Carbohydrate Polymers 79 (2010) 47–53

Contents lists available at ScienceDirect

Carbohydrate Polymers

journal homepage: www.elsevier.com/locate/carbpol

Incorporation of chlorohexidin diacetate into cotton fabrics grafted with glycidyl methacrylate and cyclodextrin

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ARTICLE INFO

Article history:
Received 13 June 2009
Received in revised form 28 June 2009
Accepted 10 July 2009
Available online 6 August 2009

Keywords:
Chlorohexidin diacetate
β-Cyclodextrin
Inclusion complex
Cotton fabric
Antimicrobial finishing

ABSTRACT

Linear electron beam radiation was used to induce grafting of glycidyl methacrylate/β-cyclodextrin mixture onto cotton fabric. Chlorohexidin diacetate was incorporated to the cavities of cyclodextrin fixed on the cotton fabric to form an inclusion complex having antimicrobial activity. After incorporating chlorohexidin diacetate, the fabric was subjected to several washing cycles to examine the durability of the antimicrobial finishing. Control and grafted cotton fabrics (before and after loading with antimicrobial agent) were characterized for their antimicrobial activity against different kinds of bacteria and fungi.

Grafted fabrics loaded with antimicrobial agent were found to show good antimicrobial activity in comparison with control and grafted fabrics which are not loaded with antimicrobial agent. The grafted fabrics loaded with antimicrobial agent were found also to exhibit good antimicrobial activity after five washings and this lasting antimicrobial activity can be attributed to the inclusion complex formed between chlorohexidin diacetate molecules and the cavities of cyclodextrin.

1. Introduction

The inherent properties of the textile fibers provide room for the growth of microorganisms. Besides, the structure of the substrates and the chemical processes may induce the growth of microbes. Humid and warm environment still aggravate the problem. Infestation by microbes cause cross infection by pathogens and development of odor where the fabric is worn next to skin. In addition, the staining and loss of the performance properties of textile substrates are the results of microbial attack. Basically, with a view to protect the wearer and the textile substrate itself antimicrobial finish is applied to textile materials (Ramachandran, 2004).

Microbes are the tiniest creatures not seen by the naked eye. They include a variety of microorganisms like bacteria and fungi. Bacteria are unicellular organisms which grow very rapidly under warmth and moisture. Further, subdivisions in the bacteria family are Gram positive (e.g. *Staphylococcus aureus)* and Gram negative (e.g. *Escherichia coli*). Fungi, molds or mildew are complex organisms with slow growth rate. They stain the fabric and deteriorate the performance properties of the fabrics. Fungi are active at a pH level of 6.5 (Ramachandran, 2004).

Antimicrobial textile finishes must exhibit the following properties (Hirc, 2005):

- Effective control of bacteria, molds and fungi.
- Selective activity towards undesirable microorganisms.
- Absence of toxic effects for both the manufacturer and the consumer.
- Durability of activity to laundering, dry cleaning, leaching.
- Applicability with no adverse effects on the fabric.
- Acceptable moisture transport properties.
- Compatibility with other finishing agents.
- Easy application, compatibility with common textile processing.

The antimicrobial agents can be applied to the textile substrates by exhaust, pad-dry-cure, coating, spray and foam techniques. The substances can also be applied by directly adding into the fiber spinning dope. It is claimed that the commercial agents can be applied online during the dyeing and finishing operations (Hirc, 2005; Ramachandran, 2004). Various methods for improving the durability of the finish include:

(1) Insolubilisation of the active substances in/on the fiber.
(2) Treating the fiber with resin, condensates or cross linking agents.
(3) Micro encapsulation of the antimicrobial agents with the fiber matrix.
(4) Coating the fiber surface.

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doi:10.1016/j.carbpol.2009.07.050

(5) Chemical modification of the fiber by covalent bond formation.
(6) Use of graft polymers, homo polymers and/or copolymerization onto the fiber.

The durability of antimicrobial finishing can be grouped into two categories, temporary and durable (Payne & Kudner, 1996; Sun & Xu, 1998). Temporary finishing of textiles is easy to achieve, but is also easily washed off. Durable antimicrobial finishing is generally achieved by the slow-release method, in which the treated fabrics slowly release the antimicrobial agent to inactivate microorganisms.

