BOROHYDRIDE: AN ALTERNATIVE TO OXIDATIVE BLEACHING OF CELLULOSIC TEXTILES

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ABSTRACT—Textile Conservators have long been reluctant to use bleaching agents, due to their detrimental effects on the fibers. The bleaching agents most often used in conservation are oxidizing agents, which can cause fiber damage. In contrast, borohydride bleaching removes degradation discoloration from aged cellulosics, while helping to stabilize the cellulose fiber. Case studies of eight discolored cellulosic objects treated with borohydride are described. These studies show that treatment with sodium borohydride gives consistent visual results, producing even, overall, mellow whitening of degraded cotton textiles. It has been shown effective in reducing a wide range of extraneous stains, and has little or no effect on the natural colorants in cotton and linen. Accelerated aging studies comparing sodium borohydride-treated samples to hydrogen peroxide-treated samples have indicated that color reversion occurs to a lesser degree in borohydride-treated samples. Results also suggest that the rate of discoloration of borohydride-treated textiles is comparable to the rate of discoloration in untreated textiles.

INTRODUCTION

Origin and Degradation Discoloration in Cellulosics

The cellulose molecule is a long chain of repeating glucose units. The repeating ring structure produces very stable polymer chains. These chains do not branch, so that cellulose remains supple despite a high degree of polymerization. There are three alcohol (C-OH) groups on each ring of the chain, and it is these groups which provide the electrostatic forces which permit the chains to stack closely, forming cellulose fibrils. These alcohol groups, however, are among the principal targets for oxidation in the aging process. Incomplete oxidation results in the conversion of alcohol groups to carbonyl groups (-C=O). Further oxidation converts the group to the acid carboxyl group (-COOH). Since any of the three alcohol groups on each ring may be attacked, a variety of products may result—all loosely termed oxycelluloses. Oxidation may be initiated by atmospheric oxygen or by a number of chemical agents, and is accelerated by heat, and catalyzed by transition metals such as iron, cobalt, and manganese.

The carbonyl groups which result from partial oxidation of cellulose are the principal source of the yellow-brown color characteristic of cellulose degradation (Feller 1971, Burgess 1987). More importantly, these carbonyl groups cause a strain on other bonds in the molecule, making them vulnerable to breakage and weakening of the fiber (Block and Kim 1984, Nevell 1985, Singh 1986).

Mechanism of Bleaching

Bleaching agents work by disrupting the molecular group responsible for color. In the case of cellulose degradation discoloration, this is the carbonyl group. Most traditional bleaching agents (chloramine-T, hypochlorite, perborate, hydrogen peroxide) are oxidizing agents which convert the carbonyl to an acid carboxyl group. Traditional reducing bleaches (sodium hydrosulfite, sodium bisulfite, sodium dithionite, and borohydride) act by reconverting the carbonyl group to an alcohol, in essence reversing the oxidation process to a degree (Burgess 1988).

Textile conservators have long been reluctant to use bleaching agents, due to their detrimental effects on fibers. The chlorinated compounds frequently result in unstable compounds, which lead to color reversion and possible fiber damage (Feller 1971). Sulfur-containing bleaches (with the exception of sodium dithionite) have poor color stability, due to their inability to produce end-products that resist oxidation by atmospheric oxygen (Burgess 1988). Hydrogen peroxide has been the bleaching agent of choice for most textile conservators because it is effective and relatively mild. Nonetheless, it is an oxidizing agent with the incumbent dangers of any oxidizing agent for cellulosic material (Nevell and Zeronian 1985). In addition, the molecular oxygen generated by hydrogen peroxide is itself damaging to cellulose under alkaline conditions (Taher 1975, Steinmiller 1976).

Sodium borohydride treatment of cellulose has a stabilizing effect. The conversion of carbonyl to alcohols relieves strain on molecular bonds, and improves stability of the molecule. Borohydride is a specific reducing agent and does not affect existing acid carboxyl groups on the molecule; it does, however, stabilize the carboxyl group through the alkaline sodium present in the process, and thereby inhibits the acid hydrolysis usually attributed to carboxyl groups (Nevell 1985). Several studies suggest that cellulose reduced through treatment with borohydride is resistant to hydrolysis, oxidation, and damage from near UV radiation (Block and Kim 1984, Nevell 1985, Block and Roy 1987).

