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Using atmospheric pressure plasma treatment for treating grey cotton fabric

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ABSTRACT

Conventional wet treatment, desizing, scouring and bleaching, for grey cotton fabric involves the use of high water, chemical and energy consumption which may not be considered as a clean process. This study aims to investigate the efficiency of the atmospheric pressure plasma (APP) treatment on treating grey cotton fabric when compared with the conventional wet treatment. Grey cotton fabrics were treated with different combinations of plasma parameters with helium and oxygen gases and also through conventional desizing, scouring and bleaching processes in order to obtain comparable results. The results obtained from wicking and water drop tests showed that wettability of grey cotton fabrics was greatly improved after plasma treatment and yielded better results than conventional desizing and scouring. The weight reduction of plasma treated grey cotton fabrics revealed that plasma treatment can help remove sizing materials and impurities. Chemical and morphological changes in plasma treated samples were analysed by FTIR and SEM, respectively. Finally, dyeability of the plasma treated and conventional wet treated grey cotton fabrics was compared and the results showed that similar dyeing results were obtained. This can prove that plasma treatment would be another choice for treating grey cotton fabrics.

1. Introduction

Cotton is one of the most widely used materials and has a pre-eminent position among other materials used in textile and clothing. In order to obtain a functional cotton fabric, grey cotton fabric goes through a series of wet chemical treatments, such as desizing, scouring and bleaching, to remove hydrophobic impurities and make the fabric ready for colouration and finishing. Although the conventional wet treatment is useful for preparing cotton material for further treatments, problems of large amounts of water and chemicals usage exist. Recently, cost efficiency and environmental protection have become important considerations. As a result, the textile industry is seeking for a more cost efficient and environment friendly cotton preparation process as an alternative to the conventional wet chemical processing (Ebrahimi, Kiumarsi, Parvinzadeh Gashti, Rashidian, & Hossein Norouzi, 2011; Gorjanc, Bukosek, Gorensek, & Vesel, 2010; Navaneetha Pandiyaraj & Selvarajan, 2008; Parvinzadeh & Ebrahimi, 2010, 2011).

Plasma treatment is a novel method for textile material modification introduced in the last few decades. The application of plasma treatment on textile materials has been proved to be successful in altering material performance without affecting bulk properties (Bhat et al., 2011; Inbakumar et al., 2010; Karahan, Özdoğan, Demir, Ayhan, & Seventekin, 2009; Malek & Holme, 2003; Samanta, Jassal, & Agrawal, 2009; Tendero, Tixier, Tristant, Desmaison, & Leprince, 2006; Tian et al., 2011; Tsoi, Kan, & Yuen, 2011;). Moreover, plasma treatment is a totally dry single step process where no chemicals are needed. Thus, plasma treatment has been considered as a potential alternative to the conventional wet treatment (Cai & Qiu, 2006; Cai, Zhang, Qiu, Hwang, & McCord, 2003; Matthews, McCord, & Bourham, 2005; Peng, Gao, Sun, Yao, & Qiu, 2009; Vladimirtseva, Sharnina, & Blinicheva, 1995).

Table 1 shows a comparison of advantages of plasma treatment over conventional wet treatment (Rauscher, Perucca, & Buyle, 2010; Shishoo, 2007). The results given by conventional wet treated and plasma treated cotton fabrics are compared and analysed so as to minimize the problems caused by waste water and associated chemicals disposal. However, limited studies have covered cotton fabric treated by plasma treatment for the preparation processes. Few works have been done in this area and most of the existing papers have been regarding application of plasma treatment for desizing PVA on cotton fabric (Cai et al., 2003; Peng et al., 2009; Matthews et al., 2005) but not desizing starch-based sizing agents. Furthermore, little work has been reported to use atmospheric pressure plasma (APP) treatment as a cleaner choice for treating grey cotton fabric (Wang, Xiang, Bai, & Long, 2013). With

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Table 1
Comparison of the advantages offered by plasma processing over conventional wet chemical processing (Shishoo, 2007; Rauscher et al., 2010).