Cyclodextrins represent an important group of textile auxiliaries because of the growing requirement for biodegradable and nontoxic textile auxiliaries (Buschmann, 1991; Wang & Chen, 2006). Novel functional surface treatments of cotton fabrics based on permanent fixation of β-cyclodextrins on the fabric are receiving increased attention in the field of textile finishing (Buschmann, Deuter, Knittel, & Schollmeyer, 1988; Knittel & Schollmeyer, 2000; Textor, Bahners, & Schollmeyer, 1999; Wang & Chen, 2004; Wang & Chen, 2005). Fabrics are being finished with cyclodextrin derivatives to attain desired performance properties like wash resistance, odor absorbency, insect resistance and antimicrobial activity (Szejtli, 2003).

Cyclodextrins are non-reducing cyclic linked oligosaccharides produced through the enzymatic degradation of starch. Six, seven or eight units bound into a ring are marked as cyclohexa-, cyclohepta- or cycloocta amylase, which are known as α-, β-, and γ-cyclodextrins, respectively (Fig. 1) (Wikipedia, 2009).

Cyclodextrins are made up of dextrose units whose molecules are joined in a ring to form a cavity that is capable of holding and releasing other molecules. This property can be exploited in textiles to produce extraordinary results. Empty cyclodextrins can be used to trap and mask unpleasant odors (Fig. 2), while filled ones can be programmed to release fragrances or skin-care components (Fig. 3) (Wacker, 2006).

The aim of the present study is to prepare cotton fabrics with durable antimicrobial activity to be capable of killing or inhibiting the growth of microorganisms such as bacteria and fungi. β-cyclodextrin was chosen in this study to be anchored to the cotton fabric through grafting process. After grafting, the antimicrobial agent chlorohexidin diacetate (Fig. 4) (Chem, 2009) was incorporated to the cavities of β-cyclodextrin to form an inclusion complex and the treated cotton fabrics were tested for their antimicrobial activity.

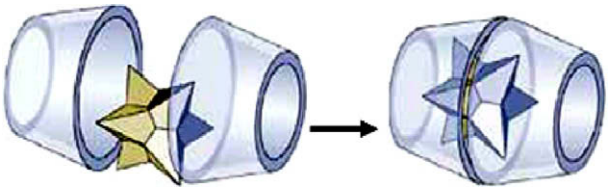

Fig. 2. Masking of unwanted odors by CD.

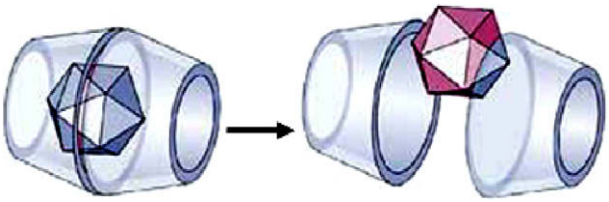

Fig. 3. Release of active ingredient from CD.

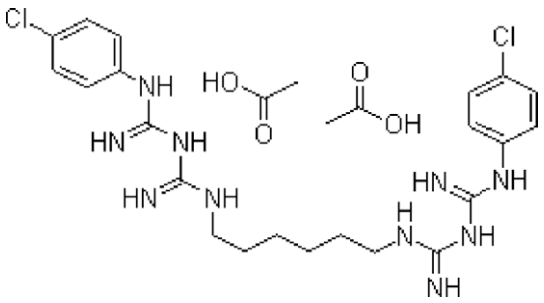

Fig. 4. Structural formula of chlorohexidin diacetate.

2. Experimental

2.1. Materials

Duck cotton fabric was supplied by Misr Company for Spinning and Weaving, Mehalla El-Kobra, Egypt. The fabric was further laboratory purified by scouring at 100 °C for 60 min in an aqueous solution containing (2 g/l) sodium carbonate and 2 g/l non-ionic wetting agent using a material to liquor ratio of 1:20, then thoroughly washed with water and dried at ambient temperature.

β-Cyclodextrin (β-CD) was supplied by Wacker Chemie GmbH, München, Germany. Glycidyl methacrylate (GMA) was supplied by Fluka Chemie AG, Buchs, Switzerland. Chlorohexidin diacetate was supplied by Synopharm GmbH & Co. Kg, Barsbüttel, Germany. All other chemicals were laboratory grade reagents.

