ECOFRIENDLY FUNCTIONAL FINISH FOR TEXTILE MATERIALS

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By
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CERTIFICATE

This is to certify that the thesis entitled "ECOFRIENDLY FUNCTIONAL FINISH FOR TEXTILE MATERIALS" submitted by Ms. ARCHANA BAHUGUNA, for the degree of MASTER OF HOME SCIENCE in TEXTILE AND APPAREL DESIGNING to the University of Agricultural Sciences, Dharwad is a record of bona fide research work carried out by her during the period of her study in this university, under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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In every one’s life, the day arises when one has to shape the feelings in words. Sometimes, the words become unable to express the feelings of the mind, because, the feelings of the heart are beyond the reach of the words.

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LIST OF ABBREVIATIONS

Abbreviations		Description
CL	:	Cross linking
cm	:	Centimeter
COT	:	Cotton
FR	:	Flame retardant
gpl	:	Gram per liter
GSM	:	Gram per square meter
HMDSO	:	Hexamethyldisiloxane
kg	:	Kilogram
kgf	:	Kilogram force
kW	:	Kilo Watt
min	:	Minute
mm	:	Millimeter
Pa	:	Pascal
PET	:	Polyethylene terephthalate
RF	:	Radio frequency
sec	:	Second
SEM	:	Scanning electron microscope
W	:	Watt
µm	:	Micro meter

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1. INTRODUCTION

Textile materials have tremendous application as clothing, furnishings as well as household goods; therefore play an irreplaceable role in day to day life of every individual. In textile manufacturing process, finishing is the final step or the last chance to provide the properties that customers will value. It is also called the beautification process of fabric. Finishing completes the fabric's performance and gives it special functional properties including the final 'touch'. However, this is the right time for textile industries to focus on environmentally safer methods of processing and finishing fabrics. In fact technologists are innovating novel techniques to cater diverse applications by modifying fibre morphology. The surface modification is under exploration in order to afford desirable textile performances without deteriorating the fundamental properties.

Every textile material has its own distinctive and appreciable textile properties which can be further enhanced by advanced finishing techniques. Among all natural fibres, cotton is the purest source of cellulose noted for its versatility, appearance, performance and natural comfort. Cellulose has highest molecular weight and structural order, hence is highly crystalline, oriented and fibrillar compared to other plant fibres thus, viewed as a premier fibre and biomass (Hsieh and Gordon, 2007).

Cotton fibre is unicellular, hollow with lumen at the centre that traps air to provide warmth. It is flat, twisted ribbon which facilitates yarn spinning. Multiple walls of spiral fibrils give convolutions to the fibre and those convolutions scatter incident light making the fibre appear dull. Chemically, cellulose is a homopolysaccharide of D-glucoses linked by β-1,4 glycosidic bond. On one hand, a large cluster of polar hydroxyl groups present in glucose units offer hydrophilicity to the fibre; whereas on the other hand the hydroxyl groups form an extensive intermolecular and intramolecular hydrogen bonding, giving strength to the fibre. The well defined intermolecular hydrogen bonds between the linear and unbranched cellulose polymer chains allow regular molecular packing in close proximity.

The hydroxyl groups render surface reactivity during wet treatments thus exhibit excellent wettability and wickability. However, high moisture content of this natural fibre possesses low resistance to staining and microorganism attacks. Thus, several finishing are aimed to control these undesirable properties as well as to improve fibre durability. Moreover, the medical textiles demand cotton to be antimicrobial and haemorepellant, which is possible only by converting the hydrophilicity of cotton into hydrophobicity by surface modifications.

In contrast to cotton, polyester is the hydrophobic synthetic fibre (65-85 per cent crystalline and correspondingly 35-15 per cent amorphous) derived from petroleum via condensation reaction of diols and dicarboxylic acids. Polyester is chemically composed of at least 85 per cent by weight of an ester of a substituted aromatic carboxylic. Two varieties of polyester filaments, namely polyethylene terephthalate (PET) and poly-1,4-cyclohexylene dimethylene terephthalate (PCDT) are commercially manufactured in textile sector.

The filament is composed of axially-oriented linear polymer molecules and this regularity furnishes hydrophobicity among polyester filaments. Polyester exhibit high mechanical strength, dimension stability and elastic recovery but lack in surface reactivity. Hydrophobicity without surface reactivity leads to accumulation of electrostatic charge and poor fabric comfort which is an undesirable property but can be overcome by making them hydrophilic or by altering the topography of the surface.

