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The long-term effect of selected conservation materials used in the treatment of museum artefacts on some properties of textiles

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Abstract

In recent years conservators have begun to recognise that preventive conservation is as important as active conservation. Conservation treatments may play a role in accelerating the deterioration of museum artefacts in the long term. Accelerated tests were designed to find conservation materials, which would be safe for long-term use and would not cause degradation of museum artefacts. This study concerns the long-term effect of different conservation materials on the properties of linen textiles. Linen textile samples were treated with 5 different types of polymers, 4 different types of fungicides and 4 different types of deacidifying agents to evaluate the long-term effect of these materials on the physical and chemical properties of linen textiles. Three different types of accelerated ageing methods, heat, light and soil were used in this evaluation. The change of the physical and chemical properties of the untreated and treated linen textiles after ageing was assessed by different methods. The results showed that both treated and untreated linen textiles became progressively darker and showed progressive losses in tensile strength after ageing by different methods. X-ray results show that the ageing of the linen samples slightly decreased crystallite size in the longitudinal dimensions, also decreasing the total crystallinity compared to unaged samples. Results obtained by IR show changes in chemical properties of treated and untreated linen textiles after ageing by different methods. The results of this study will assist a conservator who seeks information about changes in the properties of linen textiles which may occur in the long term when they are treated with common conservation treatments.

Keywords: Linen textiles; Conservation materials; Polymers; Fungicides; SEM; EDX; Colour changes

1. Introduction

The conservation of museum artefacts presents choices between applying preventive or active conservation methods. Passive conservation methods, leaving the object in the natural state, may result in subsequent damage or disintegration. Using interventive conservation methods, which will structurally assist the long-term preservation of the artefact, may lead to some change in its mechanical and physical properties of the artefact [1]. There is a wide variety of materials, such as adhesives, polymers, fungicides, deacidifying agents, detergents, solvents, etc., which can be used in conservation of museum textiles [2–4]. The fragility of certain deteriorated textiles has caused particular conservation problems, and a range of adhesives and consolidates have been applied in an attempt enhance their long-term preservation [5]. Fungicides are used to treat textiles against biodeterioration [6–9]. Deacidifying agents are effective in reducing the degradation of cellulosic textiles [10,11].

When considering the treatment of a textile object, it is important to understand the probable effects of not

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treating it, as well as the probable long-term effects of treatments and, in addition, any possible side effects [3]. It is necessary to consider the long-term effect when evaluating the suitability of conservation materials. Some materials used in the conservation of historical textiles can damage the textile artefacts, which they are intended to protect or enhance. When considering the use of new materials for the conservation of objects of cultural or historic significance, several important factors must be addressed: will the treatment degrade the physical, chemical or appearance properties of the object; will the treatment enhance these properties; and, if so, will the enhanced properties remain stable long enough so that the "useful lifetime" of the object will be substantially prolonged [12].

Accelerated tests are designed to find materials which can be safe for long-term use and would not cause degradation of treated artefacts [13]. Accelerated ageing techniques are useful for detecting harmful agents released by conservation materials without identifying their chemical composition. Some tests carried out by conservation scientists give a prediction of between 50 and 100 years of stable life of the synthetic resins [2]. Accelerated light ageing is often used in evaluating the durability of materials used in conservation of artefacts [12,14,15]. The samples are exposed continuously to artificial light. In real museum conditions, lights are not on continuously and be at lower intensity. Based on a typical museum exposure of 3000 h per year (six days a week, 10 h a day), five years of continuous exposure to fluorescent lights at 700–800 lx is equivalent to about 200 years in a museum at 50 lx [15]. It was confirmed that 500 h of continuous exposure to artificial daylight is equivalent to about 100 years in a museum at 150 lx [16]. Feller presented a rough estimate of possible testing times for different classes of thermal stability based on the crude approximation that the rate of deterioration will double for a rise of 10 °C and on the statement that heating paper for 72 h (3 days) at 100 °C is equivalent to about 25 years of ageing under normal condition ageing. He also showed that heating paper for 36 h (3 days) at 140 °C is equivalent to about 100 years of ageing under normal conditions [17]. It has been shown that the outdoor microbial population in the air is similar to the communities of organisms found in soil. Hence, one of the most frequently used test procedures on treated fabrics is the soil burial test [7,18,19]. Although these types of tests are not directly appropriate to routine conservation investigations, they have been proven of interest in the peripheral information, which has evolved from them [7].

This paper provides information that a conservator can use in weighing the effects of the conservation treatments on linen textiles against other possible treatments or no treatment at all. Accelerated ageing techniques were used to predict the change in the properties of linen textile with time under defined exposure conditions. The results of the ageing experiments can then be used by the conservator in defining a "useful lifetime" for treated linen textiles. Consideration must be given, in assessing the durability of the treated linen textiles, to the differing environmental situations that would be encountered in the display or storage of linen textile artefacts. Accelerated thermal, light and burial soil ageing were carried out to determine if either the conservation materials adversely affected the normal property degradation rates of textile or the conservation materials reduced the textile degradation rate by acting as a barrier to water vapour or light.

