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Low-temperature plasma processing for the enhancement of surface properties and dyeability of wool fabric

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ABSTRACT: In the present investigation, wool fabric was treated with a low-temperature air plasma. The plasma discharge power and treatment time were varied. The effect of plasma treatment on various fabric properties such as wettability, wickability, dyeability, crease recovery angle, breaking strength, and elongation at break was investigated. Surface morphology was studied using SEM micrographs. The fabric became substantially hydrophilic even with a short duration of air plasma treatment of 30 s with improvement in dye uptake and in the rate of dyeing when dyed at a lower temperature. Under these treatment conditions, aging was almost nil in a dry environment, even after 45 days, whereas some aging was observed in a humid (75% relative humidity) environment. A 20% increase in the breaking strength and 24% increase in the elongation at break were observed with reduction in wrinkle recovery angle to 133–144° from 169° for untreated fabric. © 2015 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2016**, *133*, 43097.

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INTRODUCTION

Wool is a protein fiber containing amino (—NH_2) and carboxyl (—COOH) end groups, which are responsible for the dyeability of wool. Wool has a complex morphological structure, being composed of two types of cells: the internal cells of the cortex that form the wool hair and the external cuticular cells (or scales) that form a sheath around it. The exposed edge of each cuticular cell points from the fiber root toward the tip, and the cuticular cells develop like tiles on a roof, causing undesirable felting of wool when agitated in water, particularly for knitted garments that are machine washed. The wool scale surface is hydrophobic because of the thin layer of the epicutical, the highly crosslinked layer of the exocuticle, and the lipids present at the intercellular junctions, making wool fabrics "shower-proof." This makes even chemical processing of wool difficult. Scales need to be removed for the improvement of wool absorbancy, leading to proper interaction with dyes, chemicals, and finishes, and for improvement in other surface-related properties like antifelting and spinnability. In recent years, efforts have been made to modify the wool surface either by physical means (mechanical, thermal, ultrasonic) or by chemical methods such as oxidation, reduction, and enzyme and ozone treatments. Chemical treatments are the most commonly used descaling methods in the wool processing industry,[1] among which chlorination is the most common and commercially successful due to its ease of application. The chlorine-containing compounds produce toxic absorbable organohalogen (AOX) compounds, liberating non-eco-friendly chlorine to the effluents.[2] However, as a result of increasing environmental restrictions, AOX-free treatment is desirable. Of the several surface-modification techniques, plasma treatment is gaining importance for the surface treatment of textile materials because of the numerous advantages associated with it.[3,4]

Fiber surface modification using a plasma is an environmentally friendly, dry-state process that consumes minimum amounts of gases or monomer vapors and has no effluent generation. Conventional wet processing, on the other hand, makes use of chemicals that are harmful to the environment. Low-temperature plasma processing is a preferred technique for surface modification of textiles and polymers.

A literature survey indicates that a gaseous (air, oxygen, nitrogen, argon, ammonia) plasma treatment on different textile fibers improves hydrophilic properties due to incorporation of polar functional groups, as well as etching of the surface, causing an increase in the effective area of contact.[5–13] Improved wettability facilitates adhesion and dyeability.

The wettability and dyeing performance of wool is governed by its surface morphology and chemical structure, which can be altered using plasma processing. Kan *et al.* listed many applications of plasma technology for the surface modification of wool to improve its surface-related properties, such as spinnability, shrink-proofing, and improvement in air permeability, printability, and dyeability.[1,14] Various researchers have used plasma technology for surface modification of wool and studied its effect on dyeability.[2,15–18] Wool shows surface etching when it is treated with an inert gas plasma, causing improvement in its dyeability and antifelting property. The strength loss increases with an increase in plasma treatment time and its intensity. Kan *et al.* have shown etching and complete removal of scales when treated in oxygen plasma for 45 min with loss in strength of the wool fabric.[19] However, there are reports of an improvement in the mechanical properties of wool after a shorter duration of air plasma treatment,[20,21] and optimization of plasma power and treatment time needs to be done considering the aging effect. Shahidi *et al.* have carried out plasma treatment of wool to make it shrink resistant and to impart an antifelting property.[22] Panda *et al.* reported the low-temperature dyeing of helium plasma treated wool and found a 40–45% increase in the dye uptake.[23] Ghoranneviss *et al.* found increased color strength of wool at low temperature with an improvement in antibacterial activity with plasma sputtering.[16] The disadvantage of gaseous plasma treatment is that it is not permanent and leads to hydrophobic recovery when the samples are stored for a long time. The hydrophobic recovery has been shown to be dependent on the polymer and type of plasma treatment,[24] though in many cases the surfaces are still better than untreated samples. Aging can therefore be considered as one of the steps of plasma processing.[25,26] In this context, in order to clearly understand the effect of surrounding environment (or aging) on the hydrophobic recovery of wool, studies on aging behavior were carried out in dry as well as humid environments. The drop absorbancy time and wicking height were measured to understand the mechanism. The optimum plasma power and treatment time for improvement in dyeability and other properties were determined after analyzing the aging behavior.