2.2. Radiation grafting onto cotton fabric

GMA or GMA/β-CD mixture were grafted onto cotton fabric using linear electron beam irradiation technique. The grafting reaction was conducted at the National Centre of Radiation Research

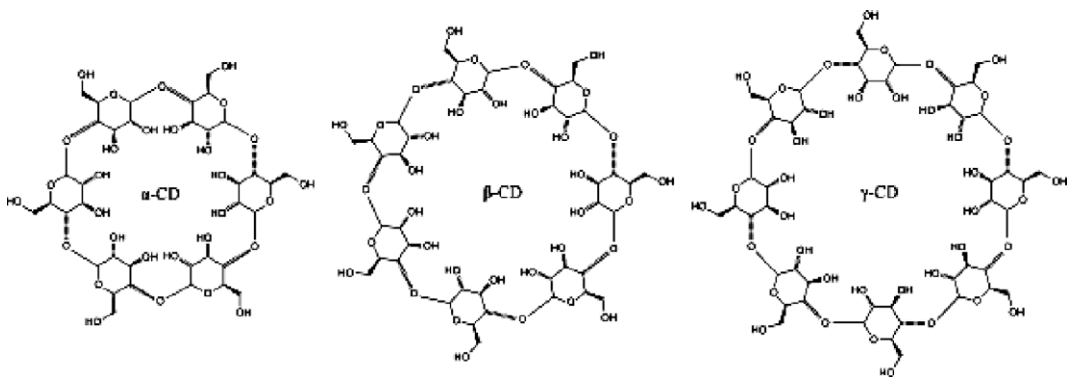

Fig. 1. Chemical structure of the three main types of cyclodextrins.

and Technology, Nars City, Cairo, Egypt. The samples were irradiated with linear electron beam accelerator (energy 1.5 MeV, power 37.5 kw, beam current 25 mA and scan width variable up to 90 cm).

Samples of pre-scoured cotton fabric were completely immersed in finishing bath containing calculated concentrations of GMA or GMA/β-CD mixture for 1 h., and then squeezed to a wet pick-up of ca 100%. The fabric samples were then irradiated with the said linear electron beam accelerator to initiate the grafting reaction. The grafted samples were then thoroughly washed with the proper solvent to remove the non-reacted matters and ungrafted polymers. The grafted samples were finally dried at ambient conditions and the graft yield was determined gravimetrically.

2.3. Reaction of β-CD with grafted cotton samples (retreatment process)

A set of cotton fabrics previously radiation-grafted with GMA or GMA/β-CD mixture was retreated with solution containing 6% (ows) β-CD, 1 M NaCl and 1% (w/v) NaOH, using material to liquor ratio of 1:20. The system was kept under continuous shaking at 80 °C for 1 h. The treated samples were washed thoroughly with distilled water and then dried at ambient conditions (Hebeish et al., in press; Textor et al., 1999).

2.4. Incorporation of chlorohexidin diacetate into grafted cotton fabrics

Treated and control cotton fabrics were further treated by dipping the fabrics at 25 °C for 2 h in ethanolic solution containing 2% (w/v) chlorohexidin diacetate (antimicrobial agent), using material to liquor ratio of 1:10. The samples were then roll-squeezed to wet pick-up of 100% and then washed to remove the adsorbed antimicrobial agent from the fabric surface.

Several methods are available for the determination of antimicrobial agents in the treated fabrics. Most of the methods developed so far for the analysis of commercially available antimicrobial agents formulations are gas chromatography (GC) and liquid chromatography (HPLC) (Scalia et al., 2006; Wang & Cai, 2008). In the present study a fast, selective and sensitive method of chlorohexidin diacetate estimation in treated cotton fabrics was employed. The analysis was carried out using gas chromatography (GC) with electron capture for both detection and quantification of the chlorohexidin diacetate. Analysis of chlorohexidin diacetate extract was conducted with a Hewlett–Packard Model 5890 A GC, equipped with column HP-1(25 cm × 0.2 mm × 0.2 μm film thickness) and flame ionization detector (FID). The injector and detector were operated at 250 °C and 280 °C, respectively. The oven temperature was programmed from 200 to 250 °C at 5 °C/min and held for 1 min.

2.5. Evaluation of treated fabrics

2.5.1. Determination of graft yield

Graft yield was determined from the gain in weight of cotton fabric due to graft polymerization after removing the ungrafted polymers with the proper solvent according to the following equation.

$$\%\ \text{Graf yield} = \frac{W_2 - W_1}{W_1} \times 100$$

where (W_2) is the weight of dry fabric sample after grafting and (W_1) is the weight of dry fabric sample before grafting.