2. Materials and methods

2.1. Fabric

Scoured, unbleached plain linen textile fabric was used (see Table 1).

2.2. Conservation materials

The conservation materials used in this work are selected polymers, fungicides and deacidifying agents commonly used in conservation of historical textiles [3,5,9,10,20,21] (see Tables 2–4).

2.3. Preparation of samples

Linen fabric samples were cut into 12 × 2 cm (length × width) warp test specimens. The warp strips were produced by ravelling away yarns on each side forming 1.5 cm wide strips with a 2.5 mm fringe down each side. Five samples were used for each test.

2.4. Treatments

Linen textile samples were treated with the selected polymers in 10% concentration except that Tylose was used in 4% concentrate according to the standard

Table 1
Specifications of used linen

Structure	Colour shade			Nominal wt.	Thread/cm.		Liner density (Tex.)		% Of elongation	Tensile strength
Plain weave	*L*	*a*	*b*	g/m	Warp	Weft	Warp	Weft	18	32.95
1/1	56.62	1.57	10.23	260	20	16	20	20		Newton

Table 2
List of polymers and resins used in this study

	Chemical name	Trade name	Producer	Conc.%
1	Ketone resin N	Beva 371 (SN)	Lascaux Restauro	10
2	Methyl hydroxy ethyl cellulose	Tylose MH300 (SD)	Hoechst	4
3	Ethyl acrylate/methyl methylacrylate	Plextol B-500 (E)	Lascaux Restauro	10
4	Vinyl acetate/acrylic ester copolymer	Mowilith DM5 (E)	Hoechst	10
5	Vinyl acetate/dibutyle maleate copolymer	Mowilith DMC2 (E)	Hoechst	10
6	Butyl acrylate/methyl methylacrylate	Lascaux 360 HV (E)	Lascaux Restauro	10

(E) = emulsion; (SD) = solid; (SN) = solution.

conservation methods [5]. Another part of the linen textile samples was treated by the selected fungicides in 1% concentrate according to the standard conservation methods[9]. A further part of the samples was treated by the selected alkaline deacidifying agents according to the standard conservation methods [11].

2.5. Accelerated ageing

2.5.1. Thermal ageing

The treated and untreated (control) linen samples were artificially thermally aged at 140 °C in precision forced convection oven for 72 h according to Kerr et al. [10].

2.5.2. Light ageing

For ageing by exposure to light, the treated and untreated linen samples were mounted in standard specimen holders and were exposed to light irradiation for 200 h. Irradiation of the samples was carried out using the Tera Light Fastness Tester [22].

2.5.3. Soil burial

Other treated and untreated (control) linen samples were buried in soil according to the standard test method for 10 days [23]. The procedure developed earlier for soil burial test was followed [24].

2.6. Testing and analysis

Colour differences were measured on Optimacth 3100 colour spectrophotometer using the CIELab colour system. The CIELab colour coordinates for L, a, and b values were recorded. Five colour readings were made and averaged for each sample. Colour changes are the differences between aged and untreated unaged linen sample and are expressed as ΔL, Δa, Δb. Calculation of total colour change (ΔE) was achieved by the use of the following equations: $\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{0.5}$.

Tensile strength and elongation of the treated and untreated linen samples before and after ageing by different methods were measured using a Lloyd Tensile Testing Machine Type T5K. These tests were done according to ASTM (2000) D 5035-95 [25]. The initial jaw spacing was 50 mm and the test speed was 25 mm/min, temperature was 23 °C, and R.H. 65%.

X-ray diffraction analysis (XRD) of the treated and untreated linen samples before and after ageing by different methods was carried out on a Philips X-ray diffractometer, type PW 1840, giving 40 kV Cu Kα radiation at 25 mA.

IR analysis was carried out for the treated and untreated linen samples before and after ageing by different methods using a Bruker IR Spectrometer. A small part of the sample was encased directly in sample holders and spectra were obtained with air as reference. The spectra were scanned from 4000–500 cm^{-1}. It was confirmed that FTIR spectroscopy is a rapid, sensitive and non-destructive tool to detect of oxidation degradation in cotton textiles [26].

3. Results and discussion

3.1. Colour change

Colour shades and colour differences of untreated and treated linen samples before and after ageing by different methods are presented in Tables 5–8. The results inTable 5 show a noticeable colour change in samples treated with resins as most of the treated samples became darker than untreated ones. Most of the samples treated with

Table 3
List of deacidifing agents used in this study

	Chemical name	Producer	Solvent
1	Calcium hydroxide	Fluka	Distilled water
2	Barium hydroxide	Fluka	Distilled water
3	Barium hydroxide	Fluka	Ethyl alcohol
4	Methoxy magnesium methyl carbonate (MMMC)	Fluka	Methyl alcohol

