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Evaluation of Guar Gum for the Consolidation of Some Cellulosic Packaging Materials for Mummies

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Abstract

As known, linen and muslin cotton fibers are used in museums and excavation areas as packaging materials for first aid of mummies. These materials with the course of long-term exposure to improper surrounding conditions become brittle, fragile, and very weak. The current research study aimed to evaluate the effect of guar gum with different concentrations for the consolidation of linen and muslin cotton samples. Additionally, the work aimed also to monitor the changes in the properties of these materials after accelerated heat aging at 100°C. The analytical techniques used for this purpose were Fourier Transform Infrared spectroscopy (FTIR) for examining the chemical changes, the morphological structure via using scanning electron microscope (SEM), mechanical properties (tensile strength and elongation), color and weight change for the treated linen and muslin cotton fabrics. The findings of FTIR proved that there were low chemical changes in the aged treated samples compared to the aged untreated samples implying that the chemical stability of the treated samples was increased while treatment with guar gum. There was good distribution in the fiber structure of the treated samples as shown from SEM data. The aged treated samples showed less destruction in the fiber structure compared to the aged untreated samples. The mechanical properties were also improved. The total color differences obtained from treated and aged treated muslin cotton samples were better than the linen samples. Moreover, the accelerated heat aging had an effect on the weight of the aged treated samples, which were better than the aged untreated samples.

Keywords: Linen, muslin cotton, mummies, deterioration, first aid, guar gum, analytical techniques

1. Introduction

Mummification is considered one of the bright and prominent signs in the history of the ancient Egyptian civilization [**1-2**]. There are lots of mummies in different locations in Egypt (museums, stores, and excavation areas) which date back to different periods and are subject to different environmental conditions. It is well known that any buried materials for a long period of time reach a state of natural equilibrium and with this environment. The problem begins after extracting these materials from the burial environment and exposing them to a different environment. Sometimes, the exposure to the environment is not completely different, and thus the materials exposed to air, pollutants, and other factors are deteriorated, and the degree of deterioration depends on the conditions running in this environment [**3-4**]. The deterioration process occurs in organic materials, particularly mummies which can deteriorate rapidly, and without having been treated they can disintegrate within few hours.

Packaging is a necessary process in excavation areas and for the storage of finds during the excavation process, especially for fragile objects. Artifacts should be placed in a controlled environment as soon as possible after the excavation, and not left un-protected until the end of the excavation period [**5**]. Packaging is also considered one of the most important processes as the first aids in the excavation area.

During excavation, the unwrapped and partially wrapped mummies need to be wrapped again with the use of linen. In Egypt, unwrapped and partially wrapped mummies need to be rewrapped, and linen is often used for this purpose in order to simulate the

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wrapping used during the mummification process. Sometimes, the linen used for the wrapped mummies becomes weak, brittle, and needs to be strengthened, so that the mummies can be consolidated during the excavation season. Sometimes, cotton muslin is also used as packing material, this is because it is cheaper and available abundantly compared to linen material.

Muslin fabric is made of cotton. It is very fine and delicate for handling and use. It is featured with being of transparent look, lightweight, and has good durability [**6-14**]. The chemical composition of cotton is cellulose (88.0-96.5%), non-cellulosic constituents (1.0-1.9%), pectin (0.4-1.2%), waxes (0.4-1.2%), inorganics (0.7–1.6%), and other substances (0.5–8.0%) [**15-19**]. Linen is considered one of the earliest materials that have been used by the Egyptians, because they are long and strong fibers [**20**]. Linen consists of cellulose, which is the principal element, and non-cellulose compounds such as hemicellulose, lignin, pectin, waxes and fats, mineral salts, natural coloring matter, and watery soluble compounds.

In museums or storages, cotton or linen fibers used as packaging materials for mummies are susceptible to various factors of deterioration; natural and non-natural.

Inappropriate conditions caused by high levels of light (natural or synthetic), fluctuations between moisture and heat, presence of pollutants and particulates, microorganisms, and insects may lead to a chain of reactions that might damage these fibers. Human factors such as mishandling, misuse, and bad shelving may also lead to some forms of deterioration [**1, 21**]. According to the deterioration process, there would be a breaking of the macromolecular chains of the fiber and a gradual loss of the endogenous humidity. The fibers become less elastic, weaker, and more fragile [**22]**.

