NC STATE UNIVERSITY

JTATM

JOURNAL OF TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

Volume 4, Issue 4, Summer2005

Non-Destructive Methods to Investigate the Deterioration Extent of Coptic Egyptian Textiles

Omar Abdel-Kreem[1] and Khaled El-Nagar[2]

[1] *Conservation Department, Faculty of Archaeology, Cairo University, Egypt:* omaa67@yahoo.com

[2] *Textile Metrology Lab., NIS-Egypt, Tersa St., El-Haram, P.O. Box: 136 Giza, Code No. 12211, Egypt,* khngare@hotmail.com

ABSTRACT

It is necessary to document the properties of the various components when estimating the condition of a textile and when considering the appropriate conservation treatment. The results for some selected Coptic Egyptian textile objects, collected from different areas in Egypt have been studied by a variety of methods. Fibres were recognised by using either optical (OM) and scanning electron (SEM) microscopes. High performance liquid chromatography (HPLC), ultraviolet/visible (UV/VIS) and Fourier transform infrared FTIR spectrophotometers, were used for identification of dyes. SEM imaging has afforded an assessment of the degradation from changes in the surface morphology of the Coptic samples. The degradation of the textile samples has been detected by both x-ray diffraction analysis (XRD) and infrared spectroscopy (IR). Wool and linen fibers from the Egyptian Coptic textiles have been tested. The analytical results suggest the degradation of the tested samples. It is also clear from XRD, that the crystallinity of total cellulose and crystallite length in Coptic linen samples have been obtained by IR shows a change in the chemistry of degraded Coptic textiles.

Keywords: Dyed Egyptian Coptic textiles, Optical Microscope, SEM with EDX, FTIR Spectroscopy, X-ray Diffraction, UV/VIS Spectrophotometer, HPLC

1. Introduction

Material investigation is a necessary step in the documentation of the properties of the component materials of a textile object, in estimating its condition, in considering appropriate conservation treatment (Timmar-Balazsy & Eastop, 1998). The nature of an object exerts a fundamental influence on what can best be done to preserve it, therefore necessary to make a very thorough examination before any decision is made as to the ways and means. The examination of an object as a preliminary to conservation is a process of familiarization with both the fabric and structure, giving not only the knowledge of what it is and what is made from but also a feeling about the degree of handling it will stand, which is a vital factor in subsequent decision making. The methods of assessing the degree of degradation are perhaps more applicable to the choice of conservation materials than to the state of the objects, as they are all destructive by nature (Landi, 1998).

Egyptian Coptic-textiles are the textiles from A Christian burial in Egypt. Linen and wool fibers are the most

important fibers used in making the Egyptian Coptic textiles (Coptic Encyclopedia, 1991, Vol.7). Egyptian Coptic textiles illustrate range of dyes being used in the late Roman, early Byzantine and early Islamic periods. The most important dyes, which have been used in dyeing of Egyptian textiles, have been reported in previous study (Wouters, 1995). Textiles deteriorate naturally by the effect of oxidation, heat, mechanical stress, radiation, moisture, microbiological and enzymatic attack (Abdel-Kareem, 1998). Degradation of cellulosic materials causes changes in their oxidation stage, degrees of polymerization (DP), cellulose crystalinities, and mechanical properties (Kohara *et al*, 1993). Deterioration of cellulosic materials causes breakdown of the molecular structure, which in turn results in a loss of strength, extensibility and general durability, in discoloration, and fading, and affects the appearance of the material (Tera and Shady, 1993).

The non-destructive (ND) methods are used to investigate the historical textile materials be able to preserve them not to destruct them. Many different useful techniques and methods have been published for investigation the chemicals and physical properties of ancient textiles (Timar-Balazsy & Eastop, 1998). Scanning electron microscope (SEM) has been reported for understanding the deterioration of the textile materials (Abdel-Kareem, 1998, Abdel-Kareem & Szostak-Kotowa, 2003). While the analysis of ancient dyes are carried out by infrared (IR) spectroscopy, thin-layer chromatography (TLC), ultra-violet/visible (UV/Vis), three-dimensional fluorescence spectrum and HPLC (Koren, 1993, Gillard, et al, 1994, Andary and Prunac, 1996, Shimoyama, and Noda, 1996). It has been reported that HPLC is one of the most useful tool that can be used to investigate the ancient dyes on the textiles (Wouters & Rosario-Chirinos, 1993 & Wouters, 1995, Petroviciu & Wouters, 2002). SEM with EDX has been used in the detection of metallic mordants (Koestler *et al*, 1985).

The main aim of this work is to examine and investigate Coptic textiles and their dyes in order to understand the nature of these textiles. This study will help the conservators in developing methods for conservation of these Coptic textiles, which are present in many Museums and Churches in Egypt.

2. Materials and Methods

2.1 Material

2.1.1 Ancient Samples: Different dyed and undyed Coptic textile samples were collected from different Egyptian areas. All of these samples were dated to the second to the seventh centuries A.D. Individual fibres were separated according to the fibre type and the colour. Then, the analyses were carried on each of them separately according to the investigation procedures.

2.1.2 New dyed wool Samples: New wool samples were dyed by different commercial natural dyes combined with different mordant to be used as standard samples in the identification of the ancient dyes under test. The dyeing proves were carried out according to methods described by (Dalpy, 1989 and Liles, 1996).

2.2 Testing and Analysis

2.2.1 Optical Microscope (OM): The surface of the tested textile samples were investigated by Optical microscope. They were viewed through a video microscope system (SDL international- UK), at magnification (1000 X). For identifying the fibres, very small fragment of weft and warp threads were transferred to slides and examined through transmitted light microscope and according to the American standard testing method (ASTM D2130). Also a thin cross section of each thread was taken by using Precision fiber microtome.

2.2.2 SEM investigation: The Scanning Electron Microscope (SEM) investigation was carried out for the tested samples, using SEM of model (Philips XL 30) attached with EDX Unit, with accelerating voltage 30

K.V., magnification 10X up to 4000X and resolution (3.5 nm). The surface morphology of textile samples was measured on very small samples coated with gold. For EDX analysis, the individual fibres were separated according to their colour, where a single fibre of each colour was carbon coated. According to Kostler *et al*, 1985, the analysis has been carried on all the received samples without any treatment (washing or cleaning).