Table 4
List of fungicides used in this study

	Chemical name	Trade name	Producer	Toxicity	Solvent
1	2,2′-Methylene-bis(4-chlorophenol)	Dichlorophene	Merck	LD_{50} to dogs 2.69 g/kg	Ethyl alcohol
2	*P*-chloro-*m*-cresol	Preventol CMC	Bayer	No toxicity found	Ethyl alcohol
3	Sodium *o*-phenyl-phenol (NaOPP)/2-hydroxybiphenyl sodium salt tetrahydrate	Preventol O-Na	Bayer	LD_{50} to rats 2.48 g/kg	Distilled water
4	2,4,4′-Trichloro-2′-hydroxydiphenylether	Irgasan DP-300	Ciba	LD_{50} to rats 2.9 g/kg	Ethyl alcohol

resins had ΔL from 7 to 15 and ΔE from 7 to 15; only samples treated with Beva and Tylose caused little change in ΔL of about 2 CIELab units. These findings are in agreement with the results obtained in a previous study where it was found that most resins cause darkening of linen fabric [27]. The results showed very little colour change in linen samples after treatment with the tested deacidifying agents and fungicides. Most of these treated samples had about 1 CIELab unit, a colour change, which is barely detectable to the human eye. Only samples treated with MMMC showed slightly more darkening than other treatments as ΔL was about (−2). These results are in agreement with results obtained by others, who found that none of the deacidifying agents visibly altered new fabrics [10].

After the burial in soil (see Table 6), the untreated samples and most of the samples treated with resins and deacidifying agents became progressively darker ($-\Delta L$), more red ($+\Delta a$), and progressively more blue ($-\Delta b$) in character. The colour change of the samples may represent deterioration of treated and untreated linen fabric by fungi in soil. The results show that colour change of most of treated samples is a little less than that of the untreated ones, except that samples treated with Lascaux became a little more coloured than the untreated one. The treatment with fungicides significantly reduced the colour change of linen fabric compared with untreated samples or those treated with resins or deacidifying agents. Dichlorophene is the most tested fungicide and gave the best reduction in colour change of linen buried in soil. This result confirms that dichlorophene is the best fungicide to enhance the resistance of linen against fungal deterioration.

After heat ageing (see Table 7) untreated linen samples and those treated with polymers and fungicides became darker ($-\Delta L$), slightly more red ($+\Delta a$), and more yellow ($+\Delta b$) in character. The combined effect was a progressive darkening and browning of the linen fabric. Such heat-induced colour changes have been observed before, but only on untreated linen [29]. The results show that deacidifying agents especially calcium hydroxide and barium hydroxide significantly reduced the colour change of linen fabric aged by heat compared to the untreated ones and those treated by resins or fungicides. These results are in agreement with results obtained by others, who found that deacidifying agents reduced the yellowing of heated fabric [10]. The browning of the fabric represents oxidation of the linen to form conjugated unsaturated structures that accelerate deterioration of linen [28]. The results in Table 8 show that after light ageing, most of the treated linen samples and the untreated ones became a little brighter than the unaged one.

3.2. Tensile properties

Tensile strength and elongation of untreated and treated linen samples before and after being aged by

Table 5
The colour change of untreated and treated linen before the ageing by different methods

Treatment		Colour shades			Colour differences			
		L	*a*	*b*	ΔL	Δa	Δb	ΔE
0	Control (untreated)	56.62	1.57	10.23	0	0	0	0
1	Beva 371	54.25	1.5	10.03	−2.4	−0.1	−0.2	2.4
2	Tylose	54.11	1.53	10.79	−2.5	0.0	0.6	2.6
3	Plextol	49.22	2.17	11.86	−7.4	0.6	1.6	7.6
4	Mowilith	48.15	1.89	10.6	−8.5	0.3	0.4	8.5
5	Lascaux	48.37	2.15	11.46	−8.3	0.6	1.2	8.4
6	Calcium hydroxide	57.71	1.37	10.59	1.1	−0.2	0.4	1.2
7	Barium hydroxide A	56.32	1.24	10.18	−0.3	−0.3	−0.1	0.4
8	Barium hydroxide B	56.35	1.25	10.7	−0.3	−0.3	0.5	0.6
9	MMMC	54.58	0.95	10.13	−2.0	−0.6	−0.1	2.1
10	Dichlorophene	56.74	1.68	10.64	0.1	0.1	0.4	0.4
11	Preventol CMC	57.27	1.68	10.37	0.7	0.1	0.1	0.7
12	Preventol O-Na	56.04	1.69	10.81	−0.6	0.1	0.6	0.8
13	Irgasan	56.1	1.88	11.03	−0.5	0.3	0.8	1.0