Effect on Natural Colorants

Processed cotton is the purest form of cellulose known in nature, being nearly ninety-nine percent cellulose. Natural color in cotton is dictated by genetics. It has been suggested that the coloring matter is present in a complexed state as waxes and organic pigments (Steinmiller 1976). Linen contains between sixty-five percent and eighty-nine percent cellulose, the actual content being dependent on the conditions of growth and processing (Poot 1964). Other components of linen include hemicelluloses, pectic substances, and lignin; it is these components that provide the natural colorant in linen. While oxidizing agents affect these natural colorants, borohydride is a mild and selective reducing agent which has little or no effect on the natural colorant.

Working Properties of Sodium Borohydride

Borohydride must be delivered to the bleach bath as a salt. Paper conservators have traditionally used ammonium borohydride and potassium borohydride as well as sodium borohydride. The large bath volumes used by textile conservators make sodium borohydride the most practical borohydride salt to use. When discussing the mechanism of borohydride in general in this paper, the term "borohydride" alone is used. When discussing a treatment or procedure where a particular salt was used, the salt is specified (sodium borohydride in the case of the studies reported in this paper).

Borohydride releases hydrogen gas as it decomposes, a process which is greatly accelerated by the presence of acid. Borohydride reacts violently with strong oxidizing agents. These characteristics cause it to be regarded as a hazardous materials when used in large quantities, as it is for industrial purposes. In the small quantities and controlled conditions in which it is used in the laboratory, however, it is benign. It should be stored tightly closed and kept dry. It should be opened under adequate ventilation. Borohydride is a skin irritant and care should be taken during its use (Morton International, Inc.). For the bleaching treatments described here, dilute solutions are used, and normal precautions have proved adequate.

Sodium borohydride is readily available as a white crystalline powder, which dissolves easily in water at room temperature. It self-buffers at pH 9. During borohydride treatment of a textile, hydrogen is continuously evolved, and appears as a thin layer of bubbles which must be moved away from the textile in order to allow optimum access of the chemical to the fiber. This can be easily done by gentle agitation, or by brushing bubbles aside with a glass rod.

The borohydride bleaching process is slow, generally requiring two to four hours. This allows close monitoring of the process, and fine tuning of the degree of bleaching.

CASE STUDIES

Eight objects showing degradation discoloration were treated with sodium borohydride.

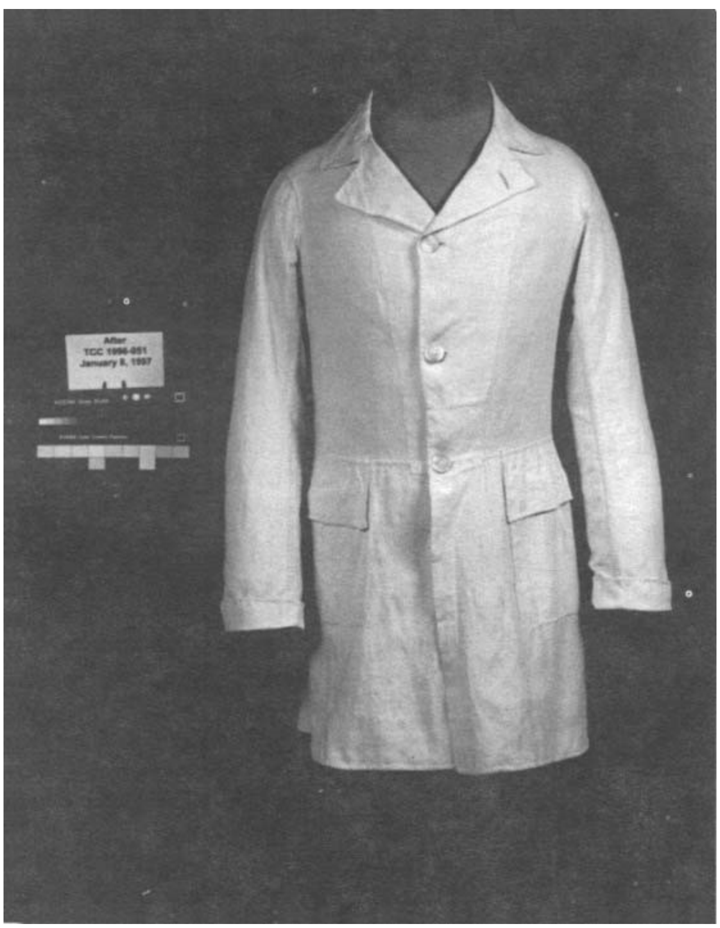
Procedures

The following bleaching procedure was adapted from that used at the National Museum of Denmark (Ringgaard):

1. The textile was surface cleaned.
2. The textile was wetcleaned with anionic surfactant and deionized water, and was thoroughly rinsed, with the final rinse made alkaline (pH 8) with ammonia.
3. The textile was introduced into 0.1 percent sodium borohydride solution, at a bath ratio of 40 ml:1 g of fabric.
4. The textile was allowed to soak for three hours, with periodic dispersal of hydrogen bubbles.
5. The textile was rinsed thoroughly and dried in an appropriate manner.