However, it is necessary for the dried and fragile linen and muslin cotton to be consolidated so as to increase their strength and durability. Over periods of time, many supportive materials (natural or synthetic polymers) have been used for this purpose. Guar gum is deemed to be a natural polymer that had not been used for consolidation purposes for the archaeological textiles fibers, but it has been used widely for the conservation of archaeological wood artifacts, especially for the waterlogged wood.

Walsh et al. [**23**] and Broda et al. [**24**] reported that there is recent research that handled the means of consolidation to the treatment of the organic artifacts. It has focused on the natural, bio-friendly agents compatible with the object structure, e.g. guar gum.

Guar is a polysaccharide having one of the highest molecular weights which contains all-natural watery soluble polymers. Mudgil et al. [**25**] noted that guar gum mainly consists of the high molecular weight polysaccharides of galactomannans which are linear chains of (1→4)-linked ß-D-mannopyranosyl units with (1→6)-linked a-D-galactopyranosyl residue as side chains as shown in Fig. 1.

Walsh et al. [**26**] stated that the advantages of using natural polymers such as guar gum that encounter some issues connected with organic artifacts: instability on drying, and biological degradation. Aqueous solutions of chitosan and guar, two naturally sourced polymers, have been shown to provide enhanced structural support and stability at reduced concentrations [**26**]. Walsh et al. [**26]** said that the natural polymer-based consolidation means, particularly guar gum, would provide better structural support for the object treated.

The artificial accelerated aging is vital in the conservation field. It has become urgent necessarily for experimental laboratory studies in order to evaluate the effectiveness of conservation materials and techniques.

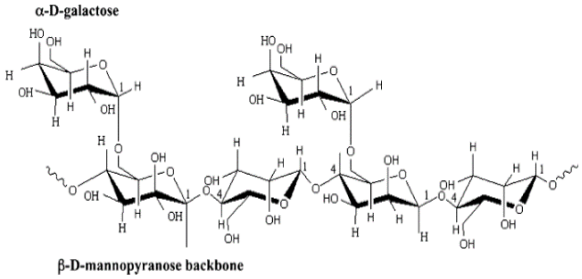

Fig. 1. Chemical structure of guar gum molecule [Reprinted with permission from Ref. 25, copyright © 2011 Springer]

Many authors have used accelerated heat aging [**27-34**]. Analysis and investigation play an important part in the conservation field. They detect the effectiveness of conservation materials and techniques used and re-veal their advantages and disadvantages through many analytical techniques. Differ-ent analytical techniques have been used in this study for the evaluation process. The analytical techniques used were change of color, mechanical properties, SEM, FTIR, and weight. Furthermore, the aged artificial heat was used to follow up the changes in the study of the properties.

This study aims to evaluate guar gum at different concentrations to finally be used as a consolidation process. The main goal of consolidation is to unite and hold the de-gradable and strained fibers together, and to give strength to linen and cotton muslin fibers.

2. Materials and methods

2.1. Materials and chemicals

Muslin cotton fibers samples without any treatments were obtained from El-Alamia Company for Medical Muslin Product at El-Qanatir El Khayriyah, Cairo, Egypt. Meanwhile unbleached linen fibers produced by the "Egyptian Company for Linen and its deriv-atives", El Gharbia, Tanta, Mit

Hebeish El-Bahrya, Egypt. Guar gum (SLG 2035) was purchased from Science Lab. Com, Inc. (India).

2.2. Methods

2.2.1. Preparation of guar gum solution for muslin cotton and linen fibers treatment

Certain solutions of guar gum were obtained by dissolving specific concentrations (0.5 g and 1 g) in 100 ml. of distilled water. The samples were impregnated in polymer solution for 5 minutes and left to dry naturally at room temperature.

2.2.2. Accelerated heat aging

Heat treatment was used for the accelerated ageing process according to Abdel-Maksoud and Marcinkowska [**27-28**], at 100°C for 5 days for both untreated and treated samples with polymer.