Table 6
The colour change of untreated and treated linen after burial in soil

Treatment		Colour shades			Colour differences			
		L	*a*	*b*	Δ*L*	Δ*a*	Δ*b*	Δ*E*
0	Untreated	32.55	7.69	3.21	−24.1	6.1	−7.0	25.8
1	Beva 371	40.33	9.91	3.52	−16.3	8.3	−6.7	19.5
2	Tylose	49.25	8.2	3.13	−7.4	6.6	−7.1	12.2
3	Plextol	40.53	9.91	3.98	−16.1	8.3	−6.3	19.2
4	Mowilith	32.81	7.43	3.44	−23.8	5.9	−6.8	25.4
5	Lascaux	30.43	9.81	2.26	−26.2	8.2	−8.0	28.6
6	Calcium hydroxide	35.17	5.07	6.78	−21.5	3.5	−3.5	22.0
7	Barium hydroxide A	40.8	9.44	2.09	−15.8	7.9	−8.1	19.5
8	Barium hydroxide B	42.15	8.09	3.43	−14.5	6.5	−6.8	17.3
9	MMMC	45.35	4.89	3.3	−11.3	3.3	−6.9	13.6
10	Dichlorophene	52.23	1.99	8.53	−4.4	0.4	−1.7	4.7
11	Preventol CMC	43.97	6.27	5.34	−12.7	4.7	−4.9	14.4
12	Preventol O-Na	50.31	3.07	7.74	−6.3	1.5	−2.5	6.9
13	Irgasan	47.74	2.5	6.83	−8.9	0.9	−3.4	9.6

Table 7
The colour change of untreated and treated linen after heat ageing

Treatment		Colour shades			Colour differences			
		L	*a*	*b*	Δ*L*	Δ*a*	Δ*b*	Δ*E*
0	Untreated	56.75	3.26	18.89	0.1	1.7	8.7	8.8
1	Beva 371	50.18	3.75	17.51	−6.4	2.2	7.3	10.0
2	Tylose	53.21	3.25	16.66	−3.4	1.7	6.4	7.5
3	Plextol	51.28	4.17	18.85	−5.3	2.6	8.6	10.5
4	Mowilith	50.04	3.57	17.03	−6.6	2.0	6.8	9.7
5	Lascaux	48.11	3.91	17.25	−8.5	2.3	7.0	11.3
6	Calcium hydroxide	59.33	2.57	16.55	2.7	1.0	6.3	6.9
7	Barium hydroxide A	57.9	2.95	18.62	1.3	1.4	8.4	8.6
8	Barium hydroxide B	56.63	3.16	21.64	0.0	1.6	11.4	11.5
9	MMMC	55.37	2.16	18.07	−1.3	0.6	7.8	8.0
10	Dichlorophene	53.38	3.47	18.3	−3.2	1.9	8.1	8.9
11	Preventol CMC	57.07	2.95	17.3	0.5	1.4	7.1	7.2
12	Preventol O-Na	53.52	4.63	21.77	−3.1	3.1	11.5	12.3
13	Irgasan	57.07	3.04	16.23	0.5	1.5	6.0	6.2

Table 8
The colour change of untreated and treated linen after light ageing

Treatment		Colour shades			Colour differences			
		L	*a*	*b*	Δ*L*	Δ*a*	Δ*b*	Δ*E*
0	Untreated	60.62	1.74	10.8	4.0	0.2	0.6	4.0
1	Beva 371	59.88	1.73	11.99	3.3	0.2	1.8	3.7
2	Tylose	57.9	2.14	10.61	1.3	0.6	0.4	1.5
3	Plextol	54.28	2.36	11.45	−2.3	0.8	1.2	2.8
4	Mowilith	50.76	2.52	11.53	−5.9	1.0	1.3	6.1
5	Lascaux	50.73	2.72	11.86	−5.9	1.2	1.6	6.2
6	Calcium hydroxide	63.2	1.41	10.45	6.6	−0.2	0.2	6.6
7	Barium hydroxide A	61.62	1.41	11.38	5.0	−0.2	1.2	5.1
8	Barium hydroxide B	60.47	1.47	11.53	3.9	−0.1	1.3	4.1
9	MMMC	57.89	1.32	11.68	1.3	−0.3	1.5	1.9
10	Dichlorophene	58.04	2.29	11.71	1.4	0.7	1.5	2.2
11	Preventol CMC	58.36	2.51	11.39	1.7	0.9	1.2	2.3
12	Preventol O-Na	60.63	2.14	11.19	4.0	0.6	1.0	4.2
13	Irgasan	58.75	1.75	10.81	2.1	0.2	0.6	2.2

different methods were measured. The percentage losses in tensile strength and elongation compared with untreated unaged linen samples are presented in Figs. 1 and 2, respectively. The results of initial characterisation (before ageing) show that the treatments increased the tensile strength and elongation of linen samples. Initially, the tensile properties of samples treated with most of the tested conservation materials were higher than that of untreated linen sample. Samples treated with resins were the strongest, followed by samples treated with deacidifying agents, and the least were samples treated with fungicides.

Accelerated ageing had the following effects on tensile strength of samples treated with all tested conservation materials except dichlorophene. Generally, samples that were light aged were the weakest, followed by thermal aged, and the strongest were the soil burial samples. After burial in soil significant loss in tensile properties was found for the untreated linen sample and those treated with polymers and deacidifying agents. By comparing the loss of tensile properties of treated and untreated linen sample after burial in soil, it was found that most of polymers and deacidifying agents caused little reduction in the degradation of linen samples. These results in are agreement with results obtained by other studies, using other evaluation methods, which found that polymers and deacidifying agents both retard fungal deterioration [5,11].