Table 1. Summary of Treatments with Sodium Borohydride.

Object	Staining	Treatment Variation	Treatment Results
Linen fichu	Overall degradation discoloration. Small medium-brown stains. Blackish soiling in rectangular pattern.		Wetcleaning removed most of degradation discoloration. Borohydride removed remaining discoloration. Significantly reduced but did not eliminate stains.
Cotton undersleeves; faded ink signature on one sleeve	Overall degradation discoloration. Small brown, liquid-based stains. Small black streaky stains. Scattered corrosion-type stains.		Wetcleaning removed much of the degradation discoloration. Borohydride removed remaining discoloration; significantly reduced stains. Signature is clearer and brighter.
Cotton undersleeves with linen trim	Overall degradation discoloration. Assorted brown stains of unknown origin. Scattered pinpoint corrosion-type stains. Random small greenish streaks.		Overall mellow white appearance. Brown stains significantly reduced. Greenish streaks remain but appear bluer.
Cotton fichu with cotton embroidery	Overall uneven degrada-tion discoloration.Two medium-brown liquid-based stains.		Even, overall mellow white. Stains significantly reduced.
Man's linen frock coat	Uneven degradation discoloration following crease pattern. Scattered corrosion-type stains.	Buttons removed before cleaning	Even, overall mellow white appearance. Stains significantly reduced.
Linen towel (39" x 21")	Overall degradation discoloration. Corrosion-type stains in center and proper right.	Bath ratio 38 ml:1 g fabric	Overall mellow white appearance. All stains reduced
Tablecloth. Cotton warp, linen weft. (58" x 66")	Overall degradation discoloration, more severe along fold lines. Scattered brown stains.	Bath ratio 38.5 ml:1 g fabric	Wetcleaning removed much of degradation discoloration. Borohydride further reduced yellowing and stains.
Eighteenth-century linen shirt.	Severe overall degradation discoloration. Tideline staining. Heavy corrosion-type staining. Foxing (positive test for iron)	No alkaline rinse. 4 1/2 hours soak time in borohydride solution.	Degradation discoloration removed. All stains significantly reduced. Overall mellow white color.

