Objective Measurement of Fabric Properties of the Plasma-Treated Cotton Fabrics Subjected to Cocatalyzed Wrinkle-Resistant Finishing

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ABSTRACT: The wrinkle resistance treatment together with plasma pretreatment is especially very important to cotton fabrics because of their high wrinkling tendency. However, the processes improved the wrinkle recovery property of cotton fabrics, but, at the same time, may worsen the fabric handle, which is an important factor when designing the end-uses of fabric because handling of fabric also a critical factor for purchasing decision. The Kawabata Evaluation System for Fabrics (KES-F) measures the scale of "basic hand" and "total hand" values determined by the combined results of sensory tests conducted by the instrumental measurements. In the present article, the effects of plasma treatment and catalyzed 1,2,3,4-butanetetracarboxylic acid (BTCA) treatment on the fabric yellowing are also studied. The results found that the wrinkle-resistant treatment had a negative effect on the tensile properties, shearing properties, bending properties, and surface friction and variation, whereas the compressional properties are improved by the treatment. In addition, the plasma treatment improves the tensile properties and bending properties but not the compressional properties, shearing properties, and surface friction and variation. Besides, it is concluded that these treatments can influence not only the fabric handle but also the yellowness of fabrics. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 119: 2875–2884, 2011

Key words: wrinkle-resistant finishing; Kawabata evaluation system; titanium dioxide; BTCA; plasma pretreatment

INTRODUCTION

Cotton is a well-known cellulosic fiber and is wrinkled in appearance easily if force is applied. Wrinkle-resistant finishing has become a common practice in the textile industry to improve the smooth appearance and crease resistance of cellulosic fabric. Detailed information concerning the effect of the wrinkle-free finishes by 1,2,3,4-butanetetracarboxylic acid (BTCA), together with titanium dioxide (TiO_2) catalyst, on the objective fabric handle and fabric yellowness of the plasma pretreated fabrics was investigated in previous study.[1] However, the compound BTCA is a more desirable reactant when catalyzed with sodium hypophosphite (SHP). Also, using TiO_2, as a cocatalyst, to improve the crease recovery property has also been found to be feasible to enhance the finishing performance and minimized side effect.[2–5]

In addition, roughen fabric surface may facilitate the attachment of TiO_2 particles on the fabric surface. Plasma treatment is a kind of surface modification, which does not affect the bulk properties of any kind of polymers and is able to achieve a desired result. Surface modifications with atmospheric pressure plasma system, in the form of atmospheric pressure plasma jet (APPJ), have been studied widely for textiles as the processes are environmentally friendly, resulting in the reduction of wet chemical and energy consumption.[6–9] The plasma is a partially ionized gas produced by the interaction of an electromagnetic field with gas under a specified pressure. The active species, produced in plasma carry high energy causing sputtering or etching effect, alter the surface characteristics by incorporating chemically active functional groups and roughening the surface of the materials.[7,8,10,11] Therefore, many researchers were interested in the development of plasma technology.[12,13]

Handle is a critical physical property of fabrics when making purchasing decision. Understanding the relationship between fabric end-use and fabric properties is fundamental for classification, selection, and control of apparel fabrics.[14] The Kawabata Evaluation System for Fabrics (KES-F) is used to measure the scale of "basic hand" and "total hand" values determined by the combined results of sensory tests conducted by the instrumental measurements.[15] In

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the present article, detailed information was studied concerning the effects, which include objective fabric handle and fabric yellowing, of plasma treatment on handle and esthetic as well as the properties of BTCA-treated fabric in the presence of SHP and TiO_2.

EXPERIMENTAL

Material

A 25 cm × 25 cm piece of 100% semibleached plain weave cotton fabric (58 picks/cm, yarn count 40 tex, in warp; 58 ends/cm, yarn count 38 tex, in weft; 175g/m^2) was used. The crosslinking agent was BTCA, supplied by International Laboratory, with 98% purity. The catalyst used was SHP supplied from International Laboratory, with analytical grade, whereas the cocatalyst used was microtitanium dioxide (TiO_2, 2 μm diameter) obtained from UniChem, Slovenia (purity of 99.5+%).

Plasma pretreatment

Plasma pretreatment of cotton fabric was carried out by an APPJ apparatus manufactured by Surfx Technologies. The cotton fabric was moved according to the specified treatment speed. The machine produced a stable discharge at atmospheric pressure with radio frequency of 13.56 MHz at 80 W. The treatment was carried out using a rectangular nozzle, which covered an active area of 25.4 mm × 1 mm and was mounted vertically, above the cotton fabric. The condition of the plasma treatment was 80 W power, 15 L/min helium (carrier gas) flow rate, 0.5 s/mm treatment time, 0.1 L/min oxygen (reactive gas) flow rate, and 2-mm jet-to-substrate distance. After plasma treatment, the fabrics were conditioned at 21 ± 1°C and 65 ± 5% RH for 24 h before any treatment.

BTCA two-bath pad-dry-cure treatment

After plasma pretreatment, cotton fabric samples were treated with three compositions of crosslinking agent: (i) 5% BTCA and 10% SHP; (ii) 5% BTCA, 10% SHP and 0.1% TiO_2; and (iii) 5% BTCA, 10% SHP and 0.2% TiO_2. A two-bath method was used for BTCA treatments. In the first bath, the fabrics were dipped and padded with BTCA until wet pick up of 80% was achieved at 25°C. The fabrics were then dried at 85°C for 5 min. In the second bath, the dipping and padding processes were performed again, using TiO_2 solution dispersed in 10% Matexil DN-VL (dispersing agent). Subsequently, padded fabrics were dried at 85°C for 5 min and were then cured at 170°C for 2 min. Finally, the fabrics were conditioned at 21 ± 1°C and 65 ± 5% RH for 24 h, before any further treatment.

Fabric objective hand value

Kawabata Fabric Evaluation System (KES-F), made from Japan, was used for testing the low stress mechanical properties of the fabrics objectively, which were related to fabric stiffness, thickness, extensibility, fabric appearance retention, surface smoothness, and bulkiness. All fabrics were conditioned at 21 ± 1°C and 65 ± 5% RH for 24 h before KES-F measurements. Table I shows the parameters that can be obtained from KES-F.