Moreover, flame retardancy is another important aspect on advancement of textile finishing which aim to stop or slow down the spread of flame. Textile materials have traditionally been known to be the major cause of spreading of fire because of their inflammability as well as ubiquitous presence in our daily lives, in the form of clothing, bed linen and furnishing materials (Siriviriyanun *et al*., 2008). Among all textile fibres, cotton, polyester and their blends are majorly used by consumers especially in children garments, kitchen wears and industries due to their respective characteristics *viz.*, comfort and strength but both of them has higher combustibility. Coating of cotton and polyester with non flammable chemicals is an easy and effective approach to reduce inflammability mainly in children's wear. Therefore, chemical treatment is necessary to prevent ignition of fire by small flames, which often cause degradation of fabrics at lower temperatures through the process of dehydration (Siriviriyanun *et al*., 2008; Wakelyn *et al*., 2004).

It is evident that during various wet processings of fabric *viz.*, scouring, desizing, bleaching, dyeing/printing, and finishing, enormous amounts of water is being used and is later the cause for water pollution. And these processes do consume large amount of energy which is also less cost effective. As a result, the industries have to look for 'environmentally safe' or 'green processes'. Recently, due to increased environmental awareness and stringent effluent norms, textile industries are gradually moving towards implementation of environment friendly *i.e.* low-water technologies such as digital printing, spray and foam finishing.

Plasma is a dry processing technique and is a means to reduce the use of chemicals, water and energy. Modification of textile physics by plasma treatment represents great opportunity for improvement on conventional, energy demanding and less eco-friendly technologies. Therefore, application of "plasma technology" in chemical processing of textiles is one of the revolutionary ways to boost the textile wet processing right from pre-treatments to finishing (Joshi *et al.,* 2015).

"Plasma" is a Greek word which means "something molded or fabricated". Plasma is a partially-ionized gas composed of many types of species such as positive and negative ions, electrons, neutrals, excited molecules, photons and UV light. Sir William Crooks suggested the concept of plasma as the 'fourth state of matter' in 1879. American chemist Irving Langmuir first used the term 'plasma' in 1926. Today, plasma is used for varieties of industrial applications ranging from arc welding, metal hardening, metal coating, nuclear fusion, television, synthesis of nano-sized materials, creation of nano-structure, surface cleaning, functional polymeric coating, and change in surface of substrates. Hot plasma is applied in metal, electrical and material industry. However, such plasma is not suitable for processing of polymeric material as the temperature of plasma zone is extremely high.

In contrast, cold plasma, where temperature of the plasma zone is nearer to the room temperature, can be used for nano-scale surface engineering of polymeric and textile substrates *(www.daviddarling.info/ encyclopedia/P/plasma.html)*.

Plasma can be generated either under low pressure or at atmospheric pressure. Ionization of a gaseous molecule to produce plasma is carried out by applying sufficient discharge voltage and frequency. It is quite easy to ionize a gaseous molecule by electrical break-down under low pressure conditions and it has been extensively studied for material processing. On the other hand, low pressure plasma technology has not been commercialized in textile and allied industries due to its inherent limitations of batch process and high cost of operation, as the process has to be carried out under vacuum *(www.daviddarling.info/encyclopedia/P/plasma.html)*. Atmospheric pressure cold plasma on the other hand can overcome these limitations of low pressure plasma and widely used in the textile industry to modify the fabric surface in an environment friendly process that helps to reduce the use of chemicals and energy (Hwang and McCord, 2005; Wang and Qiu, 2007; Bourbigot and Duquesne, 2007).

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. The free radicals and electrons of plasma collide with the exposed material 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. By selecting the gas, vapour, or combination of gases, the desired surface chemistry can be obtained.

The general reactions to be achieved by plasma treatment are the oxidation of surface substrate, the generation of radicals, and the etching of the surface; when using special gases a plasma-induced deposition polymerization may occur. Moreover, both surface chemistry and surface topography may be influenced to result in improved adhesion or repellency properties as well as in the confinement of functional groups to the surface. Plasma treatment has to be controlled carefully to avoid its detrimental action onto the substrate.

The flexibility of plasma surface modification has opened up many possibilities for using it in textile processing as a stand-alone process or as a pre-treatment for improving the efficiency of the next process, also known as plasma-assisted processing (Bhat *et al.*, 2011).

Plasma processing can modify the surface of substrates without compromising the properties of bulk material. It is a liquid free process and requires fewer amounts of chemicals with low processing time, hence considered as ecological and economical process. However, it is not a single technology or considered as a “tool box” of technologies, which can add different value functionalities to a wide range of textile materials *viz.*, stain and oil repellent, hydrophilicity, flame retardancy, antimicrobial property, U.V protection, crease resistance and so on (Kakad *et al.,* 2006).

