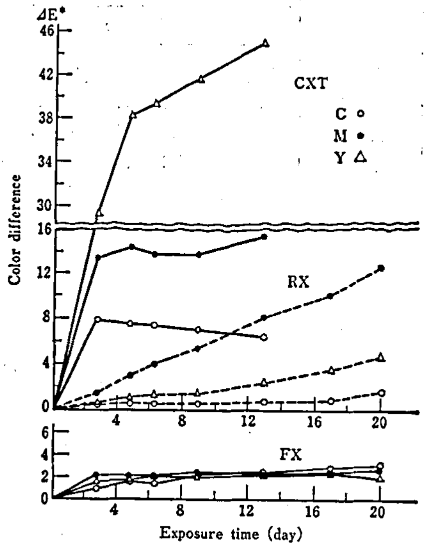

Figure 10 Fading of color patches by exposure to sunlight

Table 4 ⊿E* Values of the Color Patches Faded by Irradiation with Merculy Lamp

Color patch	Cyan					Magenta					Yellow				
II* \ I*	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10
F X	1.1	1.7	2.0	2.8	3.0	0.8	1.2	1.6	1.8	2.0	0.4	0.4	0.7	0.9	1.0
R X	0.4	0.9	1.1	1.5	1.7	1.1	2.2	2.7	3.4	4.0	0.4	0.6	0.6	0.6	0.6
CXT	0.8	1.2	1.4	1.9	2.1	3.2	4.9	6.6	8.1	9.0	3.6	5.1	7.4	9.1	10.3
CXL	1.8	2.5	3.5	4.1	4.3	5.7	9.1	11.4	13.5	15.3	0.4	0.6	0.8	0.9	1.0

I* =Fading time (h)
II* =Symbol of copy

Table 5 ⊿E* Values of the Color Patches Faded by Exposure to Sunlight

Color patch	Cyan							Magenta						
II* \ I*	2	4	6	8	12	16	20	2	4	6	8	12	16	20
F X	1.1	1.8	1.6	2.4	2.6	3.1	3.5	2.2	2.1	2.0	2.4	2.2	2.5	2.7
R X	0.6	0.7	0.6	0.7	0.9	1.0	1.7	1.4	3.0	4.1	5.6	8.1	10.2	12.7
CXT	8.3	7.6	7.4	7.0	6.5	—	—	13.6	14.4	13.8	13.8	15.6	—	—

Color patch	Yellow						
II* \ I*	2	4	6	8	12	16	20
F X	1.6	1.8	2.0	2.1	2.3	2.6	2.0
R X	0.7	1.0	1.3	1.7	2.5	3.7	4.8
CXT	29.4	38.2	39.3	41.8	45.3	—	—

I* =Fading time (day)
II* =Symbol of copy

value and irradiation time (radiation energy). From these figures, it was known that the copies showed a similar tendency compared with the results showed in Figures 7(a) and (b).

But in the copy of CXL, there was a large difference on the fading between CXT and CXL. This result showed that the fading depended upon the constituent materials of the toner.

Figure 10 shows the fading of the color patches by exposure to sunlight. It was observed from this figure that FX and RX (except M image) showed high anti-fading character under sunlight exposure. In the case of CXT, however, the fading of the patches rapidly increased at initial state of exposure and then the proportion of increase became slow with exposure. Especially, the value of C image reached the maximum at the initial state

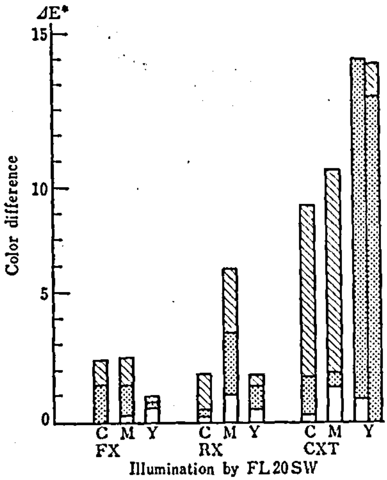

Figure 11 (a) Character of the fading specified with color difference and its component (white fluorescence lamp)