Yellowness and whiteness

The yellowness index and whiteness index of cotton fabric were evaluated in accordance with ASTM E313-05. For each specimen, four measurements were performed using a spectrophotometer of GretagMacbeth Color-Eye 7000A, with D_{65} daylight and 10° standard observer. Finally, the fabrics were conditioned at 21 ± 1°C and 65 ± 5% RH for 24 h, before any further treatment.

RESULTS AND DISCUSSION

Texture provides information on what people feel when they touch an object. It refers to the properties held and sensations by the external surface of objects received through the sense of touch, which is essentially the quality of the object. However, human sense is subjective and ambiguous when it comes to determine the physical properties of objects due to the reliance on the sensitivity of human hand. Handle measurement is based on the idea of replacing the conventionally subjective judgment of physical properties of objects with objective data that can be shared by everyone, through the reproduction of human behavior and sensitivity. In the present article, KES-F was used to determine the properties of tensile, shearing, bending, compression, surface friction, and variation. The results obtained for the cotton fabrics subjected to both plasma pretreatment and/or BTCA posttreatment in the presence of SHP and/or TiO_2 will be discussed in the following sections.

Tensile properties

The tensile properties of a fabric depend on various factors such as fabric composition, fabric structure, yarn twist, and yarn count. In the tensile test, tensile properties including tensile linearity (LT), tensile energy (WT), tensile resilience (RT), and extensibility (EMT) were evaluated. LT is the linearity of the

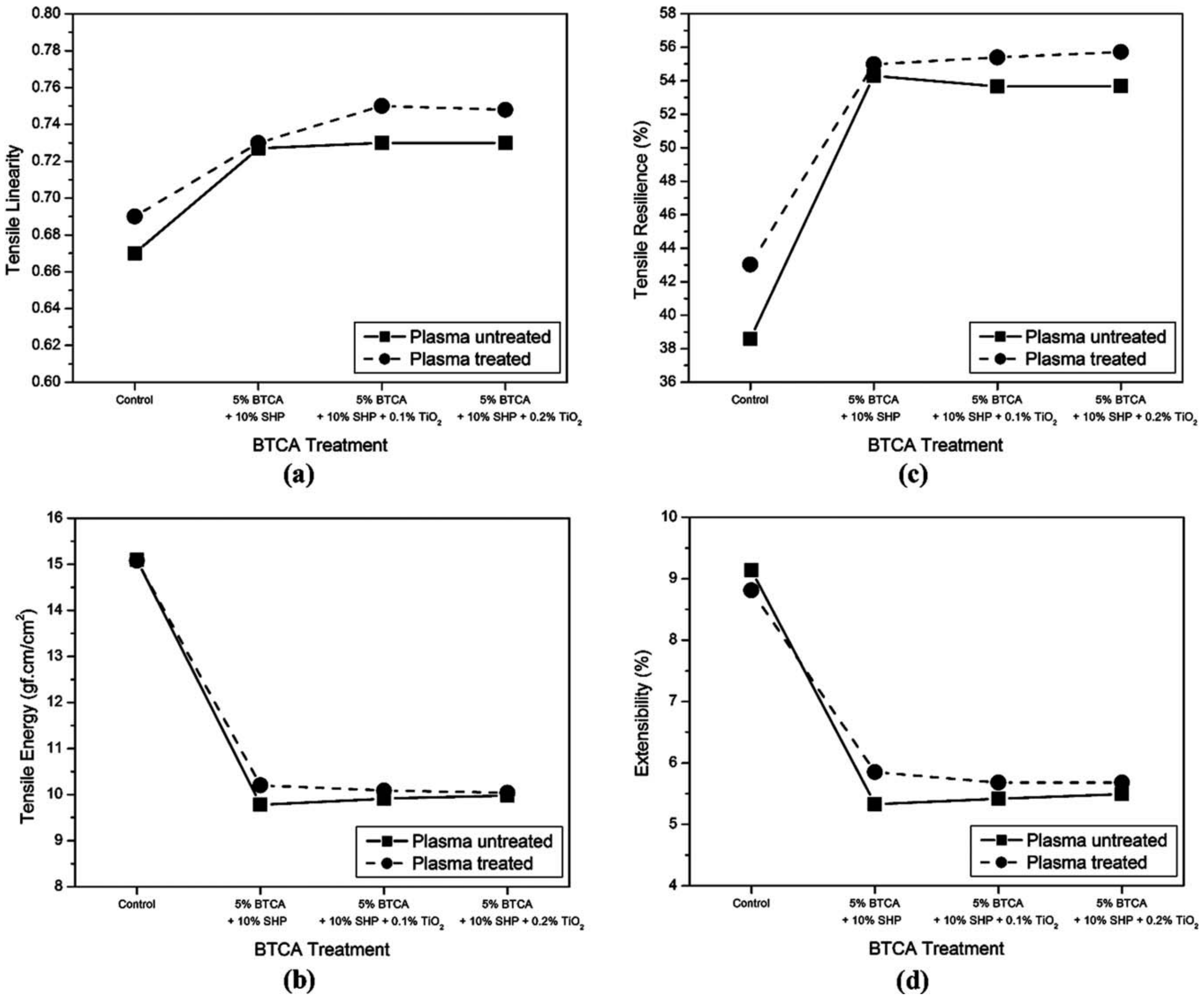
TABLE I
Parameters Obtained by the Kawabata Test

