The effect of ultraviolet-filtered light on the mechanical strength of fabrics

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Summary As ultraviolet light is known to be detrimental to organic objects, the light entering galleries containing organic objects is filtered in many museums. Conservators have, however, noted that some textiles on permanent display have weakened significantly over time, a phenomenon that has usually been attributed to the deleterious effects of light. This study aimed to investigate the effect of light from which ultraviolet radiation had been filtered on the mechanical strength of cellulose-based textiles. Modern undyed cotton, linen and jute textiles were irradiated for 30 Mlux.hours in two different lightboxes: the first lightbox was fitted with a lamp that mimicked daylight and had a relatively high ultraviolet radiation content, whereas the second lightbox was fitted with the same fluorescent lamps as used in the galleries at the British Museum and from which all the ultraviolet radiation was filtered. The mechanical strength of the jute and linen samples aged in the lightbox with a high ultraviolet content decreased significantly, which was attributed to the high lignin content in jute and to the possible presence of photo-sensitizers in linen. The mechanical strength of the cotton sample was not affected by exposure to ultraviolet radiation. In contrast, none of the samples aged in the lightbox that used light free of ultraviolet radiation showed any signs of mechanical weakening. There was a significant change in colour following light exposure for all the samples, although the change was higher when ultraviolet radiation was included. In particular, the jute samples yellowed, which can be attributed to their higher lignin content compared to cotton and linen. These experiments suggest that visible light does not affect the mechanical strength of modern undyed cellulose-based textiles, although it is responsible for changes in colour. Until the 1980s, light-sensitive objects in museums were often displayed in daylight without ultraviolet filtration on windows and skylights. It is possible that the mechanical weakening of textiles reported by conservators is a result of the exposure to ultraviolet light in the past. Alternatively, in the case of historical fabrics, this could be linked to a treatment applied to the fabric, such as the use of mordants or dyes.

INTRODUCTION

Like many other museums, the galleries of the British Museum contain numerous textiles and objects made with textiles. These include Asian objects decorated with silk banners and tassels, while in the Egyptian galleries, there are mummies, mummy-wrappings and models of boats with linen sails on permanent display, Figure 1. Ultraviolet (UV) radiation is known to be detrimental to organic objects and the light used in galleries at the British Museum that contain such objects is filtered to remove UV. There have, however, been frequent reports from conservators that some textiles on permanent display have weakened significantly with time – an effect that has usually been attributed to the deleterious effect of light. This study aimed to investigate the effect of UV-filtered light on the mechanical strength of cellulose-based textiles.

Very little research has been reported into the photo-ageing of cellulose-based fabrics [1]. Anecdotal evidence suggests that UV radiation affects their mechanical strength, but this has not been demonstrated, and little is known about the effect of UV-filtered light. In contrast, the detrimental effect of light on the properties of paper is well documented [2–7]. It has been shown that lignin plays an important role in the photo-ageing of papers containing lignin, especially in terms of photo-yellowing [2, 3], and there is evidence that lignin affects the photo-induced loss in mechanical strength. For instance, it has been reported that papers with high lignin contents become more brittle on photo-ageing than papers containing less lignin [4]. In addition, Bond et al. observed that lignin-containing papers showed a considerable loss in folding endurance after a 29 month exposure in a north-facing window, while the folding endurance of a lignin-free paper aged similarly did not change significantly

FIGURE 1. Textiles on permanent display in the British Museum: (a) linen sail of a wooden model of a boat (1901,0415.145) in gallery 61; (b) linen mummy-wrapping (1971,0403.1) in gallery 62

[5]. Ultraviolet radiation is responsible for causing lignin to cross-link, leading to the embrittlement of the fibres, but lignin cross-linking has also been observed in papers exposed to UV-filtered light for five years [6]. Lignin has a complex structure, which differs according to the plant species [2]. It is not clear, for example, that bast fibres age in the same way as wood pulp fibres and further research is needed to investigate the effects of light on cellulose-based textiles.

In this study, samples of cotton, linen and jute textiles were photo-aged in two different lightboxes. The first lightbox was fitted with a lamp that mimicked daylight

and had a relatively high UV content, whereas the second lightbox was fitted with fluorescent lamps of a type used extensively in museums and employed widely throughout the galleries at the British Museum; all UV radiation was filtered from the latter source. The aim was to investigate the detrimental effects that UV radiation had on the mechanical strength of fabrics exposed in the first lightbox and compare these with the fabric samples aged in the second lightbox, which simulated current conditions in the galleries. After photo-ageing, the mechanical strengths of the samples were compared to those of the textiles 'as received' and colour changes in the textiles were measured.

