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Image Permanence of Photographic Prints under LED lighting

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Abstract

LED (Light Emitting Diode) lighting has been widely used as a major light source to illuminate photographic prints. However, the effects of LED lighting on image stability of prints are not clear. Light stability tests were carried out using some commercially available white LED lamps, and the fading behaviour was compared to the standardised Xe light testing, which simulates indirect sunlight indoors. It was clarified that fading under LED lighting is less than under Xe lighting, but it correlates well with Xe testing regarding the order of print materials in light stability. The effects of the correlated colour temperature (CCT) and the excitation wavelength of LED lamps were also studied. As a result, it has been confirmed that the dependence on the CCT is not significant, but LED lamps with shorter excitation wavelengths are more harmful to the light stability of photographic prints. Based on these results, a guideline for determining the standard test condition for LED light stability of photographic prints will be proposed.

Background and purpose

In recent years, LED lighting has received various improvements in its efficiency and production cost. Now, it is widely used as indoor illumination in consumer homes, offices, commercial buildings, galleries and museums. Thus, it is often the case that photographic prints are displayed under LED lighting.

Photographic prints tend to fade when exposed to light over time. However, the stability of prints varies depending on the printing technology and materials. It is also affected by the characteristics of the light source. However, since the history of LED lighting is not so long, the fading behaviour under LED lighting is not well known.

Acceleration light exposure testing at higher illuminance is performed to evaluate the fading characteristics of prints. ISO 18937 stipulates the method of acceleration tests using a Xe light source with an ultraviolet (UV) cut filter, which simulates typical indoor lighting. There is no testing standard for LED illumination and no commercially available LED testing equipment for photographic prints. Right from the start, there are many kinds of LED lamps. Little is known about the effects of the colour temperature, the colour rendering index (CRI) and the excitation wavelengths of LED lamps. Therefore, it was impossible to select a standard LED lamp for image stability tests. ISO/TC 42 (photography) started a discussion on standardising the LED light stability test methods.

The purpose of this research was to first clarify the fading behaviour of photographic prints under LED lighting and also the relationship between the results of the ISO method using Xe lighting and fading behaviour under the recently developed LED lighting; the second purpose was to know the dependence of image stability of photographic prints on the characteristics, specifically the light spectral distribution, of LED lamps. With this knowledge, standard test conditions for light stability of photographic prints are proposed.

Light stability testing

Light stability tests were carried out using UV-filtered Xe light and some commercially available LED lamps, which have different correlated colour temperatures (CCTs), different CRIs and different excitation wavelengths. A wide range of photographic prints were selected and tested. The fading behaviours were compared between Xe and LED lamps and in between the LED lamps.

Experimental apparatus

For Xe light exposure, commercially available testing equipment (XL75; Suga Test Instruments Co., Ltd.) was used. A UV filter (half-cut wavelength: ca. 370 nm) was inserted between the light source and the samples. These settings are stipulated in ISO 18937 for general indoor display.

For LED light exposure, testing equipment was constructed with LED lamps and print sample holders. A schematic view of the equipment is shown in Fig. 1. Straight tube lamps were set parallel to uniformly illuminate the entire surface of the sample specimens. The four sides of the equipment were kept open to allow air flow of the laboratory. The room temperature was controlled within 23 ± 2°C at 50 ± 5% relative humidity (RH).

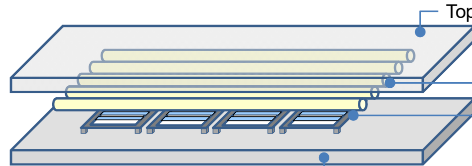

Figure 1. *A schematic view of the LED exposure test.*

For CCT dependence, three types of LED lamps, shown in Table 1, were used for the test. The spectra of the LED lamps listed in Table 1 are shown in Fig. 2.

Table 1: An LED light source for testing the CCT dependence.