2.5.2. Quantification of β-CD fixed onto cotton fabrics

In previous work (Grechin, Buschmann, & Schollmeyer, 2007), the interaction of volatile amines with CD-finished cotton fabrics has been investigated in order to develop a more useful and informative method for quantification of fixed CD on the fabric. The inclusion complexes formed between CD and gaseous organic compounds (amines, alcohols, etc.) are formed at the conditions of solid–gas equilibrium (Dantz, Meschke, Buschmann, & Schollmeyer, 1998; Grechin, Boschmann, & Schollmeyer, 2006; Tanad, Nakamura, Kawasaki, Kitayama, & Takeba, 1997).

The amount of CD fixed on the surface of cotton fabric was determined using simple volumetric acid–base titration of the extracted amine in water (Grechin et al., 2007).

2.5.3. Determination of remaining epoxide

α-Epoxides are group of cyclic ethers in which the oxygen atom forms a three-membered ring with two adjacent carbon atoms. Because of the strained three-membered ring, α-epoxides are the most reactive of the oxides and are far more reactive than ordinary ethers. Thus they react with hydrogen chloride to form the corresponding chlorohydrins. This reaction is the base for the determination of α-epoxy groups and this method is termed the acidimetric method (Vogel, 1995).

2.5.4. Quantitative analysis of antimicrobial agents

Chlorohexidin diacetate was extracted from the fabric and portion of the resulting extract was analyzed by a gas chromatograph (GC) Hewlett–Packard Model 5890 A GC, The GC analysis was carried out at Mycotoxin Central Laboratory, National Research Centre.

2.5.5. Fabric washing

Treated cotton fabrics were washed in aqueous solution containing 2 g/l sodium carbonate and 5 g/l non-ionic wetting agent at 60 °C for 15 min using material to liquor ratio of 1:20. The washing process was carried out to examine the ability of fabric to retain its antimicrobial activity after washing.

2.5.6. Estimation of fabric's antimicrobial activity

The antimicrobial activities of both treated and control fabrics were measured according to the Diffusion Disk Method (Grayer & Harbone, 1994; Irob, Young, & Apderson, 1996; Jawetz, Melnick, & Adelberg, 1974; Muanza, Kim, Euler, & Williams, 1994) at Micro Analytical Center, Faculty of science, Cairo University. Two kinds of fungus – *Candida albicans* and *Aspergillus flavus* and two kinds of bacteria: *E. coli* and *S. aureus*, were selected to investigate the antimicrobial activity. In order to investigate the durability of antimicrobial performance, the antimicrobial activity of the fabrics was also tested after washing.

The ability of fabric to exhibit antimicrobial activity after washing is expressed as percent retention.

$$\%\ \text{Retention} = \frac{\text{Antimicrobial activity after washing}}{\text{Antimicrobial activity before washing}} \times 100$$

2.5.7. Infrared spectroscopy

Cotton fabrics were evaluated using infrared spectroscopy. The infrared analysis of the treated cotton fabrics were carried out at the Infrared Laboratory, Central Services Laboratory, National Research Centre, using JAS Co 1 Japan, FTIR 6100, Fourier Transion Infrared Spectrophotometer.

2.5.8. Scanning electron microscopy (SEM)

SEM analysis of control and treated fabrics was performed at Scanning Electron Microscope Division; Central Services Labora-

tory, National Research Centre, using a JEOL (JXA-840 A); Electron Probe Micro–Analyzer, Edward, England, 150 A. Sputter Coater. Samples were coated with gold according to the method described in the operation manual provided by the manufacturer. Photos were collected at range from 1000× to 2000×.

3. Results and discussions

3.1. Infrared spectroscopy

Cellulose was subjected to grafting and the resulting preparation was loaded with chlorohexidin diacetate (antimicrobial agent). This approach represents a way to the development of new textiles of antimicrobial activities.

Structures of the grafted cellulose preparations before and after incorporation of the antimicrobial agent were tested by comparative inspection of their IR-spectra particularly in the fingerprint region (1500–650 cm^{-1}).

The cotton fabric grafted with glycidyl methacrylate (GMA) was prepared by treating the fabric with GMA. The main functional groups attributable to cellulose and GMA are apparent in the IR-spectra (Fig. 5a). These include the absorption bands at 3414 (OH), 2906 (CH, aliphatic), 1725 (C=O, ester), 1164 (C–O, stretching) and at 1114 cm^{-1} (–C–O–C, epoxide). The absorption band present at 1641 cm^{-1} can not be attributed to the CH=C– group absorption in GMA since it is also recorded in the IR-spectra of cellulose itself. This indicates that this group is implicated in the grafting process.

