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Research Paper

Quality characteristics of plasma treated polyester fabric

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■ **ABSTRACT :** Polyester is the hydrophobic synthetic fibre which lacks surface reactivity thus, leads to accumulation of electrostatic charge and poor fabric comfort. This undesirable property can be overcome through transforming the polyester into hydrophilic by modifying the surface topography. Oxygen plasma is the dry, eco-friendly finishing technique and effective means to alter the surface morphology of fibre in order to induce hydrophilicity in polyester by adding more numbers of polar groups. Surface structure was assessed by SEM (Scanning Electron Microscope) and the wettability studied by wicking action. The changes in structural, performance, durable properties after plasma treatment and on subsequent washes were basically due to etching action of plasma.

■ **KEY WORDS:** Hydrophilicity, Hydrophobicity, Oxygen plasma treatment, Polyester, Surface topography

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Polyester is one of the manmade synthetic fibre (65-85 % crystalline and correspondingly 35-15 % amorphous) derived from petroleum via condensation reaction of diols and di-carboxylic acids. Polyester is chemically composed of at least 85 per cent by weight of an ester of a substituted aromatic carboxylic acid. The filament is composed of axially-oriented linear polymer molecules and this regularity furnishes hydrophobicity among polyester. The filament exhibits high mechanical strength, dimension stability and elastic recovery but lack in surface reactivity. Hydrophobicity without surface reactivity leads to accumulation of electrostatic charges consequently, provides poor wear comfort. In fact the most desirable property among clothing material is the physical comfort; and the undesirable property of polyester can be overcome by making it hydrophilic by altering the topography of the surface.

Plasma treatment is a surface modification dry technique that readily primes any surface for better acceptance of secondary manufacturing applications by modifying the surface morphology of fibre. In plasma surface modification, the changes are principally attributed to the physical or chemical changes in the material because of the high-energy bombardment of plasma or plasma enhanced reactions (Bhat *et al.*, 2011). The free radicals and electrons of plasma collide with the exposed surface, rupturing covalent bonds and creating free radicals. The activated material surface then readily combines with the excited gas species and provides chemically reactive groups that are covalently bonded to the substrate surface. The active species produced in plasma carry high energy that causes a sputtering or etching effect, which alters the characteristics of fibre surface. The treatment roughens the surface of the materials and is conducive to subsequent use of a large variety of chemically active functional groups. Plasma processing can modify the surface of substrates without compromising the properties of bulk material (Chinta *et al.*, 2012).

Thus, the present study is conducted with the objective to study impact of washing on the quality characteristics of plasma treated polyester fabric.

■ RESEARCH METHODS

The test samples selected for the present study was white, plain woven polyester fabric. The plasma experiments were carried out on an atmospheric pressure plasma treatment equipment PLATEX-600 (GRINP S.R.L., Italy) at Bombay Textile Research Association, Mumbai. The system basically works on the principle of dielectric barrier discharge (DBD) generated between the top and bottom electrodes where plasma streamers are formed from different gases. Both sides of polyester were treated with plasma generated from mixture of Helium-Oxygen gas with a flow rate of 5 l/min, at discharge voltage of 1.5 kW for 60 sec by keeping the electrodes at a distance of 1mm. After plasma treatment, the test sample were analysed for surface topography by S-3700N Scanning Electron Microscope with an accelerating voltage of 20kV and magnification power of 2500X and 10,000X for assessment up to 20 and 5 µm level, respectively.

Treated substrate were hand washed using 2 gpl of surfactant, rinsed well and finally shade dried to find out the sustainability of finish on subsequent washings. The test samples were subjected for a total of 10 washes and quality characteristics were assessed after every 5^{th} wash.

Cloth count, cloth thickness and GSM were examined as directed in BS 2862:1957, BS 2544:1954 and IS 1964:2001 test methods, respectively. Whereas, cloth shrinkage percentage was measured by using following formula:

$$S = \frac{Lo - La}{Lo} \times 100$$

where, Lo – Initial length and La – Final length

The cloth bending length and crease recovery angle were assessed by Shirley's stiffness tester and Shirley's crease recovery tester as directed in BS 3356:1961 and IS 4681:1968, respectively. Cloth tensile strength and elongation percentage were tested on Instron tensile strength tester accordance with ASTM test method: 12616-1989 (Booth, 1996).

The ability of a fabric to absorb water, by 'wicking' or 'capillary action', observed by timing, the rate at which water rises into the narrow strip of fabric suspended vertically with its lower end dipped into the water.

Statistical analysis:

Completely Randomized Design (CRD) was used to find out the effect of plasma treatment on quality characteristics *viz.*, structural, performance, durable and functional properties of the test samples.