Among all textile materials cotton, polyester and their blends are consumed by huge number of consumers either in the form of fabric or ready-mades. Keeping in view the importance of plasma finishing, the present study on ‘Ecofriendly functional finish for textile materials’ is taken up with following objectives:

- To explore the possibility of treating cotton and polyester fabrics with plasma finish
- To study the surface morphology of plasma treated cotton and polyester fabrics
- To assess the impact of plasma finish on quality characteristics of cotton and polyester fabrics

2. REVIEW OF LITERATURE

This chapter presents the relevant researches pertaining to the present study on 'Ecofriendly functional finish for textile materials' and the review is presented under the following headings:

2.1 Plasma treatment for textile materials

2.2 Surface morphology of plasma treated cotton and polyester fabrics

2.3 Impact of plasma finish on quality characteristics of cotton and polyester fabrics

2.1 Plasma treatment

Textile materials have intrinsic properties that make the fabric very valuable: flexible, light weight, strong, large surface to volume ratio, good hand and feel and so on. Thus the fabrics are used to impart additional functionalities such as hydrophobicity, hydrophilicity, soil-resistance, flame retardancy, anti-microbial properties and similar characteristics. Traditional wet processing methods apart from utilizing large amounts of chemicals, water and energy were also labour intensive. However, plasma is a dry processing technique that could check on the use of all four entities. Several studies related to plasma treatment are conducted and presented here under:

Hartwig (2002) carried out a study on "Plasma treatment of textile fibres". Textile fibres are subjected to plasma treatment in order to impart desizing, functional properties, and design the morphology. Plasma technology is aimed to modify not only the chemical structure of the surface but also the topography of the surface. It was revealed that the treatment of cotton with a hexamethyldisiloxane (HMDSO) plasma leads to a smooth surface with increased contact angle of water up to a maximum of 130°. Thus, a strong effect of hydrophobization can be achieved. Moreover, when the surface of synthetic fibres gets oxidized, the hydrophobic character can be changed to become increasingly hydrophilic.

Kakad *et al.* (2006) reviewed on "Plasma treatment for textiles" and revealed that plasma has a specific action on the surface and modify surface properties which could not be achieved by conventional techniques. Plasma, as a very reactive material, can be used to modify the surface of a substrate (known as 'plasma activation' or 'plasma modification'); depositing chemical materials to impart desired properties and removing substances (plasma cleaning or plasma etching), which are previously deposited on the substrate.

Rani and Arora (2007) stated that plasma is an environmental friendly and safe method to modify the morphology of any natural or synthetic material by etching, while reviewing on "Plasma technology – an eco-friendly approach". It was concluded that the designer can choose and apply the plasma treatment that gives optimum result without affecting the inherent properties; as well cost effective.

Sparavigna (2008) conducted a study on “Plasma treatment-advantages for textiles”. It was reported that the plasma treatment shows distinct advantages, because of its ability to modify the surface properties of inert materials. Cold plasma treatments for fabrics require the development of reliable and large systems. It is possible to obtain three surface effects depending upon the treatment conditions *viz.*, the cleaning effect, the increase of micro roughness (anti-pilling finishing of wool) and the production of radicals to obtain hydrophilic surfaces. Meanwhile, continuous research is in progress on ‘plasma polymerization’ where the solid polymeric materials shall be deposited on the textile substrate to obtain desirable properties. However, the modification is restricted only to the uppermost layer of the substrate and not affecting the bulk properties.

Chinta *et al.* (2012) reported on “Plasma technology and its application in textile wet processing”. It was revealed that Plasma treatments are gaining popularity in the textile industry due to numerous advantages over conventional wet processing techniques. This plasma treatment does not alter the bulk property. Plasma surface treatments depict distinct advantages, as the surface properties of inert materials are altered, sometimes with environment friendly devices. Application of “Plasma Technology” in chemical processing of textiles to enhance the textile wet processing right from pre-treatments to finishing is an historical achievement. Pre-treatments and finishing of cotton with plasma technology was the focus of this review.

Shah and Shah (2013) explained on “Innovative plasma technology in textile processing: A step towards Green environment”. The fourth state of matter, first proposed by Irving Langmuir in 1926, is now successfully explored in various industries. This fourth state of matter none other than ‘plasma’ has several advantages over second and third states of matter in textile processing. Plasma treatment is one of the versatile ways to enhance both surface and bulk properties of textile materials. Hence, this treatment could be applied to various areas of textile processing *viz.*, pre-treatment, coloration and finishing. Plasma technology can be used to remove the sizing material from cotton fibres, to impart anti-felting property to wool, to enhance dyeability of natural as well as synthetic fibres. It also imparts special properties among textile fabrics. Thus, despite being costly technology initially, it offers greater production rate, less production cost, better products and most importantly, finishes on fabrics that are either difficult to obtain by other technologies or not obtained at all. And above all, plasma technology gives the freedom from environmental problems that traditional technologies pose.