2.2.3 X-ray diffraction analysis (XRD): X-ray diffraction analysis (XRD) of textile samples were carried out on Philips X-ray diffraction, type PW 1840. The samples were analyzed using Ni filter and CuKa-radiation (?=1.540°A) at 40 Kv and 25 mA with 2? in the range of 5-50 at scan rate 2° min^{-1}. The crystallinity index (CrI) for linen was computed according to Segal *et al* relation (Lewin and Boldex, 1975**):**

Cr.I =[I (002)- I (am)/I (002)] X 100

where I (002) is the maximum intensity (in arbitrary units) of lattice diffraction

I(am) is the intensity of the lattic diffraction in the same units at 2?=20°, the angle that represents the amorphous scatter of cellulose.

2.2.4 Thermal analysis: Thermogravimetric analyses (TG) of tested samples performed on Shimadzu TGA-50, Japan. The thermograms were run under nitrogen atmosphere at constant heating rate of 10°C min^{-1} in a temperature of range 25°- 800°C (Jandura *et al*, 2000). Thermogravimetric analyses were done for the historical samples and the new unfinished unbleached linen and wool samples.

2.2.5 FTIR Spectroscopy: FTIR spectra of textile samples were measured by direct transmittance using the KBr technique. Spectra were recorded using a Bruker IR Spectrometer (Micro Analytical Center-Cairo University Egypt). The samples as small as about 1 mg of each colored fiber were cutted and mixed with powdered KBr and grinded in the KBr- disk die and pressed at approximately 14 Mpa (200 psi) pressure for 2 to5 min. ***(ASTM D 276, volume 07.01:2000)*** The sample contained the internal standards was tested by Fourier transform (FTIR) spectrophotometer in the Wavenumber range from 500 to 4000 cm^{-1}. The spectra were scanned from 4000-500 cm^{-1}.

2.2.6 HPLC investigation: *D*yes of the standard and ancient textile samples were extracted in accordance with the extraction techniques described by (Koren, 1992). The extract of each color was firstly tested for its UV/ Vis absorption in the wavelength range 200-780 nm to explore the characteristic absorption wavelength using UV/VIS double beam spectrophotometer (Perkin-Elmer, Model Lambada 35). The spectrophotometer was calibrated prior each scan using Holinium oxide filters at wavelength 360.8, 279.3 and 536.4 nm (Perkin Elmer, Application note BO191803). The characteristic absorption wavelength for all dyes was found at the same wavelength of 280.0 nm. This wavelength was used for the detection of HPLC investigation. The extracts for each standard ancient sample were degassed and injected in ZORBAX HPLC ODS system (Agilent 1100 series) through the analytical column of a length of 150 and 4.6 mm internal diameter. HPLC system was equipped with UV detector to detect the separated fractions. The HPLC analysis were carried according to (Petroviciu and Wouters, 2002) under the following conditions: initial raming of 5 min; linear gradient each 30 min, flow rate 1 ml min^{-1}, creating a system back-pressure of 46 minutes. Dye component was identified according to two criteria: the retention time and the UV/VIS spectrum.

3 Results and discussion

3.1. Optical Microscope: The results of the optical microscope show that there is progressive damage in textile fibers as shown in Figure 1. However, the optical microscope is a tool, which is commonly used to identify the fibers. Fiber

identification indicates that all tested sample are linen, wool or both linen and wool. However, most of the dyed samples contain undyed linen (warp) and dyed wool (weft). These results are illustrated in Figure 2. Also, the examination by optical microscope showed that there are marked differences in the thickness of the fibers in the different samples and in the same observed thread.

Figure 1. Coptic textile object date back to 6 cen. A.D. the 3rd style of Coptic Art (Coptic museum in Egypt).

3.2 *Scanning Electron Microscope SEM*

3.2.1 ***Surface morphology:*** S.E.M. photos of examined Coptic samples ***are*** illustrated in Figure 3 These photos show that linen and wool are the fibers, which were identified from all tested samples. Besides, the tested dyed samples are composed from linen (warp threads) and dyed wool (weft threads) as shown in Figures 2. SEM. photos (Figure 3, A-D) show also, that the linen surface is extremely roughened, very damaged broken with transverse cracking and longitudinal splitting characterized by small scratches, large slits and holes cavities. Moreover, the diameters of the ancient linen fibers were apparently enlarged. Yarns collapsed and shrank resulting in flattened crowns and a netlike weave structure. The results show that the degree of the deterioration of the tested linen textiles are too much indicating that these textiles are broken and had lost most of their strength and the other mechanical properties. Which is directly proportional to the damage on the surface morphology of fibers (Abdel-Kareem, 1998).

S.E.M. photos (Figure 3, E-H) show that the wool fibers are broken also, and fibrillated, with transverse cracking and longitudinal splitting and were broken down into the cortical cells. The surface of the fibers is extremely roughened and opaque. Also the fibers are seriously damaged as the surface exhibit extensive fiber disruption and loss of scales structure. Comparing all the obtained SEM photos it can be noticed that the linen samples are more degraded than wool samples this may be due to the

dyes on the wool textile, which may play a role in inhibiting the deterioration of these textiles. It may be also, due to the faster deterioration of cellulosic textiles such as linen than wool by the different deterioration reasons. Textiles deteriorate naturally by oxidation, heat, mechanical stress, radiation, moisture, microbiological and enzymatic attack. Also it was confirmed by (Abdel-Kareem *et al*, 1997) that linen are more liable to fungal deterioration than wool samples.