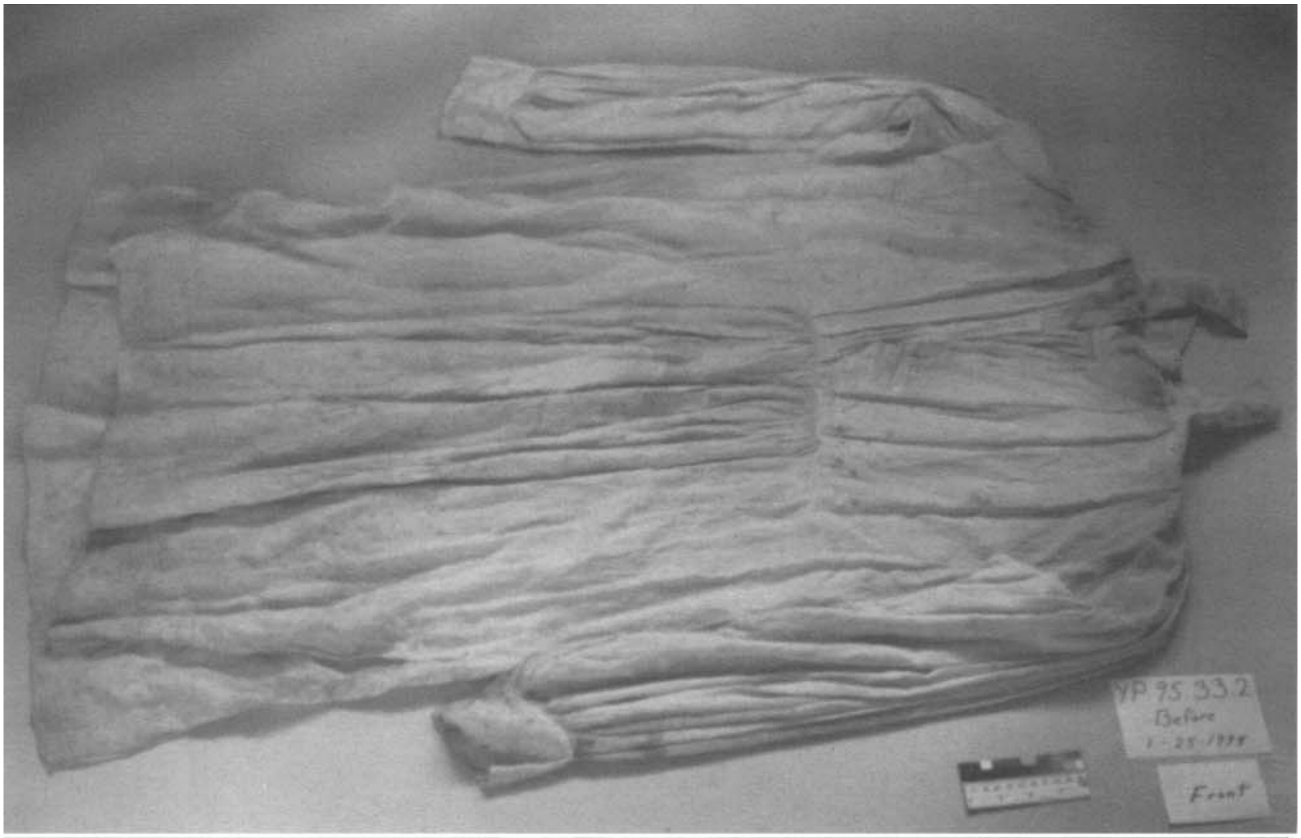


Above: Fig. 1. Man's linen frock coat, before treatment. Photo courtesy of the American Textile History Museum, Lowell, Massachusetts

Left: Fig. 2. Man's linen frock coat, after wet-cleaning and treatment with sodium borohydride. Photo courtesy of the American Textile History Museum, Lowell, Massachusetts.

Opposite above: Fig. 3. Eighteenth-century linen shirt, before treatment. Photo by permission of the Jamestown Yorktown Educational Trust, Jamestown, Virginia.

Opposite right: Fig. 4. Eighteenth-century linen shirt, after wetcleaning and treatment with sodium borohydride. Photo by permission of the Jamestown Yorktown Educational Trust, Jamestown, Virginia.


YP 95.33.2
Before
Front


After

Summary of Treatment Results

Table 1 gives an overview of the objects treated, the types of discoloration present, and the results observed after borohydride treatment.

In each of the eight case studies, Borohydride was extremely effective against degradation discoloration, resulting in an even, overall mellow white coloring (Figs. 1, 2). As a mild and selective reducing agent, borohydride would be expected to be less effective against extraneous stains than an oxidizing bleach. It proved, however, to be effective in reducing a wide range of stains. This is particularly well illustrated by the results of borohydride treatment on a late-eighteenth-century shirt that was heavily stained. The stains included corrosion stains that tested positive for iron content. Borohydride succeeded in reducing all stains on this shirt significantly, although it did not remove them entirely (Figs. 3, 4).

Of particular interest was the ink signature on one of the cotton undersleeves that was treated. The signature was somewhat brown and faded. The stability of the ink was pretested using a minute quantity of borohydride solution applied and monitored under a microscope to insure the signature's safety. Pretesting suggested that the signature would actually be enhanced by the borohydride, and subsequent treatment proved this to be true.

COLOR REVERSION STUDY

In order to gain some indication of the long-term stability of the bleaching effect of borohydride, accelerated aging tests were undertaken on borohydride-treated swatches, with hydrogen peroxide-bleached swatches aged for purposes of comparison.

Sample Sources

Because aged cellulose has very different properties from new cellulose, naturally aged textiles were selected as test sample sources. These included:

a) A cotton curtain lining which had been exposed at a sunny window for seven years, and had then been stored in conditions of extreme humidity and temperature fluctuation for twenty-five years (Cotton B-Fig. 5).

b) A cotton curtain lining exposed at a sunny window for an undetermined number of years, and then stored in conditions of extreme humidity and temperature fluctuation for thirty-two years (Cotton W—Fig. 6).

c) A portion of linen curtain lining of unknown history but showing degradation discoloration, supplied through the generosity of the Winterthur Museum Textile Conservation Department. This sample was of particular interest for the opportunity it afforded to observe the effect of bleaching on natural colorant (Linen—Fig. 7).

An iodine test for sizing proved negative for all three sources.

Protocol

The study consisted of four sample groups. Each group consisted of three swatches from each sample source, making a total of nine sample swatches in each group.

- Group 1: Controls—no bleaching treatment, no aging.
- Group 2: Bleached with hydrogen peroxide and aged.
- Group 3: Treated with sodium borohydride and aged.
- Group 4: Left untreated but aged.