The results show that after the burial in soil, the loss in tensile properties of linen samples treated with fungicides was significantly less than for untreated ones. These results confirm that fungicides increased the resistance of linen to biodeterioration. It is found that only dichlorophene prevents the biodeterioration of linen, as the sample treated with dichlorophene retained its tensile properties after the burial in soil. This is contrary to the results obtained in a previous study, using other evaluation methods which suggest that all tested fungicides prevent fungal deterioration [9]. It may be because the soil is more effective than the plate testing used before [9].

After heat ageing, the results showed that neither the heated aged linen samples treated with tested polymers and deacidifying agents nor the untreated linen sample retained their tensile properties; all showed substantially lower values after heat ageing. By comparing the loss in tensile properties of treated linen samples with untreated ones it was found that deacidifying agents caused significant reduction in the degradation of linen caused by heat. These findings are in agreement with results obtained by others, who found that deacidifying agents enhance properties of linen against heat degradation [10].

The results showed that polymers caused little reduction in the degradation of linen caused by heat. Tylose and Plextol are the polymers which most reduced the degradation by heat. The results show that after heat ageing there is no significant differences in degradation rate of tensile properties for either untreated linen samples or those treated with polymers. This finding is contrary to the results of studies on other polymers which suggest that polymers accelerate the deterioration by light [4]. This may be due to the different polymers which were used in that evaluation.

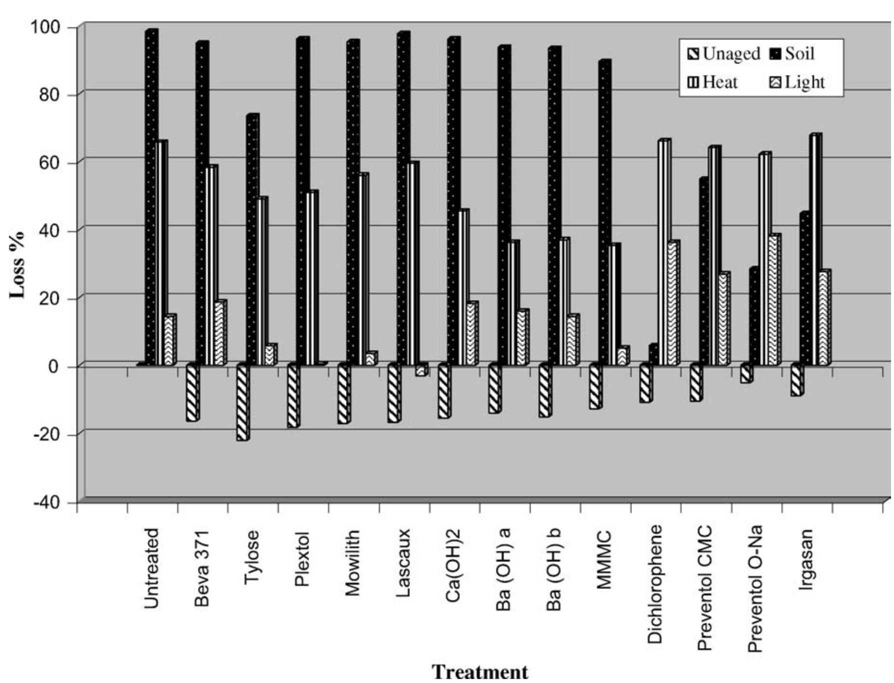


Fig. 1. Loss % in tensile strength of untreated and treated samples after aged by different aged methods.

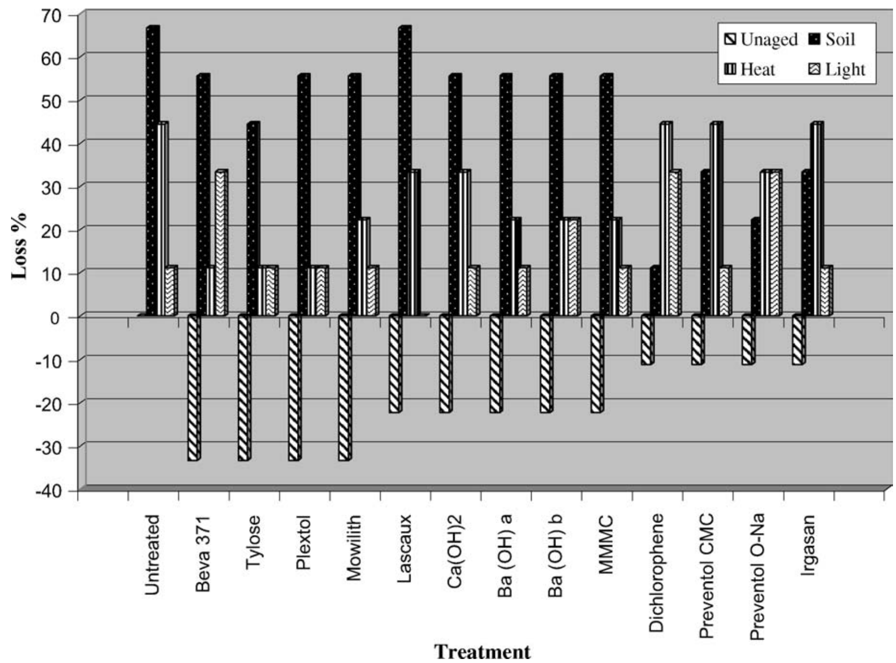


Fig. 2. Loss% in elongation of untreated and treated samples after aged by different aged methods.