EXPERIMENTAL

Materials

Ready-to-dye woven wool fabric (170 GSM) was provided by Raymonds (I) Limited, Mumbai, India. It was made up of 24s two-ply warp and 30s single-ply yarn as a weft composed of superfine merino wool. Fabric samples were washed thoroughly with 1 g/l nonionic detergent solution at 70°C for 1 h followed by rinsing with cold water and drying in air. Isolan Red 2S-BR (1:2 metal complex; C.I. Acid Red 362) dye was provided by Dystar (Mumbai, India) and used for the dyeing.

Plasma Reactor

A diagram of a tubular-type low-temperature and low-pressure plasma reactor used in the present work is shown in Figure 1. It consists of a glass tube with 8 cm diameter and 30 cm length. The length and breadth of the electrodes are 25 cm and 3 cm, respectively. The reactor has an inlet for monomer or gas. A Pirani gauge was fitted to the reactor to monitor pressure in the reactor. The aluminium electrodes were kept outside the glass tube and were connected to a radio-frequency (RF) (13.56 MHz) power supply.

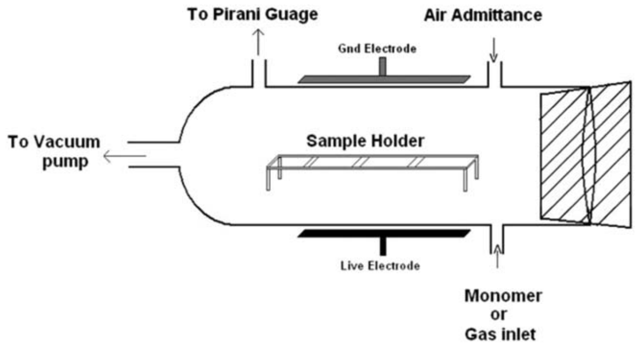

Figure 1. Schematic of vacuum plasma reactor.

Air Plasma Treatment of Wool

Wool fabric was cut into different sizes (Table I) for plasma treatment and further cut into smaller sizes according to the requirements of the test to be carried out.

The fabric sample was mounted onto the sample holder in the plasma reactor. Initially the system was evacuated using a rotary vacuum pump so that moisture present in the sample and its interstices is removed. The system was purged with air three times, and the working pressure was then adjusted to 0.15 mbar with the help of a fine-control needle valve. Suitable RF power (30 W and 45 W) was applied across the two electrodes, and the treatment was carried out for different durations ranging from 15 to 90 s. The plasma-processed samples were used for the evaluation of their hydrophilicity in terms of drop absorbancy and wicking. Ninety seconds of treatment time was used for the samples to be evaluated for tensile strength, wrinkle recovery, scanning electron microscopy analysis, and dyeing.

Hydrophilicity Measurement

Water Drop Absorbancy. The hydrophilicity of fabrics was evaluated by measuring the wetting time (absorbancy) before and after the plasma treatment according to AATCC Test Method 79. A droplet of distilled water was put on the flat fabric surface, and the time required for the water droplet to disappear was recorded as the wetting time.

Wicking. The wicking test of fabric samples was carried out according to the ISO 9073-6: 2000 (E) standard. Samples were cut into strips of size 15 × 3 cm and suspended vertically in distilled water up to 1 cm. The wicking height was noted after each interval of 30 s up to 5 min.

Average Wrinkle Recovery Angle

The average wrinkle recovery angle of treated and untreated wool fabrics was measured according to IS 4681-1981 on a Crease

Table I. Sample Size for Plasma Treatment

Sample	Test type	Sample size (cm)
1	Water drop absorbancy	20 × 5
2	Wicking	15 × 3
3	Tensile	15 × 2.5
4	Wrinkle recovery	15 × 5
5	Dyeing	20 × 5

Table II. Water Drop Absorbancy of Wool Treated with Air Plasma at 30 W and 45 W

	Time to absorb distilled water droplet (s)		
		Air plasma treated at	
Treatment time (s)	Untreated	30 W	45 W
15	>300	4	1.5
30	>300	1	0
45	>300	0	0
60	>300	0	0
75	>300	0	0
90	>300	0	0

Recovery Tester (Rossari Labtech, Mumbai, India). Strips of 4 × 1.5 cm were cut in both warp and weft directions, folded to make a 2 × 1.5 cm size by using the clamp provided with the tester, and placed below the two loads of 500 gm each for 5 min. The fabric strip was removed by holding one end of it using a clamp, and the other end of the strip was then put between the clamps of the Crease Recovery Tester and allowed to recover from the crease freely. After 5 min, the angle of recovery was noted from the scale provided on the instrument.