EXPERIMENTAL

Fabric samples

Three textiles, 'cotton canvas CC31', 'artist linen L36' and 'jute tarpaulin J65' were purchased commercially. All the textiles were said to be natural, with no dye or finish. The textiles were rinsed at 90°C before use and five strips of each textile were cut with their length parallel to the warp. The strips were 20 mm wide and at least 120 mm long. It should be noted that modern textiles are processed using techniques that differ from those employed historically. Therefore, the results obtained in this study may not be directly applicable to historical fabrics. In addition, mordants or dyes may act as photo-sensitizers and affect the strength of textile fibres and their ageing process; for example, weighted silks deteriorate to a much greater extent than unweighted silks [8]. This study is focused on undyed fabrics and different results may be obtained for dyed fabrics.

The fabrics were tested for lignin using the phloroglucinol test [9]. The test proved positive for jute, but negative for cotton and linen. The detection threshold of the phloroglucinol test is not known, so although none was detected, it is likely that the linen also contains a small amount of lignin. The compositions of cotton, linen and jute, compiled from several literature sources, are given in Table 1.

As acidity has been shown to play a role in the photoageing of paper [4], the pH of each fabric was measured using the aqueous extract pH test [9]. All the fabrics were found to have a pH very close to seven.

TABLE 1. Chemical composition of cotton, linen and jute, as found in the literature [10–12]

| Fibre | Content (%) | | |
	Cellulose	Hemi-celluloses	Lignin
Cotton	99 [10]	0 [10]	0 [10]
Linen	71 [10]	18.5 [10]	2 [10]
Jute	65.2 [11]	22.2 [11]	12 [10]
	45–63 [12]	>18 [12]	10.8 [11]
			13.7 [12]

Accelerated light ageing

The samples were aged in the two lightboxes for approximately 30 Mlux.hours; assuming the reciprocity principle holds [13], this dose corresponds to exposure for 10 hours a day at a level of 80 lux for 100 years. The first lightbox was a Microscal LFT1E (model 500) lightfastness tester fitted with a 500 W Philips ML lamp. The Philips ML lamp is a combined tungsten and mercury discharge fluorescent lamp that mimics daylight. The UV content in the Microscal lightbox was approximately 600 µW.lumen^{-1} and the average illuminance at the sample surface was 24000 lux. The second lightbox was purpose-built and fitted with eight Philips 18W/930 TL-D 90 deluxe fluorescent lamps. These lamps are the same as those used in many of the galleries at the British Museum. The UV radiation was filtered using a polycarbonate sheet to give UV levels inside the lightbox that varied between 1 and 2 µW.lumen^{-1} with an average illuminance at the sample surface of 15000 lux. For convenience, the Microscal lightfastness tester is hereafter referred to as 'lightbox I', and the purpose-built lightbox as 'lightbox II'.

It has been reported that humidity has little effect on the photochemical loss of tear strength of paper [13], so no measures were taken to control the relative humidity inside the lightboxes. The relative humidity and temperature inside the two lightboxes were monitored using Hanwell Humbug data loggers; the relative humidity and temperature in lightbox I were 26±6% and 35±3°C during the tests, while the environment in lightbox II was maintained at 28±5% and 22±2°C.

Mechanical tests

The textiles were tested using an Instron testing machine both in the state that they were received from the supplier and after photo-ageing. The gauge length of the samples was 80 mm. The samples were extended at a test rate of 20 mm per minute. The mechanical strength of the fabric was determined as the maximum load before failure.

Colour measurements

The colour of each sample was measured using a Minolta CM-2600d spectrophotometer. The sample area was 8 mm in diameter. For the purposes of colour measurement, UV radiation was not filtered from the illuminant and specular light was included in the measurements. Each measurement was repeated four times and the average value was recorded. The results are expressed as CIE (Commission Internationale de l'Eclairage) L*, a*, b* coordinates using the standard illuminant D65 as reference and the 10° supplementary standard observer [14]. The overall colour change, ΔE_{00}, was calculated using the CIE 2000 formula [15]. To give an idea of the scale of change monitored, a ΔE_{00} of approximately 1.5 corresponds to a visually perceptible change [16].

RESULTS

Mechanical tests

The results of the mechanical tests are shown in Table 2; note that the scatter in the results is relatively large, probably as a result of the inhomogeneous texture of the fabrics.

The linen and jute samples photo-aged in lightbox I became considerably weaker after photo-ageing: the linen textiles lost approximately 25% of their initial strength and the jute textiles 30%. In contrast, the strength of the cotton samples was not affected. In lightbox I, the UV radiation was not filtered. UV irradiation can result in a decrease in the degree of polymerisation of cellulose, but it has been reported that only wavelengths shorter than 310 nm can photolyse pure cellulose [2]. The emission of the Philips ML lamp in this region is very low and it is unlikely that cellulose degraded significantly during the experiment. It is more likely that the loss in mechanical strength in jute and linen is due to the presence of lignin. Given the much lower lignin content of linen compared to jute, it is surprising that the mechanical strength of the linen samples decreased almost as much as the jute samples. The linen fabric possibly contains photo-sensitizers, such as transition metals, which could be responsible for cellulose chain scission [7]. The cotton textile does not contain lignin and this probably accounts for the fact that the mechanical strength of the cotton samples was not affected. These results show that UV radiation can cause mechanical weakening of certain cellulose-based fabrics.