In contrast, after light exposure, the linen samples treated with polymers showed significant improvement in tensile properties over untreated samples, except for the sample treated with Beva. Samples treated with all tested polymers except Beva did not show increased loss in tensile properties comparing with untreated samples after light ageing. Samples treated with these polymers retain their tensile properties as well as the untreated unaged sample. Only samples treated with Beva showed higher loss in tensile properties than the untreated sample after light ageing. The results show that no significant differences in degradation rate of tensile properties for either untreated linen samples or those treated with deacidifying agents, was found after light ageing.

After light exposure, linen samples treated with fungicides showed significant reduction in tensile properties over untreated linen sample. Samples treated with all tested fungicides increased their loss in tensile properties compared with untreated samples after light ageing.

3.3. X-ray diffraction analysis (XRD)

The results show that the initial WAXS diffractograms of untreated linen samples and those treated by tested conservation materials were the same except that the intensities of the diffractograms of treated linen samples were greater than that for untreated linen. This finding suggests that the treatment does not particularly affect the size and shape of crystallites in the linen, but the treatment slightly increased the crystallite size of the longitudinal dimension, increasing the total crystallinity (see Fig. 3).

After burial in soil significant changes in WAXS diffractograms of untreated linen samples and those treated with polymers and deacidifying agents were found compared with unaged linen. The results show that burial in soil caused the crystallite size of the longitudinal dimension of all samples to decrease markedly; also their lateral dimension and crystallinity index changed. These results indicate that degradation proceeded from the surface to the interior of the fibres. After burial in soil WAXS diffractograms of linen samples treated with fungicides, except Preventol CMC, and non-buried ones were the same except that the intensity of the diffractograms of buried samples were slightly less than that for non-buried ones. Also no significant changes in WAXS diffractograms of linen treated with dichlorophene were found after burial in soil. This finding indicates that dichlorophene protects linen against fungal deterioration (see Fig. 4).

After heat ageing WAXS diffractograms of untreated linen samples and those with the tested conservation materials were the same except that the intensities of the diffractograms of aged linen samples were less than those for unaged samples. However, the intensities of the diffractograms of all treated linen samples are larger than that of untreated one after heat ageing. This finding indicates that all test treatments reduced the loss of the intensity of the diffractograms of treated linen. This suggests that the heat ageing does not particularly affect the size and shape of crystallites in the treated linen, but decreases the total crystallinity and slightly

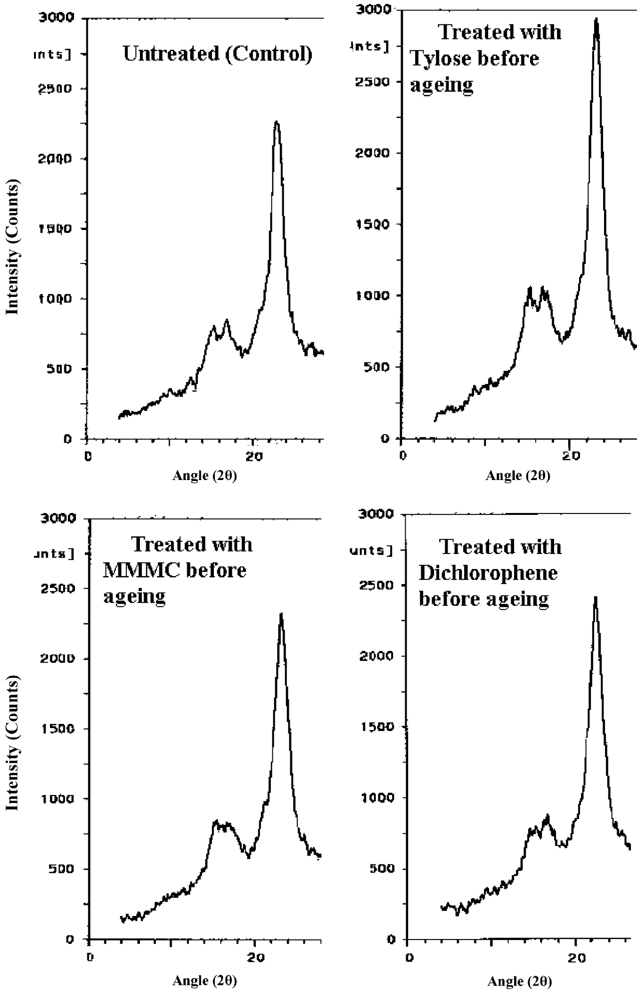


Fig. 3. Wide Angle X-ray (WAXS) diffractograms of untreated linen samples and those treated with different conservation materials, before ageing by different methods.

increases the amorphous fraction in the linen. This result is in agreement with other studies, which suggest the same result but on untreated cotton fabric [28]. The results show that of the tested materials deacidifying agents most induced the degradation of linen by heat (see Fig. 5).