Manufacturing operation	Conventional wet treatment	Plasma treatment
Handling and storage of bulk chemicals	Yes	No
Preparation of chemicals and baths	Yes	No
Water usage	Heavy	None or very low
Raw materials consumption	High	Relatively low
Drying and curing operations	Yes	No
Number of process steps incurred	Multiple	Single
Energy consumption	High	Very low
Sequential effluent treatments	Yes	No
Environmentally costly	Yes	No
Equipment footprint	Large	Small
Manufacturing versatility from single kit	Limited to single or few process options	Depending on kit, can be highly flexible with wide range of available processes
Innovation potential	Moderate	Very high

the use of APP treatment, it will bring manifold potential advantages to textile industry: (i) enable continuous processing of fabric rolls without limitation of vacuum system architecture; (ii) reduce capital and maintenance cost without the vacuum system implantation and (iii) offer a milder surface treatment to substrates with short lifetime active species. Therefore, the aims of this study are to investigate the efficiency of removal of starch-based sizing agents with APP treatment and analyse how the APP treatment affects performance of cotton fabric when compared with conventional wet treatment, i.e. desizing, scouring and bleaching.

2. Experimental

2.1. Materials

100% commercially available grey woven cotton fabric with starch-based sizing was provided by Lai Tak Enterprises Limited (Hong Kong). The weight of the fabric was 118 g/m^2 with 40 s yarn count. The fabric density was 53 ends per cm and 27 picks per cm. The warp yarn and weft yarn have 4.8 and 3.6 twists per cm, respectively. Fabric samples were prepared in the size of 15 cm × 15 cm, weighed and conditioned in a standard atmosphere (temperature: 20 ± 2 °C and relative humidity: 65 ± 2%) for 24 h before use.

2.2. Cotton desizing

The grey cotton fabric was desized with enzyme 5 g/L Bactosol PHC (an amylase to digest starch), 2 g/L calcium chloride and 0.2 g/L Sandozin NI (wetting agent) and with a liquor-to-goods ratio of 50:1 for 60 min at 70 °C. After treatment, the fabric was rinsed with hot water (90 °C) and cold water for 5 and 10 min respectively. The desized fabric was then squeezed to remove excess water and then was dried at room temperature. After drying, the fabric was conditioned in standard atmospheric conditions for 24 h before use.

2.3. Cotton scouring

The desized cotton fabric was put into the scouring bath containing 30 g/L sodium hydroxide, 2 g/L non-ionic detergent and 2 g/L sodium silicate with liquor-to-goods ratio of 50:1 at 90 °C for 60 min. After scouring, the fabric was washed with 0.5% sulphuric acid for neutralization. After neutralization, the fabric was rinsed with running water until it is free from acid. The fabric was then squeezed to remove excess water and dried completely at room temperature. After drying, the fabric was conditioned in standard atmosphere (temperature: 20 ± 2 °C and relative humidity: 65 ± 2%) for 24 h before use.

2.4. Cotton bleaching

Bleaching was done by using 10 ml/L hydrogen peroxide (35%), 1 g/L Sandozin NI (wetting agent) and 4 g/L sodium silicate with liquor-to-goods ratio of 50:1 with pH 10.5 to 11.0 (adjusted by buffer solution). The scoured fabric was put into the bleaching bath for 60 min at 90 °C. After bleaching, the fabric was rinsed in running water for 10 min. The fabric was then squeezed to remove excess water dried at room temperature. After drying, the fabric was conditioned in standard atmosphere for 24 h before use.

2.5. Atmospheric pressure plasma (APP) treatment

Atmospheric pressure plasma (APP) treatment of cotton fabric was carried out on previously used an atmospheric pressure plasma jet (APPJ) apparatus (Atomflo 200-Series manufactured by Surfx Technologies (California, USA) with one inch linear-beam head connected to the gases supply (Kan & Yuen, 2012; Kan, Yuen, & Tsoi, 2011). Helium (purity ≥ 99.995%) and oxygen (purity ≥ 99.7%) were used as carrier and reactive gases respectively. In the APP treatment, grey cotton fabric was placed under the nozzle of plasma jet. The treatment was carried out by using a rectangular nozzle which covered an active area of 1 × 25 mm^2 and mounted vertically above the fabric. The treatment was operated with oxygen flow rate of 0.2 L/min, 0.3 L/min and 0.4 L/min and output power of 140, 150 and 160 W. The helium flow rate and jet-to-substrate distance (jet distance) were kept at 30 L/min and 2 mm, respectively, during the plasma treatment. The APPJ was moving continuously with a speed of 1 mm/s with treatment time of 1 s during plasma treatment. In the APP treatment, only the face side of the fabric was treated. After APP treatment, the fabric was conditioned in standard atmosphere for 24 h before evaluation.

2.6. Assessing desizing effect

One drop (10 μl) of iodine solution (prepared according to AATCC Test Method 103 with solution colour of yellow) was added in the centre of the treated fabric. The colour on fabric indicates the degree of desizing, i.e. dark blue indicates presence of unaffected starch, light blue means slight residual, reddish violet says starch is decomposed into water soluble dextrin and yellow says complete absence of starch.