Color measurements were made of all study swatches at three points in the study: (a) after washing, (b) after bleaching procedures, and (c) after aging.

Washing Procedure

Each test sample was washed in anionic surfactant and rinsed thoroughly using distilled water. The samples were then cut into 2-inch-square swatches and each swatch was labeled with a number stitched into the lower proper-right corner using white thread. From this point on, the swatches were randomized for each step of the study.

Bleaching Procedure

A. Hydrogen peroxide bleaching. A stock bleach solution was prepared using 20 g sodium metasilicate anhydrous, 12 g sodium carbonate anhydrous, and 100 ml 35 percent hydrogen peroxide, brought to 1 l with distilled water. The

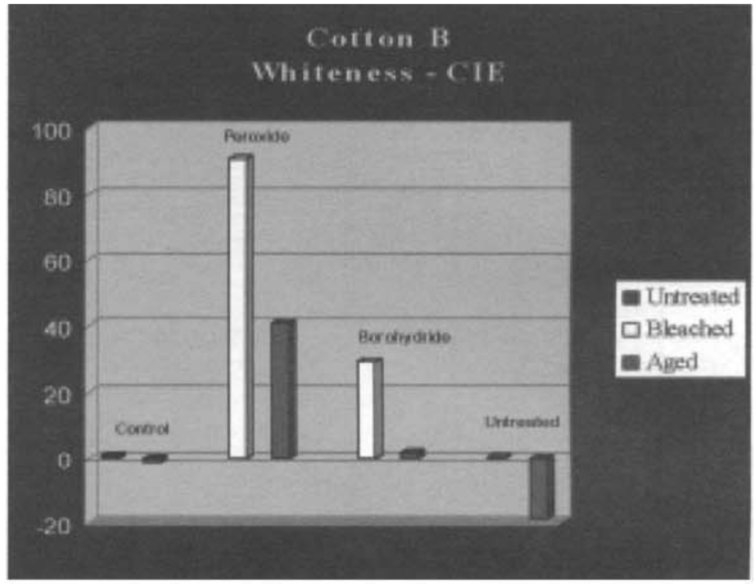


Fig. 5. CIE whiteness scale: value shifts on samples from Cotton B. (a) control samples, (b) peroxide-treated samples, (c) borohydride-treated samples, (d) untreated, aged samples.

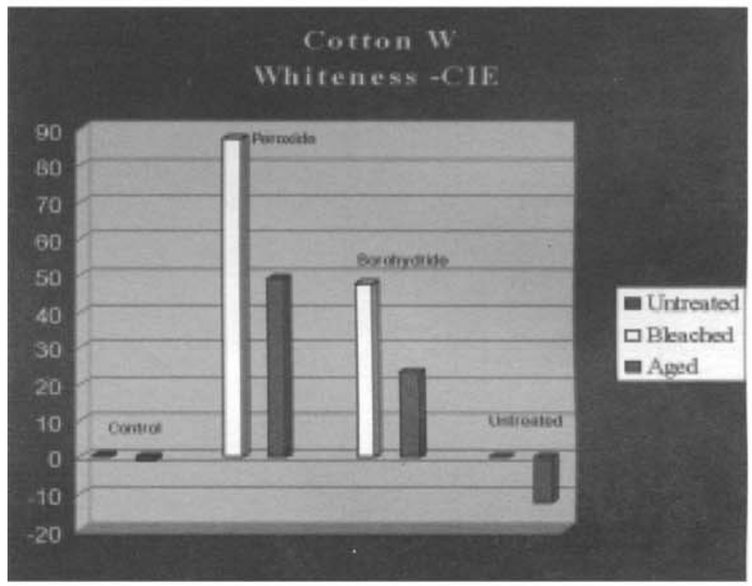


Fig. 6. CIE whiteness scale: value shifts on samples from Cotton W. (a) control samples, (b) peroxide-treated samples, (c) borohydride-treated samples, (d) untreated, aged samples.