The cotton fabric grafted with GMA was further treated with β-cyclodextrin. The IR-spectra of β-cyclodextrin alone (Fig. 5b) reveals the presence of strong absorption bands at 3385 (OH), 2922 (CH). The same bands are observed in the IR-spectra of untreated cellulose (Fig. 5c) but the IR-spectra of cyclodextrin and untreated

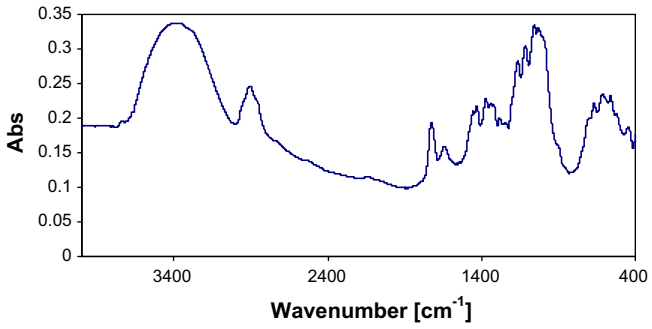

Fig. 5a. IR-Spectra of Cell-g-GMA.

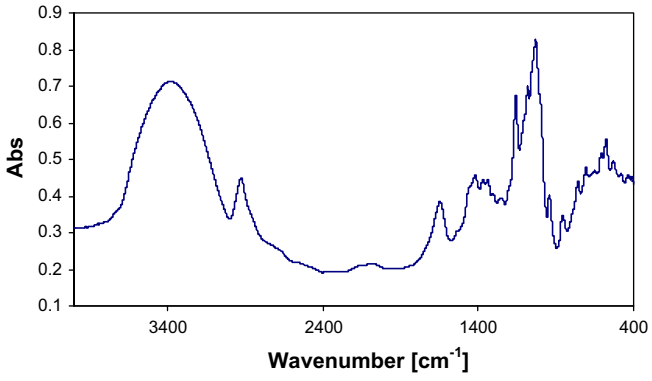

Fig. 5b. IR-Spectra of β-cyclodextrin.

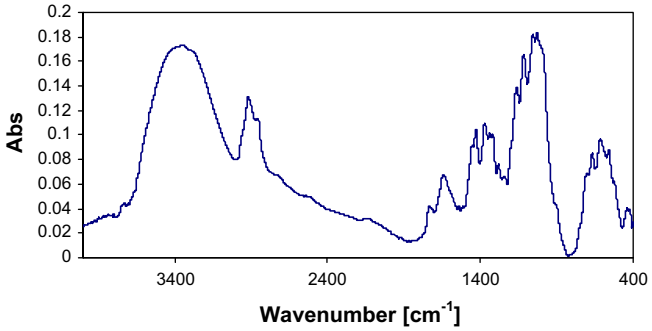

Fig. 5c. IR-Spectra of untreated cellulose.

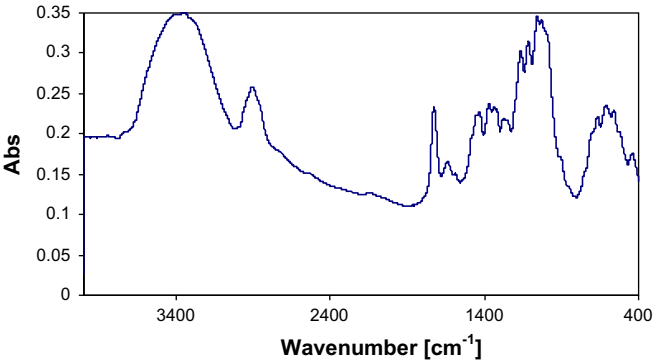

Fig. 5d. IR-Spectra of Cell-g-GMA/β-CD.

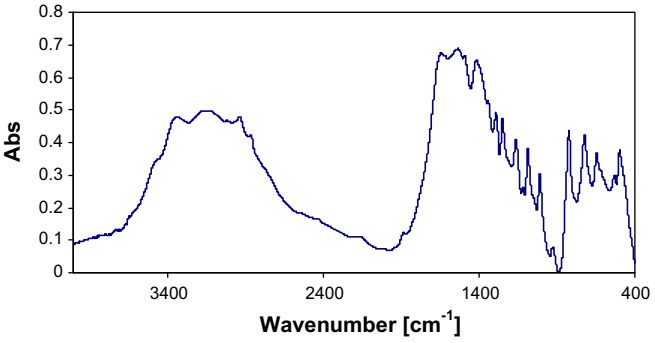

Fig. 5e. IR-Spectra of chlorohexidin diacetate.

