Obtaining Composite Cotton Fabric by Cyclodextrin Grafting


Abstract—Finishing is an important part of fabric processing with which a wide range of features are imparted to greige or colored fabrics for various end-uses. Especially, by the addition or impartation of nano-scaled particles to the fabric structure composite fabrics, a kind of composite materials can be acquired. Composite materials, generally shortened as composites or in other words composition materials, are engineered or naturally occurring materials made from two or more component materials with significantly different physical, mechanical or chemical characteristics remaining separate and distinctive at the macroscopic or microscopic scale within the end product structure. Therefore, the technique finishing which is one of the fundamental methods to be applied on fabrics for obtainment of composite fabrics with many functionalities was used in the current study with the same purpose. However, regardless of the finishing materials applied, the efficient life of finished product on offering desired feature is low, since the durability of finishes on the material is limited. Any increase in durability of these finishes on textiles would enhance the life of use for textiles, which will result in happier users. Therefore, in this study, since higher durability was desired for the finishing materials fixed on the fabrics, nano-scaled hollow structured cyclodextrins were chemically imparted by grafting to the structure of conventional cotton fabrics by the help of finishing technique in order to be fixed permanently. By this way, a processed and functionalized base fabric having potential to be treated in the subsequent processes with many different finishing agents and nanomaterials could be obtained. Henceforth, this fabric can be used as a multi-functional fabric due to the encapsulating ability of cyclodextrins to molecules/particles via physical/chemical means. In this study, scoured and rinsed woven bleached plain weave 100% cotton fabrics were utilized because cotton fabrics by the help of finishing technique in order to be fixed permanently. The production process of CDs consists of four fundamental steps such as culturing of the microorganism that produces the cyclodextrin glucosyl transferase enzyme; separation, concentration and purification of the enzyme from the fermentation medium; enzymatic conversion of prehydrolyzed starch in the mixture of cyclic and acyclic dextrans and as the last phase the separation of CDs from the mixture, their purification and crystallization. CDs consist of glucose units that are linked through 1,4-glycosidic bonds. There are three types of CD i.e. alpha-cyclodextrin, beta-cyclodextrin and gamma-cyclodextrin, that are known as first generation or parent CDs. Alpha, beta and gamma-CDs consist of six, seven and eight alpha-(1,4)-linked glycosyl units, respectively [1]-[3]. Gamma-CDs have advantages over the others in terms of the size of internal cavity, bioavailability and water solubility. However, beta-CD has the highest market potential and to lesser extent alpha-CD, whereas the market share of gamma-CD is considerably smaller because of low yield and high price [3]. Due to the dimensions of their cavities, alpha-CDs can make inclusion complexes only with low molecular weight molecules or compounds with aliphatic side chains [3]. The purification process of alpha and gamma-CDs makes the cost of production considerably higher, therefore 97% of the CDs utilized in the market are beta-CDs [1], [2].

The inclusion complexes are formed by the inclusion of one guest component which is included in the free space of the crystalline lattice of the second component, called as the host. The inclusion complexes of CD can exist both in solution and in solid state. In aqueous solution, due to polar nonpolar interactions, the weakly polar CD cavity is occupied by the water molecules that can be easily substituted by the guest molecules, less polar than the water. Exchange of water molecules with hydrophobic guest molecules causes the generation of inclusion complexes of CD. CDs are cyclic oligomers of D-glucopyranose that can be obtained with the conversion of starch by the help of certain bacteria [1], [2].

CDs have many applications in textile industry such as: absorption of undesired odors; fragrance release after making complexes, skincare products. Textile products including CDs can be used in filtration for adsorption of small pollutants in

I. INTRODUCTION

Keywords—Cotton fabric, cyclodextrin, improved durability, multifunctional composite textile.