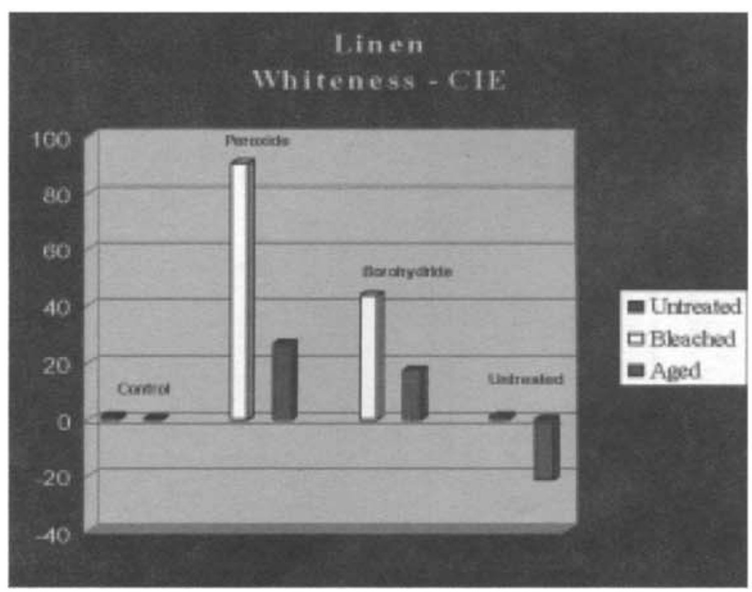


Fig. 7. CIE whiteness scale: value shifts on samples from the linen fabric. (a) control samples, (b) peroxide-treated samples, (c) borohydride-treated samples, (d) untreated, aged samples.

solution was pH 10 (as measured by 0-13 pH paper). A bath ratio of 10 ml:1 g fabric was used. Swatches from each source were bleached separately from swatches of the other sources, but using solution from a single stock. Swatches were immersed for five minutes, then blotted and placed between sheets of polyester film for three hours. The swatches were then rinsed thoroughly and allowed to air dry.

B. Borohydride bleaching. A stock solution was prepared of 0.1 percent sodium borohydride in distilled water. The solution was pH 9 (as measured by 0-13 pH paper). A bath ratio of 40 ml:1g fabric was used. Swatches of each source were treated separately from swatches of the other sources, but using solution from a single stock. Swatches were immersed in the bleach solution for three hours with intermittent light agitation to remove hydrogen bubbles. The swatches were rinsed thoroughly and allowed to air dry.

Aging

Aging was carried out at low humidity for six weeks at 80°C. Swatches to be aged were stitched to spun-polyester slings and preconditioned to fifty percent humidity. They were then suspended over the rack of a laboratory oven. The oven was vented by opening the door at two-week intervals and allowing air exchange. A low humidity level was maintained by placing a moistened piece of cotton flannel in the oven after each air exchange.

Color Measurements

Color measurements were made using the Hunter Lab MiniScan XE, model LAV, port size 31.8 mm, 45°/0° geometry. The MiniScan was linked to the Hunter Lab EZ Match Textile QC software program, which recorded each reading as tristimulus values, as well as by its value on each of several standardized scales. Two readings were made of each sample and averaged by the instrument for the recorded reading.

The instrument was calibrated against a perfect reflecting diffuser. Each reading was taken on a single thickness of fabric backed by a porcelain enamel white tile for consistency. A registration mark was stitched onto each sample swatch simply to insure consistency among repeat measurements.

For the purpose of comparing the effect of bleaching and aging on cellulosic samples, two color scales were selected: (1) Whiteness as defined by CIE standards (corresponding to ASTM E313-96), and (2) Yellowness as defined by ASTM E313. Values on both these scales are calculated by the EZ Match Textile QC software program.

Results

Color measurements for all samples at each stage in the study are listed in Table II. Measurements include the L*a*b* values as well as the CIE Whiteness and ASTM Yellowness values calculated from them.

The results are summarized in the graphs in Figures 5 through 7. Each graph displays the CIE Whiteness values for the samples from a given source. Values are presented as deviations from the initial readings, so that each pair of bars displays the color shift after bleaching (or at the second reading if untreated), and after aging (or at the third reading if not aged) for each procedure studied. The values represent the average whiteness readings of the three swatches in the study group. Shifts in yellowness values after treatment and after aging are comparable to the shifts in whiteness values.

Discussion

The discoloration of cellulose due to aging and oxidation is an ongoing process. Treatment with borohydride is not able to halt the process, but does in effect move it back significantly. The rate of discoloration in borohydride-treated samples from all three sources is similar to the rate of discoloration in untreated samples. The color shifts in samples treated with peroxide are more exaggerated, showing a greater degree of whiteness after bleaching, but a greater rate of discoloration with aging. This suggests that the functional groups affected by peroxide are more vulnerable to subsequent oxidation than those affected by borohydride.

The color shift seen in the linen samples gives an indication of the effect of peroxide on the natural colorants. A high degree of whitening after bleaching is followed by a high rate of discoloration with aging, suggesting that peroxide has affected the natural colorants, and that the resulting products are not stable. The pattern of color shift in borohydride-treated linen, however, is very similar to borohydride-treated cotton. Again the rate of discoloration of borohydride-treated linen is very close to that of untreated linen.