Hypothesis:

Plasma treatment alters the structural, performance, durable and functional properties of plasma treated polyester fabric.

■ RESEARCH FINDINGS AND DISCUSSION

The findings of the present study as well as relevant discussion have been presented under following heads :

Characterization of surface morphology :

The change of PET surface morphology is mainly caused by the bonding of activated species and depends on the plasma in coating processes. After plasma treatment, the number of particles on PET fibre surface increased apparently.

It is evident from Plate 2 that oxygen plasma is efficient to convert hydrophobic polyester into hydrophilic due to its sputtering action on the surface of the substrate when compared to untreated polyester (Plate 1). Treated fibre looks as damaged or abraded due to removal of some material by etching. However, hitting of ions can give rise to loosening of the surface which leads to easy removal not only while plasma

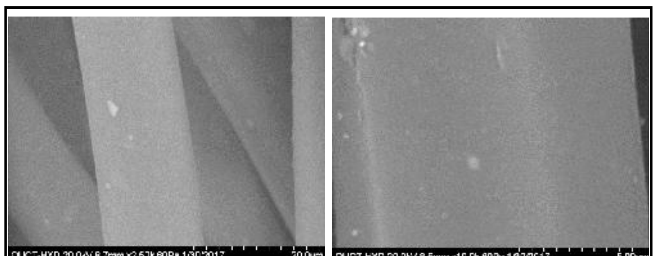

Plate 1 : Surface morphology of untreated polyester fabric

treatment but also in the subsequent process of washings. This results into increased wickability of fabrics due to enhancement of surface roughness and introduction of polar groups by the action of oxygen plasma (Bhat *et al.,* 2010).

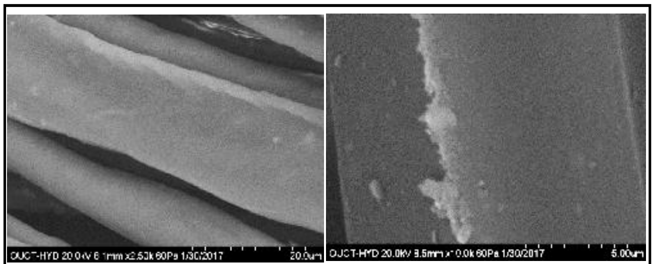

Plate 2 : Surface morphology of plasma treated polyester fabric

Structural properties :

It is apparent from Table 1, that the ends per inch of the test sample is greater than picks per inch, which indicates the compact alignment of warp yarns, compared to weft. However, there was no variation in the ends and picks per inch after plasma treatment and is mainly due to the fact that plasma is a dry treatment, which does not involve application of water as is evident in conventional processes; further polyester inherently has very little affinity towards water absorption. Nevertheless, on oxygen plasma application there was more number of polar groups affixed into the etched polyester fibre surface. As a result, on washing the polyester fabric did show some per cent of shrinkage due to which there was increase in the cloth count. However, by the end of 10^{th} wash, the test sample had attained dimensional stability, expressing its inherent performance property.

Cloth thickness was found to be higher in the untreated sample (00.25 mm) that reduced about 04.00 per cent after oxygen plasma treatment and the values are highly significant. This may be because of the electron and ion bombardment on the fibre surface that led to etching phenomenon. In other words, the reduction in cloth thickness may be either because removal of very thin top layer directly, or attack of ions on the fibre molecules (Bhat *et al.,* 2011).

It is also evident from same Table 1, that after plasma treatment the GSM of polyester fabric reduced by 01.73 per cent compared to its control values. These results are supported by the study conducted by Bhat *et al*. (2011), where it was stated that the weight loss is mainly due to etching and this reduction in weight ranges between 01.00 to 04.00 per cent. In fact, during etching there is significant reduction in fabric hairiness. Owing to plasma finish the projected and protruded fibres become more fragile during etching and thus, easily break and fall. Therefore, a trend of reduction in cloth thickness as well as GSM is prevalent. Though, a slight decrease in GSM of plasma treated sample on subsequent washes is observed but found to be non-significant.

A perusal of Table 1 showed shrinkage of 00.80 per cent each warpway and weftway at controlmay be due to prevalence of 15 to 35 per cent of amorphous region in the polyester fibre and has capacity to absorb 00.40 per cent of moisture. Similarly, 00.67 per cent of shrinkage is observed in plasma treated sample which is significant at 1 per cent level of significance, may be due to induced hydrophilicity. This shrinkage is supported by increase in threads per unit area on multiple washes. Meanwhile the test samples attained dimensional stability after plasma treatment indicates one of the quality characteristics.