2.7. Weight change

The fabric was weighed before (W_o) and after (W) treatment for comparison. The weight change was calculated by using Eq. (1).

$$\text{Weight change} \quad (\%) = \frac{W_o - W}{W_o} \times 100\% \tag{1}$$

2.8. Whiteness

Whiteness of the fabrics was measured by a reflectance spectrophotometer according to ASTM E313. CIE illuminant D65 and 10° standard observer were used.

2.9. Drop test

Fabric was cut into pieces of size 5 cm × 5 cm and Methyl Blue dye was used as the aqueous solution. The drop volume of the dye was fixed at 20 μl approximately by using an auto-pipette and the drop height was fixed at 5 cm above the fabric sample. The fabric sample was placed on top of a plastic film in order to avoid the dye being absorbed by other substrates. The dispersion size of the drop of dye was defined as the area within the liquid boundary after completely drying on the fabric and it was measured by graph paper. Three measurements were taken on each side of the test specimen and then they were averaged.

2.10. Longitudinal wicking test

Longitudinal wicking occurs when the fabric is partially immersed in a large volume of liquid that can wet the fabric. In this test, 2.5 cm × 15 cm fabric strips were cut in warp and weft direction, respectively. The fabric strips were marked with graduated scale from 1 to 10 cm on its surface by a water-pen. Then the fabric strip was suspended vertically with its 1 cm lower edge immersed in a beaker with 350 ml of distilled water. The water uptake point started from the first spot and time was recorded after each cm. In this study, if the fabric takes more than 30 min to reach 5 cm height, the result was not recorded. Three samples were tested to ensure repeatability.

2.11. Scanning electron microscopy (SEM)

The cotton fabric surface morphology was examined using a scanning electron microscope (SEM, model JSM-6490, JEOL Ltd., Japan) with magnification of 3000×.

2.12. Fourier transform infrared spectroscopy (FTIR–ATR)

The surface chemical analysis was performed by Perkin Elmer spectrophotometer (Spectrum 100, Perkin Elmer Ltd.) equipped with an attenuated total reflection (ATR) accessory. The scanning range was 650–4000 cm^{-1} with an average of 64 scans of each fabric and the resolution was 4 cm^{-1}.

2.13. Dyeing

C.I. Reactive Blue 19 was used for dyeing plasma treated (output power = 160 W and oxygen flow rate = 0.2 L/min) and conventional wet treated (go through desizing, scouring and bleaching) grey cotton fabrics. The dyeing processing was carried with an oscillating dyeing machine. The dyeing parameters and profile for the fabric samples were carried out according to method described in Kan, Yuen, Lam, and Chan (2009). After dyeing, the fabric samples were washed with 1% non-ionic detergent to remove the unfixed and hydrolysed reactive dyes. The washed fabric samples were then completely dried in an oven with temperature of 90 °C. After drying, the fabric samples were conditioned at 20 ± 2 °C with relatively humidity of 65 ± 2% for at least 24 h prior further evaluation.

2.14. Colour yield measurement

Colour of the dyed material was characterized by reflectance measured at given wavelength intervals throughout the visible spectrum by Reflectance Spectrophotometer (Macbeth Color-Eye 7000A). Illuminant D65 and 10° standard observer were used. The fabric was folded four times to ensure opacity and reflectance measurement from 400 to 700 nm with 20 nm intervals was obtained eight times. Percent reflectance values were converted into K/S values in accordance with the Kubelka–Munk equation (Eq. (2)).

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \tag{2}$$

where K is the absorption coefficient of the colourant, S is the scattering coefficient of the coloured substrate and R is the reflectance of the coloured sample. The higher the K/S value, the more the pigment uptake is, resulting in better colour yield.

2.15. Levelness

Spectrophotometric technique was used to assess the degree of unlevelness of the dyed fabric sample in quantitative terms by establishing a relative unlevelness index (RUI) (Chong, Li, & Yeung, 1992). Reflectance values at 8 different locations on the sample swatch were measured by Spectrophotometer (Macbeth Color-Eye 7000A) with D65 Illuminant and 10° standard observer within the visible spectrum (400–700 nm). RUI of the coloured sample was calculated by Eqs. (3) and (4).

$$S_\lambda = \sqrt{\frac{\Sigma_{i=1}^{n}(R_i - R_m)^2}{n-1}} \tag{3}$$

where S_λ is standard deviation of reflectance values, R_i is reflectance value of the ith measurement for each wavelength and R_m is mean of reflectance values of n measurements for each wavelength.

$$\mathrm{RUI} = \sum_{400}^{700} C_\lambda V_\lambda = \sum_{400}^{700} \frac{S_\lambda}{R} V_\lambda \tag{4}$$

where V_λ is photopic relative luminous efficiency function.