A study on “Sterilization of cotton fabrics using plasma treatment” was carried out by Shahidi and Ghoranneviss (2013) with the objective to observe the impact of plasma treatment on morphology and mechanical properties of sterilized cotton fabric. It was found that plasma treatment with oxygen could completely sterilize the sample without adversely affecting the tensile strength and morphology. However, ‘time of exposure’ was the influencing factor. The authors finally concluded that ‘oxygen plasma treatment’ is an effective treatment hence could be adopted to sterilize the cotton fabrics.

“Application of plasma finishing on cotton fabric” was the study conducted by Joshi *et al.* (2015) to assess the impact of argon and oxygen gases on cotton. The methodology focused on treating cotton with argon for 30 minutes and oxygen for 60 minutes, separately and assessed the performance properties.

The results revealed that the oxygen treated sample exhibited better resistance to crease, stiffness, water spreading or capillary rise than to that of argon treated sample. However, it was concluded that plasma treatment brings several alterations on surface properties which in turn alter some of the physical characteristics of the fabric.

2.2 Surface morphology of plasma treated cotton and polyester fabrics

Depletion of non-renewable resources is leading to a resurgence of interest in plant-derived materials in various segments of the textile industry. Cellulosic fibre possesses attractive inherent bulk properties, but surface modifications are used for diversifying its end uses (Allan *et al*., 2002; Baltazar *et al*., 2007; Canal *et al*., 2009; Karahan and Ozdogan, 2008; Termerman and Leys, 2005; Tsafack and Levalois- Grutzmacher, 2007). Plasma an eco-friendly surface modification technique, serves as an alternative to conventional wet processing of textiles.

Matthews *et al*. (2004) worked on "Investigation into etching mechanism of polyethylene terephthalate (PET) films treated in helium and oxygenated-helium atmospheric plasmas". Researcher makes an investigation on the etching mechanism of atmospheric plasma conditions on the surface of polyethylene terephthalate (PET) films. Two types of untreated PET films (S/200 and S/500) were exposed to plasma for 0 to 5.0 min. The first set of each film type was treated in helium plasma, while the second was treated in oxygenated-helium plasma. Differential Scanning Calorimetry (DSC) was used to characterize pre and post exposure films, finally weight change and the degree of solubility were also determined. Based on peak area results, the percent crystallinity of PET S/200 increased by an average of 4.57 % (helium treated) and 13.56 % (oxygenated-helium treated), while the S/500 showed only a small increase. There was no significant change in the melting or crystallization temperatures of either film types, indicating a decrease in amorphous content versus an increase in crystalline material. The weight loss analysis supported this theory. The solubility testing revealed a continual decrease in swelling with increase in exposure time. A model was developed to predict the change in the degree of solubility for polyphase surfaces considering the etching rate per phase. The model was applied to PET and obtained good correlation between the model and experimental data.

Vesel *et al.* (2008) carried out a research on "Surface modification of polyester by oxygen and nitrogen plasma treatment". The samples were treated with nitrogen and oxygen plasma for different time periods between 3 and 90s using a radio frequency (RF) generator. The gas pressure was fixed at 75 Pa and the discharge power was set to 200 W. The samples were treated in the glow region, where the electrons temperature was about 4eV, the positive ions density was about $2 \times 10^{15}\ m^{-3}$ and the neutral atom density was about $4 \times 10^{21}\ m^{-3}$ for oxygen and $1 \times 10^{21}\ m^{-3}$ for nitrogen. The change in surface morphology was observed by using Atomic Force Microscopy (AFM), surface wettability by contact angle measurement, and the chemical composition of the surface by X-ray Photoelectron Spectroscopy (XPS). The stability of functional groups on the polymer surface treated with plasma was monitored by XPS and wettability measurements at different time intervals.

It was revealed that the oxygen-plasma-treated samples showed much pronounced changes in the surface topography compared to those treated by nitrogen plasma. The contact angle of a water drop decreased from 75° for the untreated sample to 20° for oxygen and 25° for nitrogen-plasma-treated samples for 3 sec. It kept decreasing with increase in treatment time for both plasmas and reached about 10° for nitrogen plasma after 1 min of plasma treatment. For oxygen plasma, however, the contact angle kept decreasing even after a minute of plasma treatment and eventually fell below a few degrees. Researcher found that the water contact angle increased linearly with the O/C ratio or N/C ratio in case of oxygen or nitrogen plasma, respectively. Ageing effects of the plasma-treated surface were more pronounced in the first 3 days; however, the surface hydrophilicity was rather stable later.