Tensile Strength and Breaking Extension

Tensile strength and breaking elongation of single yarn and fabric strips were determined according to test method ASTM D 5035: 1995 on a universal tensile machine (UTM), model Country H5KS of Tinius Olsen (Horsham, Pennsylvania, USA). The untreated and plasma-treated wool strips of size 15 × 2.5 cm were first conditioned for 24 hr at 75% RH and mounted onto pneumatically operated jaws of the UTM with a gauge length of 7.5 cm. A cross-head speed of 30 cm/min was used for all of the samples.

Scanning Electron Microscopy Analysis

Scanning electron microscopy (SEM) micrographs of untreated and air plasma treated wool samples were recorded on a JEOL SEM (model JEM 5400), Tokyo, Japan. Different magnifications ranging from 100 to 2000× with voltage of 5 kV were recorded.

Dyeing and Its Evaluation

The dyeing of untreated and air plasma treated wool samples was carried out with a metal complex dye on a Rota Dyer (RB Electronics and Engineering Pvt. Ltd., Mumbai, India). Fabric samples (0.7 g each) were prewetted and inserted into the dye liquor (Material to Liquor Ratio, MLR = 1:50) at 50°C containing 1% (owf) of dye, 2 g/l Glauber's salt, and 2% acetic acid (30%) (on the weight of fabric). The temperature was raised to a boil at the rate 2°C min^{-1}, and then the dyeing was continued for various durations. Isothermal dyeing was also carried out at 60, 70, and 80°C. Samples were taken out of the dye pot at different time intervals and washed thoroughly with cold water, followed by air drying. Dye-bath exhaustion was calculated from the absorbance on a UV–visible spectrophotometer (model 8500, Techcomp, Kwai Chung, Kowloon, Hong Kong) at λ_{max} = 500 nm for the metal-complex dye using the following formula:

$$\text{Dye bath exhaustion, } \% = \frac{A_0 - A_1}{A_0} \times 100$$

where A_o and A_1 are the absorbance value of the dye bath before and after exhaustion, respectively. Color depth was measured in terms of K/S values of the dyed samples evaluated on the Computer Color Matching system (model SpectraScan 5100+), Lawrenceville, NJ.

Aging Study on Plasma-Treated Samples

For aging, wool fabric samples were placed in a silica gel desiccator immediately after the plasma treatment to maintain a moisture-free environment. Similarly, the samples after the plasma treatment were then kept in a desiccator maintained at 75% RH to check the effect of aging in a humid environment. After 45 and 75 days, samples were taken out and tested for the change in their hydrophilicity in terms of absorbancy and capillary rise, respectively.

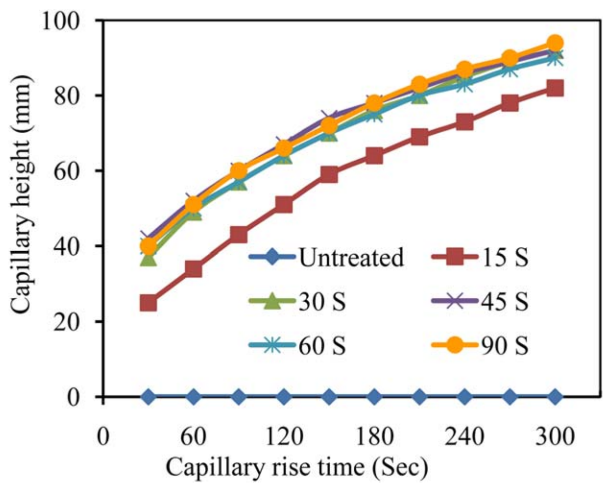

Figure 2. Wicking of wool treated with air plasma at 30 W. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

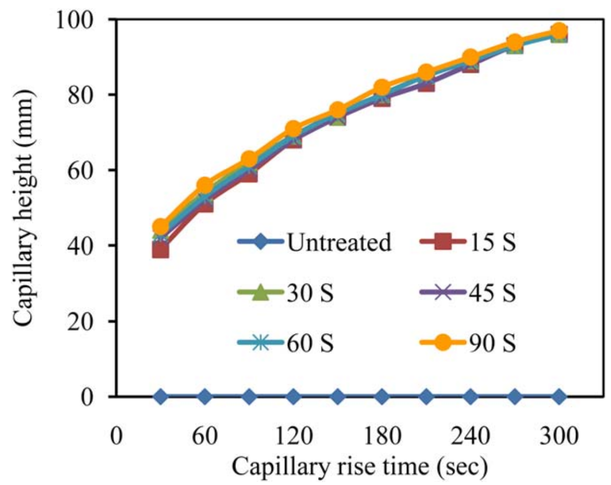

Figure 3. Wicking of wool treated with air plasma at 45 W. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table III. Effect of Aging on Drop Absorbancy of Wool Fabric Treated with Air Plasma at 30 W and Aged for 45 Days