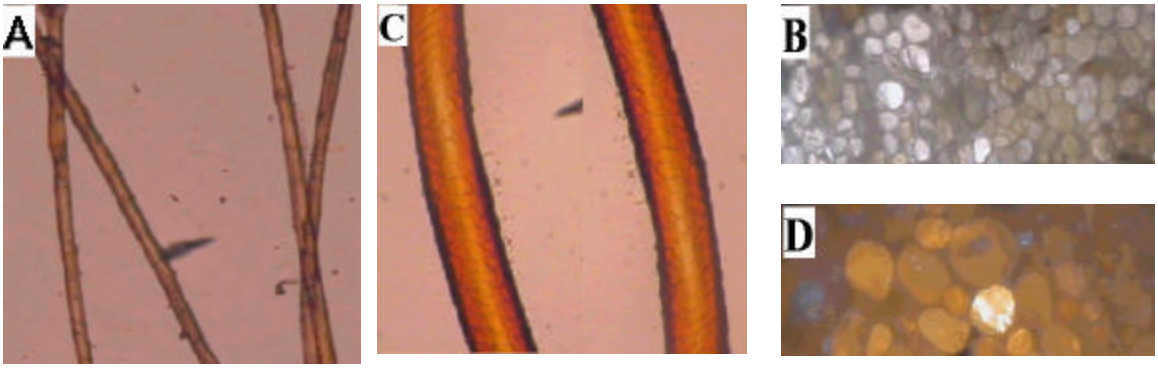

Figure 2. The morphology of textile fibers under Optical Microscope; Photos A and B for linen (A) Longitudinal view and (B) cross section); Photos C and D for wool (C) Longitudinal view and (D) cross section)

3.2.2 EDX analysis: The results of EDX scans detect the presence of elements Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, and Fe as the most elements as shown in Figure 4 present in all the tested dyed fibers except the blue fibers which does not have Ti element. The main target of using this analysis is to identify the mordant that may present in the tested samples as element percentage. It was reported by (Koestler *et al*, 1985) that the indication of the presence of the mordant could be identified upon the element/sulfur ratio. For alum mordant if this ratio is 2:1, then the mordant is present, while ratio is 1:1 or 1:2, the mordant may be possibly present, or probably absent respectively. With respect to iron mordant if this ratio is either greater than 2:1, or 1:1 these may be indicate either the presence, probably presence or the absence of the mordant respectively. The data indicated in Table 1 confirm that only the alum mordant is the mordant that present only in the red and yellow dyes. While no alum mordant was detected on the blue dyed samples. In the same time the iron mordant was not present on the blue, red and yellow tested sample as its ratio is too little. These results are in agreement with the previous work reported by (Abdel-Kareem *et al*, 1997) which showed that alum is the most mordant was used in dyeing of Coptic textiles from 2nd - 7th A.D. centuries.

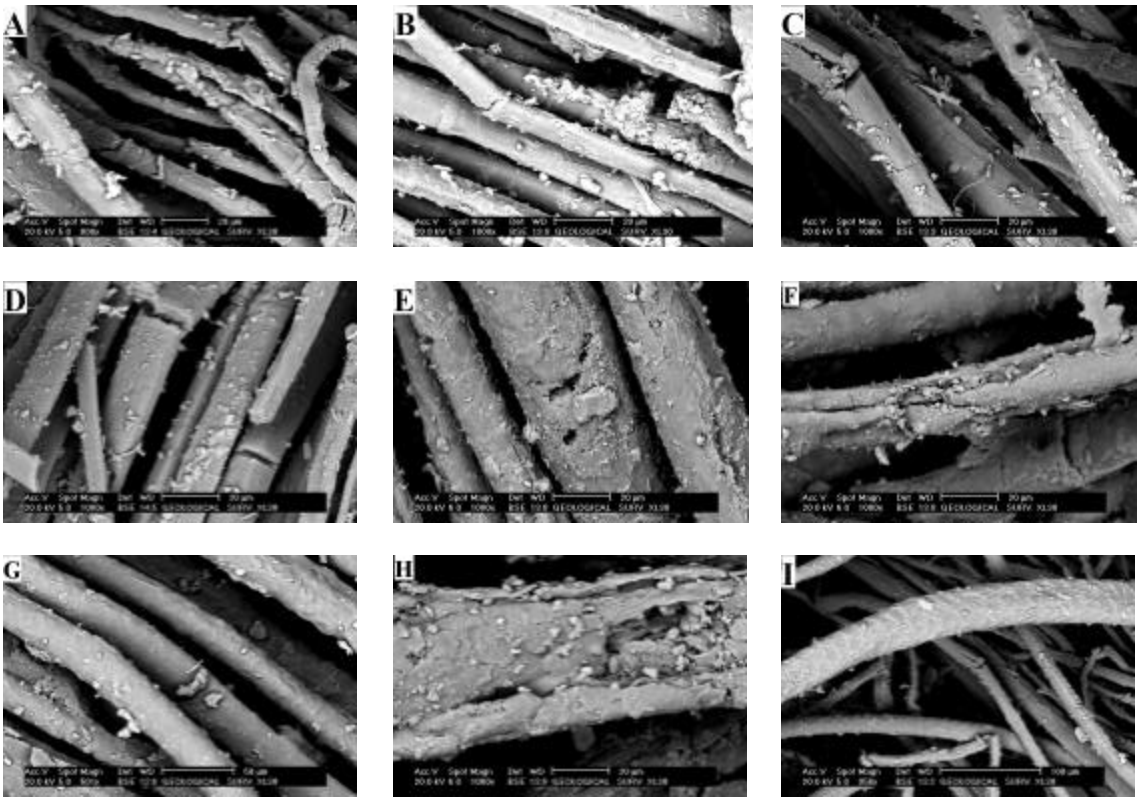

Figure 3. SEM photos of the surface of fibers of tested Coptic textile samples; A, B, C and D photos for linen samples while E, F, G and H for wool samples. The photo shows the combined structure for linen and wool in one sample.