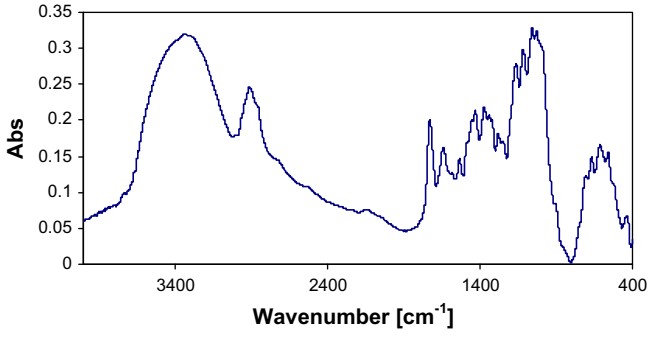

Fig. 5f. IR-Spectra of incorporated chlorohexidin diacetate into Cell-g-GMA/β-CD.

cellulose are not superimposible in the fingerprint region (1500–650 cm^{-1}). Moreover, the IR-spectra of the two grafted cellulose samples, Cell-g-GMA (Fig. 5a) and Cell-g-GMA-β-CD (Fig. 5d) are not superimposible in the fingerprint region. This indicates that grafting of Cell-g-GMA with β-CD was completed, most probably via cleavage of the epoxide ring in Cell-g-GMA with hydroxyl groups found in cyclodextrin molecule.

The main feature differentiating between the IR-spectra of the two grafted cellulose samples (Fig. 5a and d) and that of the untreated cellulose (Fig. 5c) is the strong absorption band at 1728 cm^{-1} characteristic for C=O group of glycidyl methacrylate moiety which is present strongly in Fig. 5a and d while completely absent in Fig. 5c.

The IR-spectra of chlorohexidin diacetate is presented in Fig. 5e and the IR-spectra of chlorohexidin diacetate incorporated into the cotton fabric grafted with GMA/β-CD mixture is presented in Fig. 5f.

Careful comparison of the IR-spectra of cotton fabric grafted with GMA/β-CD mixture and that of chlorohexidin diacetate incorporated into grafted cotton fabric, particularly in the fingerprint region (1500–650 cm^{-1}) shows that they are superimposible and at the same time they are completely different from the IR-spectra of pure chlorohexidin diacetate. Therefore it is safe to state that chlorohexidin diacetate was completely included inside the cyclodextrin cavities and that is why no absorption band characteristic for chlorohexidin diacetate appeared in the IR-spectra of the grafted cotton fabric loaded with the antimicrobial agent.

3.2. Scanning electron microscopy (SEM)

SEM was conducted to view the effect of grafting on the cotton fabrics morphology. Fig. 6a shows the SEM micrograph of a sample of untreated cotton fabric, where the surface is smooth and free from any additions. Fig. 6b shows a sample of cotton fabric grafted with GMA, in which it is clear that the surface has layer of addition and particulates on fibers. Fig. 6c illustrates an SEM micrograph of a cotton fabric grafted with GMA/β-CD mixture, in which the surface morphology is different from that of GMA only, some flakes of β-CD are apparent on the surface. The particulate and speckled matter on the cotton fibers in the resulting micrographs confirm the grafting of GMA and additional β-CD compound onto cotton fabric.

3.3. Effect of regrafting on the amount of incorporated antimicrobial agent

Samples from cotton fabric grafted with GMA alone (Cell-g-GMA) and cotton fabric grafted with GMA/β-CD mixture (Cell-g-GMA/β-CD) were taken and regrafted under the same conditions with β-CD. This was done with the aim of increasing the amount of fixed β-CD on the cotton fabric and to see to what extent will this increment affect the amount of chlorohexidin diacetate incorporated onto the cotton fabric in the further antimicrobial agent loading treatment.

Table 1 shows the effect of regrafting process on the epoxide content and percent of fixed β-CD and its reflection on the amount of chlorohexidin diacetate taken by cotton fabric. The obtained results (Table 1) show that by exercising the regrafting process, the epoxide content decreases from 0.9537% and 0.6791% to 0.3640% and 0.0499% for Cell-g-GMA and Cell-g-GMA/β-CD, respectively. Accordingly the amounts of fixed β-CD increase from 0.0% and 3.9% to 3.8% and 7.8% for Cell-g-GMA and Cell-g-GMA/β-CD, respectively. The amounts of loaded chlorohexidin diacetate were logic to increase by exercising the regrafting process due to increase in the availability of the hosting cavities of the increased fixed β-CD.