	Time to absorb water droplet after aging (s)		
Treatment time (s)	Fresh sample	In dry condition	In humid condition
15	4.0	9.0	80.0
30	1.0	1.5	5.0
45	0.0	0.0	1.5
60	0.0	0.0	1.0
90	0.0	0.0	0.0

Table IV. Effect of Aging on Drop Absorbancy of Wool Fabric Treated with Air Plasma at 45 W and Aged for 45 Days

	Time to absorb water droplet after aging (s)		
Treatment time (s)	Fresh sample	In dry condition	In humid condition
15	1.5	2.0	40.0
30	0.0	0.0	2.5
45	0.0	0.0	1.5
60	0.0	0.0	1.0
90	0.0	0.0	0.0

RESULTS AND DISCUSSION

Effect of Plasma Power and Treatment Time on Water Drop Absorbancy of Wool

Air plasma treatment was found to greatly influence the water absorbancy behavior of wool fabric, decreasing the time to absorb a water droplet from >5 min to <1 s by 30 s treatment (Table II). Improvement in the absorbancy was better at 45 W power because more kinetic energy is provided to the plasma species, which significantly improves the attack on the scales of wool. This is evident from the SEM micrographs. Because wetting of fibers is mainly a surface characteristic, the changes in wicking are a good indication of the modification of surface properties of textiles by plasma treatment.[27,28]

Wicking Characteristics of Plasma-Processed Fabric

Air plasma treatment was found to greatly improve the wickability of wool. Untreated fabric showed no capillary rise even after 10 min, whereas air plasma treated wool (45 s at 30 W) showed a gradual rise right from the beginning (Figure 2). The effect was more pronounced for 45 W power at all treatment times, indicating that higher treatment time and higher power