	CCT	CRI(Ra)	Model number
LED-1	3,500 K	ca. 80	DN Lighting SCF-ED1139WW-APD
LED-2	4,000 K	ca. 80	Panasonic LDL40SW1923
LED-3	6,500 K	ca. 80	Panasonic LDL40SD1923

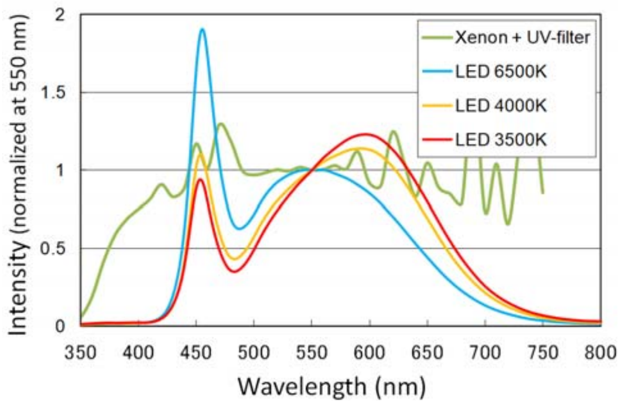

Figure 2. *The spectra of the light sources (LED-1, LED-2 and LED-3 and UV-filtered Xe) for testing.*

In order to check the dependence of the excitation wavelength and the CRI, four types of LED lamps, shown in Table 2, were used.

Table2: LED light sources for testing for CRI and excitation wavelength dependence.

	CCT	CRI (Ra)	Model number
LED-4	5,000 K	80	DN Lighting SCF-LED848N-A1-APD
LED-5	5,000 K	95	Panasonic XL573PFVBC
LED-6	5,000 K	95	Nichia Optisolis NF2W757GT-F1
LED-7	3,500 K	95	SORAA: VIVID MR16 LDR8L-W-E11

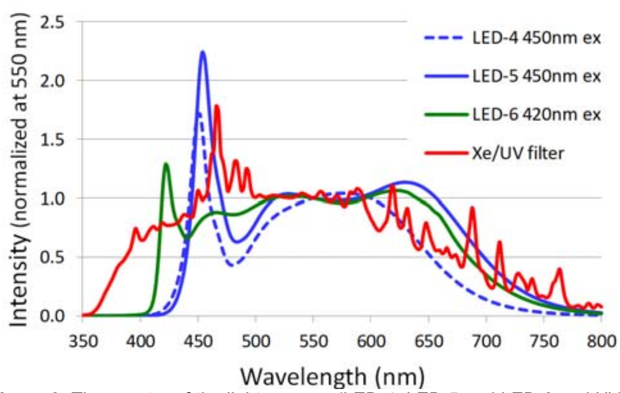

Figure 3. *The spectra of the light sources (LED-4, LED-5 and LED-6 and UV-filtered Xe) for testing.*

LED-1 to LED-5, shown in Tables 1 and 2, have a specific peak at around 450 nm, which originated from the blue LED chip. Moreover, there exist broad peaks between 550 and 600 nm, which originated from phosphors. These types of LEDs are the most popular for indoor illumination across markets worldwide.

LED-6, shown in Table 2, has a specific peak at around 420 nm, which is intended to cover a wider spectrum range. Regarding CRI, the Ra values [5] of LED-5 and LED-6 are about 95, whereas those of LED-1 to LED-4 are about 80. LED lamps with higher Ra values have recently increased in the market.

LED-7, which has a specific peak at around 410 nm, was used to check the effect of the shorter excitation wavelength of LED lamps; however, it is a spotlight-type LED lamp and can produce a small area of uniform illumination, which covers an area of only four patches of the test chart. Therefore, only four grey patches with different densities were exposed.

Testing conditions

The Xe light exposure test was performed according to the stipulation of ‘Simulated indoor light typical home display’ in ISO 18937. The light intensity was set at 80 klx on the sample surface, chamber air was conditioned at 25°C, at 50% RH and the black panel temperature was controlled at 35°C

For LED light exposure testing, the distance between the lamps and the surface of the prints was adjusted to about 30 mm, where validation in light exposure is within the range of 3% over the whole sample area. The data of the light intensity (illuminance) and the temperature of the print surface are shown in Table 3.