2.3. Characterization tools for fabric evaluation

FTIR spectra of control, aged untreated, treated and aged treated linen and muslin cotton samples (at 1%) were obtained using Jasco FT/IR spectrometer, Perkin Elmer. The IR spectra were scanned over the wavenumber range of 4000–400 cm−1.

The surface morphology was examined by scanning electron microscopy (HITACHI S–3000 microscope, Czech Republic) to study the surface characteristics of control, aged untreated, treated and aged treated linen and muslin cotton samples.

The tensile strength and elongation of the samples were carried out using Tinius Olsen, SDL, UK, according to the standard method ASTM D5035 – 11 **[35]**.

Color values were measured using Hunter Lab spectrophotometer 600 with a pulsed xenon lamp (Ultra Scan Pro, United States) associated with a 10° viewer, d/2 geome-try, D65 illuminant, and a 2 mm area). The color changes were recorded by the CIE L*a*b* system, where L* represents the brightness from 0 (black) to 100 (white), a* represents the red (positive value) or green chromatic coordinate (negative value), and b* represents the yellow (positive value) for blue chromatic coordinate (negative value). The total color change (ΔE*) was calculated according to the equation:

$$\Delta E^* = [(\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)2]1/2$$

Weight of the untreated and treated samples before and after the accelerated heat ageing was measured using a four digital sensitive balance.

3. Results and discussion

3.1. Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR analysis is very important in the evaluation of the conservation materials. It gives a good indication regarding the chemical changes of the treated samples before and after the artificial accelerated aging. The results of FTIR analysis of the treated linen and muslin cotton samples before and after aging were explained as follows:

3.1.1. FTIR analysis of treated linen samples

From the data obtained (Fig. 2) it is evident that the band at 3332 cm^{-1} of the control sample has been as-signed to the stretching of ν(OH) vibration, which referred to the hydroxyl group. The band of the aged untreated sample decreased. This was due to the accelerated heat ageing, which leads eventually to the oxidation of some of the hydroxyl groups to carbonyl groups. The intensity of this band for the treated and aged treated samples was simi-lar, but their intensity was less than the control and aged untreated sample. This indi-cated that Guar gum gives an improvement in the treated samples and showed a good resistance when exposed to accelerated heat ageing. The intensity of the band at 2899 cm^{-1} of the control sample assigned to the stretching vibrations of ν(CH_3) and ν(CH_2), which refer to methyl and ethyl groups decreased after accelerated heat ageing due to the oxidation of cellulose compounds. A high reduction in the intensity of this band was obtained in the treated sample. Less decrease of this band was obtained for the aged treated sample. It can be said that the percentage loss of the intensities of the aged untreated compared to the control sample was 11%, but the percentage loss of the aged treated sample compared to the treated sample was 7%. The band at 1710 cm^{-1} assigned to OH bending and C=O stretching (carbonyl band) of oxidized cellulose of aged untreated and aged treated samples, showed a reduction in the intensity; the aged sample recorded an intensity of (53%), which was higher than the intensity of the aged treated sample (22%) compared to the control and treated samples respectively. The band at 1428 cm^{-1} refers to CH_2 vibrations, HCH, and OCH in-plane bending; intermolecular hydrogen bonds bending. The intensity of this band decreased in the aged untreated and aged treated samples, where their percentage loss were 11% compared to the control and treated samples respectively. The band at 1364 cm^{-1} refers to COH and HCC vibrations of

cellulose and hemicellulose. The intensity of the aged untreated and aged treated samples decreased, but the aged treated sample was better than the aged untreated sample. The band at 1335 cm^{-1} refers to OH and CH_2 vibrations. The band at 1280 cm^{-1} refers to CH and OH vibrations. The intensity of the aged untreated sample was higher than the aged treated sample. The band at 1159 cm^{-1} refers to COC asymmetric vibrations, and the band at 1110 cm^{-1} refers to asymmetric vibrations of glucose rings. The intensities of the two bands of the aged treated samples were higher than the aged untreated samples. The band at 895 cm^{-1} refers to COC vibrations of glycoside bonds. The intensity of the aged untreated sample increased compared to the control sample, and the intensity of the aged treated sample decreased compared to the treated sample. The reduction in the intensity of the aged untreated or aged treated samples has been indicated on the oxidation of cellulose, but the aged treated sample had more resistance than the aged untreated sample at most bands assigned and specified to cellulose. This gives an indication that the guar gum recorded an improvement in the chemical stability of the linen samples.