Hence, the Null hypothesis set for the study that plasma treatment alters the structural properties of plasma treated fabrics is partially accepted, *i.e.* the structural properties *viz.,* cloth thickness, GSM and cloth shrinkage of plasma treated polyester fabric were altered to some extent after plasma treatment except the cloth count.

Table 1 : Structural properties of plasma treated polyester fabric

Polyester samples	Structural properties					
	Cloth count (threads per inch)		Cloth thickness (mm)	Cloth weight (GSM)	Cloth shrinkage (%)	
	Warp	Weft			Warpway	Weftway
Untreated	80	45	00.25	50.80	00.80	00.80
Treated (hydrophilicity)	80 (00.00)	45 (00.00)	00.24** (04.00)	49.92 (01.73)	00.67**	00.67**
5^{th} wash	81** (01.25)	46** (02.22)	00.24 (00.00)	49.36 (01.12)	00.67	00.67
10^{th} wash	81** (01.25)	46** (02.22)	00.24 (00.00)	49.20 (01.44)	00.67	00.67

Figures in parenthesis indicate percentages **indicates significance of value at P=0.01

Performance properties :

The impact of laundering on performance properties *viz.*, bending length and crease recovery on plasma treated polyester fabric is presented in Table 2.

In general the warpway bending length was found to be greater than the corresponding weftway bending length. Table 2 gives clear picture of decrease in bending path of test sample after plasma treatment and further reduced on multiple washes, too; and the values of both warp and weft are highly significant except weftway bending length after plasma treatment, which is significant at 5 per cent level of significance. This clearly indicates that polyester fabric at control exhibited longer bending length compared to treated and washed samples *i.e.* at control the test sample was stiffer. On plasma treatment the fabric became more soft, pliable and resilient due to etching of fibre surface and washing further improved the resiliency of the treated sample. These results are supported by the study conducted by Chinnammal and Arunkumar (2014) who stated that pre dyed samples were stiffer compared to post dyed *i.e.* the test samples dyed before plasma treatment exhibited greater stiffness than the test samples dyed after plasma treatment. In other words, plasma finish induces softness among fabrics.

The cloth crease recovery is nothing but the resiliency of the fabric. Higher the crease recovery angle better is the ability of fabric to come back to its normal shape after crease. From Table 2 it is evident that the weft recovery angle is found to be greater than its corresponding warpway recovery, at all levels of observations. On oxygen plasma treatment the sample showed increase in crease recovery angle (significant at 1% level of significance) which may be due to the rough surface build up on plasma treatment which in turn created more contact points within the fibres and yarns microscopically, resulting into enhanced inter-yarn and inter-fibre frictions. This lead to slight reduction in the relative movement of fibres and yarns thus prevented crease formation. These results are in line with the study conducted by Joshi *et al.* (2015) who concluded that crease resistance is higher among oxygen treated samples than argon treated samples.

Thus, the null hypothesis set for the study that plasma treatment alters the performance properties of plasma treated fabrics is accepted.

Durable properties :

The values of tensile strength and elongation percentage of plasma treated polyester fabric is displayed in Fig. 1 and 2, respectively and it is evident that these values are higher compared to the corresponding control values. These results are supported by the study conducted by Kan *et al.* (2011) wherein, it was stated that the tensile strength of a fabric greatly depends on several factors such as fabric structure, yarn twist and yarn count. The plasma treatment lead to surface modification and surface roughening did create more contact points in the fibres microscopically, resulting into an increased inter yarn or inter fibre friction leading to development of larger cohesive force during application of tensile stress. But, when the plasma treated samples were subjected to multiple washings, there was small reduction in both tensile strength and elongation percentage basically due to the introduction of polar groups to make the fabric hydrophilic. However, these

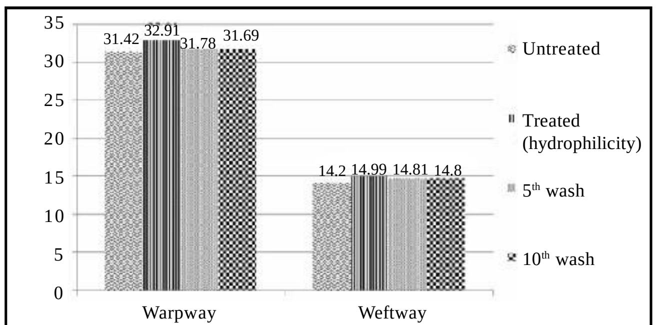

Fig. 1 : Cloth tensile strength (kgf) of plasma treated polyester fabric

Table 2 : Performance properties of plasma treated polyester fabric

Polyester samples	Performance properties				
	Cloth bending length (cm)		Cloth crease recovery angle (degree)		
	Warpway	Weftway	Warpway	Weftway	Cloth recovery
Untreated	02.15	01.70	114	120	117
Treated (hydrophilicity)	02.07** (03.72)	01.68* (01.17)	118** (03.50)	133** (10.83)	125** (06.83)
5th wash	02.01** (02.89)	01.20** (28.57)	121* (02.54)	135 (01.50)	127** (01.60)
10th wash	01.63** (21.25)	01.17** (30.35)	124** (05.08)	137* (03.00)	130** (04.00)