Table 3: Illuminance and temperature of the print surface

LED no. (cf. Tables 1 and 2)	Illuminance	Surface temperature of the samples		
		White	Grey (D = 0.5)	Black
LED-1	35 klx	28.7	30.5	31.5
LED-2	35 klx	—	—	—
LED-3	70 klx	32.9	35.9	36.8
LED-4	70 klx			36
LED-5	55 klx			33
LED-6	42 klx			33

Print samples

Commercially available photographic prints for consumer and commercial use, including inkjet (dye and pigment base), electrophotography (solid and liquid type), silver halide and D_2T_2 (commonly called ‘dye sub’), were prepared.

For the CCT dependence test carried out in 2018, 12 samples (Samples A–L) were used. For the CRI and excitation wavelength dependence test carried out in 2019, 11 samples (Samples M–W) were used.

In Fig. 4, 22 colour patches were printed as shown. Printed sheets were cut into strips with a size of 22 × 122 mm. Three out of the 22 colour patches were identical grey ones with an optical density of 1.0 for checking the locality of fading.

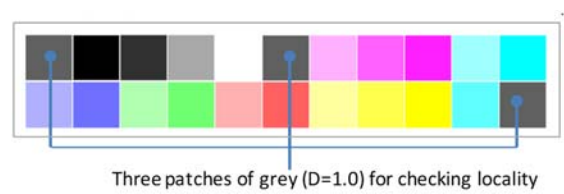

Figure 4. *A print sample for light stability testing.*

Evaluation method for image stability

The fading behaviour of each sample was evaluated with the colour difference ΔE_{76} of the average of the 22 patches, which is reported to correlate well with human perception [2]. The chromaticity of each colour patch was measured before and after light exposure of several durations. The measuring condition M0 described in ISO 13655 [3] was applied. The geometry was 45°/0° with a 2° observer for the detector, and the illuminant was a CIE illuminant D50. The colour differences, ΔE, for each initial and each faded sample after light exposure were calculated. For ΔE, the CIE 1976 ΔE_{76} (ΔE^{*}_{ab}) values stipulated in ISO 11664-4 [4] were calculated.

Results and consideration

1. Effects of CCT

The profiles of the averaged colour difference ΔE_{76} were evaluated for 12 print samples (Samples A–L) using three LED lamps (i.e. LED-1 for 3,500 K, LED-2 for 4,000 K and LED-3 for 6,500 K) and also a UV-filtered Xe lamp. The cumulative light exposure, which is the product of illuminance (lx) and duration (h), was applied to the x-axis. Examples of three types of prints are shown in Fig. 5 (Sample A) and Fig. 6 (Sample E).