Properties	Symbol	Definition	Unit
Tensile linearity	LT	Linearity of the load/extension curve	–
Tensile energy	WT	Energy used for extending fabric to 500 gf/cm width	gf.cm/cm^2
Tensile resilience	RT	Percentage energy recovery from tensile deformation	%
Extensibility	EMT	Percentage extension at the maximum applied load of 500 gf/cm specimen width	%
Shear stiffness	G	Average slope of the linear regions of the shear hysteresis curve to ±2.5° shear angle	gf/cm degree
Shear stress at 0.5°	2HG	Average width of the shear hysteresis loop at ±0.5° shear angle	gf/cm
Shear stress at 5°	2HG5	Average width of the shear hysteresis loop at ±5° shear angle	gf/cm
Bending rigidity	B	Average slope of the linear regions of the bending hysteresis curve to 1.5 cm^{-1}	gf.cm^2/cm
Bending moment	2HB	Average width of the bending hysteresis loop at 0.5 cm^{-1} curvature	gf.cm/cm
Compressional linearity	LC	Linearity of compression-thickness curve	–
Compressional energy	WC	Energy used for compressing fabric under 50 gf/cm^2	gf.cm/cm^2
Compressional resilience	RC	Percentage energy recovery from lateral compression deformation	%
Fabric thickness at 0.5 gf/cm^2 pressure	T_O	Fabric thickness at 0.5 gf/cm^2 pressure	mm
Fabric thickness at 50 gf/cm^2 pressure	T_M	Fabric thickness at 50 gf/cm^2 pressure	mm
Coefficient of friction	MIU	Coefficient of friction between the fabric surface and a standard contactor	–
Geometrical roughness	SMD	Variation in surface geometry of the fabric	μm

load/extension curve, which reflects the elasticity of the fabric, i.e., the higher the value, the stiffer the material will be.[16] LT value equal to 1.0 indicates that the stress-strain curve rising below a 45° is a straight line.[17] Moreover, WT is also known as tensile work, which is defined as the energy required for extending a fabric, i.e., the ability of a fabric to withstand external stress during extension. Fabric with good tensile strength and toughness would have a large value of WT. RT is another interesting factor associated with the tensile properties of the treated fabric. RT is defined as the ability of a fabric to recover after the application of tensile stress by measuring the percentage energy recovery from tensile deformation. The reduced fabric RT value implies that the fabric becomes difficult to restore to its original shape after releasing the applied tensile stress. Under a specific tensile stress, EMT is defined as the percentage of the extended length when compared with the original length and it is the percentage of strain at maximum applied force (500 gf cm^{-1}).[16] EMT has a good correlation with fabric handle. The greater the value of EMT, the larger the elongation of the fabric under a known applied stress will be. The results of these tensile properties are presented in Figure 1(a–d).

In general, fabric with high WT, RT, and EMT values as well as low LT values possesses excellent tensile strength. As presented in Figure 1(a–d), the control sample showed the lowest LT and RT value together with highest WT and EMT values. Once the fabrics were treated with plasma gas, the LT and RT values were increased as shown in Figure 1(a,c), respectively. The enhancement in these values after plasma treatment could be explained by the removal of surface fibrils. The less spongy fabric became harsh in hand feel, thereby reducing the LT value in the subsequent process. However, after the fuzz and tangled fibrils were removed, it was confirmed that the plasma-treated fabrics had greater recovering ability from stretching. On the other hand, the overall WT and EMT values of the fabrics were slightly enhanced by the plasma treatment. The change in fabric structure would extremely affect the tensile strength. However, the plasma treatment could not alter the fabric structure as it only etched the fabric surface.[18–20] The roughening effect might create more contact points within the fibers and yarns microscopically, resulting in the enhancment of the interyarn and interfiber friction.[18,20,21] The increased WT values were probably due to the greater cohesive force being developed during extension, whereas the increased interaction force between fibers and yarns, leading to slight reduction in the relative movement of the fibers and yarns during extension.

When the fabrics were treated with BTCA, the LT values were significantly increased as presented in Figure 1a. It was found that the fabrics were



(a) (c)

(b) (d)

Figure 1 (a) LT, (b) WT, (c) RT, and (d) EMT of the plasma-treated cotton specimens subjected to BTCA treatment in the presence of SHP and/or TiO_2.

severely damaged by the extremely low pH during treatment, i.e., pH, 1-2, resulting in stiffened fabric. Also, there was significant decrease in WT and EMT values and obvious increase in RT values as presented in Figure 1(b–d). It was well known that cellulose molecules could crosslink with carboxylic acid groups presented in the BTCA, imparting an elastic property.[22] The increment in RT revealed that the BTCA molecules were able to crosslink the hydroxyl groups of the cellulosic macromolecules effectively, thereby contributing to greater recovering ability from tensile stress. However, WT and EMT are highly correlated, and the results proved that severe tensile strength loss occurred after wrinkle-resistant treatment and such a loss was mainly caused by the irreversible acid catalyzed depolymerization, i.e., at pH, 1-2, and reversible crosslinking of cellulose.[22,23] Previous investigation confirmed that BTCA itself could contribute to tensile strength loss together with better elastic property.[1,24] SHP, a catalyst in the wrinkle-resistant treatment, was able to enhance the effectiveness of the reaction.[24] The results showed that SHP was able to enhance the effectiveness of the reaction, i.e., further increased LT and RT values and further decreased WT and EMT values, contributing to worse tensile strength and slight improvement in elastic properties. In addition, previous investigation proved that TiO_2 in the BTCA treatment could improve the effectiveness of BTCA treatment.[1,24,25] However, as demonstrated in Figure 1(a–d), the catalytic reaction of BTCA treatment was dominated by the SHP catalyst, the effect of 0.1% and 0.2% TiO_2 on the reaction was negligible. Therefore, the change of tensile properties was irrespective of the TiO_2 in the treatment.

Shearing

Fabric with low shear stiffness (G), shear stress at 0.5° (2HG) and shear stress at 5° (2HG5) has superior shearing properties. G, also known as shear rigidity, is defined as the ability of a fabric to resist shear stress. G is the ease with which the fibers slide against each other resulting in a pliable or stiff structure. It depends on the mobility of cross yarns at the intersection point and is thus related to the fabric weave, yarn diameter, and the fabric surface characteristics.[17] Lower values indicate less resistance to shearing corresponding to a softer material having better drape.[16] On the other hand, 2HG and 2HG5 shear hysteresis are defined as the ability of a fabric to recover after applying shear stress. The fabric recovery ability after applying the shearing stress can be reflected by the shear stress value of 0.5° and 5° shear angle. In the shearing test, these properties were measured in both warp and weft directions, and the results were presented in Figure 2(a–c).