3.1.2. FTIR analysis of the treated muslin cotton samples

The results obtained in (Fig. 3) show the functional groups of muslin cotton fibers treated with guar gum at 1% before and after the artificial accelerated heat ageing. The results showed that the band at 3332 cm^{-1} (intra-molecular) and 3291 cm^{-1} (inter-molecular hydrogen bonding) were determined and assigned to ν(OH) stretching vibrations of O-H groups in cellulose. These two bands showed a reduction in the intensity of the aged untreated and aged treated samples compared to the controlled and treated samples. The reduction was 69% and 70% for the aged untreated sample, and 35% and 34% for the aged treated sample at 3332 cm^{-1} and 3291 cm^{-1} respectively. The band at 2899 cm^{-1} refers to CH and CH_2 bands in aliphatic groups. The aged un-treated sample of this band decreased to 85% in its intensity, while the aged treated samples decreased to 37%.

The band at 1636 cm^{-1} refers to (O–H) in-plane bending vibration of the adsorbed water, or further can also refer to ν(C=O) carbonyl group in the samples. The reduction in the intensity of the aged treated sample was 23% and was less than the aged untreated sample (60%). The band at 1428 cm^{-1} refers to H–C–H and O–C–H in-plane bending vibrations. It is also characteristic of cellulose I with the band at 1103 cm^{-1}. The band at 1364 cm^{-1} has been assigned to COH and HCC vibrations of cellulose. The band at 1315 cm^{-1} refers to COH and HCC vibrations. The band at 1032 cm^{-1} refers to the existence of the C-O bridge stretching and C-O-C pyranose ring skeletal vibration (β-glycoside linkages, cellulose compounds). The band at 894 cm-1 refers to COC vibrations of glycoside bonds. All bands mentioned above are distinctive for cellulose in the muslin cotton fibers. The intensities of the aged untreated samples had higher re-duction more than the intensities of the aged treated samples compared to the con-trolled and treated samples respectively. The results indicate that the use of guar gum at 1% gives good resistance against the accelerated heat ageing, and has given good chemical stability compared to the aged untreated samples.

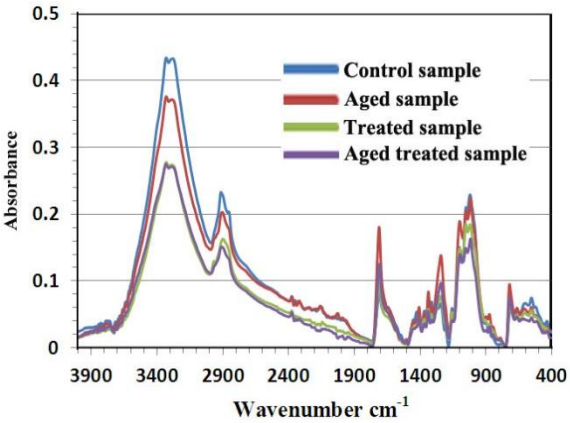

Fig. 2. FTIR-ATR analysis of treated linen samples with Guar gum at 1% before and after artificial accelerated heat aging

These results were confirmed by some authors [**36-38**] who reported that the band at 1653 cm^{-1} indicated the oxidation of cellulose. Hao et al. [**39**] stated that the thermal ageing has affected the chemical stability of cellulose bands. Garside and Wyeth [**40**] identified the cellulose bands of cotton and flax fibers. Smith et al. [**41**] said that the use of ATR-FTIR is considered a good tool to detect the changes in the chemical stability of cellulosic materials. Mohapatra and Malik [**42**] reported that the bands at 2850 and 2918 cm-1 are attributed to detect the state of preservation of C-H groups in methyl and methylene groups [CH_3, CH_2, CH_2-OH] which are assigned to cellulose. They also said that the band at 2900 cm-1 indicated cellulose. Some other authors [**43-45**] explained the use of FTIR in the

identification of cellulosic materials and for the determination of the deterioration process caused by the artificial ageing, or the efficiency of some conservation materials used for cellulosic materials.