Table 1: EDX analysis for different dyed Coptic wool fibers

Element	Red		Yellow		Blue	
	Wt%	At%	Wt%	At%	Wt%	At%
Na	2.85	3.24	2.82	3.20	5.88	7.20
Mg	4.13	7.22	3.62	6.32	2.72	5.12
Al	14.02	9.69	14.45	9.98	8.27	6.16
Si	36.34	42.65	42.53	49.85	7.23	9.14
P	4.01	1.99	2.00	0.99	0.96	0.52
S	7.33	6.45	6.35	5.59	54.46	51.65
Cl	4.10	3.33	4.34	3.52	8.58	7.50
K	3.66	2.74	3.05	2.28	2.22	1.79
Ca	14.36	18.05	10.10	12.69	7.20	9.75
Ti	1.30	1.15	1.94	1.71	-	-
Fe	7.91	3.49	8.80	3.88	2.48	1.18

3.3 X-ray diffraction analysis (XRD): The data presented in Table 2 of X-ray diffraction spectra for each of the Coptic samples exhibit the structure (101), 14.98; (101), 16.76; 002, 22.79 which is similar to the typical structure of cellulose Type I: (101), 14.73; (101), 16.56; 002, 22.55. The results in Table 2 also show that the tested Coptic linen textile samples have mean interplanar spacing, d-value a2, 3.91 ± 0.04°A. This result is in agreement with the interplanar spacing, d-value a2, of cellulose

type I as Tripp and Conrad (d-value a2, of cellulose type I is ranging from 3.90 to 3.96^{O}A with an average interplanar spacing of 3.94^{O}A) (Forman, and Jakes, 1993) .

By comparing the results of wide angel x-ray (WAXS) diffractograms of tested Coptic linen textile samples as shown in Table 2 and those of new linen textile samples as shown in Table 3, it is clear that there is a differences between WAXS diffractograms of untreated linen textile with that of the ancient one, specially in the peak intensity (counts). The data show that the ancient samples exhibit a significance reduction in the peak intensity (counts). Which may indicate that the ancient samples are too deteriorated because deterioration reactions probably occur in the crystalline region as well as in the amorphous region.

Table 2: XED data of Coptic linen samples

Sample No.	Angles (2?)	d-value a1 [Å]	d-value a2 [Å]	Peak width (2?)	Peak intensity (counts)
1	23.200	3.8308	3.8403	0.180	4134
2	22.660	3.9208	3.9306	0.140	4720
3	22.565	3.9371	3.9469	0.150	5700
4	22.710	3.9123	3.9220	0.180	4083
5	22.785	3.8996	3.9093	0.180	8391
Total	113.920	19.501	19.549	0.830	27028.0
Mean	22.784	3.900	3.910	0.166	5405.6
S.D* ±	0.246	0.041	0.041	0.019	1791.34
UA**	0.110	0.018	0.018	0.009	801.11

* S.D is the standard deviation of the data
**UA is the uncertainty (repeatability) of measurement

3.4 **Thermogravimetric analysis:** The Thermogravimetric curves for each of four deteriorated Coptic linen samples together with the curve of a new unbleached linen textile sample are illustrated in Figure (5) and presented in Table (4). From TGA curves in Figure (5), it is evident that all tested samples degraded in three stages of decomposition similar to that which are suggested by the thermal degradation of cellulose (Abdel-Kareem and Samaha, 2004). Ancient samples show the same profile of degradation similar to the new one as shown in Figure 5 except that the main thermal degradation (the second stage) of the former starts at relatively lower temperature than the latter, also the weight loss for each degradation stage is comparably different. It is evident from the data in Table 4 and Figure 5 that the loss of weight for unfinished unbleached linen sample is little more than those for the ancient samples. This indicates that the ancient samples are drier compared with the new one because the first stage of is due to loss of absorbed water.

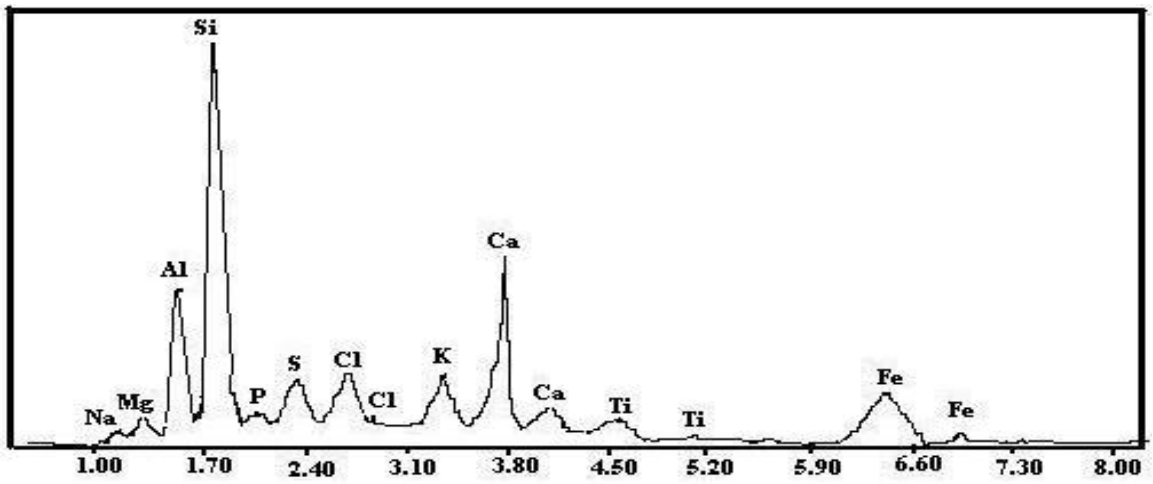

Figure 4. EDX Scans of the elements present on a madder dyed Coptic wool fiber

Table 3: XRD data of new linen samples

Sample No.	Angles (2?)	d-value a1 [Å]	d-value a2 [Å]	Peak width (2?)	Peak intensity (counts)
1	22.405	3.9649	3.9747	*1.000*	7921
2	22.725	3.9097	3.9195	*0.560*	9006
3	22.485	3.9509	3.9607	*0.490*	9960
4	22.665	3.9200	3.9297	*0.900*	7482
5	22.485	3.9509	3.9607	0.400	5730
Total	112.765	19.696	19.745	3.350	40099
Mean	22.553	3.939	3.949	0.670	8019
S.D* ±	0.135	0.023	0.023	0.264	1603
UA**	0.061	0.010	0.010	0.118	716