Figure 2a indicates that the G values of the plasma-treated cotton fabrics were increased significantly, especially for those posttreated cotton with catalyzed wrinkle-resistant finishing. In addition, Figure 2(b,c) indicate that the 2HG and 2HG5 values of the plasma-treated cotton fabrics was also increased obviously. The results showed that the shear stress was directly proportional to the shear stiffness. The greater the value of shear stress, the worse the recovery ability of the fabric and stiffer the fabric would be. The shear rigidity reflects the ability of the fabric to resist shear stress. Hence, such an increment in shear rigidity will enhance the subjective stiffness of fabric. The shear rigidity of the fabric primarily depends on yarn interaction, i.e., an increase in yarn interaction will normally increase shear rigidity and is perhaps related to the smoothing effect.[18,26] These results are indicative of the greatly increased interyarn friction in the plasma-treated fabrics, as well as the increased number of fiber and fiber contacts at yarn crossover points and interyarn pressure.

Figure 2a shows that there was a sudden increase in G values after the catalyzed BTCA treatment of cotton fabrics, implying stiffer hand feel of the fabrics. Moreover, there was an increase in 2HG and 2HG5 values once the fabrics were treated with catalyzed BTCA as illustrated in Figure 2(b,c). It was evident that the crosslinking might lead to the formation of brittle polymer layers although the mobility of cellulose macromolecules was limited. Furthermore, the changes were mainly caused by the irreversible acid-catalyzed depolymerization and reversible crosslinking of cellulose.[22,23] The low pH reaction medium made the test specimens stiffer. Comparing with these shearing properties of BTCA-treated fabrics in previous study,[1,24] these figures also showed that the effect was obvious when the SHP was added in the treatment as SHP promoted the reaction and thus contributing to severe rigid effect. As shown in the figures, the rigid effect and

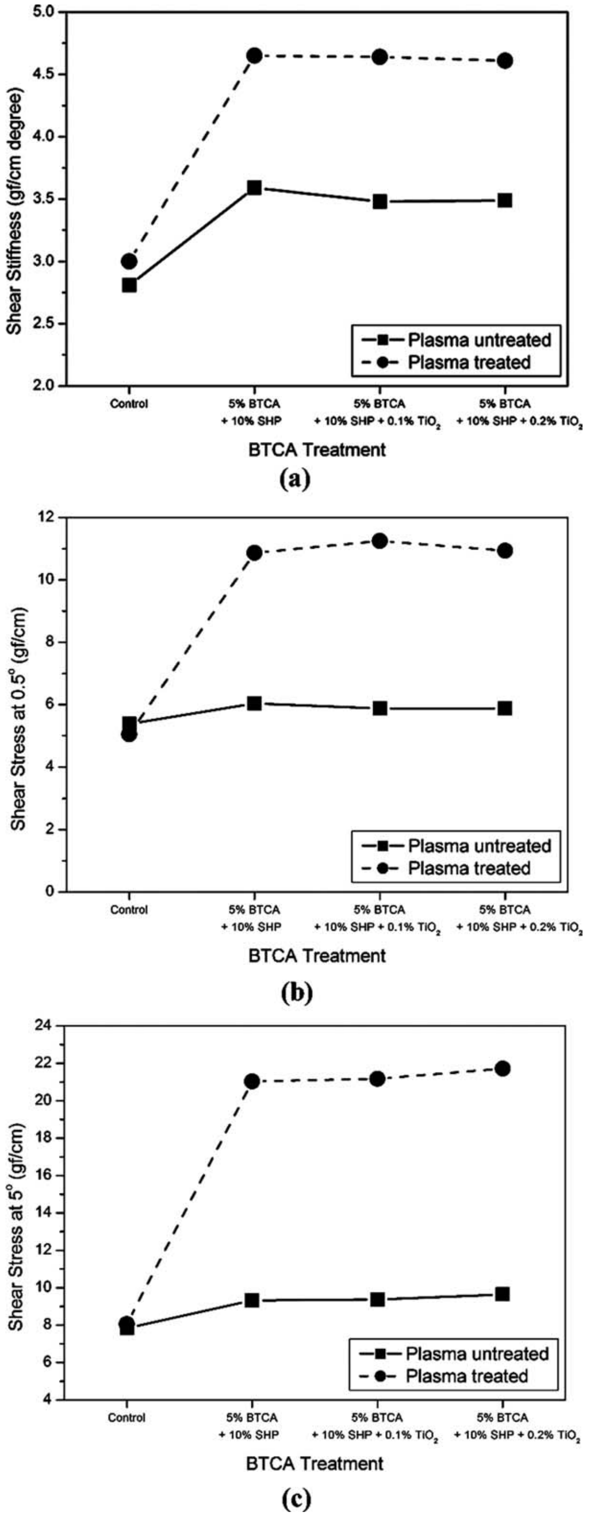


Figure 2 (a) G, (b) 2HG, and (c) 2HG5 of the plasma-treated cotton specimens subjected to BTCA treatment in the presence of SHP and/or TiO_2.

fabric recovering ability were even worse for the plasma-treated cotton specimens subjected to catalyzed BTCA treatment, i.e., remarkable enhancement in G, 2HG, and 2HG5 values. This phenomenon could be explained by the etching effect on the fabric surface by plasma pretreatment. The roughened fabric surface provided a new pathway for the finishing agent enter into the fibers, resulting in more effective wrinkle-resistant treatment, i.e., increased G values. Furthermore, the increased wettability property of the cotton fibers might also facilitate the catalyzed BTCA treatment. Besides, the figures showed that the effect on the G, 2HG, and 2HG5 values after adding 0.1% and 0.2% TiO_2 cocatalyst in the BTCA treatment was negligible.