Takke *et al.* (2009) reported on “Studies on the atmospheric air–plasma treatment of PET (polyethylene terephtalate) woven fabrics: Effect of process parameters and of aging”. The effects of process parameters and of aging on the atmospheric air–plasma treatment of polyethylene terephtalate (PET) woven fabric were studied using surface analysis methods: wettability/capillarity method as well as tapping mode atomic force microscopy imaging. Treatment time and plasma power have significant effect on the variation in fabric capillary weight, surface water contact angle and surface topography. Plasma treatment of PET surface with plasma species not only alters the surface but also causes surface restructuring as the speed is lowered and the power is increased. An optimal treatment of the PET fabric samples, in terms of increased hydrophilicity both inside and on the PET fabric, is achieved at 60 KJ/m^2 and at a lower speed of 1–2 m/min: water contact angle decreasing from 81° to 40° and capillary weight increasing from 55 to 380 mg. Aging experiments showed that, the plasma-treated surface is degraded to a more disordered structure without light, whereas in presence of light a more eroded but organized structure is observed. Indeed wettability/capillarity test showed that light degrades the plasma treatment both on and inside the fabric structure. However, in absence of light, although aging is very slow at the fabric surface, a decrease in capillary uptake by the fabric is detected.

Kale and Desai (2010) in a study on “Atmospheric pressure plasma treatment of textiles using non-polymerising gases” and stated that the atmospheric pressure plasma treatment does modify the textile surface in variety of ways that could impart desired functional properties among the textile substrates. Treatment of textiles with plasma generated from non-polymerising gases does enhance the wettability, adhesion promotion and surface energy improvement; further brings about chemical, physical and morphological changes in the substrate; as well it offers unique advantage of being dry and environment-friendly process. Further the authors reported that different gases used in the plasma induce different kinds of morphological and chemical changes on the surface of PET fabric. Therefore, gas for plasma modification needs to be meticulously selected to get desired functional groups on the surface of textile substrate.

“Surface modification of cotton fabrics using plasma technology” was the study conducted by Bhat *et al.* (2011) and highlighted the impact of plasma finish on fibre morphology due to electron and ion bombardment on fibre surface that give rise to etching phenomenon which leads to weakening of the protruding fibres and cause loss in fabric weight.

Whereas, the amount of additional material deposited, gradually increases the weight of fabric with increase in the treatment time. Air and dichlorodifluoromethane (DCFM) were the two sources of gas selected in the investigation and aimed to measure the contact angle, wicking length and dyeability of the substrate after plasma treatment. It was observed that on one hand air plasma treatment enhanced the wickability of the test sample by addition of polar groups and on the other hand DCFM modified the test sample to be highly water repellent and hydrophobic which is evidenced by obtuse contact angle. As far as dyeability was considered the plasma treated substrate exhibited an improvement in dyeability when dyed with reactive and natural dyes; but the behavior was found to be reverse when dyed with direct dye.

The plasma treatment leads to surface oxidation, polymer chain-scissions and filament nano-roughness of polyester fabric. It was also observed that there was change in warp amplitude and inter-yarn spaces that in turn would facilitate water spreading and its absorption rate. These results are the outcome of the study on "Topographical effects of O_2- and NH_3-plasma treatment on woven plain polyester fabric in adjusting hydrophilicity" conducted by Calvimontes *et al.* (2011). Finally the authors concluded that the hydrophobicity of polyester fabric could be changed into hydrophilicity by treating with O_2- and NH_3-plasma.

Ibrahim (2012) reviewed on "Clean trends in textile wet processing" and quoted that, three main effects on textile surface could be obtained depending on the treatment conditions: the cleaning effect, the increase of micro roughness and the production of radicals to obtain hydrophilic surface. Plasma polymerization, *i.e.* the deposition of solid polymeric materials with desired properties on textile substrates is however, under development. The advantage of such plasma treatment is that the modification turns out to be restricted in the uppermost layers of the substrate, thus not affecting the overall desirable bulk properties. Both the surface chemistry and the surface topography may be influenced to result in improved adhesion or repellency properties as well as in the confinement of functional groups to the surface.

