

ULTRAVIOLET ABSORBERS: A TREATMENT TO REDUCE FADING AND DEGRADATION OF TEXTILES

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Abstract. Fiber artists, as well as museum personnel, have attempted to reduce fading and/or deterioration in textiles by 1) using lower levels of lighting, 2) using incandescent lights instead of fluorescent lights, and 3) using ultraviolet filters on fluorescent lights. However, in many public buildings and in some daylighted museum galleries, textiles may be displayed without protection from light by any of the above measures. Therefore, many contemporary textiles are subjected to unusually high levels of lighting because most North American buildings are well lighted by fluorescent lamps and/or daylight through large expanses of window glass that emit or transmit sizable amounts of ultraviolet radiation. Ultraviolet radiation is particularly damaging to textiles, paper and other organic materials because it is capable of inducing photochemical changes that result in fading and strength loss. This study examined ultraviolet absorbers as an alternative method for reducing light-induced fading and degradation.

Most ultraviolet absorbers commercially available in the United States were initially screened for potential use on textiles on the basis of color, toxicity, solubility, and ability to reduce fading. After preliminary evaluations, four benzophenone-based absorbers were selected for further study. The UV absorbers were applied to colored wool textiles plus undyed cotton, linen, silk and wool by an immersion procedure. After treatment the specimens were exposed to light in a xenon-arc Weather-Ometer, an accelerated lightfastness testing instrument. Total color change was instrumentally measured using a HunterLab tristimulus colorimeter. Strength loss was evaluated by breaking strength tests using a CRE Scott Tester.

Results showed that three of the UV absorbers modestly reduced fading in approximately fifty percent of the dyed wool specimens and slightly suppressed degradation in the undyed fibers. The treatment shows promise for use on wool textiles such as tapestries colored with natural dyes.

Introduction.

The rate of fading and degradation of textiles and other organic materials on display is influenced by the intensity and wavelength distribu-

tion of the light source to which they are exposed and by other environmental factors, such as temperature, relative humidity, and atmospheric pollutants. Light sources, such as daylight through window glass and fluorescent lamps that transmit or emit sizable percentages of ultraviolet radiation, are particularly damaging to textiles, paper and other items of organic materials. Therefore, contemporary North American textiles installed in public buildings are especially at risk because most buildings are lighted by large numbers of fluorescent lamps and/or by daylight through huge expanses of window glass.

Fiber artists, as well as museum personnel, have attempted to reduce fading and/or degradation in textiles in a variety of ways including the use of lower levels of lighting in exhibit areas, the use of incandescent lighting instead of fluorescent lighting, and the use of ultraviolet filters on fluorescent lights (4, 9). However, in many public buildings and in some daylighted museum galleries, textiles may be displayed without protection from light by any of the above measures (14).

Textile scientists and conservation scientists have speculated on the usefulness of ultraviolet absorbers as a method of reducing fading and degradation in textiles on display (13, 18). Ultraviolet absorbers are compounds that preferentially absorb ultraviolet radiation and re-emit it as harmless infrared radiation thereby stabilizing fibers and dyes against light-induced changes (15). Some research has shown that UV absorbers improved the lightfastness of selected synthetic dyes from ten percent to six hundred percent (5, 8). However, most research on ultraviolet absorbers has focused on the prevention of yellowing of undyed wool and cotton, rather than on the reduction of fading of dyed textiles (7, 16-17, 19, 21-23). No previous research has examined the ability of ultraviolet absorbers to reduce fading when applied directly to fabrics colored with natural dyes. Improving the lightfastness of natural dyes is of interest to fiber artists as well as museum personnel responsible for historic textiles colored with fugitive natural dyes.

The objectives of this study were to 1) screen commercially available ultraviolet absorbers and identify those with characteristics suitable for use by fiber artists and conservators, 2) determine if ultraviolet absorbers applied by an immersion procedure could reduce fading of textiles colored with natural dyes, and 3) determine if ultraviolet ab-

sorbers applied by an immersion procedure could reduce photodegradation in undyed cotton, linen, silk and wool, plus wool dyed with natural dyes.

Experimental procedure.