* S.D is the standard deviation of the data
**UA is the uncertainty (repeatability) of measurement

Table 4: Thermal analysis of the new linen sample and tested Coptic Egyptian linen samples

Sample	(100 ^{o}C) (Wt %)	T_d(^{o}C)	T_{dm} (^{o}C)	(450 ^{o}C) (Wt %)	(650 ^{o}C) (Wt %)
New (B)	96.13	432	531	85.19	17.97
1	96.33	387	528	73.04	17.34
2	96.78	336	527	70.13	31.16
3	97.09	404	519	76.58	22.41
4	96.76	371	521	68.81	25.06

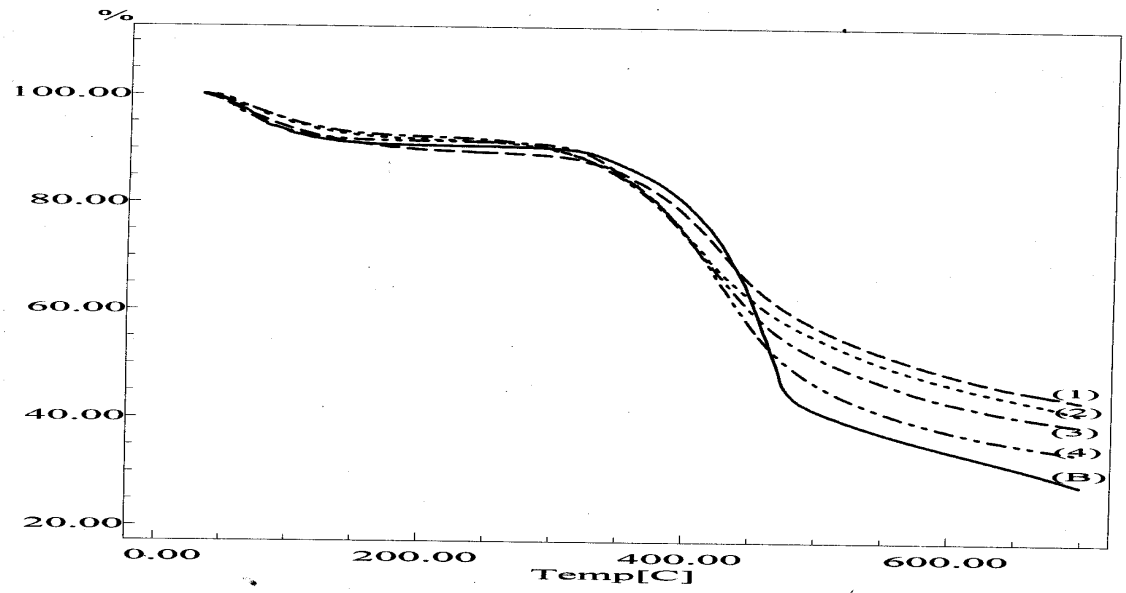

Figure 5. Thermogravimetric curves for the linen samples; B) new unfinished sample; 1–4) ancient linen samples.

The second degradation stage of all tested samples, show that the thermal stability of the ancient linen samples is lower than that of original cellulose. By comparing the residual weight percentage (Wt %) of all tested samples at 450 °C, there is a noticeable decrease for the ancient samples than for the new one as shown in Table 3. From data in Table 4 it is clear that (Wt %) of ancient samples are 73.04, 70.13, 76.58, 68.81, while for the new one is 85.19. This indicates that the % loss by weight of the ancient linen samples are about 28% while the new one is about 15%. These results confirm that the thermal stability of all of tested ancient linen samples is lower than that of original cellulose. These results may be due to the crystallinity of the ancient samples are lower than that of the new one. As it is confirmed in other studies, the thermal stability of cellulose fibres is affected by crystalline order, which decreases after substitution of cellulose hydroxyls with organic acids (Sealy, et al, 1996, Jandura, et al, 2000). In this region dehydration leads to anhydride formation at the 1,4; 2,3 and 1,6 positions of the anhydroglucose unit of cellulose (Chauhan, et al, 2000). Further depolymerization sets is due to breakage of 1,6 glycosidic linkages of cellulose backbone followed by pyrolysis of smaller products.

The results show that in the last stage (the third decomposition stage), there are noticeable differences between the ancient samples and the new one. The residual weight percentage (Wt %) of all ancient tested samples is less than that of the new one (see table 4). From the data in Table 4 (Wt %) of ancient samples at 650 °C are 17.34, 31.16, 22.41 and 25.06, while for the new one is 17.97. This indicates that the % loss of weight of the ancient linen samples were about 76% while was for the new one about 82%. This decomposition, which appears at higher temperatures, may be due to the thermal degradation of a new cross linked material formed by thermal cross linking reactions occurring at the initial stages of a degradation process. As the ancient samples are seam little dirty and this dust may leads to cross-linking reactions during the thermal degradation of the cellulose polymer.

The Thermogravimetric curves for four deteriorated Coptic wool samples with the curve of a new unfinished wool textile sample are illustrated in Figure 6. The main thermo stability results of tested sample

were summarized and given Table 5. From TGA curves in Figure 6, it is clear that all tested samples degraded in three stages of decomposition. Ancient wool samples show the same profile of degradation similar to the new one as in Figure 5 except the thermal degradation (the second stage) of the former which starts at relatively lower temperature than the latter, also the weight loss for each degradation stage is comparably different. By comparing the results given in Table 5 and represented in Figure 6 it was evident that the loss of weight for the new wool sample is little more than those for the ancient samples, which indicates that ancient wool samples are dry enough compared with the new one.