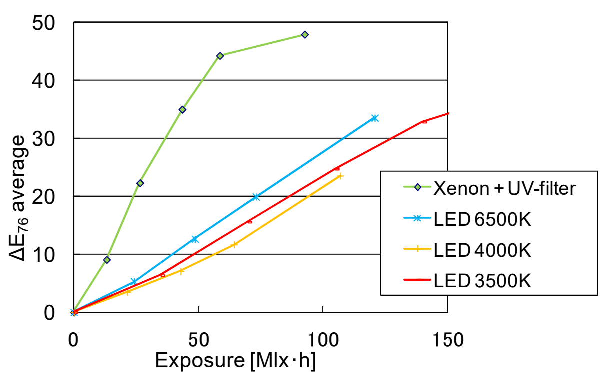

***Figure 5.** Change in the averaged colour difference of Sample A.*

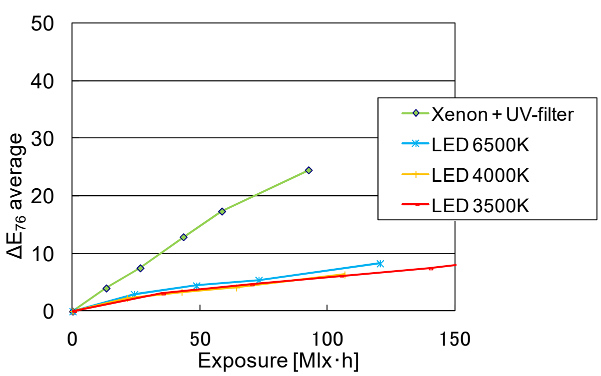

***Figure 6.** Change in the averaged colour difference of Sample E.*

The averaged colour difference ΔE_{76} of 12 samples (Samples A–L) at a cumulative light exposure of 60 Mlx·h is shown in Fig. 7. Fading under the three aforementioned types of LED lighting was much smaller compared to the UV-filtered Xe lighting for all 12 samples, and the effects of the CCT were relatively small.

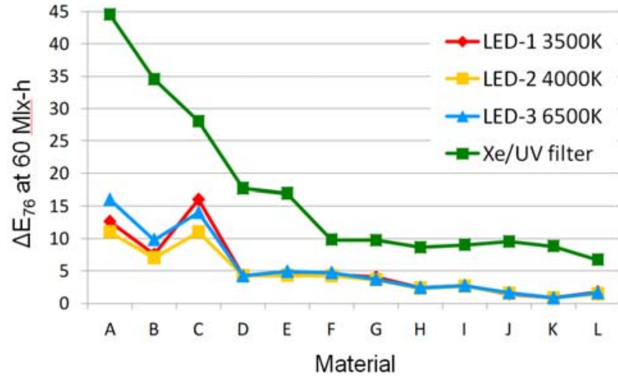

***Figure 7.** Dependence of CCT – ΔE_{76} at 60 Mlx·h of the 12 samples.*

2. Effect of excitation wavelength of an LED

Blue-pumped LEDs, in which an LED with a wavelength of 450 nm is used for blue light and also for the excitation of yellow or red + green phosphors, are the most common LED lamps on the market. LED lamps with a shorter wavelength, such as violet-pumped LEDs, were developed to improve the colour rendition even more. However, since the blue LED chip is efficient and not expensive compared to shorter-wavelength LED chips, it is predicted that blue-pumped white LEDs will be the major LEDs for at least the next five years or even more.

In this sub-clause, the effect of the excitation wavelength of the LED, which appears as a specific peak at around 400~460 nm in the spectrum of LEDs, is discussed.

The profiles of the averaged colour difference ΔE_{76} are evaluated for 11 print samples (Samples M–W) using UV-filtered Xe and three LED lamps (i.e. LED-4, LED-5 and LED-6). An example of the results in ΔE_{76} versus light exposure (Mlx·h) is shown in Fig. 8.

The averaged colour difference ΔE_{76} at the cumulative light exposure of 60 Mlx·h is shown in Fig. 9.

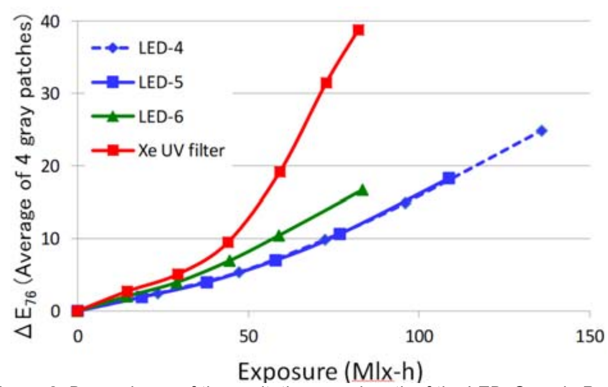

***Figure 8.** Dependence of the excitation wavelength of the LED, Sample P.*

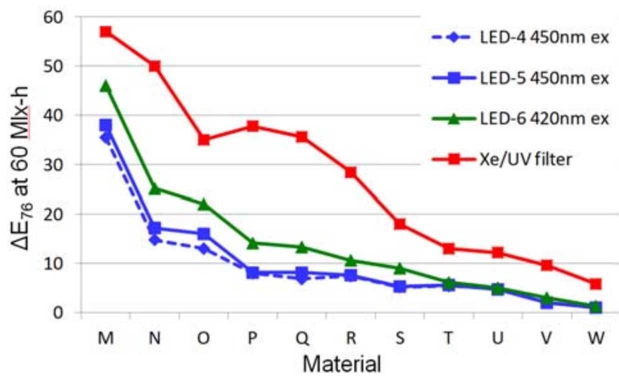

Figure 9. Dependence of the excitation wavelength of the LED – ΔE_{76}, at 60 Mlx·h.