Figures in parenthesis indicate percentages * and ** indicate significance of values at P=0.05 and 0.01, respectively

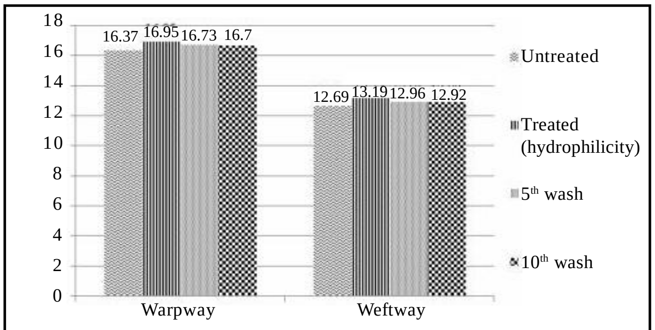

Fig. 2 : Elongation (%) of plasma treated polyester fabric

values of tensile strength and elongation after multiple washes were greater than the untreated control sample and are significant at 1 % level of significance.

Hence, the null hypothesis set for the study that plasma treatment alters the durable properties of plasma treated fabrics is accepted.

Assessment of plasma treated polyester fabric for hydrophilicity by wicking test :

High and uniform absorbency is one of the most desirable qualities mandate for all types of clothing and household textiles. Absorbency of any fabric is influenced by several structural features like- cloth count, thickness, GSM, construction etc. and is assessed by its wicking ability. Wicking plays an important role in its performance during transporting perspiration from wet skin for quick evaporation and absorption of fluids.

The results of wicking test is presented in Table 3 and found that oxygen plasma treated polyester sample showed gradual capillary rise with increase in time. The increase in wickability of treated fabric is due to introduction of polar groups generated by oxygen plasma finish as well as the enhancement in the surface roughness properly (Bhat *et al*., 2011).

These results are also supported by the study conducted by Karahan *et al*. (2009) who indicated that atmospheric dielectric barrier discharge (DBD) plasma using oxygen as the plasma medium improves the wettability of substrates. The value of capillary action rose gradually upto 5th wash and there after declined. This reveals that upto 5th wash, the plasma treated fabric attracted maximum level of water molecules; after saturation it exhibited a trend of repellency. As far as wicking time was considered, the treated sample on washing showed quick rise of water by wicking action in the first minute. But, with increase in time, wick up action was slowed down may be due to decrease in the affinity of treated material towards water and existence of already entrapped water molecules between the fibres in the yarn, which acted as barrier for further more water molecules to occupy the grooves. Meanwhile the values of wicking recorded at 1, 2 and 3 minutes are found to significant at 1 per cent level of significance.

Conclusion :

The oxygen plasma treatment abrades the fibre and roughens the surface greatly. Addition of polar groups on the abraded region converts hydrophobicity of polyester into hydrophilicity. Oxygen plasma treatment did not alter the cloth count of polyester fabric but on multiple washes there was significant increase in threads per inch and is mainly due to shrinkage. Etching and cleaning of surface significantly reduced the cloth thickness which leads to loss in GSM after plasma treatment. In fact the fabric became soft, pliable and resilient, which further improved on multiple washes. The tensile strength and elongation of polyester fabric enhanced after plasma treatment but on washing there did decline may be due to more sterilization and dehairing. Plasma finish modifies the hydrophobicity of polyester into hydrophilicity, an important feature contributes to wear comfort. An increasing trend of wicking was observed upto 5th wash but a small fall was found after 10th wash, may be due to attainment of saturation by 5th

Table 3 : Wicking length of plasma treated polyester fabric

Polyester samples	Wicking length (cm)					
	1 minute		2 minute		5 minute	
	Warp	Weft	Warp	Weft	Warp	Weft
Untreated	00.00	00.00	00.00	00.00	00.00	00.00
Treated (hydrophilicity)	02.80**	03.50**	03.60**	04.70**	05.30**	06.10**
5th wash	04.70**	04.90**	06.50**	06.80**	08.50**	08.80**
10th wash	04.60**	04.60**	06.10**	05.80**	08.10**	07.90**

** indicates significance of value at 0.01

wash itself.

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