3.2. Investigation of the surface morphology by scanning electron microscope

3.2.1. Investigation of the surface morphology of the treated linen samples before and after accelerated heat aging

It is clear from the data obtained (Fig. 4A) regarding the control sample that the fibers are characteristic for linen, and the fibers appeared in good distribution. The bundles of the fibers were strong, and although in the aged untreated sample (Fig. 4B) the fi-bers shrunk, but they were still in a good condition. The photo showed that the fibers were thin compared to the control sample. Moreover, it can be said that the linen tol-erated the aged accelerated heat, and little changes occurred compared to the control sample. In the sample treated with guar gum at 1% (Fig. 4C), the fibers were coated with the polymer giving a good coating on the surface of the fibers and no residues of polymer were observed. The fibers became strong and smooth. For the aged treated sample (Fig. 4D), little changes occurred. Some tear-like-drops were noticed in some fibers. Some polymer gains were observed on the fibers, which appeared due to the effect of the aged accelerated heat process.

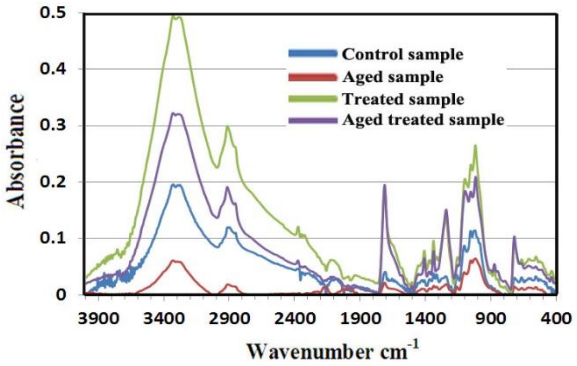

Fig. 3. FTIR-ATR analysis of treated muslin cotton samples with Guar gum at 1% before and after artificial accelerated heat ageing

3.2.2. Investigation of the surface morphology of the treated muslin cotton samples before and after accelerated heat ageing.

SEM photo (Fig. 5A) showed the characteristics of the good distribution of the structure of the strong cotton fibers which were noticed clearly. In the aged untreated sample (Fig. 5B), slight erosion in some fibers was noticed, and the distance between fiber structures became wider. The roughness of the fibers was also noticed. However, for the treated sample with guar gum at 1% (Fig.5C), the surface had become smooth, but the fibers had become strong. The distribution of the polymer on the fiber surfaces was good, but some residues of the polymer were noticed. As to the aged treated sample (Fig. 5D), the fibers were still strong, smooth with the stability of the fibers, and slight roughness of the fibers was also noticed.

It can be argued that the samples treated with guar gum before and after the accelerated heat ageing have given good results, and indicated that the treated samples re-leased/tolerated the heat ageing. Further, one can say that 1% of guar gum has given good distribution to the surfaces of the fibers for both the linen and muslin cotton fibers.

These results were confirmed by Abdel-Kareem et al. [**46**] who proved that the investigation of the surface morphology by SEM of the untreated linen sample showed gradual distribution to the linen fibrils after the thermal ageing procedures. Naebe et al. [**47**], Hung et al. [**48**], and Venkateshaiah [**49**] reported that the surface morphology of the untreated cotton fibers was smooth. They also confirmed that some changes can occur when different treatments are used.

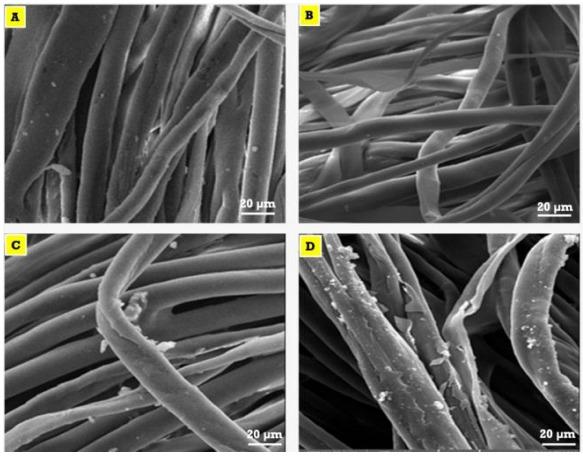

Fig. 4. SEM photos for the surface morphology of linen samples: (A) Control sample, (B) Aged untreated sample, (C) Treated sample, (D) Aged treated sample