Bending

The bending properties of a fabric depend on the bending resistance properties of fibers and yarns as well as the fabric structure and increase dramatically when the fabric thickness increases. The friction between fibers and yarns also affects the bending rigidity.[16] Generally, fabric with low bending rigidity (B) and bending moment (2HB) has good bending properties. B is defined as the ability of a fabric to resist the bending moment. The bending properties have important effect on both the handle and flexibility of a fabric, which is related to the quality of stiffness when a fabric is handled. A higher B value indicates greater resistance to be bent. In addition, 2HB, also known as bending hysteresis, is defined as the recovery ability of a fabric after being bent. 2HB is measured as a specimen is bent through a range of curvatures from 2.5 cm^{-1} to -2.5 cm^{-1}.[27] Bending hysteresis indicates the ability of the fabric to recover after bending. The smaller the value of 2HB, the better the bending recovery of the fabric will be. The results of the bending properties were measured in both warp and weft directions as presented in Figure 3(a,b).

Figure 3(a,b) show that the overall values of B and 2HB of the plasma-treated fabrics dropped slightly comparing with the untreated fabric. A decrease in these values would greatly enhance the fabric flexibility and elastic recovery from bending. From Figure 3(a,b), when the SHP was added in the BTCA treatment, it was shown that B and 2HB values were increased when compared with the control fabric. The bending results were proved that severe tensile strength loss after wrinkle-resistant treatment and such a loss was mainly caused by irreversible acid-catalyzed depolymerization and reversible cross-linking of cellulose.[22,23] SHP, a catalyst in the wrinkle-resistant treatment, was able to enhance the effectiveness of the reaction, contributing to greater tensile strength loss. Severe tensile strength loss after wrinkle-resistant treatment weakened the fibers and thus the fabrics become hard with low flexibility. The plasma treatment, in this case, minimized the drawbacks and demonstrated lower B and 2HB values. Furthermore, when TiO_2 was used as cocatalyst in the BTCA treatment, both the B and 2HB values increased slightly. It was because the particles on the fabric surface would restrict from bending. Figure 3(a,b) also reveal that the higher the concentration of TiO_2 acting as cocatalyst, the higher the B and 2HB values will be.

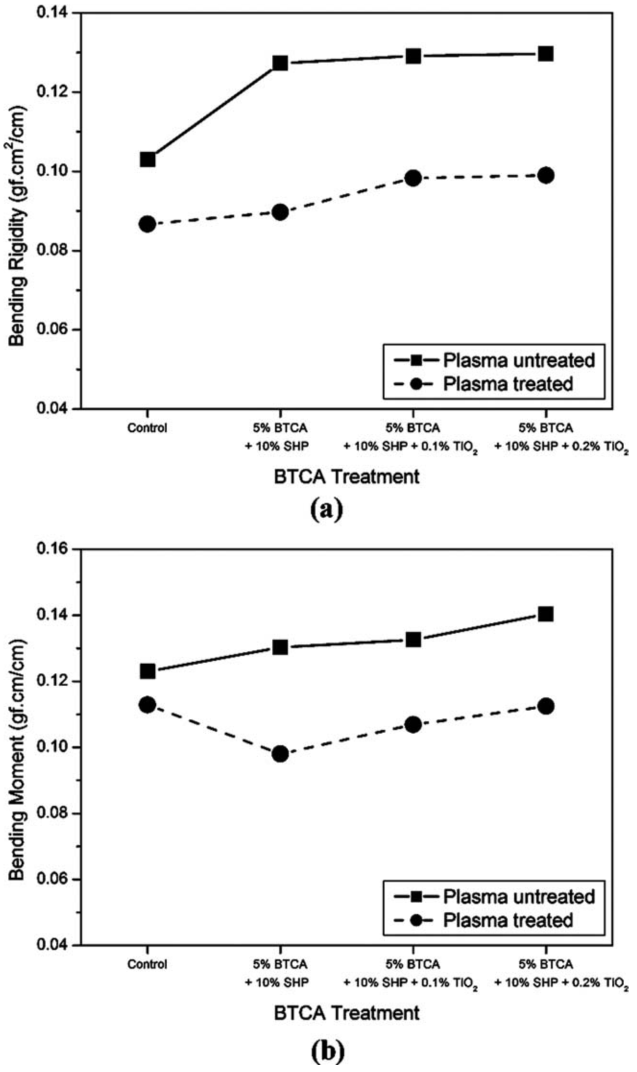


Figure 3 (a) B and (b) 2HB of the plasma-treated cotton specimens subjected to BTCA treatment in the presence of SHP and/or TiO_2.

Compression

Compression properties of cotton fabrics such as fabric thickness at a pressure of 0.5 gf/cm^2 (T_o) and 50 gf/cm^2 (T_m), compressional linearity (LC), compressional energy (WC), and compressional resilience (RC) were measured at three district points from the

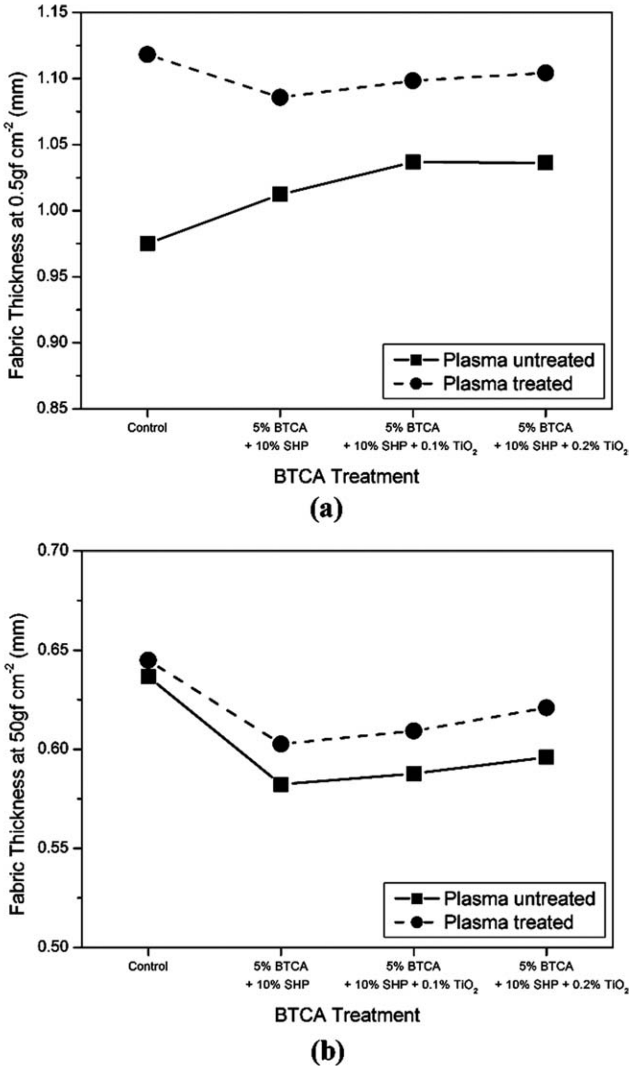


Figure 4 (a) T_o and (b) T_m of the plasma-treated cotton specimens subjected to BTCA treatment in the presence of SHP and/or TiO_2.