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waste water. By making comprehensive studies regarding mutagenicity, toxicology, carcinogenicity and teratogenicity, the toxicological properties of the substances applied on the textiles should be investigated before utilizing them. CDs were proven to be not only non-toxic but also useful for making complexes with flavors, vitamins and natural colors. CDs have great importance for the textile industry because they can be utilized in the processes of dyeing, encapsulation, surface modification and washing of textiles, and preparation of polymers as well as in fiber formation [1], [2].

There are different studies in the scientific literature utilizing CDs. Wang and Cai studied incorporation of an antibacterial agent into CD cavities covalently bonded onto cotton fabric. The cotton fabric was grafted with β-CD molecules through reaction with monochlorotriazine β-CD (MCT-β-CD). Increasing the uptake of antibacterial agent and improving the resistance of the entrapped antibacterial agent to washing cycles, prolonging the antibacterial effect afforded by the fabric were obtained by finishing application of MCT-β-CD and analyzed by spectrophotometer and HPLC [4]. Abdel-Mohdy et al. investigated grafting of β-CD onto cotton fabric using monochlorotriazine to obtain insecticide treated fabrics which were durable against washing. MCT-β-CD finished cotton fabrics treated with insecticide showed fast repellent action, slower knockdown action and killing action and there are great losses in the amount of insecticides in blank samples by washing, while treated fabrics retain high amount of insecticides [5]. Abdel-Halim et al. investigated grafting of glycidyl methacrylate/β-CD onto cotton fabric to prepare cotton fabrics with durable antimicrobial activity to be capable of inhibiting the growth of microorganisms using chlorohexidin diacetate by linear electron beam radiation technique. 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 [6]. El Shafei et al. investigated the impact of grafting of MCT-β-CD with butyl acrylate onto cotton fabric along with epichlorohydrin and/or ZnO nanoparticles using conventional pad-dry-cure. The grafting imparted antibacterial activity that withstand 20 times washing and also improved air permeability that helped garments to display better breathability and comfortability. The characterization of the grafted fabrics using IR spectral analysis and scanning electron microscopy (SEM) was reported [7]. Ibrahim et al. investigated increasing disperse dye substantivity for cotton cellulose containing fabrics via modification with MCT-β-CD under different conditions. The obtained dyeing applications showed a remarkable improvement in their depth of shades along with a significant enhancement in their UV-protection properties [8]. Hebeish et al. investigated grafting of β-CD with poly butyl acrylic acid [βCD-g-PAA] onto cotton fabric. Silver nanoparticles colloidal solution was applied on this fabric along with epichlorohydrin in alkaline medium to obtain sufficient and durable antibacterial property. Characterization is done by color and UV–visible spectral analysis and transmission electron microscopy. The new finishing formulation resulted in good and durable bacterial properties for fabrics [9]. Abdel-Halim studied grafting of glycidyl methacrylate/ monochlorotriazinyl-β-CD mixture (GMA/MCT-β-CD) onto cotton fabric using linear electron beam radiation technique to obtain antimicrobial effect against different bacteria and fungi by loading chlorohexidin diacetate. It was demonstrated that GMA/MCT-β-CD fabrics loaded with antimicrobial agent retained antimicrobial activity after five washings [10]. Nazi et al. studied grafting of β-CD modified with itaconic acid containing carboxyl and vinyl groups via the esterification reaction onto cotton fabric to create useful polyfunctional building blocks in different biomedical fields. The presence of bounded CD and its ability on the surface of the fibers were demonstrated by using SEM and infra-red spectroscopy (FTIR). This modification did not show any negative effects on the performance of cotton fabric [11]. Radu et al. studied grafting of MCT-β-CD onto cotton made pajamas as a support of an inclusion compound (IC) with natural anti-allergic