Fabric

Cotton (style 400), linen (style L-51), silk (style 604) and wool (style 523) were purchased from Testfabrics, Inc., Middlesex, New Jersey for use in this study. Samples measuring 22.7 cm by 30.5 cm were scoured individually in 0.5 percent soap (AATCC) solutions in an Atlas Launderometer at 90°C for thirty minutes to remove impurities from manufacturing.

Dyeing procedures

The natural dyes evaluated were cochineal, madder, fustic, weld, turmeric, and indigo. Except for turmeric, they were among the most widely used dyes for red, yellow and blue colors in historic American and European textiles (10-12). In addition, they continue to be used by contemporary fiber artists. Although turmeric, a very fugitive dye, was not used as frequently as other yellow dyes historically, it was included in this study so that dyes with a range of lightfastness properties would be represented.

Most wool samples were premordanted with alum, tin or chrome mordants, then dyed. Wool samples dyed with fustic (alum and tin mordants) were dyed and mordanted in a single bath because level dyeings could not be achieved with a premordanting process. The hydrosulfite reduction method as described by Adrosko (1) was used to apply the indigo vat dye. A complete description of the dyeing and mordanting procedures is reported elsewhere (6).

Ultraviolet absorbers treatments

Ultraviolet absorbers were selected on the basis of commercial availability, color, toxicity, solubility, their effect on hand, and their ability to prevent fading in pilot tests. They had to be non-toxic so that artists and conservators could easily apply them without the necessity of spe-

cial apparatus and extensive safety precautions. In addition, they had to be colorless or near colorless so that they would not discolor the textiles to which they are applied. Finally, they had to be soluble in water or perchloroethylene, the solvents commonly used in cleaning or finishing procedures. In total, twenty-three ultraviolet absorbers available commercially in the United States were screened for potential use on textiles. After preliminary evaluations, four alkyl hydroxybenzophenone absorbers were selected for further study and designated by the researchers as UVA-1 (Inhibitor DOBP, Eastman Chemical Products, Inc.), UVA-2 (Cyasorb UV 531, American Cyanamid Co.), UVA-3 (Uvinul M-40, BASF Wyandotte Corp.), and UVA-4 (Uvinul MS-40, BASF Wyandotte Corp.).

Outside of commercial textile mills, ultraviolet absorbers can be easily applied to dyed textiles by one of two methods: spray application or immersion of the textile in ultraviolet absorber solutions. Immersion of a textile in an aqueous or organic solvent solution of ultraviolet absorber and air drying provides a more uniform and intimate dispersion of the ultraviolet absorber. In addition, it closely approximates a wet cleaning or dry cleaning treatment that conservators would consider acceptable. Therefore, the ultraviolet absorbers were applied by an immersion procedure in this study so that the treatment, if beneficial, would not require additional handling of museum textiles and would provide for the most intimate treatment of contemporary as well as museum textiles.

Specimens (6.5 cm by 18 cm) were immersed in solutions of the absorbers using either perchloroethylene or water as the diluent. Solutions of the organic solvent soluble absorbers were prepared by dissolving 2 grams of UVA-1, UVA-2, or UVA-3 in 98 ml of perchloroethylene, and solutions of the water soluble absorber were prepared by dissolving 2 g of UVA-4 in 98 ml of 0.1 percent (wt./vol.) soap and water solution to increase wettability.

Two sets of untreated control specimens were prepared because of the diluents required for the ultraviolet absorbers. The controls for the organic solvent soluble absorbers (Control P) were immersed in perchloroethylene, whereas the controls for the water soluble absorber

(Control S) were immersed in a 0.1 percent (wt./vol.) soap and water solution, followed by air drying for twenty-four hours.

Fabric specimens (6.5 cm by 18 cm) for color and strength analysis were immersed individually in the ultraviolet absorber solutions for two minutes, then air dried on fiberglass screens for twelve hours. The average percent add-on of the ultraviolet absorbers was $3 \pm 1\%$, which was the concentration recommended by the manufacturers. Higher add-ons were evaluated during pilot tests, however, they stiffened the treated specimens and did not reduce fading any better than did the three percent add-ons.