The degree of levelness is described according to the RUI value obtained; the suggested interpretations of RUI values are (i) <0.2 = excellent levelness; (ii) 0.2–0.49 = good levelness; (iii) 0.5–1.0 = poor levelness and (iv) >1.0 = bad levelness (Chong et al., 1992).

3. Results and discussion

3.1. Desizing efficiency and weight change

After enzyme and APP desizing, a drop of iodine solution was put on the fabric and the results revealed that no dark blue colour was noted in any sample of desized fabrics. Yellow spots with different intensities were observed for all desized fabrics. This means that both enzyme and APP processes can achieve different degrees of desizing due to the removal of starch-based sizing material from the fabric surface. As the pick-up of the starch-based sizing material in the commercial fabric was not disclosed, the weight change percentage was used as an indicator to reflect the efficiency of desizing (Kan & Yuen, 2012).

The weight change percentage of enzyme desizing was 3.17% and Table 2 shows the fabric weight was decreased after APP treatment. The decreased weight reveals the starch-based sizing agent was removed by APP treatment. The weight change percentage of APP desized fabric is less than that of enzyme desized fabric but the APP desizing effect varies with APP treatment conditions. APP treatment is a surface modification technique and only the yarn exposed on the fabric surface is affected by the APP treatment. However, enzyme desizing is a wet treatment where every yarn is immersed in the desizing bath, and thus the starch-based sizing

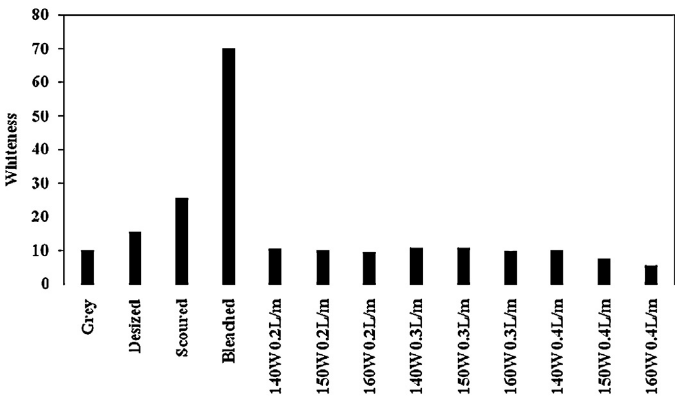

Fig. 1. Whitness of cotton fabrics.

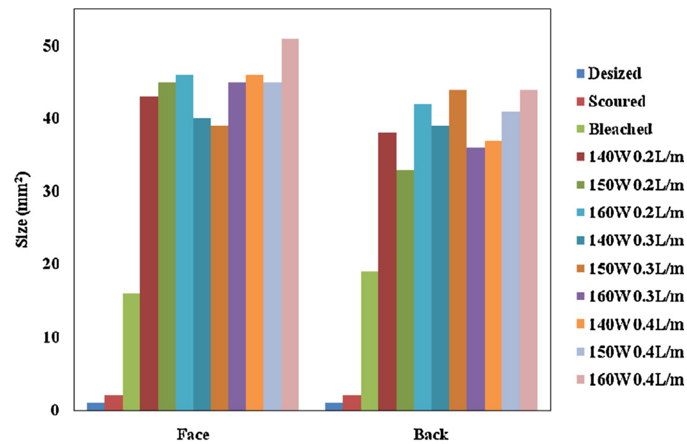

Fig. 2. Drop test results of cotton fabrics.

agent applied on the fabric can be effectively removed. When compared among different sets of plasma parameters, results in terms of change in weight of the cotton fabric after APP treatment are similar. Although plasma treatment only affects the surface yarns, the results of APP desizing are satisfactory when compared with conventional enzyme desizing method.

3.2. Whiteness

Fig. 1 shows the whiteness values of different cotton fabrics. When grey cotton fabric treated with conventional wet treatments, i.e. desizing, scouring and bleaching, whiteness is increasing continuously with the best results in bleaching. The whiteness results in Fig. 1 show that APP treatment did not contribute any improvement in fabric whiteness. In some treatment conditions, e.g. 150 W and 0.4 L/min and 160 W and 0.4 L/min, the whiteness is worse than the grey fabric because of the thermal oxidation effect in the APP treatment leading to yellowing (Kan et al., 2011).

