Effect of Plasma on the Mechanical Strength of Khadi Cotton

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Abstract
Exposure to plasma does lead to surface erosion of textile material, we were interested in evaluating the effect of plasma treatment on the mechanical strength condition for Khadi cotton fabrics. Although surface erosion roughens and creates a larger contact area, and it is ideally suited for better dye uptake of the cotton fabrics. The surface erosion also led to the change in the content of carboxyl and carbonyl groups of the cotton fibers which was established by XPS studies. Through the study, it was inferred that the mechanical strength of Khadi cotton was affected significantly less during 1 minute of the plasma exposure.

Key words:
Plasma treatment, Khadi cotton, XPS measurements, mechanical strength

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1.0 Introduction

Plasma technology has been proven to be having considerable potential in textile processing. It is advantageous as it is a clean, dry and energy-saving technology. Air plasma treatment has been used by several researchers et al.[1] reported a substantial increase in the wettability and wickability of grey cotton fabrics by the treatment of atmospheric air plasma. The introduction of polar groups due to the air plasma was observed by them. Karahan and Ozdogan[2] studied the effect of DBD plasma on raw cotton fabric using air and argon gases. There was an increase in the hydrophilicity and the wickability of plasma-treated samples. Modification on the surface properties of cotton fabric was reported by them, which did not alter the interior parts of the cotton fiber. Similarly, Lam et al.[3] reported improved hydrophilicity of cotton fabric, which led to enhanced effectiveness of post-finishing processes by the oxygen plasma treatment. Similar observations were found by Inbakumaret al.[5] on exposure of low-pressure DC glow discharge in argon to cotton fabric, which showed a significant increase in wicking properties. This was found to be directly related to treatment time, discharge power, and pressure during the plasma exposure.

The physical properties of natural fabrics are also affected by plasma treatment. It does have a detrimental influence on weight loss, whiteness, and yellowness indexes. Even air permeability and water-vapour permeability are affected. The pilling resistance, thermal properties, and fabric hand properties are also affected by plasma treatment. Inbakumar and Anukaliani[5] used low-temperature glow discharge air plasma to treat silk and wool fabrics. They found that with increasing exposure time, there seemed to be increased loss of the weight of the fabric.

The surface erosion after the plasma treatment of the cotton fibers, has been found to change the carboxyl group and carbonyl group contents of the fiber. Air/oxygen plasma pre-treatment causes improvement in the wettability of the fabric. The enhanced wicking ability can be attributed to the chemical changes caused due to plasma treatment which is responsible for introducing polar oxygen-containing groups such as C–O, C=O, O–C– O, and O–C=O groups on the cotton fibers. As the FTIR –ATR penetrates only on the thin surface of the fabric, the spectra of untreated and plasma-treated samples showed very insignificant changes in chemical composition particularly in C–O and O–H bonds. No conclusion could be drawn from the spectrum.

Some researchers have worked on the effect of Plasma on wool fibers; however, not much have been researched on cotton fiber.

The tensile properties at breaking load, surface morphology, and several low-stress mechanical properties of LTP-treated and untreated wool fabrics have been studied by Goud [6]. Surface morphological changes were found to be dependent on plasma processing parameters. According to this study, the surface thickness, bending rigidity, and shear rigidity of

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the wool fabrics seem to have increased after the plasma treatment. These properties were found to be directly proportional to the applied voltage and inversely proportional to the inter-electrode spacing. The etching effect of low-temperature plasma resulted in fiber roughening. This roughening is higher at higher voltage and lower electrode spacing. There is a decrease in extensibility of the plasma-treated fabrics at lower loads. However, at breaking load, the extensibility as well as the breaking strength of the plasma-treated fabrics are found to increase. This study creates a basic understanding of how different plasma process parameters affect the properties of wool fabrics.

The effect of oxygen plasma treatment on the surface roughness, morphology, chemical surface structure, crystallinity and tensile properties of wool fiber yarn was evaluated. The wool fibers were treated with oxygen plasma at different treatment times. High-resolution scandisk confocal microscopy and scanning electron microscopy were used for the morphological surface characterization of wool fibers. Attenuated Total Reflectance Fourier Transform Infrared spectrometry was used for the analysis of the chemical structures of untreated and plasma-treated wool fiber surfaces. In addition, the percentage of crystallinity and the size of the crystals were investigated using an X-ray diffractometer. Barani et al.reported that oxygen plasma treatment led to the removal of surface lipids and, oxidized the cysteine in the exocuticle, and increased the surface roughness of the wool fiber [Barani andCalvimontes, [7].