Table 5: Thermal analysis of the new wool sample and tested Coptic Egyptian wool samples

Sample	(100 ^{o}C) (Wt %)	T_d(^{o}C)	T_{dm} (^{o}C)	(450 ^{o}C) (Wt %)	(650 ^{o}C) (Wt %)
New (B)	92.91	320	483	77.34	31.62
1	94.86	292	481	59.24	41.16
2	93.62	304	571	64.30	45.70
3	94.94	282	541	61.97	44.11
4	93.09	293	525	56.94	35.85

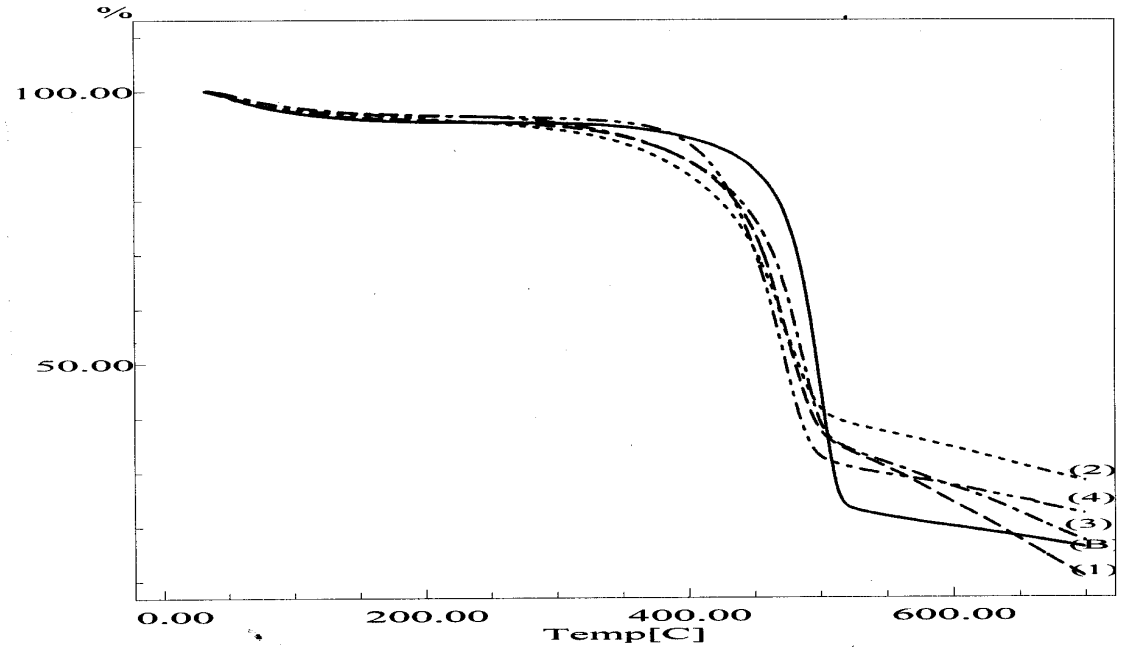

Figure 6. Thermogravimetric curves for the wool samples; B) new unfinished sample; 1 – 4) ancient wool samples

From the second degradation stage, the tested samples, it is clear that the thermal stability of ancient wool samples is lower than that of original wool. By comparing the residual weight percent (Wt %) of all tested samples at 450 ^{o}C, there is a noticeable decrease for the ancient samples than for the new one as shown in Table (4). From obtained data in table (5) (Wt %) of ancient samples were 59.24, 64.30, 61.79 and 56.94, while for the new one is 77.34. This means that the weight % loss of the ancient wool

samples are about 39% while it is 23% for the new one. These results indicate that the thermal stability of all tested ancient wool samples is lower than that of original wool.

In the third decomposition stage, there are noticeable differences between the ancient wool samples and the new one. The residual weight percentage (Wt %) of all ancient tested wool samples is more than that of the new one as shown in Table 4. From data given in Table 5 the Wt % of ancient samples at 650 ^{o}C, are 41.16, 45.70, 44.11 and 35.85, while for the new one is 31.16. This indicates that the weight % loss of the ancient wool samples are about 58% while it is about 68% for the new one. This decomposition, which appears at higher temperatures, may result from the thermal degradation of a new cross linked material formed by thermal cross linking reactions occurring in initial stages of a degradation process. As the ancient samples are seam little dirty and this dust may leads to cross-linking reactions during the thermal degradation of the cellulose polymer.

3.5 ***FTIR Spectroscopy:*** Since the IR spectroscopy is very important tool for detecting the functional groups. The ancient fibers were identified by the interpretation of the absorption spectra from IR spectrometric analysis of the homogenous specimen obtained using potassium bromide as internal standards. The results confirm that linen and wool are the fibers that identified from all tested samples. It was noticed from the chart in Figure 7 that the absorption band shown at 3355.1 cm^{-1} indicates the presence of the hydroxyle groups (OH) that exhibit abroaddening due to the internal and intrahydrogen bonding with peak intensity of 0.183. The ancient sample has carbonyl groups at 1653.129 cm^{-1} due to the oxidation, some of the hydroxyl groups that was found in the native samples are carbonyl group (CO) of either acid or ketone functional groups (Day and Underwood, 1991). This result show that linen textile fibers are very deteriorated as it is reported in previous work, that the presence of these peaks indicate the deterioration of cellulose fibers (Cardamone, 1988).