active principles in order to improve the curative properties and the comfort. The textile material grafted with MCT-β-CD and with active principles absorbed in the CD cavity was investigated by EDX [12]. Hebeish et al. studied grafting of glycidyl methacrylate or grafting of its combination with β-CD onto cotton fabric by irradiation using fasting electron beam. Aim of this study was to produce high performance chemically modified cotton fabric against mosquitoes [13]. Abdel-Halim et al. studied grafting of β-CD onto cotton fabric by use of butane tetracarboxylic acid as cross linking agent to give antimicrobial activity to cotton fabric. The antimicrobial cotton fabric was subjected to several washing cycles and the antimicrobial activity was measured after each washing cycle to examine the durability of this antimicrobial finishing against repeated washing. The measurements showed that the finished cotton fabrics retain reasonable amount of their antimicrobial activity even after 20 washing cycles [14]. Popescu et al. investigated grafting of β-CD with MCT and chitosan onto cotton fabric to obtain wrinkle-proofing and hydrophilizing effects by means of three pad-dry-cure treatment. FTIR, XPS, XRD, DSC and TGA analyses were used for characterization. CS increases the WRA and tensile strengths and MCT-β-CD makes the hydrophilicity higher than that of the witness sample, slightly improving the tensile strength [15]. Hebeish et al. studied treatment of cotton fabric with MCT-βCD and PAA to obtain antibacterial activity by means of inclusion of Ag nanoparticles. Characterization of cotton fabric before and after its chemical modification was carried out using FTIR, XRD and SEM. According to results, silver nanoparticle adsorption was much greater on cotton bearing CD moieties than unmodified cotton and antibacterial activity depends on the content of silver nanoparticles in the cotton sample [16]. Dehabadi et al. studied grafting of β-CD onto cotton fabric using polyaminocarboxylic acids (PACAs) as crosslinking agent for the fixation of β-CD onto cotton fabric. Fixation of β-CD was quantitatively estimated by measuring the weight increase of the treated samples. Using PACAs as crosslinking agents provides a useful way for fixation of CDs on cotton textiles [17]. Myung Hak Lee et al. studied grafting of β-CD
using N-methylol-acrylamide (NMA). The amount of chemically attached CD was determined by fluorescence measurements. The possibility of textile finishing of CD containing cotton fibers was investigated using benzoic acid as an antibacterial finishing agent or vanillin as an aroma finishing agent. According to results, the durability of the antimicrobial property to laudering was excellent and CD-NMA grafted cellulose fibers can be utilized in the aroma finishing of cotton [18]. Scalia et al. investigated grafting of β-CD with MCT onto cotton fabric to study the incorporation of the sunscreen agent, octyl methoxycinnamate into CD cavities covalently bound to cloth fibers. The unmodified and modified fabrics were characterized by UV spectrophotometry and thermogravimetric analysis (TGA). Hence, even after repeated washings, the β-CD finished fabric exhibits higher sunscreen agent retention and photoprotective properties than the unmodified textile material [19]. Nostro et al. studied grafting of β-CD onto surface of cellulose fabrics according to different procedures. After the treatment, benzoic acid, vanillin, iodine, N,N-diethyl-mtoluamide, and dimethylphthalate were loaded, by either spraying their solutions on the CD-grafted fabric, or by grafting the previously prepared inclusion compound on CD. The untreated and treated fabrics were evaluated through SEM, differential scanning calorimetry (DSC), UV-vis spectra, X-ray diffractometry, water absorbency, breaking load loss, aroma and antimicrobial finishing tests [20]. Medronho et al. studied grafting of β-CD with BTCA onto cellulose to investigate physicochemical characterization of cellulose modified with CDs by means of FTIR, cross polarization magic angle spinning solid state nuclear magnetic resonance (CP-MAS NMR), polarized optical microscopy (POM) and TGA. NMR and FTIR showed that ester bonds are formed between cellulose and CDs however, it was not possible to fully dissolve the CD [21].