specimens automatically. Fabric thickness (T_o and T_m) of the cotton fabrics subjected to both plasma pretreatment and/or BTCA posttreatment in the presence of SHP and/or TiO_2 are measured by KES-F system and are illustrated in Figure 4(a,b), respectively.

Fabric thickness always changes on any physical or chemical treatment. It is measured by the KES-F system at a pressure of 0.5 gf/cm^2 and 50 gf/cm^2, representing surface and intrinsic thickness, respectively. Figure 4(a,b) indicate that both T_o and T_m increased obviously after plasma treatment. It was evident that the plasma-treated fabrics became fuller when compared with the untreated fabrics. In general, the results show that the plasma treatment might enhance the fabric thickness and create a fuller handle. However, the etching effect might create some cracks on the fibers and yarns microscopically, in which the extent of roughening was irregular. This reflected the phenomenon that plasma treatment could increase the fabric thickness slightly whereas the extent was unreliable due to only three measurements conducted at district points. Figure 4a shows that the T_o values were slightly increased after catalyzed BTCA treatment. The increment in T_o value was mainly due to the formation of fuzzy fibrils contributing a bulky fabric. However, when the sensory device pressed on the bulk surface at 50 gf/cm^2, T_m values were dropped accordingly after the catalyzed BTCA treatment as shown in Figure 4b. It could be explained by the fact that wet treatment on fabric may decrease the fabric intrinsic thickness, especially during the drying process. In addition, the presence of TiO_2 on the fabric surface would enhance the fabric thickness.

Fabric with good compression properties usually possesses higher LC, WC, and RC values, in which the compressional properties highly depend on the thickness of the fabrics. LC shows the linearity of compression-thickness curve. LC determines the compressibility along with the change in fabric thickness after treatment. High value of LC indicates a fluffy fabric with high compressibility. On the other hand, WC is the work done during compressing a fabric. The WC value represents a fluffy feeling of the fabric. The higher the value of WC, the higher compressibility the fabric will be. In addition, compressional resilience is defined as the ability to remain the fullness of fabric after being compressed, i.e., indicating the recoverability of the fabric after the compression force is removed. A higher value indicates better recovery ability from compression. In the compression test, these properties were measured in both warp and weft directions, and the results were presented in Figure 5(a–c).

Figure 5a illustrates that the catalyzed BTCA treatment had an upward tendency on the change in LC values, especially when TiO_2 was added in the treatment. LC determines the compressibility along with the change in fabric thickness after treatment. The fluffy fabric, caused by the wet treatment, enhanced the compression property. However, the results showed that the WC values enhanced after BTCA treatment in the presence of SHP as catalyst as demonstrated in Figure 5b. This could be explained by surface raising of cotton fabric during posttreatment, thereby providing a high compressibility structure. The effect of TiO_2 cocatalyst is unimportant in this case. In addition, there was a remarkable reduction in the RC values, especially in the presence of TiO_2 cocatalyst as evidenced in Figure 5c. The wrinkle-resistant-treated cotton fabrics demonstrated a less spongy fabric due to the attack of strong acid during reaction. The effectiveness of the reaction was further enhanced by the catalytic reaction with TiO_2 particles. Thus, the compressional recovering ability of the BTCA-treated test specimens was dropped.