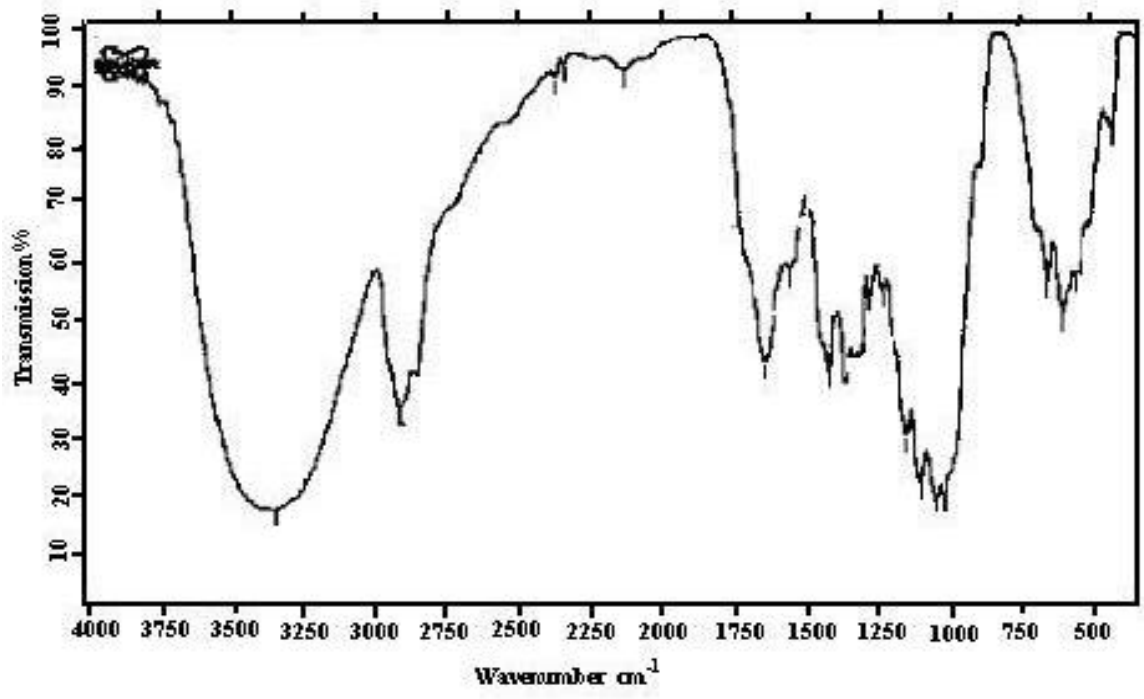

Figure 7. FTIR spectrum of linen fiber from Coptic linen textile sample

The identification of dyes is very large work; therefore, three main dyes (red, yellow and blue) have been chosen to investigate the main dyes used in dying the Coptic textiles. On comparing, the obtained spectra of unknown dyes (ancient samples) with the reference samples (the new dyed samples), the dye used to give red color to the wool textiles is madder dye (Figure 8). The dye used to give yellow color to the wool textiles is weld dye while the dye used to give blue color to the wool textiles is indigo dye.

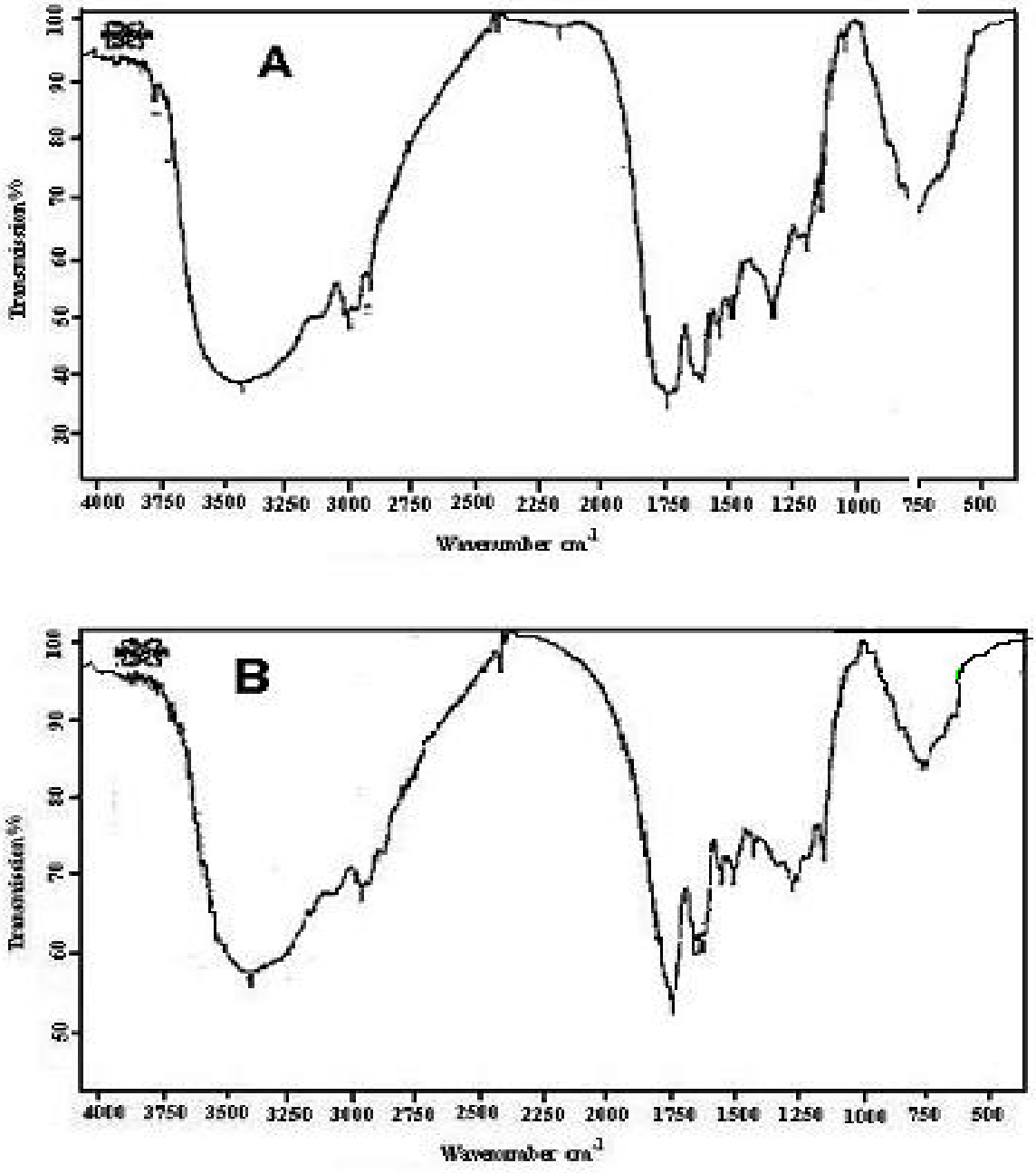

Figure 8. FTIR spectra of known and unknown dyes, A) standard madder dyed wool textile, B) Coptic madder wool textile (B)

It was confirmed that FTIR spectroscopy is a rapid, sensitive and non-destructive tool to detect of oxidation degradation in cotton textiles (Cardamone, 1989). For identification of dyes the obtained spectra of unknown ancient dyes were compared with the spectra of the new dyed samples as references.