Exposure to light

The specimens were mounted in exposure masks and exposed to xenon light in an Atlas Electric Devices (Chicago, Illinois) 2500 watt xenon-arc Weather-Ometer for 80 AATCC Fading Units (AFU's), according to procedures in AATCC Test Method 16-E, Colorfastness to Light: Water-Cooled Xenon-Arc Lamp, Continuous Light (2). The xenon-arc lamp was used in the accelerated light exposure because it simulates the spectral characteristics of daylight better than any other artificial light source. Borosilicate inner filters and soda lime outer filter glasses were used with the xenon lamp to simulate daylight exposure behind window glass. Because the spectral intensity of the xenon-arc lamp declines with age, exposure periods were reported in terms of AFU's rather than clock hours. Xenon Reference Fabric was used to control the exposure periods. Xenon Reference Fabric is a disperse dyed polyester material with a constant rate of fade (2). It was exposed to the xenon light along with the test specimens until it showed a color difference of 20 ± 1.7 CIELAB units at which point the specimens were considered exposed to 20 AFU's. Light exposure continued until the test specimens were exposed to a total of 80 AFU's of xenon light as determined using the Xenon Reference Fabric. The length of exposure was limited to 80 AFU's because most natural dyes show significant fading in that period (20).

Instrumental color evaluation

The specimens were evaluated after exposure to 80 AFU's of xenon light with a HunterLab D25-M tristimulus colorimeter, according to AATCC Test Method 153-1978, Color Measurement of Textiles: Instrumental (2). Color measurements were made using a 2.54 cm viewing aperture and two readings were averaged for each specimen. Total color difference (DE) was measured on the dyed wool specimens after light exposure. Specimens were backed with one layer of self material. Color difference was calculated according to CIE 1976 L*a*b* equation: $DE = [(DL)^2 + (Da)^2 + (Db)^2]^{1/2}$ where DL = difference in lightness-darkness, Da = difference in redness-greenness, and Db = difference in yellowness-blueness.

Evaluation of degradation

Warp breaking strength tests (one-half inch ravelled strip method) were conducted on the fabric specimens following exposure to 80 AFU's of light. Procedures in ASTM D 1682, Standard Test Methods for Breaking Load and Elongation of Textile Fabrics were followed using a CRE Scott Tester (3).

Statistical analysis

One-way analysis of variance procedures were used to measure the effects of ultraviolet absorber treatments on color difference and breaking strength of undyed cotton, linen, silk and wool plus wool colored with selected natural dyes. Duncan's Multiple Range Test was used to further analyze the means when analysis of variance procedures showed that UV absorber treatment was a significant variable.

Results and discussion.

Color change in the dyed wool

The mean color difference values and results of the Duncan's Multiple Range Test by dye/mordant combination after 80 AFU's of xenon light exposure are given in Table I. Higher color difference values represent greater change in color. As expected, indigo, a very lightfast dye, showed the least amount of color change (DE = 1.3 for Control-P)

while turmeric (alum), a fugitive dye, showed the greatest amount of fading (DE = 59.0 for Control-P).

Examination of the color difference values showed that the organic solvent soluble absorbers (UVA-1, UVA-2, and UVA-3) significantly reduced fading in five of the twelve dye/mordant combinations: fustic (alum and chrome) madder (alum and tin), and turmeric (alum). Although statistically significant, the reduction in fading was modest with differences between the controls and treated specimens ranging from 1.1 to 6.3 CIELAB units. In addition, absorber UVA-2 significantly reduced fading in cochineal (tin) and weld (alum). Madder (alum) was protected against fading by the UV absorber treatments more than any other dye.

Water soluble absorber UVA-4 significantly reduced fading in three of the twelve dye/mordant combinations: madder (alum and tin) and weld (alum). However, it did not improve the lightfastness in cochineal (alum and tin), fustic (alum, chrome and tin), turmeric (tin), or weld (tin). Unfortunately, this absorber caused a significant increase in fading in two of the dye/mordant combinations: turmeric (alum), and indigo.