After light ageing WAXS diffractograms of untreated linen samples and those treated by tested conservation materials were the same except that the intensities of the diffractograms were slightly less than that for unaged samples. However the results show that the intensities of the diffractograms of all treated samples are slightly more than that of untreated one after heat ageing. This finding indicates that all tested treatments reduced the loss of the intensity of the diffractogram of linen on light exposure. This result is in agreement with other studies, which suggest that light ageing decreases the crystallite size of the longitudinal dimension of linen fabrics, while the size of their lateral dimensions and the crystallinity index remained almost unchanged [29]. These results indicate that degradation did not proceed from the surface to the inner of the fibres, but longitudinally.

3.4. IR spectrometry analysis

Infrared spectra of untreated and treated linen samples before and after ageing by different test methods were recorded from 4000–500 cm^{-1}. The results showed that there are changes in the IR spectra of all test samples compared with the spectra for untreated unaged sample. However the results showed that soil burial most affected most of the samples tested, except those treated with fungicides. By comparing the results in Fig. 6, it is evident that there are significant spectral changes in the region from 1750–1600 cm^{-1} for untreated samples after ageing. There are new bands

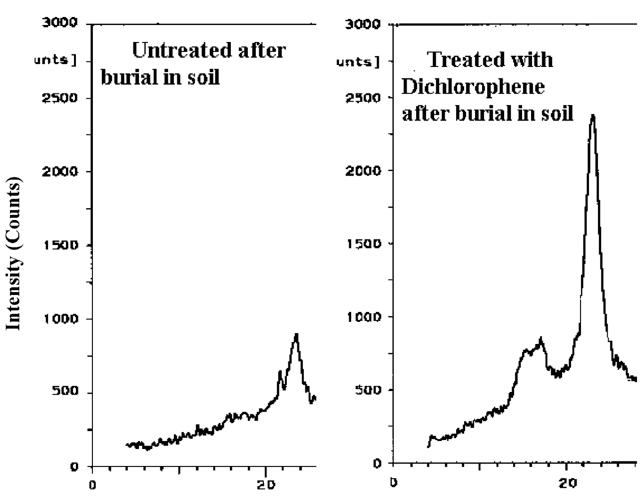


Fig. 4. Wide Angle X-ray (WAXS) diffractograms of untreated linen samples and those treated with dichlorophene, after burial in soil.

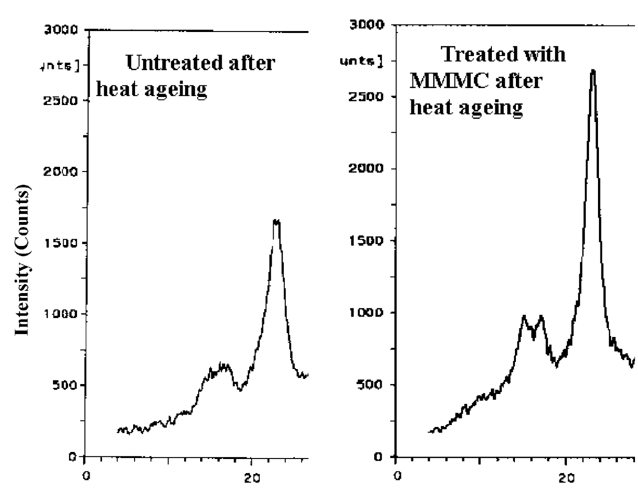
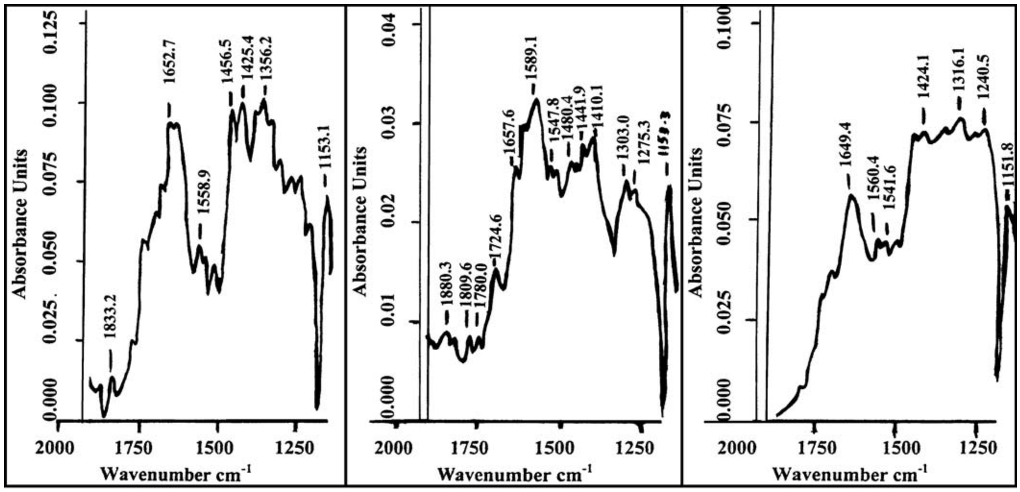


Fig. 5. Wide Angle X-ray (WAXS) diffractograms of untreated linen samples and that treated with MMMC, after heat ageing.