Recently, many different nanoparticles are utilized in textile industry in order to provide functionalities for textiles and improve their inherent properties in terms of physical and chemical properties, mechanical behavior and performance characteristics. In the current study, to achieve improved durability for the textile chemicals, CDs were chemically attached to cloth fibers. The unmodified and modified fabrics were characterized by UV spectrophotometry and thermogravimetric analysis (TGA). Hence, even after repeated washings, the β-CD finished fabric exhibits higher sunscreen agent retention and photoprotective properties than the unmodified textile material [19]. Nostro et al. studied grafting of β-CD onto surface of cellulose fabrics according to different procedures. After the treatment, benzoic acid, vanillin, iodine, N,N-diethyl-mtoluamide, and dimethylphthalate were loaded, by either spraying their solutions on the CD-grafted fabric, or by grafting the previously prepared inclusion compound on CD. The untreated and treated fabrics were evaluated through SEM, differential scanning calorimetry (DSC), UV-vis spectra, X-ray diffractometry, water absorbency, breaking load loss, aroma and antimicrobial finishing tests [20]. Medronho et al. studied grafting of β-CD with BTCA onto cellulose to investigate physicochemical characterization of cellulose modified with CDs by means of FTIR, cross polarization magic angle spinning solid state nuclear magnetic resonance (CP-MAS NMR), polarized optical microscopy (POM) and TGA. NMR and FTIR showed that ester bonds are formed between cellulose and CDs however, it was not possible to fully dissolve the CD [21].

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spectrophotometer, cotton fabric samples were tested four times to control coloring quality of the samples.

FTIR with Attenuated Total Reflectance (FTIR-ATR) was utilized to examine the bond structure and bonding energy of surfaces of the fabric samples and thereby to identify the types of chemical bonds (functional groups). Therefore, by FTIR-ATR technique, the presence and distribution of CD on the functionalized cotton fabric samples were investigated. The FTIR-ATR spectra were taken from 5 different areas of the surface of the cotton fabric samples in order to analyze if CD is distributed homogeneously on the entire fabric surface.

C. Methods

6 wt.% BTCA and 3 wt.% SHP were used with different amounts of β-CD such as 15, 20 and 25 wt.% in the study. Experimental design of the study can be seen in Fig. 1.

Preparation of Treating Bath

For the preparation of treating bath, initially β-CD was put into water under mechanical effect. Then, BTCA was added during blending process. Blending was continued until the solution reaches the steady state. Subsequently, SHP as a catalyst was added into the solution and treating bath was obtained. In order to prepare treating baths for different amounts of β-CD as 15%, 20% and 25%, this process was executed three times and three different treating baths were obtained.

Impregnation of the Cotton Fabric Samples

Cotton fabric samples were immersed in the prepared treating baths for 60 minutes. In the meantime, the samples were squeezed in the beaker and again immersed into the same solution over and over.

Padding

The fabric samples were weighed at first and then they were immersed in the solution at the padder. Cotton fabric samples were padded to a wet pick-up of approximately 100%.

Pre-drying of the Cotton Fabric Samples

Cotton fabric samples were dried in an air oven at 110 °C for 20 minutes.

Grafting Reaction (Curing Step)

The reaction was carried out in dry-state at temperatures 160 °C and 180 °C for 5 min. and 10 min, respectively. As a result, 16 different fabric samples processed with different conditions in the curing step were obtained as shown in Table I.

Cleansing (Rinsing Step)

Treated and cured fabric samples were washed thoroughly with warm distilled water.

Drying of the Cotton Fabric Samples

Rinsed cotton fabric samples were dried in oven and then left to dry overnight at room temperature.

Weight Gain of the Finished Cotton Fabric Samples

First of all, cotton fabric samples were weighed at initial conditions and after β-CD grafting was concluded fabric samples were again weighed in order to find out the amount of β-CD in the cotton fabric structure. The formula for the weight gain of the finished cotton fabric samples is:

\[
\%GY = \left( \frac{W_2 - W_1}{W_1} \right) \times 100
\]

\(W_2\) = Dry weight of the grafted cotton fabric sample; \(W_1\) = Dry weight of the cotton fabric sample before grafting.