3.4. Antimicrobial assessment

The antimicrobial fabrics were prepared by means of the methods outlined above. The antimicrobial activities of differently treated cotton fabrics were tested using diffusion disk method, and the

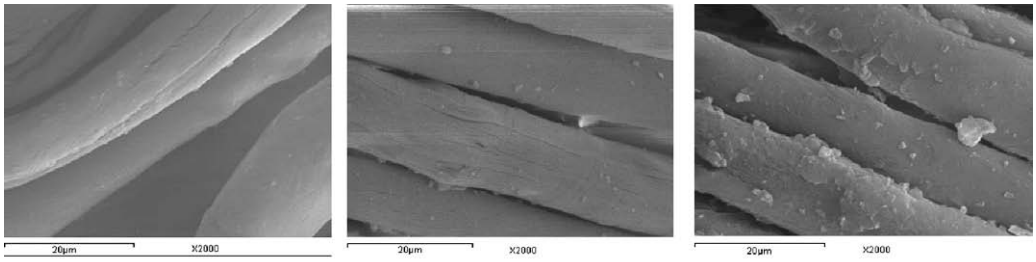

Fig. 6. Scanning electron micrographs of differently treated cotton fabrics.

Table 1
Effect of regrafting on the amount of incorporated antimicrobial agent.

Fabric sample	Extent of treatment						
	Samples grafted by irradiation only			Samples grafted by irradiation and then regrafted with β-CD			
	Epoxide content (%)	Fixed β-CD (%)	Loaded CHDA* (mg/m^2)	Remaining content (%)	Consumed epoxide	Fixed β-CD (%)	Loaded CHDA* (mg/m^2)
Cell-g-GMA	0.9537	0.0	0.0	0.3640	61.76	3.8	17.3
Cell-g-GMA/β-CD	0.6791	3.91	15.7	0.0499	92.65	7.8	32.2

Grafting conditions: Soaking the fabric in a solution containing 50% (w/w) GMA or mixture of 50% (w/w) GMA + 5% (w/w) β-CD for 1 h then irradiated to initiate grafting. *Regrafting conditions:* 6% (ows) β-CD, 1 M NaCl and 1% (w/v) NaOH, using material to liquor ratio of 1:20. The system was kept under continuous shaking at 80 °C for 1 h.
* CHDA, chlorohexidin diacetate.

Table 2
Antimicrobial activities of differently treated cotton fabrics.

Extent of treatment	Incorporated antimicrobial agent (mg/m^2)	Inhibition zone diameter (mm/1 cm sample)			
		Escherichia coli (G^-)	*Staphylococcus aureus* (G^+)	*Candida albicans* (fungus)	*Aspergillus flavus* (fungus)
Untreated fabric (control)	0.0	0.0	0.0	0.0	0.0
Fabric grafted with only GMA	0.0	0.0	0.0	0.0	0.0
Fabric grafted with GMA/β-CD mixture	0.0	0.0	0.0	0.0	0.0
Fabric grafted with GMA/β-CD mixture and then loaded with antimicrobial agent	15.7	18	16	15	13
Above grafted fabric was regrafted with β-CD then loaded with antimicrobial agent	25.2	23	24	23	21

Antimicrobial agent, chlorohexidin diacetate; antimicrobial test, diffusion disk method; test carried out after one wash.

results are shown in Table 2. Besides testing the antimicrobial activity of fabrics loaded with the antimicrobial agent, the antimicrobial activities of untreated cotton fabric (control) and cotton fabrics grafted with GMA or GMA/β-CD mixture were also tested.

Results in Table 2 show that untreated cotton fabric and cotton fabrics grafted with GMA or GMA/β-CD mixture do not show any antimicrobial activity. This means that neither cotton itself nor GMA and β-CD moieties have any antimicrobial activities by themselves. When cotton fabric grafted with GMA/β-CD mixture is loaded with the antimicrobial agent, the latter is incorporated to the cavities of β-CD moiety and the fabric shows good antimicrobial activity. When cotton fabric grafted with GMA/β-CD mixture is regrafted with β-CD and loaded with the antimicrobial agent, the fabric shows improvement in its antimicrobial activity. This is because the regrafting process increases the number of hosting cavities and accordingly the amount of incorporated antimicrobial agent increases which leads to better antimicrobial activity.