Table 2. Colorimeter Readings

Source	Treatment	Reading	Sample	L*	a*	b*	White	Yellow
Cotton B	Control	1st	B-11	84.82	2.53	19.46	-30.57	39.13
			B-8	85.94	2.12	18.2	-21.32	36.28
			B-12	85.88	2.15	18.12	-21.10	36.20
		2nd	B-11	85.53	2.52	19.41	-28.27	38.80
			B-8	86.56	2.12	18.15	-19.34	36.02
			B-12	86	2.36	18.56	-22.86	37.09
		3rd	B-11	84.78	2.54	19.68	-31.80	39.53
			B-8	85.94	2.05	18.38	-22.20	36.53
			B-12	85.64	2.17	18.32	-22.74	36.62
	Peroxide	1st	B-9	85.03	2.5	19.18	-28.63	38.57
			B-3	85.7	2.32	17.73	-19.69	35.73
			B-4	85.59	2.22	18.24	-22.49	36.54
		2nd: after bleach	B-9	93.82	-0.71	4.66	63.42	8.34
			B-3	94.11	-0.5	3.23	70.75	5.79
			B-4	93.93	-0.55	3.98	66.86	7.17
		3rd: after aging	B-9	90.77	-0.58	13.27	15.30	24.34
			B-3	90.98	-0.53	12.99	17.21	23.85
			B-4	91.05	-0.59	12.75	18.53	23.38
	Borohydride	1st	B-6	85.73	2.22	18.25	-22.13	36.52
			B-1	86.46	1.97	16.65	-12.37	33.36
			B-10	84.76	2.47	18.77	-27.40	37.94
		2nd: after bleach	B-6	88.99	0.67	14.35	5.47	27.63
			B-1	89.76	0.64	12.37	16.97	23.96
			B-10	88.84	0.72	14.83	2.77	28.54
		3rd: after aging	B-6	86.57	1.61	18.72	-22.13	36.52
			B-1	87.12	1.47	17.42	-14.35	34.06
			B-10	86.67	1.6	18.51	-20.85	36.13
	Untreated	1st	B-7	85.1	2.24	18.59	-25.63	37.33
			B-5	85.52	2.32	18.41	-23.50	36.95
			B-2	86	2.17	17.13	-15.96	34.49
		2nd	B-7	86.05	2.32	18.81	-23.94	37.46
			B-5	85.92	2.43	18.73	-23.90	37.46
			B-2	86.08	2.28	17.39	-16.98	35.01
		3rd: after aging	B-7	84.35	2.9	21.73	-42.94	43.39
			B-5	84.18	2.93	21.59	-42.76	43.25
			B-2	84.25	2.78	20.12	-35.39	40.66
Cotton W	Control	1st	W-12	82.81	4.5	21.24	-44.63	44.58
			W-8	82.54	4.46	20.61	-42.29	43.60
			W-6	83.13	4.27	20.32	-39.23	42.72
		2nd	W-12	83.29	4.56	21.41	-44.01	44.72
			W-8	83.3	4.6	20.98	-41.88	44.05
			W-6	83.53	4.36	20.58	-39.31	43.07
		3rd	W-12	82.88	4.47	21.41	-45.25	44.81
			W-8	82.87	4.49	20.98	-43.14	44.11
			W-6	83.12	4.25	20.53	-40.30	43.06
	Peroxide	1st	W-4	83.7	3.99	20.39	-38.01	42.38
			W-7	82.78	4.42	20.65	-41.82	43.54
			W-3	83.66	3.94	20.2	-37.18	42.02
		2nd: after bleach	W-4	94.22	-1.2	8.02	48.99	14.04
			W-7	94.3	-1.26	8.46	47.21	14.76
			W-3	94.15	-1.18	8.03	48.78	14.08
		3rd: after aging	W-4	91.35	-0.37	14.6	10.77	26.65
			W-7	91.05	-0.16	15.62	5.15	28.62
			W-3	91.28	-0.4	14.57	10.68	26.60
	Borohydride	1st	W-9	82.91	4.45	20.72	-41.76	43.63
			W-5	83.23	4.16	20.37	-39.22	42.66

Table 2. Colorimeter Readings cont.