LED-6 with the excitation wavelength of 420 nm caused the faster fading compared to LED-4 and LED-5 with the excitation wavelength of 450 nm. Even so, all the LED tested were less aggressive compared to UV-filtered Xe.

It is concluded that these types of LED lighting are less aggressive than the Xe lighting with UV filter, which simulates indirect daylight of typical home display. This might be because these types of LED lighting have less UV component as shown in Fig. 2 and Fig. 3.

LED-7 with an excitation wavelength of ca. 410 nm was also tested to check the effect of shorter-wavelength excitation. Here only four grey patches with four density levels were used, because LED-7 is a spotlight-type LED and LED-7 could not produce uniform illumination that covers more than four patches. The test results were compared with the data of those four grey patches for LED-4, LED-5 and LED-6. The results are shown in Fig. 10. LED-7 showed the fastest fading compared to LED-6. It is considered that the shorter wavelength of the excitation LED caused faster fading.

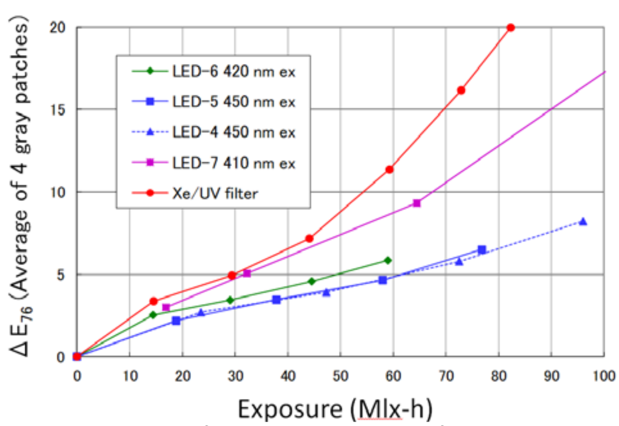

Figure 10. Dependence of the excitation wavelength of LEDs, the average ΔE_{76} of four grey patches.

3. Correlation of evaluation of imaging materials between LEDs and UV-filtered Xe lamps

The fading order of 12 prints was compared between the UV-filtered Xe test and the LED test. The ΔE_{76} values of Xe testing at 35 Mlx·h and that of LED testing (LED-2; 4,000 K, Ra = 80) at 90 Mlx·h for Samples A–L are plotted in Fig. 11. The ΔE_{76} values of Xe testing at 35 Mlx·h and that of LED testing (LED-6; 5,000 K, Ra = 95) at 90 Mlx·h for Samples M–W are plotted in Fig. 12.

Figures 11 and 12 clearly show that the test results of Xe correlated well with those of LEDs regarding the order of print materials in light stability; however, Xe lighting is about two to three times more aggressive compared to LED lighting.

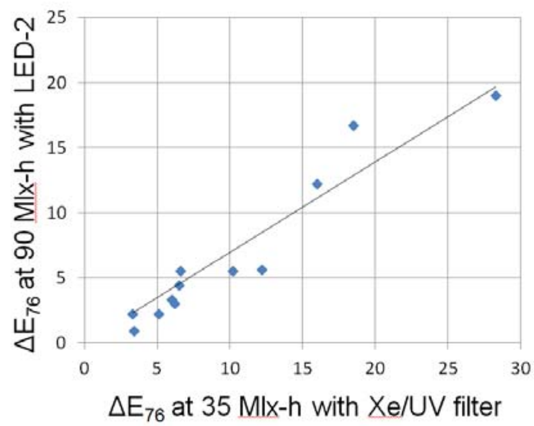

Figure 11. Comparison of 35 Mlx·h with Xe to 90 Mlx·h with LED-2 testing in 2018 for Samples A–L.