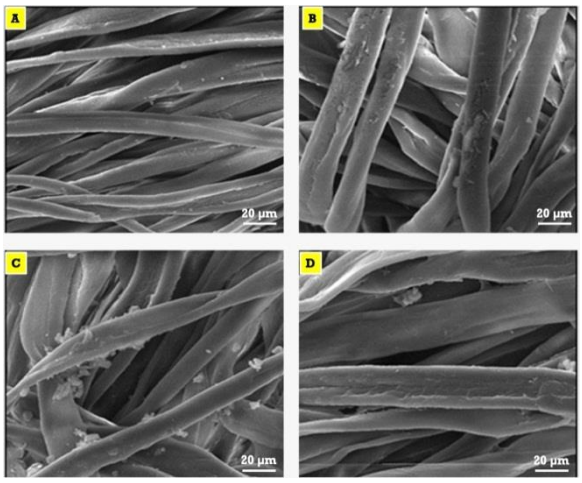

Fig. 5. SEM photos for the surface morphology of muslin cotton samples: (A) Control sample, (B) Aged untreated sample, (C) Treated sample, (D) Aged treated sample

3.3. Mechanical properties (tensile strength and elongation)

The following observations were noticed from the data obtained (Tables 1 and 2) for tensile strength and elongation:

- Tensile strength and elongation of the aged untreated samples were reduced com-pared to the control sample. The reduction was 50%, and 60% for tensile strength and elongation of linen samples, and 79%, 25% for muslin cotton samples.
- Tensile strength of the treated linen samples increased compared to the aged untreated sample. The increase was 30% and 59% at 0.5% and 1% of guar gum. The tensile strength of muslin cotton samples also increased compared to the aged sample. The increase was 56% and 65% at 0.5 and 1% of guar gum respectively.
- The elongation of the treated linen and muslin cotton samples increased compared to the aged untreated sample at 0.5 and 1% of guar gum. The increase was 63% and 67% for the linen samples, 44% and 32% for muslin cotton samples.
- Tensile strength and elongation of the aged treated samples increased compared to aged untreated sample. The increase was 63%, 53%, 33%, and 60% for tensile strength and elongation of linen samples at 0.5 and 1% of guar gum respectively. The increase was 46%, 61%, 25%, and 0% for tensile strength and elongation of muslin cotton samples at 0.5 and 1% of guar gum respectively.

It was clear that the treatment of the linen and muslin cotton samples with guar gum had a good resistance against accelerated heat aging process.

These results were confirmed by Abdel-Maksoud and Al-Saad [**31**], who proved that the mechanical properties (tensile strength and elongation) increased with the increasing concentrations of the used supportive consolidation. They also confirmed that the materials of consolidation had given good resistance against the deterioration caused by the artificial accelerated ageing. Nechyporchuk et al. [**50**] reported that the treatment materials increased the resistance of the cotton samples against the aged accelerated heat. They also stated that the mechanical properties of the treated samples in-creased compared to the untreated samples. Bridarolli et al. [**51**] explained that the treatment of the cotton samples with the consolidating materials have given an improvement to the mechanical properties of the treated samples.

3.4. Change of color

3.4.1. Lightness (L value)*

It has become clear from the data obtained (Tables 3 and 4) that there were some changes in the L* value among all the samples which have been studied. The reduction in the L* value was 5.19%, 9.22%, 9.34%, 9.91%, and 10.88% for the aged untreated, and the aged treated linen samples at 0.5% and 1% of guar gum respectively. For muslin cotton samples, the reduction in L* value was 3.475, 5.90%, 6.63%, 6.92%, and 10.61% for the aged untreated, treated, and aged treated linen samples at 0.5% and 1% of guar gum respectively. The data showed that the treated and aged treated samples gave a higher decrease in the L* value than the aged untreated sam-ple. It was also noticed the reduction in the L* value of the treated and aged treated linen samples was higher than the treated and aged treated muslin cotton samples.