3.5. Effect of repeated washing on the durability of the antimicrobial finishing

Table 3 and Fig. 7 show the effect of repeated washing on the durability of antimicrobial activity of Cell-g-GMA/β-CD loaded with antimicrobial agent. The durability of antimicrobial activity was expressed in terms of percent retention of antimicrobial activity (inhibition zone of different types of bacteria and fungi) after repeated washings. Although the antimicrobial activities of the said fabrics decrease by repeated washing, but the fabrics still retaining good deal of their antimicrobial properties. This good retention of antimicrobial activity after repeated washing means that the antimicrobial agent is not only just physically adsorbed on the fabric surface but the cavities present in β-cyclodextrin moieties play an important role in hosting and keeping the antimicrobial agent inside them, resulting in long lasting antimicrobial activity of the treated fabrics (Wang & Cai, 2008).

Typical cyclodextrins are constituted by 6–8 glucopyranoside units, can be represented as toroids with the larger and the smaller openings of the toroid exposing to the solvent secondary and primary hydroxyl groups, respectively. Because of this arrangement, the interior of the toroids is not hydrophobic, but considerably less hydrophilic than the aqueous environment and thus able to host other hydrophobic molecules (Wikipedia, 2009).

Table 3
Effect of repeated washing on the antimicrobial activity of Cell-g-GMA/β-CD loaded with chlorohexidindiacetate as an antimicrobial agent.

Number of washes	Remaining antimicrobial agent (mg/m^2)	Inhibition zone diameter (mm/1 cm sample)			
		Escherichia coli (G^-)	*Staphylococcus aurous* (G^+)	*Candida albicans* (fungus)	*Aspergillus flavus* (fungus)
0	35.2	33	35	34	35
1	24.4	23	24	23	21
5	15.7	20	21	18	14

Washing conditions: 2 g/l sodium carbonate, 5 g/l non-ionic wetting agent, M/L ratio 1:20, washing at 60 °C for 15 min.

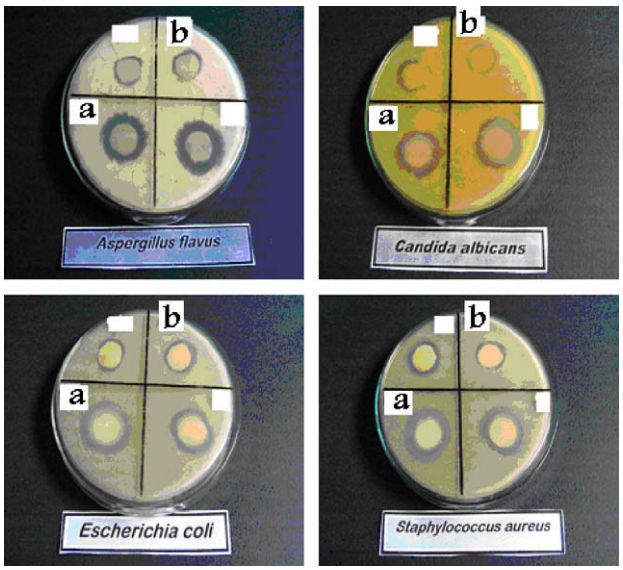

Fig. 7. Inhibition zone of antimicrobial finished cotton fabrics before and after washing. (a) Inhibition zone before washing; (b) inhibition zone after washing.

4. Conclusions

GMA or GMA/β-CD mixture were grafted onto cotton fabric by irradiation technique using linear electron beam for initiation. The so obtained grafted cotton fabric was loaded with commercially available antimicrobial agent (chlorohexidin diacetate). Grafted cotton fabric loaded with the antimicrobial agent, in addition to control and cotton fabrics grafted with GMA or GMA/β-CD (not loaded with any antimicrobial agent) were tested towards their antimicrobial activity. The fabrics loaded with the antimicrobial agent were found to show very good antimicrobial activity in contrary to control and grafted fabrics which are not loaded with antimicrobial agent. On the other hand, it was found that as the amount of β-CD, fixed on the fabric increases, the amount of incorporated antimicrobial agent and accordingly the antimicrobial activity of the fabric increases. The results reported in this study demonstrate that the GMA/β-CD grafted fabrics loaded with antimicrobial agent retain good deal of their antimicrobial activity after five washings. This good retention of antimicrobial activity after repeated washing is due to the cavities present in cyclodextrin moieties which are used to host and keep the antimicrobial agent, resulting in long lasting antimicrobial activity.

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