Jelena *et al.* (2012) conducted a research study on "Water-vapour plasma treatment of cotton and polyester fibres" by subjecting the test samples to low-pressure water-vapour plasma. The main aim of the research was to investigate the impact of single plasma treatment on the surface of two textile fibres which are chemically and morphologically different. The surface properties of cotton and polyester fibres were evaluated before and after plasma treatment using the X-ray Photoelectron Spectroscopy (XPS), Atomic Force Microscopy (AFM) and Scanning Electron Microscopy (SEM) analyses. The plasma treatment of the textiles was analyzed using an Optical Emission Spectroscopy (OES). The results showed that the etching rate increased with the treatment time for both types of polymers due to gradual elevation in the temperatures. The etching effect of low-pressure water vapour plasma was more pronounced for the hydrophilic cotton fibres than for hydrophobic polyester fibres. The cleaning effect on the surface of cotton fabric was evident, resulting in the removal of surface impurities.

Twardowski *et al.* (2012) conducted a study on "Plasma treatment of thermoactive membrane textiles for super hydrophobicity".

The objective of the study was to improve visual properties of thermoactive textile membranes with a modification to achieve self-clean super hydrophobic surface. In order to implement this idea, a glow discharge Radio Frequency (RF) capacitively coupled plasma processing of industry materials with inert as well as polymerizing gases was performed; and surface analyses was performed by Scanning Electron Microscopy (SEM). Researcher found that a thin layer deposited with characteristic globular structure on the fibre surface treated by hexamethyldisiloxane (HMDSO) which significantly increased the contact angle to superhydrophobic level.

Kan *et al.* (2012) investigated on “Microscopic study of cotton fibre subjected to different functional treatments” with an objective to evaluate the change in surface morphology of cotton using Scanning Electron Microscopy (SEM) by subjecting to different functional treatments. The surface morphology analysis showed some integrity of cotton fibres with normal spiral structure, at control. Nevertheless, the surface roughness of plasma pre-treated fabric samples, with or without post-functional treatment, was higher than that of untreated fabric. This may probably due to plasma etching effect and the attack of acidic chemicals. Further, it learned from SEM images that the surface of cotton fibre changes differently when treated with different functional finishes.

Assessment of low pressure oxygen plasma on polypyrrole adhesion was the main objective of the study conducted by Mehmood *et al.* (2013) and found that this treatment improved adhesion between PPy and PET. It was revealed that plasma reactions change the surface chemistry by decomposition of polymer chains and by oxidation adds C-O and O-C=O groups. This probably results into an increase in surface energy and roughness. Nevertheless, the increase in treatment time did increase the level of hydrophobicity; but increase in oxidation time up to a saturation point of 500 seconds did not show proportionate increase in surface roughness except a linear relationship with treatment time. Improved PPy bonding is more dependent on surface chemistry than surface morphology. This research on “Study of oxygen plasma pre-treatment of polyester fabric for improved polypyrrole adhesion” provided valuable information for better understanding and predicting the effect of oxygen plasma treatment on physical and chemical properties of polyester fabric and thin films.

Marija *et al.* (2013) carried out a research on “Tailoring surface morphology of cotton fibres using mild tetrafluoromethane (TFM) plasma treatment”. The bleached and mercerized cotton fabric samples of 20 × 20 cm were mounted onto a cylindrical plasma reactor and treated for a period of 10s, 20s and 30s. The type of radicals created in plasma was determined using Optical Emission Spectroscopy (OES) and found CO-bonds as spectral feature. The evolution of surface morphology V/s plasma treatment time was monitored by Scanning Electron Microscopy. Results revealed that even a short treatment of about 10s allowed for a clear visible roughening of fibres, and consequently increased breaking strength due to increased friction properties of etched fibres.

2.3 Impact of plasma finish on quality characteristics of cotton and polyester fabrics

The characteristic of any fabric is determined by the fibre composition, yarn, fabric construction and any chemical or mechanical treatment applied to the yarn or fabric.

These need to be assessed within the context of the requirements of the specific end-use for which the fabric is destined within the broad categories of clothing (apparel) textiles, home textiles and technical textiles. Generally the fabric aesthetics or appearances dominate apparel characteristics whereas the technical or performance properties predominates the industrial textiles.

Oktem *et al.* (2000) studied on "Modification of polyester and polyamide fabrics by different in-situ plasma polymerization methods". The aim of the study was to increase the hydrophilicities, to impart soil resistance and to improve dyeability on polyethylene terephthalate (PET) and polyamide (PAm) fabrics by low-temperature plasmas. Five different modification types were applied and the fabrics were directly treated in acrylic acid, water, air, O_2 and Argon plasma. The plasma conditions (*i.e.*, exposure time and discharge power) were changed to control the extent of plasma surface modification. The results revealed that wettability, soil resistance and dyeability of PET fabrics were significantly improved, irrespective of the methods. The researcher inferred that the improved wettability has been attributed to greater number of polar groups, surface oxidation and increased surface roughness. Further, the results of study confirmed that there was increase in surface wettability of PET and PAm fabrics, due to formation of several hydrophilic (polar) groups *i.e.* – NH, – CN, – N:N, – C=O,– COOH, – CHO on fabric surface either during plasma or through post-plasma reactions.