*3.4.2. Hue green-red (CIE*a)*

The data obtained (Tables 3 and 4) showed that the control, aged untreated, treated and the aged treated linen samples were more green in color. It was noticed that the treated and the aged treated samples gave more green color than the aged untreated linen samples especially with 0.5% of guar gum. For muslin cotton samples, the data obtained from a* value were redder except the treated sample at a the concentration of 0.5% and the aged treated sample at the concentration of 1%. The high red color was obtained from the treated sample at 0.5% of guar gum, and the less red color was obtained from the aged treated sample.

Table 1: Mechanical properties of linen samples treated with guar gum at different concentrations

linen samples treated with Guar gum at 0.5%		
Samples	**Tensile Strength (Kg)**	**Elongation (%)**
Control sample	14.0	25.0
Aged sample	7.0	10.0
Treated sample	20.0	27.0
Aged treated sample	19.0	15.0
linen samples treated with Guar gum at 1%		
Samples	**Tensile Strength (Kg)**	**Elongation (m)**
Control sample	14.0	25.0
Aged sample	7.0	10.0
Treated sample	17.0	30.0
Aged treated sample	15.0	25.0

Table 2: Mechanical properties of muslin cotton samples treated with guar gum at different concentrations

Muslin cotton samples treated with Guar gum at 0.5%		
Samples	**Tensile Strength (Kg)**	**Elongation (%)**
Control sample	17.0	20.0
Aged sample	3.5	15.0
Treated sample	8.0	27.0
Aged treated sample	6.5	25.0
Muslin cotton samples treated with Guar gum at 1%		
Samples	**Tensile Strength (Kg)**	**Elongation (m)**
Control sample	17.0	20.0
Aged sample	3.5	15.0
Treated sample	10.0	22.0
Aged treated sample	9.0	15.0

*3.4.3. Hue blue-yellow (CIE*b)*

The data obtained (Tables 3 and 4) showed that the control, aged untreated, treated, and aged treated linen and muslin samples were more yellow. There was a reduction in the b* value of aged untreated (19%) and treated (0.0%) linen samples at 0.5% and

The treated samples (10%) at 1% of guar gum. There was an increase in the b* value of the aged treated linen samples at 0.5% and 1%. The reduction was 9% and 17% respectively. For muslin cotton samples, the yellow color obtained from b* value for the aged untreated, treated, and aged treated samples has been reduced compared to the control samples. The reduction was 8% for the aged untreated sample, 30%,9%, 32%, and 3% for the treated and aged treated samples at 0.5% and 1% of guar gum respectively. The higher reduction was obtained from the treated muslin cotton samples.

3.4.4. Total color differences (ΔE)

The data obtained (Tables 3 and 4) showed that there were some changes in the total color differences. The fewer changes in ΔE were obtained from the aged linen (2.95) and muslin cotton (3.17) untreated samples. The higher changes were obtained from the treated and aged treated linen and muslin cotton samples. It was also noticed that the changes in ΔE of the treated and aged treated muslin cotton samples were higher than linen samples. The results obtained proved that the use of guar gum at 0.5 and 1% leads to changing the color of the samples. These changes in the color can happen due to the natural color of guar gum which tends to be whitish and yellowish. The artificial accelerated heat ageing played an important role in the change of color.

These results were confirmed by Chowdhury et al. [**52**] who reported that the heat ageing leads to changing of the color. They noted that the color can change from red to red-yellowish color by increasing temperature. Abdel-Maksoud and Al-Saad [**31**] mentioned that the accelerated heat ageing through different methods can cause the change of the color of the cellulosic materials such as paper. The more the ageing time increases, the more the change of color increases.