Dyeing

The solution used for the dyeing process was prepared with reactive dyes. The solution included 0.375 g Setazol red, 10 g salt, 5 g sodium carbonate and 235 g water. After that, it was put into Gyrowash at 90 °C for 1 h along with cotton fabric samples. Then, water was added slowly into Gyrowash to decrease the temperature to 60 °C. Both washing and rinsing processes were completed with hot water. Dyeing recipe can be seen in Fig. 2.

![Fig. 1 Experimental design](image_url)

<table>
<thead>
<tr>
<th>TABLE I SAMPLES AND TREATMENT CONDITIONS</th>
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<td>Sample 14</td>
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<td>Sample 15</td>
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III. RESULTS AND DISCUSSION

A. FTIR Spectroscopy Results

In Figs. 3-6, FTIR spectra of untreated cotton fabric, cotton fabric treated with only water, cotton fabrics treated with different amounts of CD under the same process conditions (160 °C, 10 min) and FTIR spectra of CD itself can be seen. The findings are summarized as:

1) There is no difference in between untreated fabric and fabric treated with only water meaning that there is no effect of water treatment and process conditions on chemical structure of cotton fabric.

2) There is a slight difference in between untreated fabric and cotton fabrics treated with different amounts of CD (15%, 20%, 25%) under the same process conditions (160 °C, 10 min) meaning that
   a) Not many differences were identified due to the similarities in the content of the structures of CD and cotton fabric.
   b) There is a difference at 1641 cm⁻¹ wavelength caused by CD addition to the structure of the cotton fabric which can also be seen from FTIR spectra of CD (CD has a peak at 1641 cm⁻¹ while cotton does not).
   c) There is a difference at 2925 cm⁻¹ wavelength caused by CD addition to the structure of the cotton fabric which can also be seen from FTIR spectra of CD (CD has a peak at 2925 cm⁻¹ while pure cotton does not. Pure cotton has only at 2950 cm⁻¹ and both of the peaks can be seen in the FTIR spectra of CD treated cotton fabrics.)
   d) These show that CD is successfully imparted to the structure of the cotton fabric.
In Figs. 7-10, all of the peaks are at the same wavelengths for 5 different areas of the samples with 15% β-cyclodextrin with different process conditions. Therefore, it means that the process conducted properly. The findings are summarized as:

1) There are no contaminations and foreign materials.
2) There are no considerable variations on the fabrics surface with homogeneous distribution of CD.
Fig. 11 FTIR spectra of sample 5 (20% CD, 160°C, 5 min)

Fig. 12 FTIR spectra of sample 6 (20% CD, 160°C, 10 min)

Fig. 13 FTIR spectra of sample 7 (20% CD, 180°C, 5 min)
Fig. 14 FTIR spectra of sample 8 (20 % CD, 180°C, 10 min)

Fig. 15 FTIR spectra of sample 9 (25 % CD, 160°C, 5 min)

Fig. 16 FTIR spectra of sample 10 (25 % CD, 160°C, 10 min)
In Figs. 11-14, all of the peaks are at the same wavelengths for 5 different areas of the samples with 20% β-cyclodextrin with different process conditions. Therefore, it means that the process conducted properly. The findings are summarized as:
1) There are no contaminations and foreign materials.
2) There are no considerable variations on the fabrics surface with homogeneous distribution of CD.

In Figs. 15-18, all of the peaks are at the same wavelengths for 5 different areas of the samples with 25% β-cyclodextrin with different process conditions. Therefore, it means that the process conducted properly. The findings are summarized as:
1) There are no contaminations and foreign materials.
2) There are no considerable variations on the fabrics surface with homogeneous distribution of CD.
In Figs. 19-21, fabric samples (S1, S2, S3, S4) having 15% β-CD, fabric samples (S5, S6, S7, S8) having 20% CD and fabric samples (S9, S10, S11, S12) having 25% β-CD can be seen, respectively. The findings are summarized as:

1) Characteristic peaks are at the same wavelength except the one for 2925 cm\(^{-1}\).
2) As the temperature and duration increases, CD impartation efficiency increases as can be seen from Figs. 19-21, since the peak at 2925 cm\(^{-1}\) becomes more apparent. (Two peaks at 2950 cm\(^{-1}\) and 2925 cm\(^{-1}\) can be most clearly seen for the one treated at 180°C and 10 min.) There are no considerable variations on the fabrics surface with homogeneous distribution of CD.
3) This shows that temperature and duration has positive effect on CD impartation meaning that the process conditions are really important for the reaction.
In Figs. 22-25, fabric samples (S1-15%CD, S5-20% CD, S9-25% CD) treated at 160 °C for 5 min, fabric samples (S2-15% CD, S6-20% CD, S10-25% CD) treated at 160 °C for 10 min, fabric samples (S3-15% CD, S7-20% CD, S11-25% CD) treated at 180 °C for 5 min and fabric samples (S4-15% CD, S8-20% CD, S12-25% CD) treated at 180 °C for 10 min can be seen, respectively. The findings are summarized as:

1) Characteristic peaks are at the same wavelength except the one for 2925 cm⁻¹.

2) As the amount of CD increases, CD impartation efficiency correspondingly CD amount on the fabric surface increases as can be seen from Figs. 22-25, since the peak at 2925 cm⁻¹ becomes more apparent. (At the same process conditions, two peaks at 2950 cm⁻¹ and 2925 cm⁻¹ can be most clearly seen for the one treated with 25% CD amount.)
3) This shows that CD amount has positive effect on the CD impartation efficiency meaning that to some extent as the amount of CD increases, the amount of CD imparted to the structure of cotton fabric increases.

B. Weight Gain Analysis Results

According to the weight gain analysis, when the weights of the fabric samples before and after treatment with CD are compared, it is apparent that certain amount of weight gain is obtained for all of the fabric samples, which demonstrates the successful CD incorporation to the fabric structure (Table II).

C. Tear Strength Results

Tear strength of the warp yarns decreases when the curing temperature and curing time are increased according to the findings shown in Fig. 26. It was also found that tear strength values of the warp yarns of the fabrics treated with different amounts of CD are lower than tear strength value of the warp yarns of the untreated fabric which is approximately 7.64 N. The decrease in the strength of warp yarns of cotton fabric is expected, because the treatment in acidic medium causes some degree of depolymerization for cotton materials. The best result is obtained for the CD treated fabric sample with 20% β-CD.

<table>
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Fig. 26 Main effects plot for tear strength of the warp yarns

Fig. 27 Main effects plot for tear strength of the weft yarns
Tear strength of the weft yarns decreases, when the curing temperature and curing time are increased as shown in Fig. 27 as is the case with the warp yarns. Additionally, tear strength values of the weft yarns of the fabrics treated with different amounts of CD are lower than tear strength value of the weft yarns of the untreated fabric which is around 7.21 N. The decrease in the strength of weft yarns of cotton fabric is expected, since the treatment in acidic medium causes some degree of depolymerization for cotton materials. Unlike the case for the warp yarns, almost the same values are obtained for the fabric samples in the presence of different amounts of β-CD.

As can be observed in Fig. 28, tear strength values of the warp yarns of each fabric sample treated with β-CD decrease with the increasing curing time, since the structure of cotton degrades by the increase in the curing time. The maximal change in tear strength obtained is the one for the fabric sample with 15% β-CD. However, the values obtained for each fabric samples with different amounts of β-CD are found to be close to each other for the both separate cases.

As seen in Fig. 29, tear strength values of the weft yarns of each fabric sample treated with β-CD get lower with the increasing curing time, because the structure of cotton degrades by the increase in the curing time, which is similar with the case for the warp yarns. The highest change in tear strength obtained is the one for the fabric sample with 15% β-CD. However, the values obtained for each fabric samples with different amounts of β-CD are close to each other for the both individual cases.