The mechanical strengths of the samples photo-aged in lightbox II were not significantly different from the samples as received. These results suggest that UV-filtered light does not affect the mechanical strength of cellulose-based fabrics under the conditions used in the experiments.

Colour change

The data in Tables 3 and 4 indicate that all the fabrics changed colour after exposure to light and that the colour change was greater when ageing was carried out in lightbox I, in which UV radiation was included. The cotton and linen fabrics became visually much lighter in colour, as reflected by the change in the L* (lightness) values. This was also the case for the jute samples aged in lightbox II. Lightening in these samples is probably due to the destruction of chromophores by light. In contrast, the colour change for the jute samples in lightbox I was mainly yellowing, as can be seen from the large increase in b*. Lignin is known to form yellow-coloured products when exposed to UV radiation and it has been reported that the intensity of yellowing in cellulosic fibres is dependent on the lignin content [17]. As shown in Table 1, jute contains approximately 12% lignin and this would account for photo-yellowing. Unlike jute, linen did not yellow when exposed to UV radiation; linen contains only approximately 2% of lignin and the concentration of

TABLE 2. Mechanical strength before and after photo-ageing in the two lightboxes

Textile	Maximum load at failure (N)		
	As received	Lightbox I	Lightbox II
Cotton	261±52	273±32	269±32
Linen	372±41	280±20	402±72
Jute	705±28	476±24	743±67

Note: figures are ± standard deviation for a set of five samples.

TABLE 3. L*, a*, b* coordinates and ΔE_{00} values for the samples photo-aged in lightbox I, before and after ageing

Textile	As received			Photo-aged			
	L*	a*	b*	L*	a*	b*	ΔE_{00}
Cotton	85.01	2.06	11.22	90.78	0.11	6.26	5.65
Linen	65.18	1.65	10.25	80.14	2.08	11.33	11.25
Jute	58.95	5.80	16.47	65.13	6.63	28.73	8.19

TABLE 4. L*, a*, b* coordinates and ΔE_{00} values for the samples photo-aged in lightbox II, before and after ageing

Textile	As received			Photo-aged			
	L*	a*	b*	L*	a*	b*	ΔE_{00}
Cotton	85.33	2.01	10.91	87.67	0.69	7.73	3.12
Linen	64.82	1.60	10.36	71.44	2.57	10.23	5.39
Jute	58.79	6.42	17.38	66.14	3.60	17.57	7.00

chromophores produced during photo-ageing was perhaps too low to affect the colour measurably. Alternatively, the linen textile may have been treated during processing using antioxidants or UV screens to prevent photo-yellowing. These results show that exposure to light can be detrimental to textiles, even when UV radiation is filtered.

CONCLUSIONS

Cotton, linen and jute textiles were exposed to a light dose of 30 Mlux.hours in two lightboxes, one with light with a high UV content and the other with the UV radiation filtered. The mechanical strength of the jute and linen samples aged in the lightbox with a high UV content decreased significantly, which was attributed to the high lignin content in jute and to the possible presence of photo-sensitizers in linen. The mechanical strength of the cotton samples was not affected by UV radiation under the conditions used. In contrast, for the lightbox with UV radiation filtered from the illuminant, the samples did not show any signs of mechanical weakening. There was a significant change in colour for all the samples, although the change was higher when UV radiation was included. The jute samples yellowed, which has been attributed to their higher lignin content compared to cotton and linen. These experiments suggest that visible light does not affect the mechanical strength of modern undyed cellulose-based textiles, although it is responsible for changes in colour. Until the 1980s, light-sensitive objects were often displayed in the British Museum (as in

many other museums) in daylight without UV filtration on windows and skylights. It is possible that the mechanical weakening of fabrics reported by conservators is a post-irradiation effect, following earlier exposure to UV radiation. Post-irradiation degradation is an effect that has been known for more than 60 years; see for example the work of Havermans and Dufour [7]. Alternatively, in the case of historical fabrics, mechanical weakening could be linked to a treatment applied to the fabrics, such as the use of mordants or dyes.

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MATERIALS AND SUPPLIER

- Cotton canvas CC31, artist linen L36 and jute tarpaulin J65: Whaleys Ltd, Harris Court, Great Horton, Bradford BD7 4EQ, UK. Email: info@whaleysltd.co.uk

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