Some important physical and mechanical properties of a wool fabric treated with a roll-to-roll atmospheric plasma jet equipment were carried out by [Ceria et al., 8]. Wool fabrics were processed at three different velocities (1, 3 and 6 m/min); the other process variables were kept constant. They reported that the tensile strength, elongation at break, surface thickness, wettability, and air permeability increased after the plasma treatment.

Kan et al. [10] showed that grey cotton fabrics when treated with different combinations of plasma parameters with helium and oxygen gases,showed better desizing, scouring, and bleaching processes when compared with the conventional methods. Wicking and water drop tests showed improvement in wettability of grey cotton fabrics after plasma treatment and yielded better results than conventional desizing and scouring.

The use of Air Plasma treatment brings several advantages to textile processing (i) It can be applied to the continuous processing of fabric rolls; (ii) It is not capital and maintenance intensive (iii) most importantly, it offers a milder surface treatment to substrates within short duration of exposure of the plasma active species.

Therefore, this study aims to investigate the efficiency of plasma and its effectivity on the mechanical strength of Khadi cotton and to analyze how the Air plasma treatment affects the surface of the Khadi cotton when exposed to 1 min of plasma treatment.

We have attempted to study the mechanical strength of the yarn and fabric of Khadi cotton in the present work and correlated it with XPS measurements.

2. Experimental details

2.1. Materials: Khadi cotton fabric was bought from the KVIC store, in Mumbai.

2.2. Atmospheric plasma treatments: Atmospheric air plasma was used. This was operated with, four cylindrical electrode pairs with three power sections. Each electrode pairs were placed 4 cm apart from each other. The samples were placed between the electrodes and passed at various plasma powers (100–300 W) for 8-10 exposures within 1 min. In all treatments, air was used.

2.3. Characterization techniques

2.3.1. Tensile testing : The tensile strength of Khadi fabric was measured in accordance with ASTM standards-For single yarn strength test - ASTM D- 2256, for fabric tensile strength - ASTM D - 5035.

2.3.2. X-ray photoelectron spectroscopy (XPS) analysis-Surface characterization of Khadi cotton and plasma-treated Khadi cotton was performed with a Specs ESCA instrument. Spectra were recorded by using a monochromatic Al Ka radiation source at a power of 200 W (10 kV, 10 mA) electrostatic energy analyzer. X-ray photoelectron spectroscopy (XPS) survey spectra were collected. The concentrations of different chemical states of carbon in the C1s peak were obtained by fitting the curves with Gauss–Lorentz functions.

3. Results and discussion

3.1. Tensile : According to Kawabata [1980], the surface property of the fabric is related to its physical-mechanical properties indirectly. In both the physical properties and chemical properties of the plasma treated substrate, there is evidence evidence that the surface of the fabric gets altered, which depends on the used plasma gas(or gases) and treatment parameters. To determine the extent to which plasma treatment of Khadi Cotton affects the strengths of treated fibers, the tensile strengths of Khadi fibers were determined using a tensile test of the yarn and Khadi cotton fabric which is presented in Table – 1-2. After air plasma treatment of Khadicotton yarn and fabric at 200 W, fabric strength loss occurred at about 8.54% and 5.91%, respectively. From these tests, we can certainly see that the strength of the Khadi yarn and Khadi cotton fabric was retained by 91.46 % and 94.09 % respectively. The loss in fabric strength of the plasma-treated sample shows very minimal for both Khadi cotton yarn and cotton fabric. Thus, we can say that plasma treatment does not cause any detrimental loss during the exposure when the exposure time was kept for 1 min.