3.3. Drop test

The APP discharge power used was between 140 and 160 W in this study. Generally speaking, under the same oxygen flow rate, 160 W has more significant effects in wetting of the face side than 140 or 150 W. However, in the back side of the cotton fabrics, the wetting behaviour varies, depending on the plasma parameters used. This variation may be due to the penetration effect of plasma species (Wang & Qiu, 2007). The discharge power is also known as the ignition power. Hydrophilisation of the grey fabric can be enhanced by increasing ignition power as a higher power is capable of producing more active species, resulting in a higher concentration of active species present in plasma (Wang & Qiu, 2007). Theoretically, a higher oxygen flow rate with higher oxygen concentration should be able to incorporate more polar functionalities into the fabric. The hydrophilicity of the fabric surface is enhanced by the polar groups applied (Kan et al., 2011). However, the results from the drop test do not show a linear correlation between the oxygen flow rate and improvement in wettability of fabric. This phenomenon may be attributed to dilution of active species in plasma. The increase in gas flow rate beyond optimum value increases the gas molecules/atoms per unit volume and thus the chances of plasma species recombining are greater at higher flow rates, causing a quenching effect in the resultant plasma (Wang & Qiu, 2007). Different optimum gas flow rates may actually be found under different ignition powers.

The results of the drop test (Fig. 2) show that values of dye droplet dispersion were larger than of the conventional wet treated samples, whether desized, scoured or bleached. The purpose of the preparation of grey cotton fabric for further processes of colouration and finishing is to remove impurities in the fibres. Although the weight lost of grey cotton fabric after APP desizing was less than the case of conventional desizing (Table 2), the APP treated fabrics produces more impressive wettability improvement. The fabric weight decreased after APP treatment and the dramatic improvement in wettability indicates that APP treatment can remove size materials from cotton fibre and help improved fabric wettability which enhances the subsequent colouration and finishing processes by skipping the scouring and bleaching processes.

3.4. Longitudinal wicking test

In this study, if the fabric takes more than 30 min to reach 5 cm wicking height, the result was not recorded (Fig. 3). In conventional wet treatment, desizing cannot remove fatty and oily impurities from the cotton. Thus, no wicking occurs in desized fabric.

Table 2
Weight before and after desizing processes.

Oxygen flow rate (L/m)	Power (W)	Weight (g)		Weight change percentage (%)
		Before plasma desizing	After plasma desizing	
0.2	140	3.11	3.02	2.89
0.2	150	3.08	2.99	2.92
0.2	160	2.91	2.85	2.06
0.3	140	3.11	3.03	2.57
0.3	150	3.13	3.04	2.88
0.3	160	2.93	2.86	2.39
0.4	140	2.93	2.88	1.71
0.4	150	2.94	2.87	2.38
0.4	160	2.94	2.87	2.38
Enzyme desizing		2.84	2.75	3.17

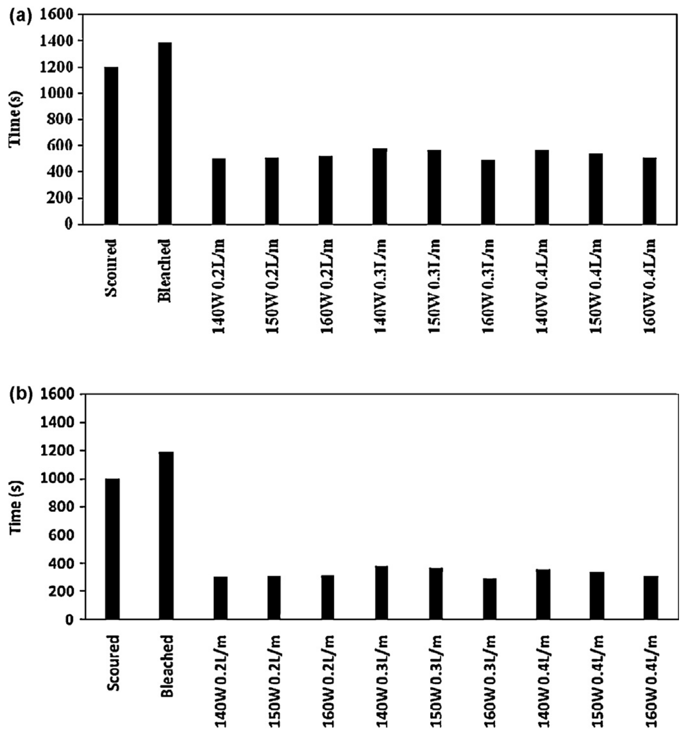

Fig. 3. Longitudinal wicking test (a) Warp direction and (b) Weft direction.