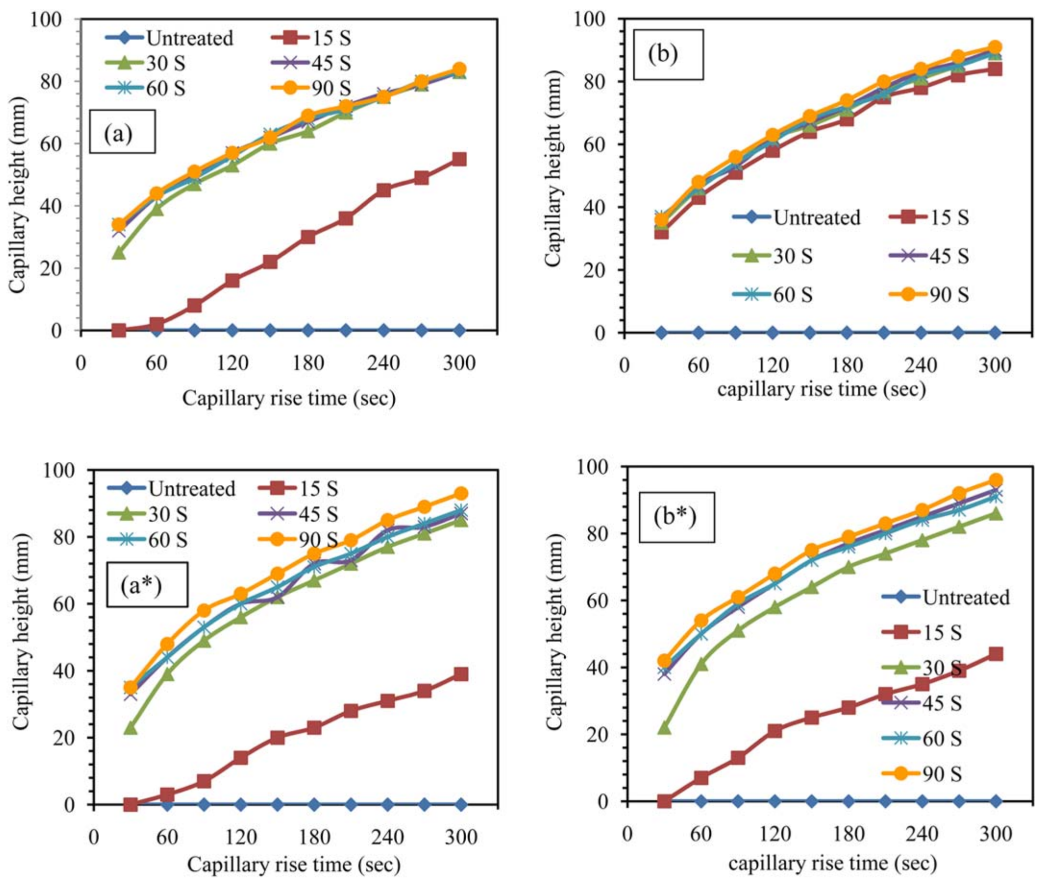

Figure 4. Wicking of wool treated with air plasma after 75 days of aging: (a) 30 W, aged in dry environment; (a*) 30 W, aged in humid environment; (b) 45 W, aged in dry environment; (b*) 45 W, aged in humid environment. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

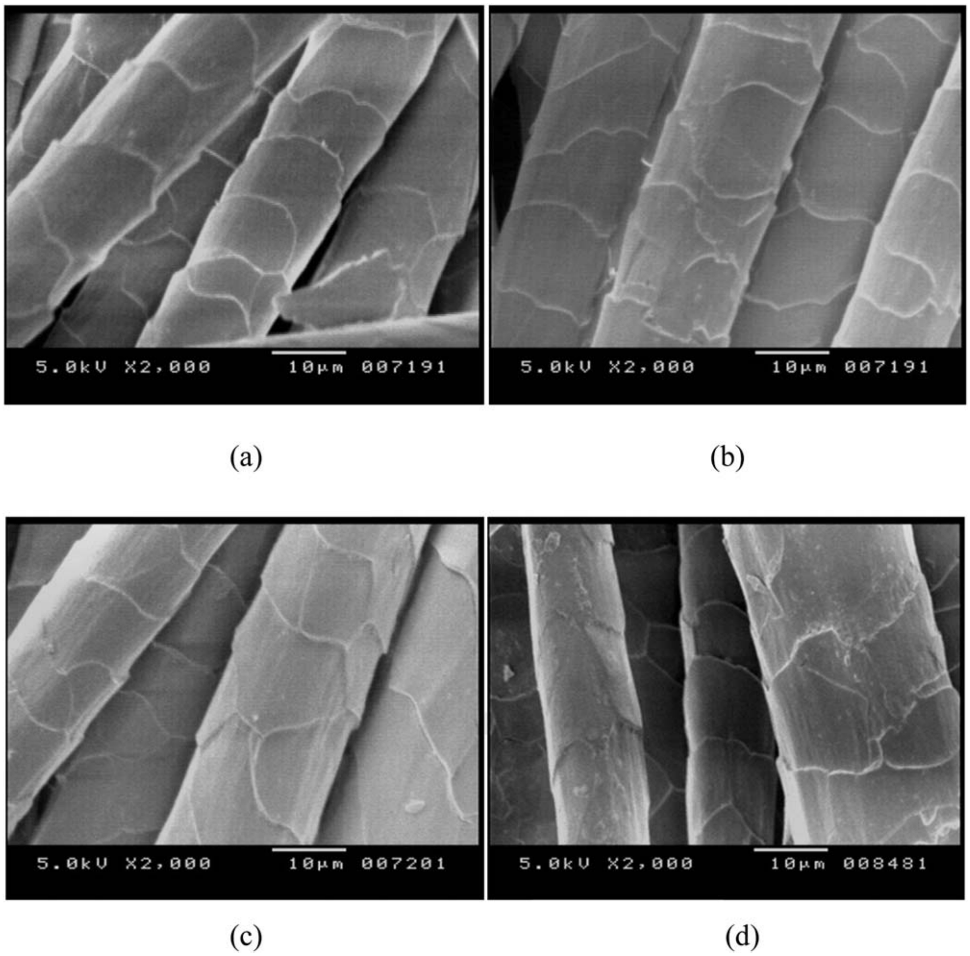

Figure 5. SEM micrographs of wool: (a) untreated; (b) treated with air plasma at 30 W for 60 s; (c) treated with air plasma at 30 W for 90 s; (d) treated with air plasma at 45 W for 90 s.

causes more descaling effect while creating small capillaries as a path for water transmission (Figure 3).