Table - 1 a and b Strength of Control and Plasma treated Khadi Cotton Yarn

Single Yarn Strength of Untreated khadi cotton	
Sl.No	Breaking Force (gF)
1	100.8
2	107.9
3	104.7
4	108.3
5	103.2
Mean	105

Single Yarn Strength of Plasma treated khadi cotton	
Sl .No	Breaking Force (gF)
1	95.21
2	92.53
3	100.4
4	97.83
5	94.25
Mean	96.04

Strength Retained(%) =91.46

Table - 2 Strength of Control and Plasma treated Khadi Cotton Yarn

Strength of Untreated Fabric	
Sl.No	Max Force (N)
1	235.8
2	230.3
3	246.8
4	233.56
5	237.72
Mean	236.87

Strength of Plasma Treated Fabric	
Sl .No	Max Force (N)
1	226.8
2	221.56
3	228.95
4	214.63
5	222.48
Mean	222.88

Strength Retained(%) = 94.09

3.2 XPS measurement

It was done for control and plasma-treated Khadi cotton samples. It is the most widely used surface analysis technique where surface characterization near the surface region up to 1-2 nm can be determined. In all samples, carbon and oxygen elements were detected. For plasma treated sample, a prominent increase in the height of the oxygen peak to that carbon peak was observed in the survey spectrum. Figure1 shows the C1 scan of the Control Khadi cotton fabric and Figure2 shows the C1 scan of the Plasma treated Khadi cotton fabric. Figure3a and b show the scan survey of control and plasma treated Khadi cotton samples.

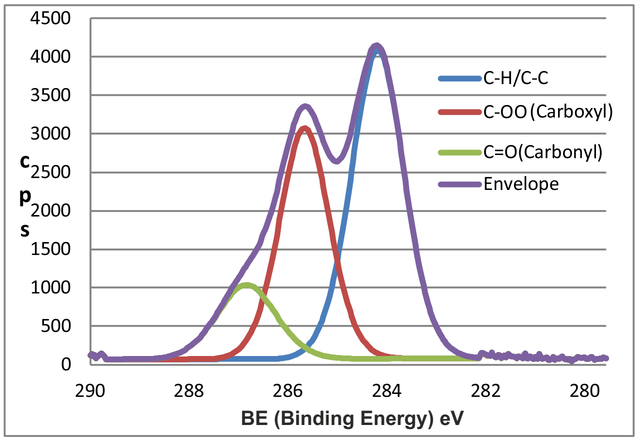

Figure -1 : C 1 scan of control Khadi cotton fabric

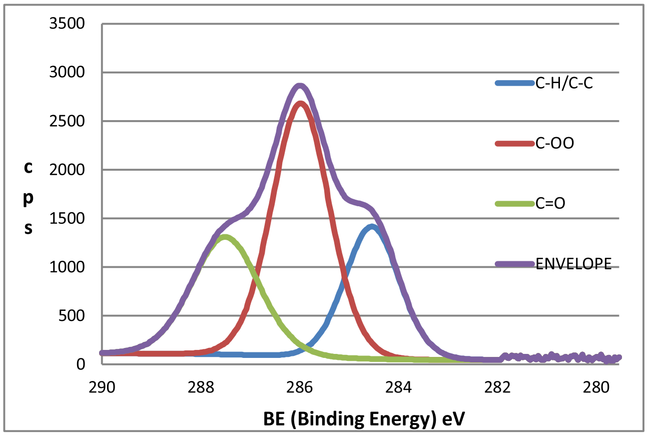

Figure-2 C 1 scan of plasma treated Khadi cotton fabric

The X-ray photoelectron spectroscopy analysis showed discrete differences in the surface groups of Khadi cotton fabric. After the plasma treatment, there was an increase in the oxygen content on the sample surface. This was due to the generation of C=O and C–OO species during the plasma process, which was confirmed by the data obtained from the high-resolution XPS spectra as shown in Table 3, in which an increasing number of carbonyl and carboxyl groups can be seen as well as a relative decrease in the C-H/C-C species. The intensity of the oxygen peaks from the air plasma-treated surface is much stronger than untreated surfaces. It is in concurrence with the findings of Sarma et al.[9].

In the case of the Khadi cotton sample treated by the plasma for 1mins through 8-10 exposure cycles), the C=O increased almost one and a half times (13.62 to 22.84), which confirms the strong surface oxidation mainly to produce the C=O and O–C=O species.C-H/C-C species showed a reduction from 50.55 to 39.54, however the C-O-O species showed a marginal increase from 35.82 to 37.61 in control and plasma-treated cotton fabrics, respectively..