Compared with conventional wet treatments, i.e. scoured and bleached fabrics, the time required for APP treated fabrics to reach 5 cm height is greatly reduced, which reveals that fabric wickability is improved by APP treatment. Moreover, wickability of weft yarns is better than that of warp yarns because warp yarns have higher twist. Migration of liquid in the yarn occurs only when there is enough space for the liquid to wick (Nyoni & Brook, 2006; Petrulyte & Baltakyte, 2009). Higher twist reduces the diameter of the yarn because of the inward transverse pressure from the outer layers on inside layers, which forces them to approach a closely packed structure making filament displacement difficult (Nyoni & Brook, 2006). The closely packed yarn structure reduces the internal space in yarn for liquid transportation. As a result, the lower the number of twists, the more easy is migration of liquid in the yarn resulting in a faster wicking rate.

3.5. Scanning electron microscope (SEM)

Large amounts of starch-based sizing agent can be found in the original grey cotton fabric (Fig. 4(a)) but the starch-based sizing agents were completely removed after enzyme desizing and a smooth surface is noted (Fig. 4(b)). With subsequent scouring (Fig. 4(c)) and bleaching (Fig. 4(d)), the fibre surface becomes cleaner. However, wrinkles appear in scoured and bleached cotton fibre surface because of the chemical attack during scouring and bleaching process. In the enzyme desizing process, the enzyme affects only the starch-based sizing agent, not the cotton fibre itself. After conventional desizing process, the amount of sizing agent was obviously reduced and the fibre surface was cleaned after scouring and bleaching processes.

Fig. 5 shows the cotton fibre surface morphology under different plasma desizing conditions. It is noted that the amount of starch-based sizing agents was greatly reduced after plasma desizing. From Fig. 5, microcracks are found on the plasma treated fibre surface which reveals that etching occurred on the fibre surface. The development of the microcracks is due to the direct bombardment of the fibre surface by active species in the plasma after removal of starch-based sizing agent on the fibre surface (Kan & Yuen, 2012). The surface characteristics of the fibres are similar under

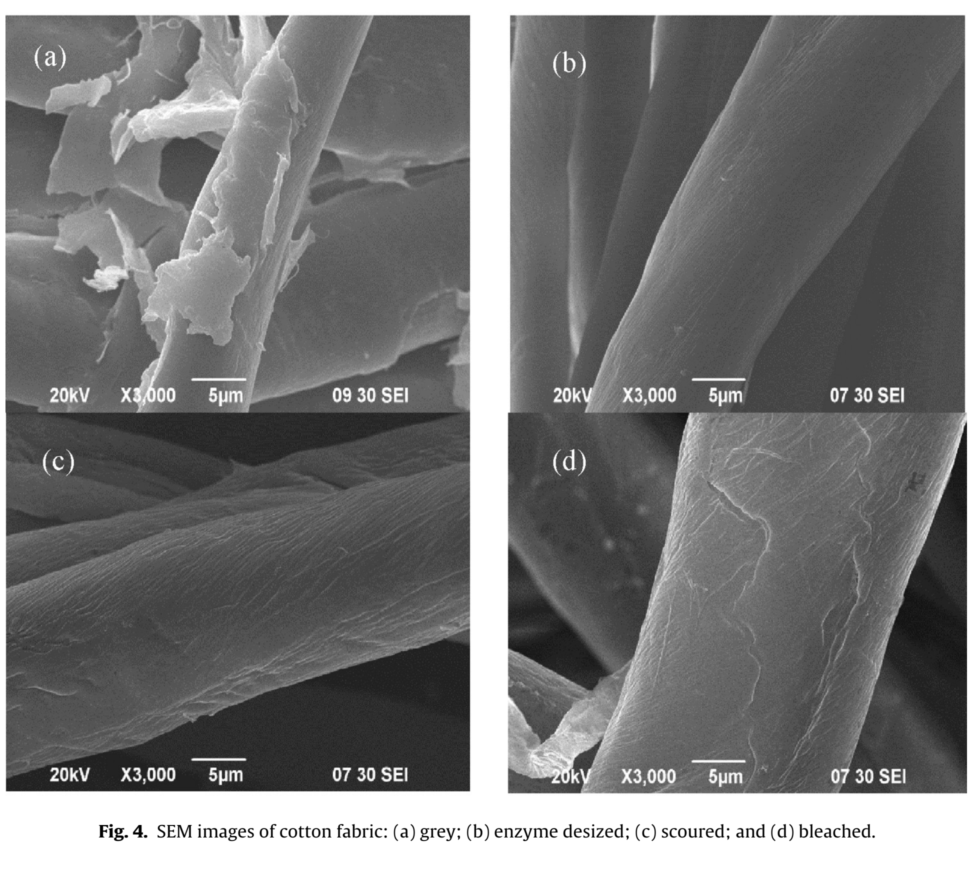

Fig. 4. SEM images of cotton fabric: (a) grey; (b) enzyme desized; (c) scoured; and (d) bleached.