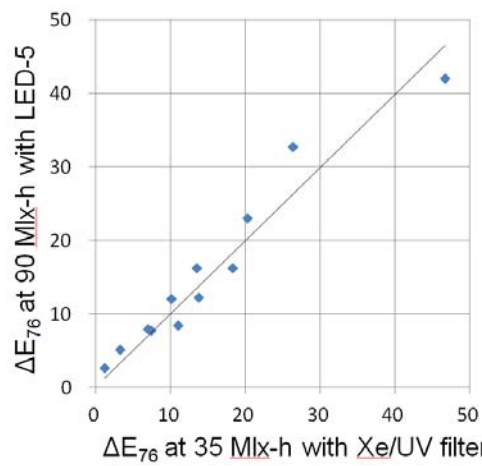

Figure 11. Comparison of 35 Mlx·h with Xe to 90 Mlx·h with LED-5 testing in 2019 for Samples M–W.

The data described above indicate that the UV-filtered Xe test was sufficient to identify the light stability of imaging materials for photographic prints. The reasons are as follows:

(1) UV-filtered Xe lamps are more aggressive compared to LED lamps. Photographic prints will be exposed to various sources of light, including the more aggressive indirect indoor sunlight, which can be simulated using a UV-filtered Xe lamp.
(2) The test results of LEDs correlate well with the Xe test regarding the order of print materials in light stability.
(3) Two or more test data results will confuse the customers.
(4) LED light tests require a long time, which leads to an increase in the cost of imaging products.

Conclusion

The LED light exposure test equipment used in this study was built using commercially available LED lamps. The intensity of light that the samples were exposed to reached 35–70 klx, and the non-uniformity of the light intensity at the sample surface was less than 3%. Using straight tube lamps rather than spotlight-type lamps is recommended to obtain good uniformity of light intensity on the samples when commercially available lamps are used.

The difference in the CCT of LED lamps does not have much of an effect on the fading behaviour between 3,500 and 6,500 K. As the standard test condition for imaging materials, one condition, such as 5,000 K, is sufficient for evaluating the durability of materials to LED light, rather than testing under multiple conditions, such as 3,500 and 6,500 K, which may cause confusion for the customers.

With respect to the excitation wavelength of the LED, the shorter the excitation wavelength, the faster the fading, when 450, 420 and 410 nm excitations are compared. As the standard test conclusion, blue-pumped (450 nm) LEDs are recommended for general indoor and backlight applications. Even for galleries and museums, 420 nm or longer-excitation-wavelength LEDs should be selected, and the standard LED light stability test should use LED lamps with 420 nm or longer wavelength excitation.

In this study, all the LED lamps tested were much less aggressive compared to UV-filtered Xe lamps, which simulate indirect sunlight indoor display. In addition, the durability to light exposure of the imaging materials correlates well between the LED tests to the UV-filtered Xe test regarding the order of print materials. Therefore, to evaluate imaging materials that can be exposed to various kinds of light, including sunlight, a UV-filtered Xe test should be performed for overall light stability.

Acknowledgement

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[3] ISO 13655: Graphic technology–Spectral measurement and colorimetric computation for graphic arts image.

[4] ISO 11664-4: Colorimetry–Part 4: CIE 1976 L*a*b* Colour space.

[5] CIE Publication No.13: Method of measuring and specifying colour rendering properties of light sources.

Author biography

Hiroshi Ishizuka obtained his master's degree in engineering from Tokyo Institute of Technology in 1989. He worked on the development of imaging and display materials in Fujifilm. His work is now focused on international standards for those materials. He is an expert of ISO/TC42 (photography) and IEC/TC110 (electronic display devices).

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Shin Soejima obtained his master's degree from the Science University of Tokyo in 1994 and started to work at Fujifilm. He had been involved in the research and development of silver halide colour photographic paper for a decade. He is currently a general manager of the international standards promotion office in the IP headquarter division in Fujifilm.