3.6 ***HPLC Analysis****:* The chromatograms of the standards yellow weld dye, blue indigo dye and madder red dye and the ancient dyed textiles explained that similar peaks at the same retention times were found. These peaks indicate that both the dyes used in the new dyed samples (weld, indigo, madder) are similar to that of the ancient ones. For example the results in Figures 9 illustrate the peaks obtained at retention times of 32.647, 32.227, 2.283, 2.022, 1.719 and 1.558 in the chromatogram of the new madder dyed textile samples with alum as a mordant. These peaks were detected at the same retention times for the ancient textiles. This indicates that the HPLC is a successful non-destructive tool to be used in the archeological studies.

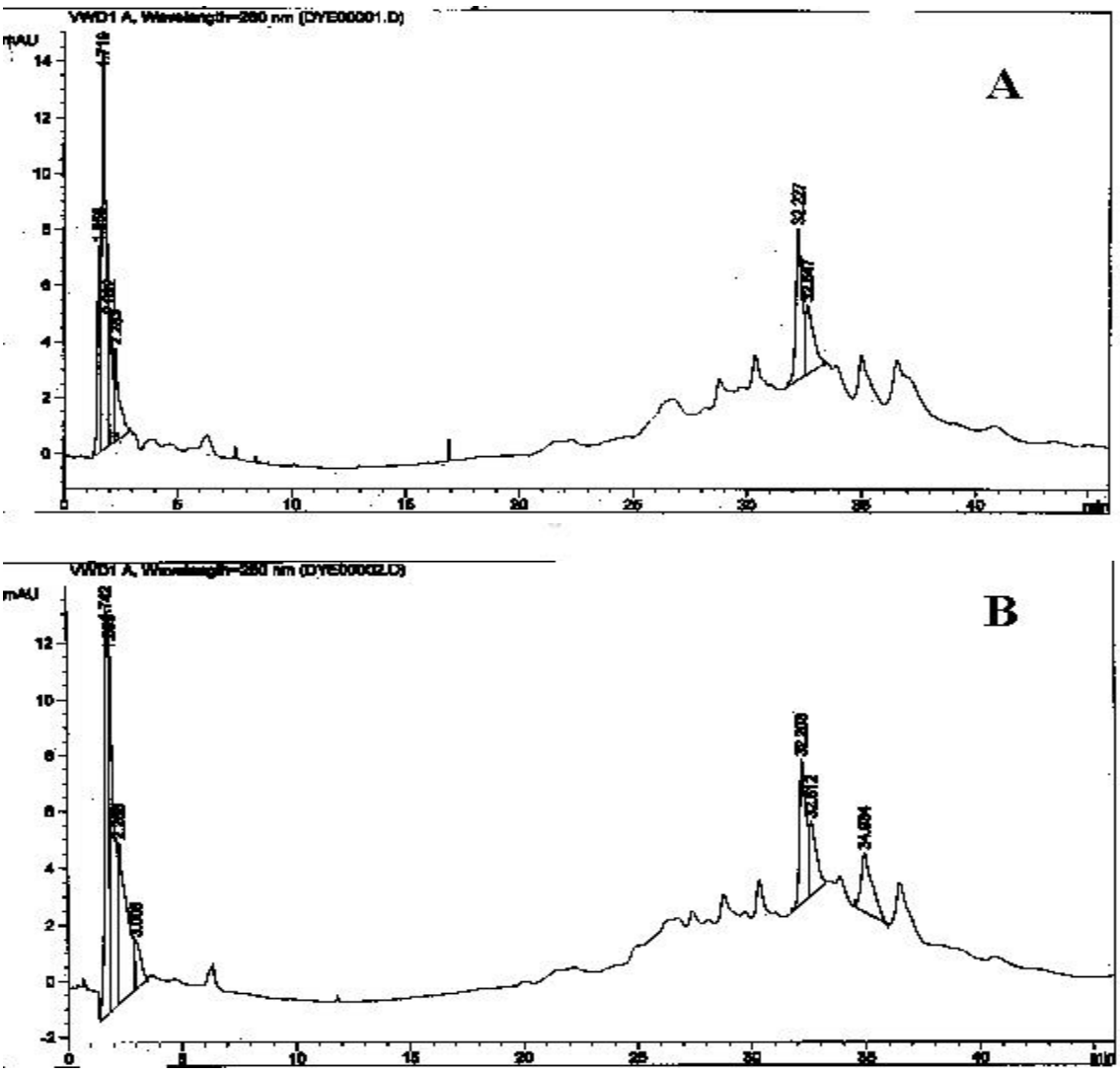

Figure 9. Chromatograms of HPLC of the known and unknown dyes, A) new madder dyed wool textile, B) Coptic madder wool textile sample.

Conclusion

1) Linen and wool are the most fibers identified from the tested Egyptian Coptic textiles dated from the 2nd century to 7th century.
2) These fibers are characterized with degraded fiber surface, appearing with new bands by FTIR that indicate the extensively changes in the chemical composition of the fibers.
3) The total cellulose crystallinity of linen Coptic textiles is reduced and crystallite length is smaller compared to those of new linen.
4) The thermal stability of all of tested ancient linen samples is lower than that of un-aged new linen.
5) The thermal stability of all of tested ancient wool samples is lower than that of un-aged new wool.
6) There is a variety of natural dyes used to give colors on Coptic textiles.
7) The study shows that the madder was used for red color, the weld was used for yellow color, and the Indigo was used for blue color.
8) The alum was the mordant identified on dyed Coptic fibers
9) Optical Microscope, SEM, FTIR spectrophotometer and XRD, are very useful tools to investigate the ancient fibers.
10) Among all tested tools HPLC technique is the best one to identify the ancient dyes.
11) SEM with EDX is very important as non-destructive tool to detect the mordants in Coptic dyed textiles.

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