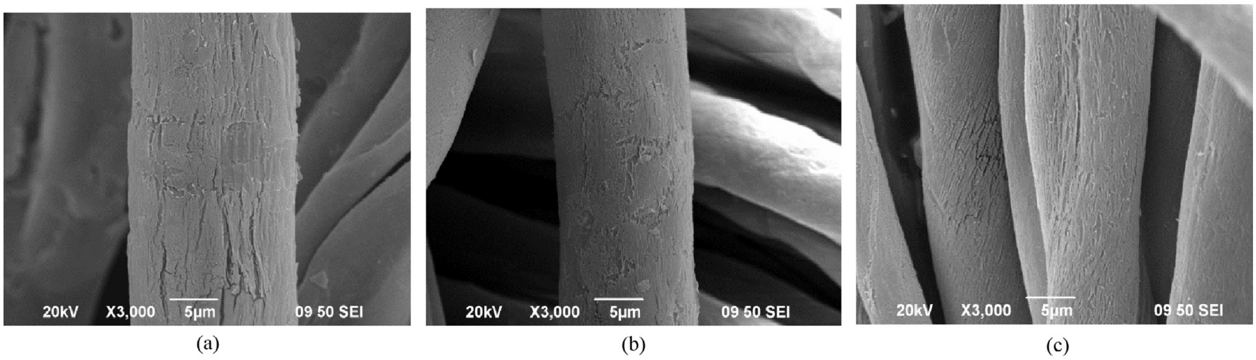

Fig. 5. SEM image of plasma desized cotton at 160 W: (a) 0.2 L/m; (b) 0.3 L/m; and (c) 0.4 L/m.

different oxygen flow rates. Moreover, the amount of starch-based sizing agent was found to be significantly reduced after enzyme and plasma desizing. The SEM images indicate that there is a significant surface change in the surface of cotton fibre after plasma treatment. The etching effect affects the surface smoothness and the performance of fabrics. The surface property change due to the etching effect can be observed from the drop test and the wicking test. The results in terms of wettability of the plasma treated fabrics are greatly improved when compared with the conventionally desized fabrics. The plasma treatment gives a similar result in desizing compared with enzyme treatment, which means plasma treatment can be an alternative to conventional desizing methods.

3.6. Fourier transfer infrared spectroscopy (FTIR–ATR)

Fig. 6 is the FTIR–ATR spectra of cotton fabrics treated with different treatments. Fig. 6(a) is the FTIR–ATR spectrum of untreated cotton fabric, i.e. grey fabric. The peaks in the region 3400–3200 cm^{-1} indicate the polymeric hydroxyl groups related to the starch-based sizing material. The peaks in region 2980–2800 cm^{-1} are corresponding to the asymmetric and symmetric stretching of methylene ($-CH_2-$) groups in long alkyl chains which present the presence of waxes in the grey fabric (Chung, Lee, & Choe, 2004).

Fig. 6(b) shows that after enzyme desizing, intensities of peaks in the region 3400–3200 cm^{-1} were decreased while peaks in region 2980–2800 cm^{-1} remained. This indicates that enzyme desizing is effective in removing starch-based sizing materials but not the waxes from the grey cotton fabric. After scouring, peaks in 2980–2800 cm^{-1} (as shown in Fig. 6(c)) were diminished indicating the waxes were removed from the cotton fabric (Chung et al., 2004).

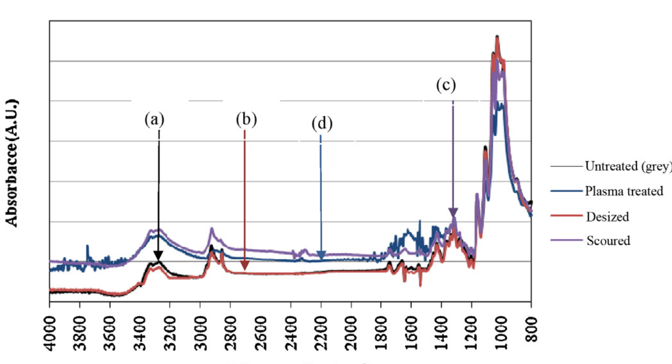

Fig. 6. FTIR–ATR spectra of cotton fabrics treated with different treatments: (a) untreated (grey); (b) enzyme desized; (c) scoured; and (d) plasma-treated (160 W, 0.2 L/m).