Aging Study in Humid and Dry Environments

It is believed that gaseous plasma treated material shows an undesirable hydrophobic recovery a few days after treatment, called an aging effect. In the present investigation, wool showed greater hydrophobic recovery when it was aged for 45 days in the humid environment of 75% RH compared to the sample aged in a dry environment, as judged by the time taken for water drop absorbance (Table III). The shorter treatment time showed considerable hydrophobic recovery, especially for

Table V. Dyeability of Untreated and Air Plasma Treated Wool at 30 W and 45 W for 90 s

	Dye exhaustion (%)			K/S value		
		Plasma treated at			Plasma treated at	
Dyeing time (min)	Untreated	30 W	45 W	Untreated	30 W	45 W
3	1.37	1.75	1.79	1.24	1.45	1.82
5	1.73	2.10	3.02	1.50	1.80	2.43
10	4.83	4.18	5.28	2.19	2.65	3.13
15	18.36	19.93	24.75	3.91	4.25	5.92
20	59.33	67.74	71.78	7.40	9.47	10.32
25	92.87	96.66	96.00	10.36	11.90	12.45
30	97.00	98.55	98.31	11.89	13.94	14.56
45	98.89	99.35	99.56	13.46	15.84	15.92
60	99.30	99.57	99.42	13.67	16.73	17.58

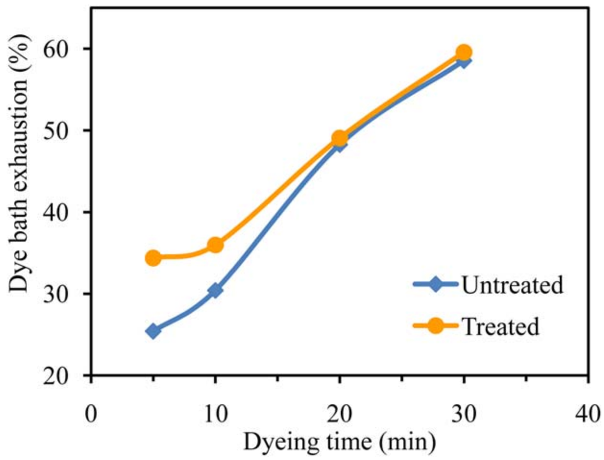

Figure 6. Dye bath exhaustion in isothermal dyeing at 60°C of wool fabric treated with air plasma at 45 W for 90 s. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

samples aged in a humid environment. This might be due to the incorporation of temporary hydrophilic functional groups on the wool surface that might be inhibited or partially vanish in the humid environment. However, higher treatment time and higher power did not show much aging effect because the improvement in absorbancy was caused by the removal of surface hydrophobic scales, as can be clearly observed from the SEM micrographs. The hydrophobic recovery was lower for wool treated for a longer time at higher power and aged in a dry environment compared to wool with shorter treatment time, lower power, and aged in a humid environment.

It may also be observed from the data (shown in Tables III and IV) that with 90 s treatment at any power there was no hydrophobic recovery, and the results were also stable in a humid atmosphere. Therefore, a wicking study was carried out for samples aged 75 days in both environments.

It is clear from Figure 4(a*,b*) that the hydrophobic recovery (as seen by less capillary rise) in the humid environment is considerable for samples plasma treated for 15 s as compared to longer treatment time for both power levels. This could be because a 15-s plasma treatment just introduces polar functional groups onto the surface without much change in surface morphology, and these polar groups are readily diminished or inhibited in the moist, humid environment as compared to the dry environment. Sun *et al.* have reported similar observations when wool was treated in an oxygen plasma.[29] However, for longer treatment time, as evident from SEM morphology, etching is observed. This etching causes the creation of voids and very narrow channels, which facilitates a rise in capillary heights. These changes are permanent. Second, a longer treatment time causes chain scission and the creation of radicals on the surface, along with incorporation of polar functional groups. Therefore, even after aging for a longer time, the wickability and wettability are still better than that of untreated wool fabric. Aging in a dry or humid environment has a similar effect on the wickability of wool fabric for the samples treated for 45 s and longer. Though it would seem that the hydrophobic recovery for samples kept in a moist, humid environment should be more (because of a loss of polar functional groups) than in a dry environment, the actual observation is that the rise in capillary height is more for the wool samples treated in air plasma for 45 s and longer. The longer treatment time makes wool fiber surfaces rougher (the partial removal of scales makes the surface hydrophilic, as seen from the SEM micrographs in Figure 5), and it facilitates the adsorption of moisture, which in turn helps in capillary rise; thus the effect of loss of polar groups is compensated for by the adsorbed moisture in the structure of the wool fibers. Therefore, the capillary rise is more for wool samples treated for a long time in an air plasma and kept in a 75% RH environment [Figure 4(a*,b*)] as compared to the dry environment [Figure 4(a,b)]. It is also clear from Figure 4 that the aging effect is less severe for samples treated with a high-power plasma kept in both environments compared to their counterparts treated with a low-power plasma. Thus it is clear from the aging study in water absorbancy and wickability that a 90-s treatment time is the