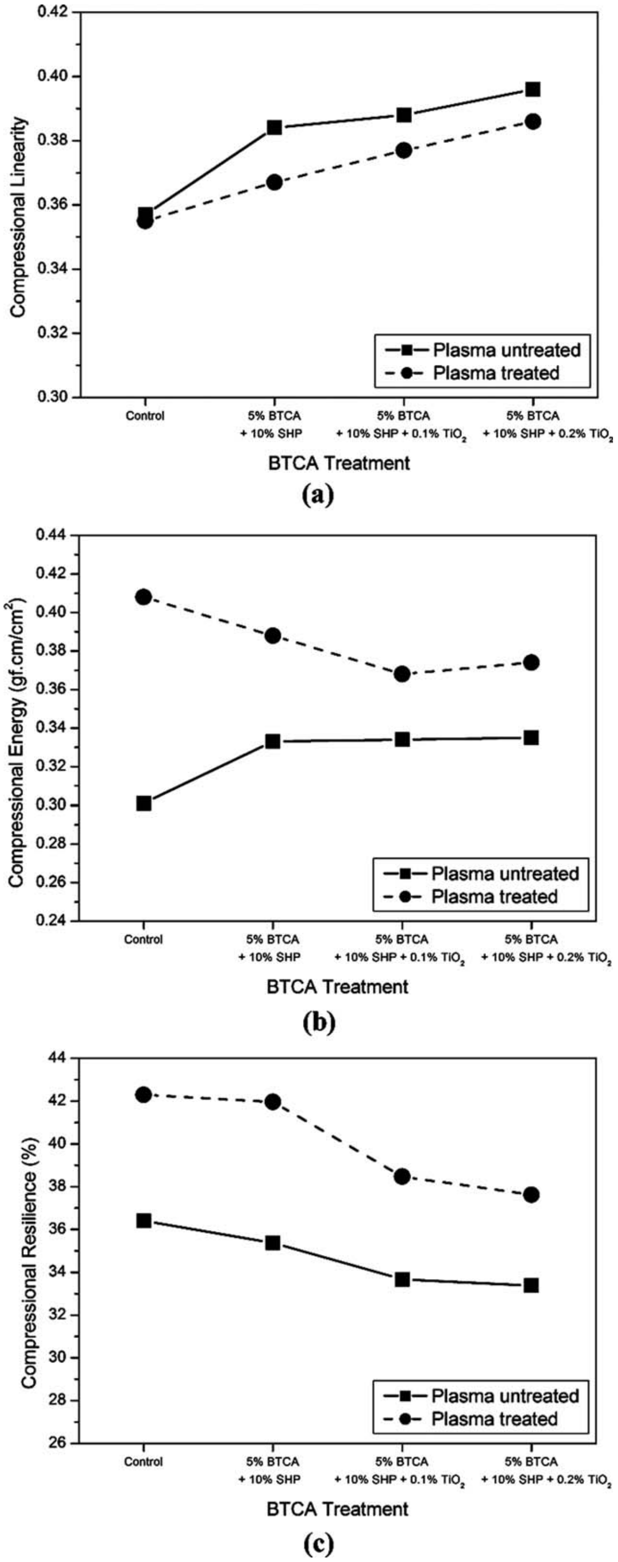


Figure 5 (a) LC, (b) WC, and (c) RC of the plasma-treated cotton specimens subjected to BTCA treatment in the presence of SHP and/or TiO_2.

In addition, the LC value of the plasma-treated fabrics was slightly decreased. The results showed that the plasma treatment etched the surface fibrils and causing 0.6% decrease of LC values, which is a very small extent. Figure 5a also shows that the LC values of the plasma-treated fabrics increased after the catalyzed BTCA treatment. Furthermore, Figure 5(b,c) also show that the plasma pretreatment enhanced the overall WC and RC values, implying that the compressibility of the plasma-treated fabrics is higher in comparison with untreated fabrics. It was evident that the entangled fibrils from the fabric surfaces were removed by the plasma treatment and hence, the recoverability of the fabric after the compression force enhanced. However, the post-BTCA treatment would produce tangles fuzzy fibrils again and causing the drop of WC and RC values.

Surface friction and variation

The surface characteristics of a fabric influence the handle, comfort, and esthetic properties of the cloth made from it.[17] Surface properties including coefficient of friction (MIU) and geometrical roughness (SMD) were measured. MIU represents the coefficient of friction of the fabric surface, which is determined by the ease of two surfaces slide against each other. MIU also represents the fabric smoothness, roughness, and crispness. The results demonstrate the ratio of the force required to slide the surfaces to the force perpendicular to the surfaces, i.e., the higher the value of MIU, the greater the friction the fabric will be. SMD measures the geometrical roughness of the fabric surface, which is the fabric surface evenness characteristics. The lower the SMD value, the more even the fabric surface will be. Generally, fabrics with low MIU and SMD values have better surface properties.

All these measurements were repeated at three distinct points on the fabrics in both warp and weft directions, and the mean value is the average of both warp and weft directions. The results of MIU and SMD were illustrated in Figure 6(a,b). The control sample showed the lowest MIU value as presented in Figure 6a, whereas the MIU values increased significantly after the fabric was treated by plasma gas. The results could be attributed to the etching effect caused by the bombardment of plasma species on the cotton specimens.[26] The rough plasma-treated fabric could also be explained by the increment of intrinsic thickness, resulting in an increase of contact area between the testing detector and the fabric surface. Besides, Figure 6b illustrates the SMD of the cotton fabrics subjected to both plasma pretreatment and/or BTCA posttreatment in the presence of SHP and/or TiO_2. It was obvious that the SMD values increased slightly after plasma treatment. The roughed fabric surface was attributed to the fact that plasma treatment would etch the fabric surface by the plasma species.

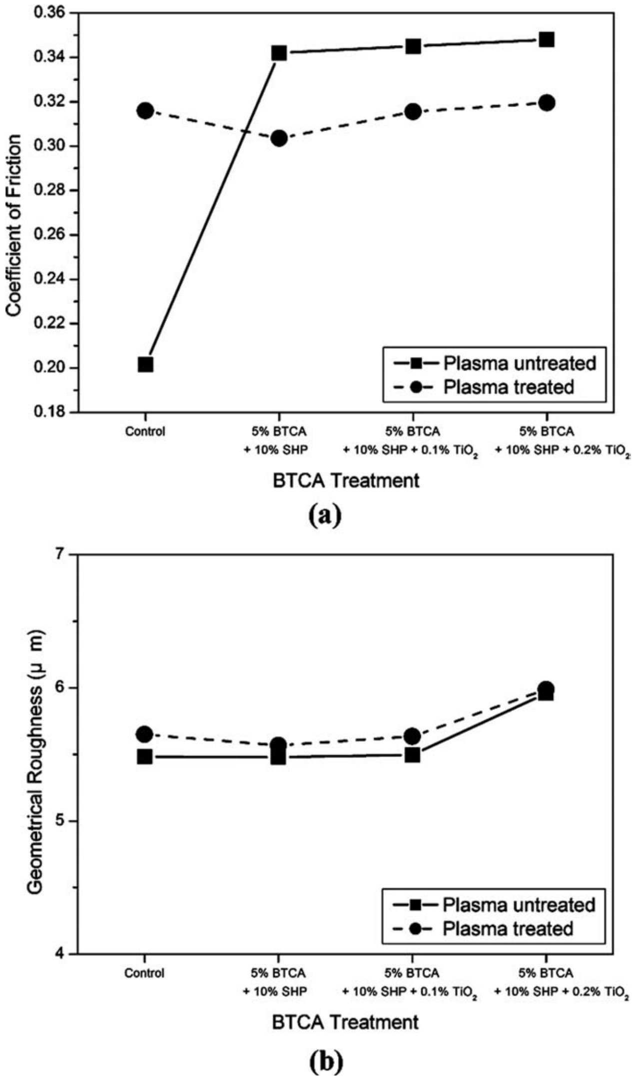


Figure 6 (a) MIU and (b) SMD of the plasma-treated cotton specimens subjected to BTCA treatment in the presence of SHP and/or TiO_2.