Table 3: Change of color of treated muslin cotton samples with guar gum at different concentrations before and after accelerated heat ageing

Samples	**Guar gum 0.5%**			
	Color value			**Total color differences**
	L*	**a***	**b***	**ΔE**
Control Sample	83.53	0.82	6.13	0.00
Aged Sample	80.63	1.19	5.67	2.95
Treated Sample	78.61	-0.91	4.29	6.90
Aged treated Sample	77.99	0.94	5.57	5.57
Samples	**Guar gum 1%**			
	Color value			**Total color differences**
	L*	**a***	**b***	**ΔE**
Control Sample	83.53	0.82	6.13	0.00
Aged Sample	80.63	1.19	5.67	2.95
Treated Sample	77.75	1.37	4.18	6.12
Aged treated Sample	74.67	-0.33	5.97	8.87

Table 4: Change of color of treated linen samples with guar gum at different concentrations before and after accelerated heat ageing

Samples	Guar gum 0.5%			
	Color value			Total color differences
	L*	a*	b*	ΔE
Control Sample	59.74	-0.04	3.48	0.00
Aged Sample	56.64	-0.14	2.82	3.17
Treated Sample	54.23	-0.15	3.48	5.51
Aged treated Sample	54.16	-0.22	3.83	5.59

Samples	Guar gum 1%			
	Color value			Total color differences
	L*	a*	b*	ΔE
Control Sample	59.74	-0.04	3.48	0.00
Aged Sample	56.64	-0.14	2.82	3.17
Treated Sample	53.82	-0.16	3.14	5.96
Aged treated Sample	53.24	-0.15	4.17	6.54

3.5. Weight

It was clear from the data (Table 5 and 6) that the weight of the aged untreated samples have been reduced compared to the controlled samples. The reduction was 12% for linen and 21% for muslin cotton samples. The results showed that the weight in-creased after the application of guar gum at 0.5% and 1% compared to the control sample. The increase was 5%, and 27% for the treated linen samples, while the in-crease was 24% and 28% for the treated muslin cotton samples. There were reductions in the aged treated samples of linen and muslin cotton samples.

These reductions were 50%, 56%, 43%, and 33% for linen and muslin cotton samples at 0.5% and 1% of guar gum respectively. The reductions in the aged untreated and the aged treated samples may have occurred due to the evaporation of water from linen and muslin cot-ton samples and evaporation of water as a solvent used for guar gum. It can also be supposed that the deterioration of the polymer used may cause loss of weight.

4. Conclusion

The study of the chemical changes of linen and muslin cotton fibers by FTIR for all bands has proved that there are high reductions in the aged untreated samples com-pared to the control samples (before aging), and this may be due to the oxidation pro-cess of cellulose. There was also a low reduction in the aged treated samples compared to the treated sample. The results have proved that the use of guar gum has caused an increase in the chemical stability of the linen and muslin cotton samples and increased their resistance against thermal aging. For the surface morphology, the treated samples at 1% (linen and muslin cotton fibers) gave good distribution on the surfaces of the fibers. The fibers have become clear and strong after treatment.No residues of polymer with linen have been found but little residues were obtained with muslin cotton fibers. The treated samples with guar gum at 0.5% and 1% gave an improvement in the mechanical properties studied. The mechanical properties of treated and aged treated samples were better than the mechanical properties of aged untreated samples. There were some little changes in the color values and total color difference with treated and aged treated linen and muslin cotton samples. The changes in muslin cotton samples were higher than the changes in linen samples at 0.5% and 1% of guar gum. There was an increase in the weight of the treated samples with guar gum at the concentrations used. There were also reductions in the aged and the aged treated sam-ples, which may due to the accelerated heat ageing, which lead to the loss of water from the linen and muslin cotton fibers. Moreover, the reductions in weight of the aged treated linen samples were higher than the muslin cotton samples.

Table 5: Weight of the linen samples treated with guar gum at different concentrations before and after accelerated heat ageing

Samples	Guar gum 0.5%
	Weight (g)
Control Sample	1.078
Aged Sample	0.945
Treated Sample	1.35
Aged treated Sample	0.540

Samples	Guar gum 1%
	Weight (g)
Control Sample	1.078
Aged Sample	0.945
Treated Sample	1.48
Aged treated Sample	0.475

Table 6: Weight of muslin cotton samples treated with guar gum at different concentrations before and after accelerated heat ageing

Samples	Guar gum 0.5%
	Weight (g)
Control Sample	1.078
Aged Sample	0.945
Treated Sample	1.35
Aged treated Sample	0.540

Samples	Guar gum 1%
	Weight (g)
Control Sample	0.407
Aged Sample	0.322
Treated Sample	0.566
Aged treated Sample	0.274

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