Wong *et al.* (2001) carried out a study on "Wicking properties of linen treated with low temperature plasma" with an objective to find the wetting and wicking behavior of linen treated with low-temperature oxygen and argon plasma. Wetting and wicking abilities of plasma treated linen were investigated using contact angles and upward and downward water wicking methods. It was concluded that the downward wicking method is more suitable for distinguishing the effects of plasma treatment under various conditions.

Allan *et al.* (2002) carried out a research on "The use of plasma and neural modelling to optimize the application of a repellent coating to disposable surgical garments". The advantages of using excited gases include low process cost and duration, and the avoidance of effluents such as solvents or chlorine. Low-pressure plasma treatment with hexafluoroethane (HFE) did create a hydrophobic surface on cotton, which would normally be hydrophilic. Cotton is a popular material for surgical garments and drapes because of its comfort and low cost. The acquisition of hydrophobic behavior will provide haemo-repellancy and the prevention of bacterial attack. In this study a series of experiments were designed by varying 3 parameters *viz.,* gas concentration, power and duration. The degree of hydrophobic behavior on the cotton surface was recorded by observing water droplets. Neural networks can provide rapid development of simulation models of processes by adaptation; where observed conditions considered as inputs and the results as outputs. The model itself is optimized for interpolative ability, and allows a search to be made through the data space to find the best possible combination of the process parameters to encourage optimal surface treatment, and thus make the cotton most hydrophobic. Although plasma processes involve complex chemical and physical reactions, it was found that the fluorination of cotton fabric could be controlled and optimised using commercial plasma equipment and adaptive modelling.

The use of neural networks can provide models to accelerate progress toward optimal solutions and minimise the volume of experiments without reliance on simplifying assumptions and mathematical analysis of such complex systems. This work has shown that a low-cost, environmentally-friendly process is available to allow the comfort of a natural material to be utilised by nurses and theatre staff whose safety depends on the hydrophobic nature of their clothing.

Zhang *et al*. (2003) conducted a study on “Hydrophobic cotton fabric coated by a thin nanoparticulate plasma film”. The audio frequency (AC) plasma of fluorocarbon chemical was applied to deposit a nanoparticulate hydrophobic film onto a cotton fabric surface. The measurement of the video contact angle showed that the super hydrophobicity of the cotton fabric was obtained at 30 seconds. The softness, water retention, moisture regain, color retention, abrasion, friction, and permeability were thoroughly investigated by a standard method that compared the fabric with a commercial Scotchgard-protector-sprayed cotton fabric. The results showed that the performance of the plasma-coated fabric was superior to those of Scotchgard-sprayed samples, except for the moisture regain, which was almost the same. A post-treatment at high temperature was conducive to increasing the hydrophobicity but on washing the plasma treated fabric recovered its inherent property of water repellency. Atomic Force Microscopy images and time-of-flight secondary-ion mass spectra of plasma thin films on silicon wafers indicated that some physical and chemical changes did take place during the post-treatment process.

Kaplan (2004) conducted a study on “Plasma processes for wide fabric, film and non-wovens” and revealed that oxygen is the warehouse for cleaning as it removes all the contamination present in the fabric. The complete sterilization of the fabric surface helps to avoid numerous interference of bonding of finishing agents to the fibre surface.

“Contact angle determination on plasma-treated poly (ethyleneterephthalate) fabrics and foils” was the study carried out by Hossain *et al.* (2006). The surfaces of polyester (PET) fabrics and foils were modified by low-pressure Radio Frequency (RF) plasmas with air, CO_2, water vapor as well as Ar/O_2 and He/O_2 mixtures. To increase the wettability of the fabrics, the plasma processing parameters were optimized by means of a suction test with water. It was found that low pressure (10–16 Pa) and medium power (10–16 W) could yield good penetration of plasma species in the textile structure for all oxygen-containing gases and gaseous mixtures used. While the wettability of the PET fabric was increased in all cases; the Ar/O_2 plasma revealed the best hydrophilization effect with respect to water suction and aging. The hydrophilization of PET fabrics was closely related to the surface oxidation and was characterized by X-ray Photoelectron Spectroscopy (XPS) analysis. Static and advancing contact angles were determined from the capillary rise with water. Both wetting and aging demonstrated a good comparability between plasma-treated PET fabrics and foils, thus indicating a uniform treatment.