After the catalyzed BTCA treatment of cotton fabric, there was a remarkable increase in MIU values as presented in Figure 6a. This might be due to the attack of strong acidic BTCA molecules resulting in rougher fabric surface and the effectiveness of treatment was enhanced by the catalyst as compared to previous study.[1] Furthermore, when the TiO_2 was used as cocatalysts in the BTCA treatment, the MIU values were increased slightly which revealed that rougher fabric was contributing by presence of particles on the surface. From Figure 6b, the SMD values of catalyzed BTCA-treated fabrics, with or without plasma pretreatment, were similar to those untreated fabric. However, there was slightly enhancement in SMD values when 0.2% TiO_2 was added as cocatalyst. The results showed that the presence of TiO_2 on the fabric surface would enhance the fabric roughness.

As discussed above, the plasma-treated fabric had a remarkable enhancement on the MIU values when compared with the untreated fabrics. The enhancement diminished for those plasma-treated fabrics subjected to BTCA treatment, or even the MIU values were slightly dropped for those plasma-treated fabrics subjected to BTCA in the presence of SHP catalyst. Posttreatment by BTCA might compensate friction due to the surface etching produced by the plasma treatment.

Yellowness and whiteness

Yellowness refers to the attribute of color perception by which an object color is judged to depart from colorless or a preferred white toward yellow. On the other hand, whiteness refers to the attribute of color perception by which an object color is judged to

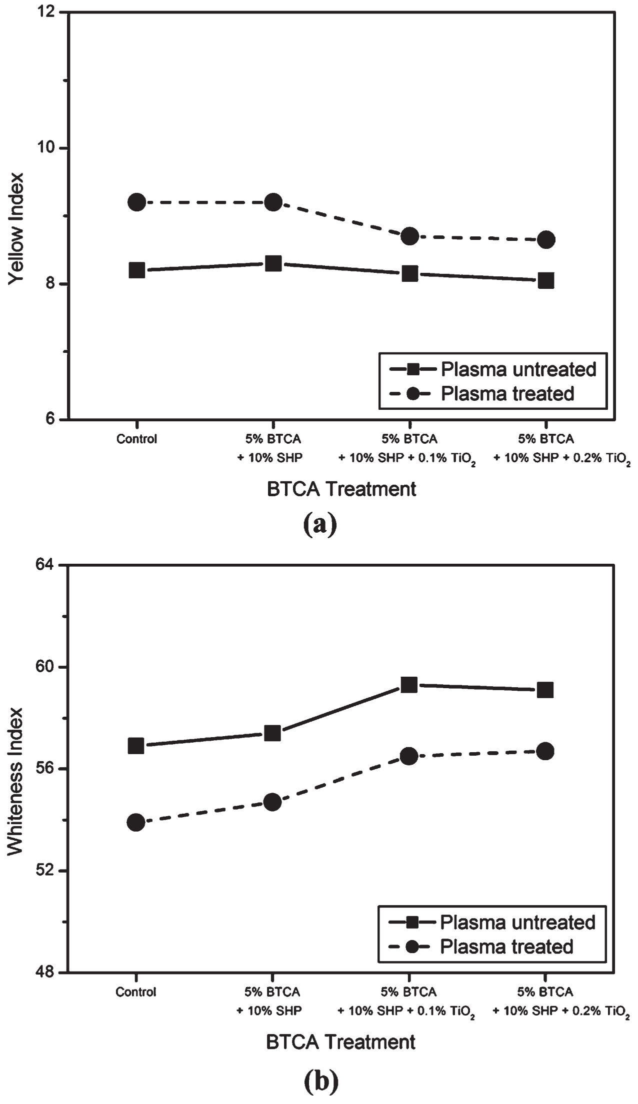


Figure 7 (a) Yellowness Index, and (b) Whiteness Index of the plasma-treated cotton specimens subjected to BTCA treatment in the presence of SHP and/or TiO_2.

approach the preferred white. Figure 7(a,b) illustrate the yellowness index and whiteness index of the cotton fabrics subjected to both plasma pretreatment and/or BTCA posttreatment in the presence of SHP and/or TiO_2, respectively.

Figure 7a shows that the yellowness of the fabric treated with plasma gas enhanced obviously. From Figure 7b, the results of whiteness index were inversely proportional to the yellowness index, which further proved that the plasma treatment would increase the fabric yellowness. This could be explained by the fact oxidation occurs on fabric surface upon oxygen plasma gas treatment. In addition, the plasma was a partially ionized gas containing ion, electrons, and neutral particles produced by interaction of electromagnetic field with gas under specified pressure. The active species produced in plasma carry high energy, including heat energy. The heat energy was another source causing fabric yellowing. Figure 7a also illustrates that the catalyzed BTCA treatment slightly increased the yellowness of the fabric. The changes were attributed by the oxidation upon oxygen plasma gas treatment in a relatively high temperature. From Figure 7b, the results of whiteness index were inversely proportional to the yellowness index, which further proved that the BTCA and plasma treatment would increase the fabric yellowness. However, the presence of white TiO_2 particles on the fabric surface would minimize the problem of fabric yellowing.

CONCLUSIONS

Cotton fibers, made up of repeating anhydroglucose units, are often subjected to chemical finishing imparting easy care properties. Alcohol groups on the adjacent cellulose chains are partially crosslinked to keep the chains fixed relative to each other and resist wrinkles. The application of BTCA together with SHP has been investigated to provide similar performance as other popular crosslinking agents, e.g., dimethylol dihydroxy ethylene urea but without formaldehyde formation. Also, using TiO_2, as a cocatalyst, to improve the crease recovery property has also been found to be feasible to enhance the finishing performance and minimized side effect. In this article, it was found that plasma treatment and/or catalyzed wrinkle-resistant treatment affect the fabric handle in various extents in which some properties were improved while some were adversely affected. The low stress fabric surface correlates closely with the fabric low-stress mechanical properties. The change in fabric stiffness, thickness, extensibility, fabric appearance retention, surface smoothness, or bulkiness may affect each other. In addition, it was concluded these treatments could influence not only the fabric handle but also the whiteness of fabrics.

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