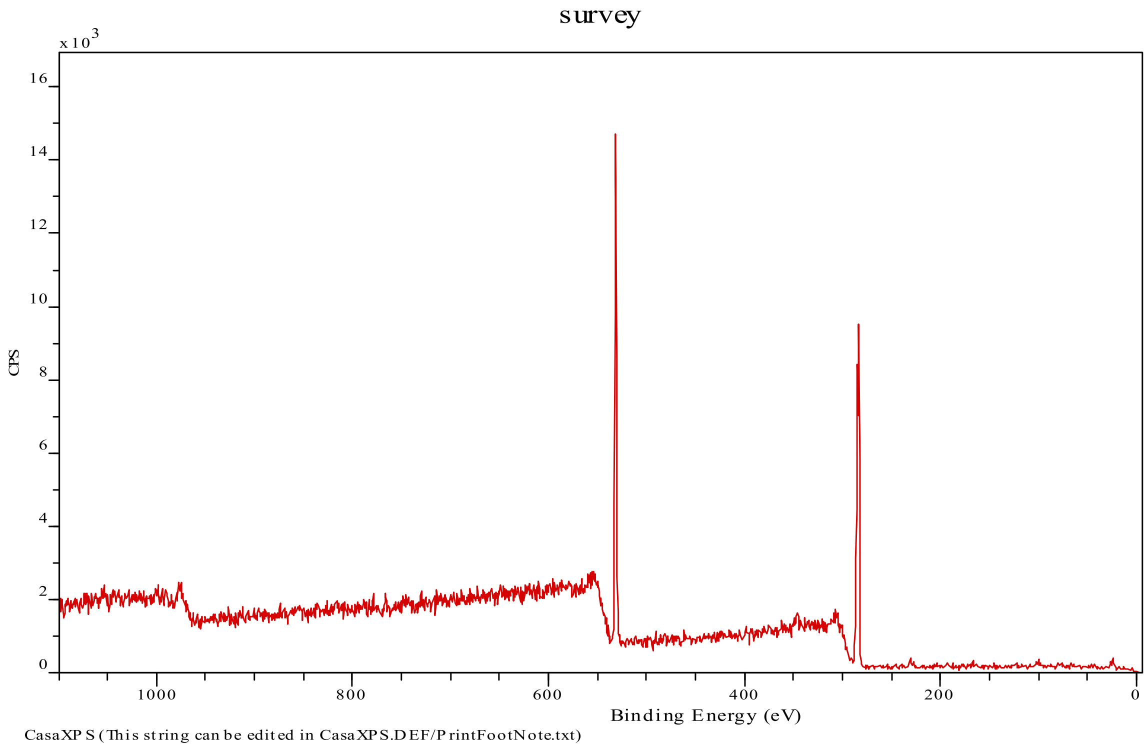

Figure 3 a XPS scan survey of Control Khadi Cotton

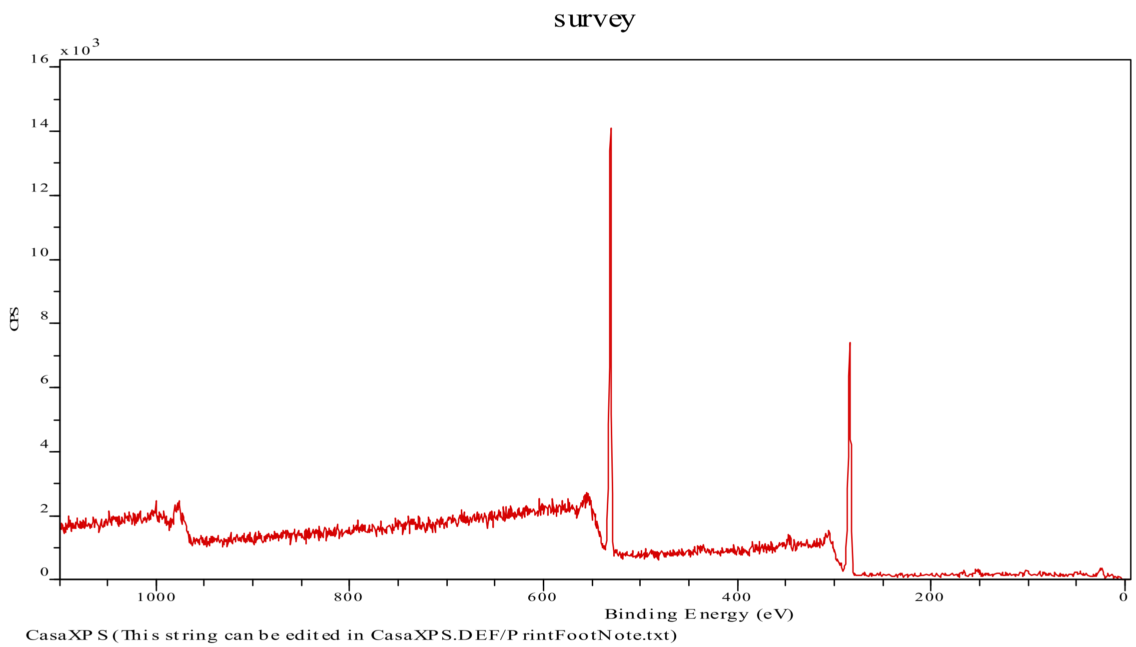

Figure 3b XPS scan survey of Plasma Treated khadi cotton

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Table 3 : Atomic Composition of Control and Plasma Treated Samples

FUNCTIONAL GROUP ATOMIC WT %	PEAK POSITION	UNTREATED KHADI COTTON	PLASMA TREATED KHADI COTTON
C—H/C-C	284.4	50.552	39.547
C-OO	286	35.828	37.613
C=O	287.2	13.62	22.84

Although the plasma treatment increased the oxygen content on the surface of the Khadi cotton fabric as shown by XPS analysis it did not affect the mechanical strength of the fabric during 1 min exposure to the plasma treatment.

4. Conclusion: In this paper, a simple correlation has been drawn between the loss of tensile strength of plasma-treated Khadi cotton through tensile strength evaluation of Khadi cotton and yarn. The XPS evaluation of the Khadi cotton showed that after plasma-treatment, surface oxidation takes place, which enhances the formation of C=O and C–OO species. It was found that the 1 min plasma treatment showed very little change in the tensile strength.

References

1. Bhat, Narendra, Bharati, R.N., Gore, A.V. and Patil, Amol. (2011). Effect of atmospheric pressure Air Plasma treatment on desizing and wettability of cotton fabrics. Indian Journal of Fibre and Textile Research. 36, 42-46.
2. Karahan HA, Ozdogan E (2008) Improvements of surface functionality of cotton fibers by atmospheric plasma treatment. Fiber polym 9:21–26.