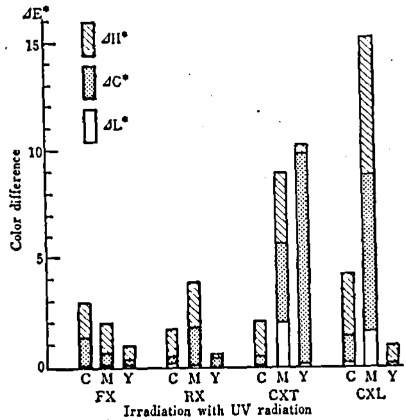

Figure 11(b) Character of the fading specified with color difference and its component (mercury lamp)

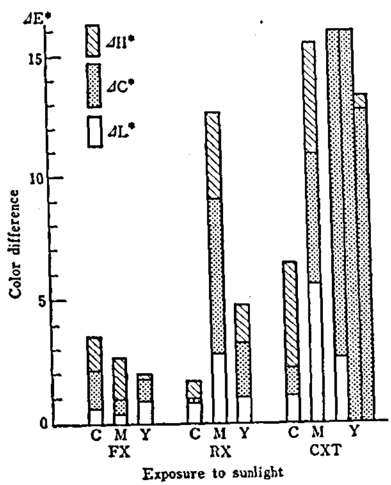

Figure 11(c) Character of the fading specified with color difference and its component (sunlight)

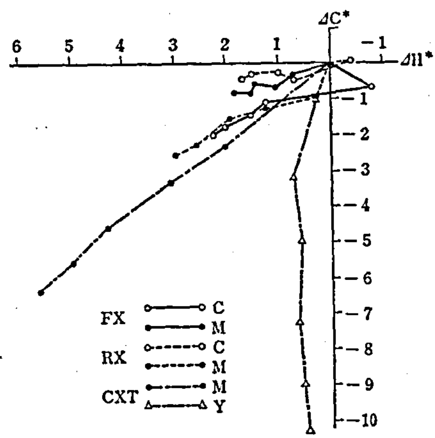

Figure 12 Specification of the character of the fading with the change of the value of ΔC^* and ΔH^*

and then it gradually decreased in accordance with exposure time. It seem that the chemical change of the toner material resulted this phenomenon. Y image was almost disappeared after exposure of 12 days.

Table 5 shows the values of faded color patches exposed to sunlight.

3.3. Evaluation of the character of fading by analysis of color difference

The component of color difference was devided with three contents, ΔH^*, ΔC^* and ΔL^*. The character of fading can be evaluated from the ratio of the contents in ΔE^*. Figure 11(a)-(c) show the devided contents in ΔE^* of the copies in every light source. From these figures, it was cleared that a component of ΔE^* was largely occupied with ΔH^* and/or ΔC^*, and a space occupied with ΔL^* was small. On the character of the fading in every color patch, it was showed as follows.

1) In the case of C image, ΔH^* occupied the main part in ΔE^* so that the discoloration was the leading part of fading. 2) In the case of M image, both ΔH^* and ΔC^* occupied the main part, and the ratio of ΔH^* and ΔC^* was equal so that both effects were equal in the fading. 3) In the case of Y image, ΔC^* occupied almost part in ΔE^* so that color fading was main factor in the fading. These characters of the fading shows in Figure 12. The characters of faded images of the copies through the fading time were indicated as the direction of transfer of the point plotted on the coordinates of ΔH^*, ΔC^*.

4. Summary

1) Color xerographic images apparently showed light fading, and the rate of the fading depended upon the kind of light source. Anti-fading type fluorescence lamp showed the effect of prevention

on the fading.

2) Degree of the fading of color xerographic copies were specified numerically with the value of color difference in CIELAB. The value depended upon the kinds of copies and the kinds of toners in a copy.

3) The character of the faded image was evaluated quantitatively by analysis of ΔE^* with ΔH^*, ΔC^* and ΔL^*. The fading could be devided with discoloration and fading of color.

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