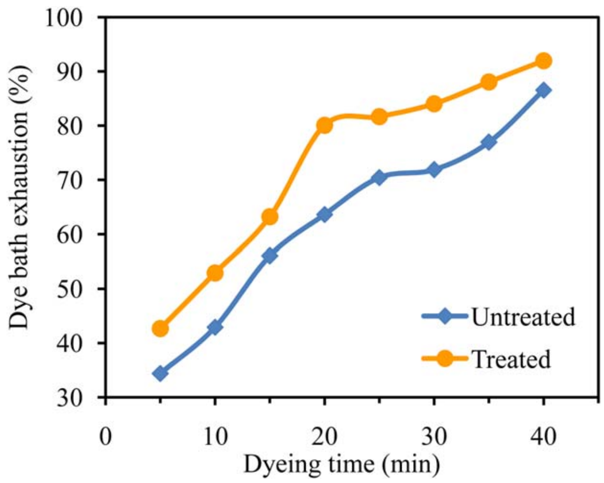

Figure 7. Dye bath exhaustion in isothermal dyeing at 70°C of wool fabric treated with air plasma at 45 W for 90 s. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

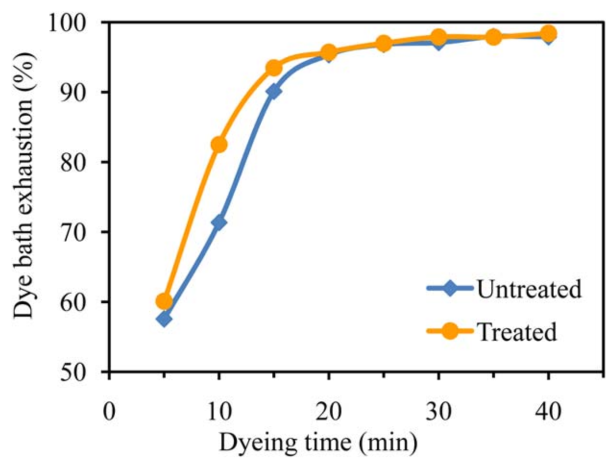

Figure 8. Dye bath exhaustion in isothermal dyeing at 80°C of wool fabric treated with air plasma at 45 W for 90 s. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table VI. Average Crease Recovery Angle of Untreated and Air Plasma Treated Wool

Sample type	Crease recovery angle (°)		
	Warp	Weft	Average
Untreated	167.8	169.4	168.6
Plasma treated at 30 W for 90 s	129.3	149.2	139.3
Plasma treated at 45 W for 90 s	111.2	154	132.6

optimum time to avoid the losses in hydrophilicity. Therefore, in the further investigation, we have kept the treatment time constant at 90 s, and the samples were treated in an air plasma under two different power levels, 30 and 45 W.

Morphological Studies

The SEM micrograph of the untreated wool fabric clearly shows quite sharp scales on the fiber surface, as shown in Figure 5(a). This is responsible for the hydrophobic nature of wool. On subjecting to air plasma treatment, the sharpness of these scales is reduced, which is due to the partial removal of the hydrophobic cuticular layer on the wool surface [Figure 5(b–d)]. This reduction in scales improves the antifelting property of wool. In addition, some etching was observed on the treated fabric, creating a rougher surface. Both are responsible for the improved water absorbancy of wool. This effect was profound for longer treatment time as well as for higher plasma power.

Dyeing Behavior of Plasma-Processed Wool Fabric

Progressively Increasing Temperature Dyeing and Normal Dyeing. It is clear from Table V that the air plasma treatment of wool for 90 s at 30 W and 45 W did not show any significant improvement in dyeability (in terms of dye bath exhaustion) as well as in K/S values with 1:2 metal-complex dye as compared with the untreated one up to 10 min in the dyeing cycle. A significant improvement in dye exhaustion (in particular for the sample treated at 45 W) was observed for 15 and 20 min of dyeing, reaching the maximum for longer dyeing time. The K/S values were found to improve for plasma-treated samples, being more for 45 W power of plasma treatment and for longer dyeing time. This indicates that plasma treatment gives a deeper shade. It is clear from the dyeability study that, with suitable plasma treatment, dye uptake can be enhanced in a shorter dyeing time. Sun *et al.* have correlated the improvement in dyeability and scouring of O_2 plasma treated wool fabric with the formation of polar groups and with etching.[29] The improvement in dyeing in the present case can also be related to the formation of new functional groups and etching of the hydrophobic scales and cutical layer, as seen from the SEM micrographs. The chemical and physical changes achieved after air plasma treatment are responsible for the enhancement in hydrophilicity, wettability, water absorbancy, wickability, and dyeability. Thus, with the treatment with suitable low-temperature plasma power and treatment time, a higher dye bath exhaustion can be obtained at a shorter dyeing time.