D. Tensile Strength Results

Tensile strength of the warp yarns decreases, when the curing temperature and curing time increase as displayed in Fig. 30. It was also obtained that tensile strength values of the warp yarns of the fabrics having different amounts of β-CD in their structure are lower than tensile strength value of the warp yarns of the untreated fabric which is approximately 451 N. The decrease in the strength of warp yarns of cotton fabric is expected due to some degree of depolymerization of cotton materials caused by the treatment in acidic medium. The best
result is obtained for the CD treated fabric sample possessing 20% β-CD in its structure.

![Main Effects Plot for Tensile-warp (N)](image1)

Fig. 30 Main effects plot for tensile strength of the warp yarns

![Main Effects Plot for Tensile-weft (N)](image2)

Fig. 31 Main effects plot for tensile strength of the weft yarns

Tensile strength of the weft yarns decreases, when the curing temperature and curing time are increased as shown in Fig. 31 as is the case with the warp yarns. Additionally, tensile strength values of the weft yarns of the fabrics treated with different amounts of CD are lower than tensile strength value of the weft yarns of the untreated fabric which is around 295 N. The decrease in the strength of weft yarns of cotton fabric is expected, since the treatment in acidic medium causes some degree of depolymerization for cotton materials. The best result is obtained for the β-CD treated fabric sample with 25% β-CD.

As can be observed in Fig. 32, tensile strength values of the warp yarns of fabric samples treated with 20% and 25% β-CD decrease with the increasing curing time, since the structure of cotton degrades by the increase in the curing time. However, no significant change is observed for the one with 15% β-CD. The maximal change in tensile strength obtained is the one for the fabric sample with 20% β-CD. However, the values obtained for each fabric samples with different amounts of β-CD are found to be very close to each other for the case of 10 minutes.

As it is shown in Fig. 33, tensile strength values of the weft yarns of each fabric sample treated with β-CD get lower with the increasing curing time, because the structure of cotton degrades by the increase in the curing time, which is similar with the case for the warp yarns. The highest change in tensile strength obtained is the one for the fabric sample with 25% β-CD. However, the values obtained for each fabric samples with different amounts of β-CD are close to each other for case of 10 minutes.
Fig. 32 Interaction plot for the change in tensile strength of the warp yarns according to curing time

Fig. 33 Interaction plot for the change in tensile strength of the weft yarns according to curing time

Fig. 34 Main effects plot for K/S
E. Color Analysis

Because of the grafting of β-CD onto cotton fabric, the number of [-OH] bonds that reactive dye can attach is increased and correspondingly fabric surface takes much more dyestuff on itself, which is demonstrated by the increase in K/S value. In Fig. 34 the decrease in K/S value can be observed with the increase in the curing temperature and curing time. Additionally, the highest K/S value is obtained with 20% CD.

As seen in Fig. 35, washing fastness of cotton fabric with 20% β-CD is found to be the highest when compared to the other fabric samples treated with β-CD. In addition to this, the level of staining of cotton fabric samples treated with 15% and 20% β-CD are higher than the untreated one whose value is 4.

As mentioned before, when fabric surface takes much more dyestuff, K/S value of that fabric increases due to a darker color shade, which means lightness of dyed fabric is decreased. In Fig. 36, it is seen that the lowest lightness is obtained for the fabric sample with 20% β-CD.

IV. CONCLUSION

In this study a conventional cotton fabric was functionalized with β-CDs by grafting method in conventional textile finishing process for improved durability against external factors caused by many activities during use such as laundering without any sacrifice from the inherent performance characteristics of cotton fabric to obtain a multifunctional fabric having the ability of encapturing molecules/particles via physical/chemical means resulting in some potential for the fabrics to be easily dyed with various dyestuff, good level of printability, being easily treated with various finishing agents. The results of the study are promising; however, they need to be improved with further studies by tuning the process conditions.

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