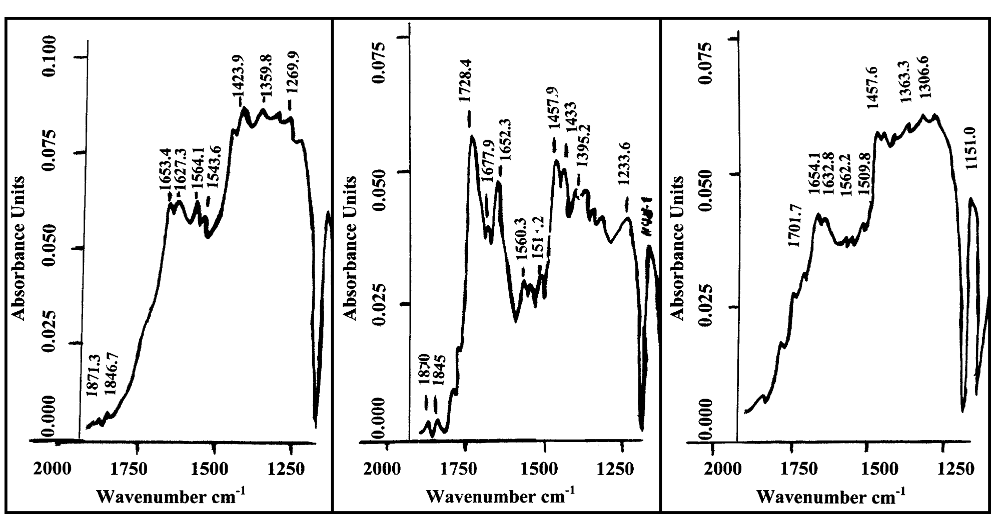


A) untreated, before ageing B) untreated, after burial in soil C) untreated, after heat ageing

Fig. 6. FTIR spectra of untreated linen samples before and after ageing by different methods.

related to carbonyl function groups created in the molecular structure of the deteriorated textiles. However the region from 1750–1600 cm^{-1} proved most convenient for monitoring cellulose degradation. It was confirmed that heat ageing of cotton cellulose involves carbonyl and carboxylate group functions, which can be monitored by the infrared absorptions at 1750–1600 cm^{-1} with FTIR Spectroscopy [26]. This carbonyl functional group could be derived from either aldehyde groups at 1600 cm^{-1} or carboxylate groups at 1750 cm^{-1}, reflecting the degradation of glycosidic linkages and/or the primary alcoholic groups. By comparing the variation in the intensity of the bands in this region (Fig. 5B and C) we see that there are pronounced increases in the 1720 cm^{-1} band in the spectra of the untreated sample after burial in soil, more than that for samples aged by heat. The pronounced increase in the 1720 cm^{-1} carboxylate band indicates that the oxidation may not form by direct conversion of the other functional groups whose absorptions change only slightly. This result indicates that the soil burial test is more effective in the degradation of linen textile than the heat test method.

The results show that all tested conservation materials affected the IR spectra of linen textiles after ageing by different methods. The changes in the spectra depend on the type of treatment and the ageing method. For example the results in Fig. 7, show that dichlorophene and Lascaux cause the linen sample to become more degradable, as the ratio of developed carbonyl and carboxylate functional groups are high after heat ageing. Other conservation materials such as Tylose reduced the ratio of developed carbonyl and carboxylate function groups (see Fig. 7).



A) Treated with dichlorophene, after heat ageing B) Treated with Lascaux, after heat ageing C) Treated with Tylose, after heat ageing

Fig. 7. FTIR spectra of treated linen samples before and after heat ageing.

4. Conclusions

- ☐ All tested polymers except Lascaux 360 HV enhance the long-term preservation of linen textiles. However there is no polymer that can completely prevent the deterioration.
- ☐ Among tested fungicides only dichlorophene can prevent biodeterioration of linen textiles, but on the other hand, dichlorophene accelerates the deterioration by heat and light.
- ☐ The tested alkaline deacidifying agents enhance the long-term preservation of linen textiles against heat deterioration.
- ☐ X-ray diffraction, which is commonly used in conservation, in identification of crystalline archaeological materials such as pigments, can also be successfully used in investigation and evaluation of linen textiles after their treatment with conservation materials.
- ☐ FTIR spectroscopy, which is widely used in conservation, for identification of dyes, resins, and so on, also can be successfully used in investigation and evaluation of the changes in the chemical properties of linen textiles after the treatment with conservation materials.
- ☐ Accelerated ageing techniques are useful for detection either if the conservation materials adversely affected the normal property degradation rates of textile or if the conservation materials act as a barrier to reduce the degradation rate.

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