Table I Mean color difference values for UV absorber treatments on dyed wool after 80 AFU's of light exposure

Treatment	DE	Duncan's ¹ Grouping	Treatment	DE	Duncan's ¹ Grouping
Cochineal (Alum)			Cochineal (Tin)		
Control-P	8.0	A	UVA-1	8.9	A
UVA-1	7.6	A	Control-P	8.3	A B
UVA-2	7.4	A	UVA-3	8.3	A B
UVA-3	7.1	A	UVA-4	7.7	B C
Control-S	6.1	B	UVA-2	7.4	C
UVA-4	6.0	B	Control-S	7.2	C
Fustic (Alum)			Fustic (Chrome)		
Control-P	23.9	A	Control-P	6.1	A
UVA-3	22.0	B	Control-S	5.2	B
UVA-1	22.0	B	UVA-3	5.0	B C
Control-S	21.9	B	UVA-1	4.7	B C
UVA-2	21.4	B	UVA-2	4.7	B C
UVA-4	20.3	B	UVA-4	4.3	B C
Fustic (Tin)			Indigo		
Control-P	28.0	A	UVA-4	6.0	A
UVA-1	26.3	A B	UVA-2	2.3	B
UVA-4	26.1	A B	UVA-1	1.9	B
UVA-3	26.1	A B	UVA-3	1.6	B
UVA-2	24.9	A B	Control-P	1.3	B
Control-S	24.4	B	Control-S	1.3	B
Madder (Alum)			Madder (Tin)		
Control-P	14.1	A	Control-P	10.3	A
Control-S	12.7	A	Control-S	9.0	B
UVA-3	9.7	B	UVA-3	9.0	B
UVA-2	9.6	B	UVA-2	8.4	B C
UVA-1	8.9	B C	UVA-1	8.0	B C
UVA-4	7.5	C	UVA-4	7.6	C
Turmeric (Alum)			Turmeric (Tin)		
UVA-4	60.3	A	Control-P	57.4	A
Control-P	59.0	A	UVA-2	57.2	A
Control-S	56.0	B	UVA-1	57.0	A B
UVA-2	54.6	B C	UVA-3	56.9	A B
UVA-1	53.3	C	Control-S	56.2	A B
UVA-3	52.7	C	UVA-4	54.9	B
Weld (Alum)			Weld (Tin)		
Control-P	18.9	A	UVA-3	18.5	A
UVA-3	18.1	A B	UVA-1	17.8	A B
Control-S	17.7	A B	Control-P	16.4	A B C
UVA-1	16.8	B	UVA-2	16.0	B C
UVA-2	14.3	C	Control-S	14.6	C
UVA-4	6.1	D	UVA-4	14.1	C

¹Duncan's Multiple Range Test. Means with the same letter are not significantly different at the .05 level of confidence.

Breaking strength of the undyed fabrics

Breaking strength tests were used to evaluate the ability of the ultraviolet absorbers to reduce degradation in undyed fabrics of four natural fibers. The mean breaking strength values for the UV absorber treated fabrics of cotton, linen, silk and wool are given in Table II. All of the fabrics treated with the organic solvent soluble UV absorbers, UVA-1, UVA-2 and UVA-3, exhibited larger breaking strength values than their controls (Control-P) after 80 AFU's of light exposure showing that the UV absorber treatments had suppressed degradation. However, the differences in breaking strength between the treated fabrics and their respective controls was modest and usually not statistically significant (see Table II).

Table II Mean breaking strength for UV absorber-treated cotton, linen, silk and wool fabrics after 80 AFU's of xenon light exposure

Treatment	Kg-force	Duncan's Grouping ¹	Treatment	Kg-force	Duncan's Grouping ¹
Cotton			Linen		
UVA-3	26.1	A	UVA-3	42.8	A
UVA-1	25.3	A	UVA-2	38.5	A B
UVA-2	25.2	A	UVA-1	36.4	B
Control-P	24.2	A B	Control-P	33.6	B
Control-S	21.7	B	Control-S	32.3	B
UVA-4	1.1	C	UVA-4	0.9	C
Silk			Wool ²		
UVA-1	14.2	A	UVA-4	30.0	
UVA-2	14.0	A	UVA-3	29.9	
Control-S	13.7	A	UVA-1	29.4	
UVA-3	12.6	A	UVA-2	29.1	
Control-P	12.5	A	Control-S	28.4	
UVA-4	10.2	B	Control-P	27.9	

¹Duncan's Multiple Range Test. Means with the same letter are not significantly different at the .05 level of confidence.

²Duncan's Multiple Range Test was not reported on these data because analysis of variance procedures showed that none of the treatments significantly affected strength in undyed wool.

Cotton, linen and silk treated with water soluble absorber UVA-4 exhibited significantly lower breaking strength values than their controls (Control-S) after 80 AFU's of light exposure. This shows that absorber UVA-4 accelerated degradation in these fabrics rather than protecting them. Cotton and linen fabrics had virtually no strength remaining after the light exposure (see Table II).