From Fig. 6(d), peaks in the regions 3400–3200 cm^{-1} are reduced after plasma treatment, indicating the polymeric hydroxyl groups related to starch-based sizing materials were removed by plasma. A sharper peak was observed at 1054 cm^{-1} which was ascribed to the oxygen-containing groups of C—O stretch. The absorption peak in the range of 1657–1605 cm^{-1} represented the C=O stretch. The increase in C—O and C=O stretch revealed that polar groups had been introduced onto the fibre surface by oxygen plasma treatment and thus hydrophilicity of plasma treated cotton fabric was enhanced significantly (Bhat et al., 2011; Cai et al., 2003; Ma, Wang, Xu, & Cao, 2009; Sun & Qiu, 2012). The FTIR–ATR results for enzyme desized and plasma desized cotton fabrics are displayed in Fig. 6(b) and (d), respectively. The intensities of the absorption peaks at the ranges of 1760–1690 cm^{-1} of plasma treated fabric were higher than that of enzyme treated fabric, which revealed additional C=O stretch introduced by the oxygen plasma treatment. When compared with the result of scoured fabric, peaks representing waxes in the region 2980–2800 cm^{-1} disappear after plasma treatment. This result indicates that other than the chemical modification of the fibre surface in plasma treatment, the plasma treatment can act physically to remove the starch-based sizing material and wax from the fibre surface, as confirmed by Fig. 5 and thus wettability of plasma treated fabric is greatly enhanced.

3.7. Dyeing properties

Generally speaking, dyeing should be carried out for grey cotton fabric after conventional wet treatment of desizing, scouring and bleaching. The purpose of the conventional wet treatment is to remove impurities such as sizing agent and oily/fatty impurities (e.g. waxes) so that the cotton fabric can accept dyes and chemical easily in the later stages of textile wet processing. In this study, grey cotton fabrics were treated with plasma treatment and conventional wet treatment. The K/S values of the plasma treated and the conventional wet treated grey cotton fabrics are 30.49 and 30.90 respectively which have the similar colour yield. The results shown in "Drop test" and "Longitudinal wicking test" indicate that the wettability of plasma treated cotton fabric is better than the conventional wet treated fabric. In addition, the results in FTIR confirm that oxygen-containing groups are available in the plasma treated cotton fabric. Both factors contribute to the increase dye absorption ability of plasma treated cotton fabric in a dyeing process. However, if the RUI is taken into consideration, the conventional wet treated grey cotton fabric (0.35) has a better levelness than plasma treated cotton fabric (0.32) but they can both be classified as good levelness. In case of conventional wet treatment, grey cotton fabric is completely immersed into treatment solution and the reagent can penetrate completely into the fabric to achieve a uniform treatment effect. However, in plasma treatment, only the face side was treated and thus the surface treatment is not as uniform as conventional wet treatment. Thus, the difference in the surface uniformity may lead to the different degree in levelness after dyeing. In conclusion, the plasma treatment can remove size and waxes from the grey cotton fabric surface and then improve the fabric wettability which could enhance the subsequent colouration process by skipping the scouring and bleaching. This would shorten the conventional production processes in dyeing.

4. Conclusion

APP treatment was employed for treating grey cotton fabrics as an alternative and clean choice to conventional wet treatment. The weight change and the decrease in weight of plasma desized fabric reveal that APP treatment is able to remove starch-based sizing agents. However, whiteness values of cotton fabrics were not improved after APP treatment when compared with grey and conventionally treated fabrics. Wetting and wicking results were significantly improved by APP treatment, which were also better than the results of the conventional wet treated fabrics. Among the plasma parameters used in this study, fabrics treated with 160 W output power displayed significant improvement in wettability. The changes of surface morphology of the plasma treated fabric were observed by removal of size materials and formation of micro-cracks on fibre surface and additional oxygen-containing groups were introduced by the plasma, which result in enhanced wettability. Thus, the APP treatment can remove sizing materials from grey cotton fibre and help improved fabric wettability which enhances the subsequent colouration and finishing processes by skipping the scouring and bleaching processes. As a result, less energy, chemical and water would be used. The APP treatment could then be a clean choice for treating grey cotton fabric by shortening the production process.

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