Isothermal Dyeing. From the previous work it is clear that the results of wettability, wickability, aging effect, and normal dyeing are better for wool samples plasma treated for 90 s at 45 W. Therefore, isothermal dyeing was carried out for wool samples treated in an air plasma for 90 s at 45 W. To understand the effect of air plasma treatment on wool dyeability, an isothermal dyeing was carried out. It has been observed that the difference between the dyeability of untreated and air plasma treated wool was prominent when dyeing was carried out at lower temperatures such as 60°C and 70°C, as shown in Figures 6 and 7. When dyeing was carried out at 80°C, little or negligible improvement in dyeability was observed for treated fabric, as shown in Figure 8. However, at longer dyeing time, the maximum dye bath exhaustion was almost the same for treated and untreated wool fabric for all dyeing temperatures. This proves that with plasma treatment the dyeing temperature can be reduced, thereby saving energy.

Fastness properties have been studied by various researchers, who have found either improved fastness properties or at least no adverse effect of plasma treatment. Therefore, we have not studied this property. Shin *et al.* have studied the lightfastness properties of air plasma treated wool fabric dyed with acid dye and found that the lightfastness is less for plasma-treated samples than for the untreated ones.[30] The effect of oxygen plasma treatment on the various fastness properties of wool/polyester fabric dyed with C. I. Disperse Blue 56 showed an improvement in fastness properties.[31] Haji *et al.* have studied light and washing fastness of low-pressure oxygen plasma treated wool and found that the plasma treatment had no adverse effect on the fastness properties of samples.[32]

Effect of Plasma Treatment on Mechanical Properties of Wool

Effect on Average Crease Recovery Angle. Wool fabric has an excellent elastic recovery property among all the natural fibers. Untreated wool fabric possesses a good crease-resistance property, with an average crease recovery angle of 169°. However, the treatment with air plasma worsened its crease recovery and reduced the average crease recovery angle to 132°, as shown in Table VI. This was attributed to the breaking of hydrogen bonds of wool keratin that is due to the energetic medium of the plasma. In addition, disulfide bonds at the fiber surface might have been oxidized by the oxygen plasma, as proved by Kutlu *et al.* with X-ray photoelectron spectroscopy analysis.[18]

Tensile Properties. Air plasma treatment lead to an improvement in tensile strength and the breaking extension of wool in the form of fabric as well as yarn (Table VII). The increase in strength may be attributed to some crosslinks forming during air plasma

Table VII. Tensile Properties of 90 s Air Plasma Treated Wool

Sample type	Fabric strip: Breaking strength (kgf)	Fabric strip: Breaking extension (%)	Single yarn: Breaking strength (kgf)	Single yarn: Breaking extension (%)
Untreated	19.6	39.63	0.17402	20.1826
Treated at 30 W	23.49	49.24	0.2179	26.4733
Treated at 45 W	23.61	48.85	0.2212	28.9303

treatment, and the increase in elongation is attributed to the reduction in fiber-to-fiber friction that is due to the partial removal of surface scales. It is known that, when a polymeric material is treated in a plasma of nonreactive gases such as argon and nitrogen, crosslinking on the surface takes place. It is called CASING (crosslinking by activated species of inert gases).[33] In the present investigation, wool samples were treated in an air plasma that contains ≈78% nitrogen and ≈20% oxygen. The presence of oxygen in the plasma chamber is responsible for the generation of free radicals on the wool surface, which promotes CASING action. An increase in the treatment power might have increased crosslinking, resulting in improved breaking strength and breaking extension. However, Goud and Udakhe have observed a decrease in mechanical properties when wool fabric was subjected to a long period (>10 min) of air plasma treatment.[34] Therefore, the optimum plasma power and treatment time are important for surface modification without adversely affecting the bulk.

CONCLUSIONS

- Low-temperature plasma processing can effectively convert the hydrophobic wool surface into hydrophilic with an improvement in its tensile property while adversely affecting the crease recovery.
- Air plasma treatment increases the rate of dyeing at lower temperatures. The K/S value increases to a higher extent as compared to dye bath exhaustion, confirming the surface modification only.
- Air plasma treated wool shows lesser hydrophobic recovery when it is aged in a dry environment as compared to humid. However, for longer treatment times, hydrophobic recovery was not observed in either environment.
- A plasma treatment power of 45 W is more suitable than 30 W because the former gives a more permanent effect.
- The aging pattern on hydrophobic recovery needs to be taken into account to determine the optimum plasma parameters.

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