Absorber UVA-4 was a sulfonated hydroxybenzophenone. The sulfonic acid groups in this absorber may have directly degraded the fibers or may have affected the absorber molecule in some way, thereby making the entire absorber molecule more acidic. Cotton and linen, which are degraded readily by acids, exhibited the greatest reduction in strength when treated with UVA-4.

Breaking strength of the dyed wool

The mean breaking strength for the dyed wool treated with UV absorbers is shown in Table III. In general, the UV absorbers were unable to significantly reduce strength losses in dyed wool as shown by the similarity of breaking strength values for the controls and the dyed wool. Analysis of variance showed that only turmeric (tin) was significantly affected by the treatments.

Table III Mean breaking strength for UV absorber-treated dyed wool after 80 AFU's of xenon light exposure

Breaking Strength (Kg-force)				
Treatment	Cochineal (Alum)	Cochineal (Tin)	Fustic (Alum)	Fustic (Chrome)
Control-P	27.1	26.9	27.3	26.4
Control-S	26.3	26.5	26.9	26.0
UVA-1	26.8	28.1	28.1	27.3
UVA-2	27.4	27.7	26.7	26.5
UVA-3	27.3	27.4	28.5	27.2
UVA-4	27.7	26.9	27.7	27.7

Breaking Strength (Kg-force)				
Treatment	Fustic (Tin)	Indigo	Madder (Alum)	Madder (Tin)
Control-P	27.5	28.2	26.2	22.9
Control-S	27.2	26.3	26.7	22.0
UVA-1	27.9	27.7	26.9	26.5
UVA-2	27.2	27.1	26.4	23.7
UVA-3	27.9	26.9	27.0	22.8
UVA-4	28.4	28.6	27.8	23.7

Breaking Strength (Kg-force)				
Treatment	Turmeric (Alum)	Turmeric (Tin)	Weld (Alum)	Weld (Tin)
Control-P	26.5	21.9	23.0	24.9
Control-S	26.3	22.5	27.0	23.6
UVA-1	27.5	26.3	27.2	25.1
UVA-2	26.9	27.5	26.9	25.0
UVA-3	28.3	23.6	28.0	25.6
UVA-4	28.3	24.1	28.1	25.2

Conclusions

Results showed that organic solvent soluble absorbers, UVA-1, UVA-2, and UVA-3, modestly reduced fading in approximately fifty percent of the dye/mordant combinations after 80 AFU's of light exposure. Water soluble absorber UVA-4 reduced fading in three of the dye/mordant combinations, but it also increased fading in two of the dye/mordant combinations [that is, turmeric (alum), and indigo].

Although most of the absorbers failed to significantly reduce the strength losses in the majority of the wool, cotton and silk, they did slightly suppress degradation in these fabrics. In addition, linen treated with organic solvent soluble absorber UVA-2 exhibited significantly less strength loss than its control. Unfortunately, the water soluble absorber, UVA-4, increased strength losses in cotton, linen, and silk during light exposure. Perhaps the sulfonic acid group on the water soluble absorber promoted rather than retarded degradation of these fibers.

In conclusion, treatment of textiles containing cotton, linen, or silk by immersion in water-soluble absorber UVA-4 cannot be recommended because it causes appreciable strength losses in these fibers. In addition, it accelerates fading in indigo and turmeric (alum). On the other hand, organic solvent soluble ultraviolet absorbers UVA-1, UVA-2 and UVA-3 show promise for use on wool textiles such as tapestries colored with natural dyes. This immersion treatment may be of particular interest to contemporary fiber artists who install their textile art in areas that preclude other measures for reducing the intensity and level of lighting. *Fiber artists could apply the UV absorbers to their tapestries and wall hangings as a part of routine finishing in preparation for installation. The treatment is simple and requires little time.*

It is possible that the absorbers would prove more effective if applied to wool during an exhaust dyeing procedure. This would likely provide a more intimate dispersion of the absorber among the dye particles than did the immersion procedure used in this study. Application of the absorbers and dyes simultaneously during dyeing procedures would be impossible, of course, for museum textiles, but merits further investigation for use on contemporary textiles.

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