3. Lam Y, Kan C, Yuen C (2011) Physical and chemical analysis of plasma-treated cotton fabric subjected to wrinkle-resistant finishing. Cellulose 18:493–503.
4. Inbakumar S, Morent R, De Geyter N, Desmet T, Anukaliani A, Dubruel, P and Leys, C (2010) Chemical and physical analysis of cotton fabrics plasma-treated with a low-pressure DC glow discharge. Cellulose 17:417–426.
5. Inbakumar S and Anukaliani A (2010) Effect of plasma treatment on the surface of protein fabrics. J Phys 208:012111–012121.
6. Goud, V.(2012) Influence of plasma processing parameters on mechanical properties of wool fabrics.Indian Journal of Fibre& Textile Research, Vol. 37, 292-298.
7. Barani, H. and Calvimontes, A. (2014): Effects of Oxygen Plasma Treatment on the Physical and Chemical Properties of Wool Fiber Surface. Plasma Chemistry and Plasma Processing, 34, 6, 1291-302, 0272-4324.
8. Ceria, A., Rombaldoni, F., Rovero, G., Mazzuchetti, G. and Sicardi, S. (2010): The Effect of an Innovative Atmospheric Plasma Jet Treatment on Physical and Mechanical Properties of Wool Fabrics. Journal of Materials Processing Technology, 210, 5, 720-26, 0924-0136.
9. Rani, K.V; Sarma, B., and Sarma,(2018) Plasma treatment on cotton fabrics to enhance the adhesion of Reduced Graphene Oxide for electro-conductive properties, Diamond and Related Materials, 84, 77-85.
10. Kan, Chi-wai,(2014) A Novel Green Treatment for Textiles
11. Plasma Treatment as a Sustainable Technology, CRC Press, Boca Raton.
12. Kawabata, S., The standardization and analysis of hand evaluation, The Textile Machinery Society of Japan, OSAKA (1980).