			W-1	81.85	4.8	21.74	-49.81	46.07
Cotton W	Borohydride	2nd: after bleach	W-9	89.57	0.84	15.03	3.90	28.79
			W-5	89.77	0.58	14.36	7.56	27.39
			W-1	88.96	0.91	15.61	-0.57	30.00
		3rd: after aging	W-9	86.75	2.32	18.58	-20.77	36.83
			W-5	87	2.04	18.14	-18.03	35.79
			W-1	86.21	2.4	18.69	-22.86	37.27
	Untreated	1st	W-11	83.31	4.28	20.61	-40.14	43.15
			W-2	82.54	4.42	20.83	-43.42	43.94
			W-10	83.23	4.34	20.68	-40.65	43.33
		2nd	W-11	83.79	4.33	20.78	-39.53	43.28
			W-2	82.78	4.57	21.18	-44.36	44.55
			W-10	83.78	4.39	20.84	-39.84	43.44
		3rd: after aging	W-11	81.72	4.98	22.36	-53.20	47.31
			W-2	81.63	4.92	22.37	-53.55	47.32
			W-10	81.97	5.02	22.68	-54.05	47.78
Linen	Control	1st	L-3	68.92	7.09	22.84	-91.89	56.51
			L-12	68.91	6.79	22.35	-89.36	55.32
			L-9	68.69	6.85	22.33	-89.80	55.47
		2nd	L-3	69.42	7.14	23.08	-91.77	56.70
			L-12	69.65	6.7	22.27	-86.84	54.67
			L-9	69.46	6.83	22.42	-88.11	55.17
		3rd	L-3	69.02	7.11	22.98	-92.39	56.72
			L-12	69.12	6.69	22.3	-88.50	55.01
			L-9	68.95	6.75	22.35	-89.25	55.26
	Peroxide	1st	L-1	69.49	6.81	22.43	-88.12	55.16
			L-11	68.83	6.68	22.16	-88.53	54.90
			L-4	69.91	6.79	22.26	-85.96	54.58
		2nd: after bleach	L-1	89.49	-0.83	15.09	3.06	27.55
			L-11	88.6	-0.51	15.14	0.38	28.12
			L-4	89.65	-0.91	14.78	4.95	26.92
		3rd: after aging	L-1	82.85	3.37	25.38	-65.25	50.28
			L-11	82.91	2.9	23.63	-56.63	47.04
			L-4	83.45	2.94	24.94	-61.37	48.95
	Borohydride	1st	L-8	69.65	6.68	22.12	-86.00	54.37
			L-10	68.9	6.76	22.21	-88.58	55.04
			L-2	69.06	6.82	22.37	-88.97	55.29
		2nd: after bleach	L-8	77.5	3.3	18.17	-44.25	40.25
			L-10	77.1	3.25	17.92	-44.05	39.91
			L-2	77.33	3.41	18.23	-45.00	40.53
		3rd: after aging	L-8	74.74	4.96	21.84	-70.76	49.55
			L-10	74.52	4.91	21.49	-69.54	48.99
			L-2	74.67	5.17	22.02	-71.84	50.10
	Untreated	1st	L-5	69.42	6.69	22.16	-86.87	54.58
			L-7	69.23	6.56	21.88	-85.89	54.04
			L-6	69.7	6.59	21.94	-84.91	53.93
		2nd	L-5	70	6.71	22.3	-85.98	54.53
			L-7	69.92	6.59	21.99	-84.52	53.88
			L-6	70.34	6.63	22.06	-83.72	53.83
		3rd: after aging	L-5	67.74	7.52	25.26	-108.60	61.96
			L-7	67.49	7.4	25.19	-109.00	61.87
			L-6	68.34	7.38	24.88	-104.80	60.78

These studies have looked at the reversion of color due to degradation. Discoloration due to stains involves different chemical processes, and may water. The solution was pH 9 (as measured by 0-13 pH paper). A bath ratio of 40 ml:1 g fabric was used. Swatches of each source were treated separately from swatches of the other sources, but using solution from a single stock. Swatches were immersed in the bleach solution for three hours with intermittent light agitation to remove hydrogen bubbles. The swatches were rinsed thoroughly and allowed to air dry.

CONCLUSIONS

Sodium borohydride is a convenient, economical, and effective means of treating discoloration in undyed, aged cellulosic textiles. Treatment with sodium borohydride contributes to the long-term stability of the cellulose fiber. It consistently results in even, overall mellow whitening of the aged textile, and is effective in reducing a wide spectrum of extraneous stains as well. Borohydride treatment does not interfere with natural colorants as peroxide bleaching does. The degree of color reversion of borohydride-treated cellulosic textiles is less than that observed for peroxide-treated textiles. The rate of discoloration of borohydride-treated textiles appears to parallel closely the rate of discoloration in untreated textiles.

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