Jahagirdar and Tiwari (2006) investigated on “Plasma treatment of polyester fabric to impart the water repellency property” and concluded that polyester fabric could be modified suitably by treating with dichlorodimethylsilane (DCDMS) solution so as to make it water repellant without loosing its original strength.

The modified polyester fabrics did attain good level of water repellency even after ten wash cycles. The plasma finished fabric post treated with DCDMS modified the fabric surface leading to deposition of more and more silane groups making it water repellant as compared to those treated directly with DCDMS.

Supasai *et al.* (2007) reported that there was improvement on hydrophobicity of fabrics when treated with inductively coupled SF_6 by Radio-Frequency (RF) plasma. The selected test samples *viz.,* polyethylene terephthalate (PET), silk, cotton and cotton-silk mixed woven fabrics were treated under different operating conditions; where plasma was generated in the pressure range of 0.005-1 Torr and RF power range of 25-75 Watts. The treated samples were analyzed by Scanning Electron Microscopy, contact angle and absorption time (seconds) to evaluate the storage time (incubation time or shelf life or durability) . The atomic species in SF_6 plasma were analyzed by Optical Emission Spectroscopy (OES), while the chemical compositions on fabric surface were also investigated by X-ray Photoelectron Spectroscopy (XPS). The “Effect of SF_6 plasma treatment on hydrophobicity improvement of fabrics” revealed that evidence of spectrum lines of F 1 in SF6 plasma and peaks of F 1 on sample surface which is nothing but surface etching and deposition of C-F residue, respectively; that collectively enhanced hydrophobicity.

“Effect of atmospheric pressure plasma treatments on certain properties of cotton fabrics” was the study carried out by Karahan *et al.* (2009) where air and argon atmospheric plasma were used to modify the physical properties like pilling, thermal resistance, thermal conductivity, water vapour permeability, air permeability and surface morphology of bleached plain woven cotton fabric. Etching action of atmospheric plasma treatment weakens the structure of the protruding fibres of the yarn and hence makes it fragile. This alteration in the yarns leads to reduction in abrasion resistance. Tensile strength was decreased when the cotton fabric treated with argon. However, there was improvement in the water vapour permeability of cotton fabric after plasma treatment; since, the surface properties and porous structure of the material are of importance in terms of liquid transfer properties. The atmospheric pressure plasma treated fabric showed poorer air permeability since the etched fibres acted as a boundary to hinder the air flow through the fabric. This caused reduction of air permeability among the treated fabrics *i.e.* air held within the plasma treated fabric could not escape easily. Moreover, there was occurrence of micro cracks and grooves formed due to etching during plasma treatment, and were clearly visible. The argon plasma treated cotton fibre has more grooves than air plasma treated due to higher percentage of etching tendency. In a nutshell, the research outcome revealed that there was remarkable improvement in the pilling resistance, thermal resistance, water vapour permeability, and surface friction coefficient after plasma treatment. However, there was decline in the values of thermal conductivity and air permeability. The SEM images clearly showed that the atmospheric plasma modified the fibre surface outwardly.

Bhat *et al.* (2010) investigated on “Effect of atmospheric pressure air plasma treatment on desizing and wettability of cotton fabrics”. Atmospheric pressure air plasma is used to treat grey cotton fabrics and the effect of treatment on desizing and wettability properties were studied using the dielectric barrier discharge plasma with air and helium gas mixture.

The weight loss due to etching was determined by gravimetric method, the surface structure observed by SEM and the wettability studied by wicking action and contact angle. It is found that the plasma alters the surface morphology, results into desizing and enhances the wettability by wicking action due to micro roughness and introduction of polar groups. The plasma pre-treated fabric showed higher rate of desizing and the process was found to be time, energy and water effective. The plasma process being dry, ecofriendly has instant on/off operations, hence can be easily amalgamated with the present industrial set-up.

Kamlangkla *et al.* (2010) carried out a study on “Mechanical strength and hydrophobicity of cotton fabric after SF_6 plasma Treatment”. The etching effect is strongly related to changes in physical properties such as weight loss and tensile strength. The tensile strength of the fabric decreases with increase in treatment time and SF_6 pressure due to etching process. The exposure time plays an important role in change of mechanical properties of fabric with the SF_6 pressure having secondary effects. In conclusion there was no dramatical change in surface morphology through SEM images, but the change was measured by the yard stick of weight loss which was less than 1 %. A two-stage weight loss was observed which was attributed to desorption and fragmentation of surface molecules. Overall good and durable hydrophobic properties on cotton could be achieved by increasing the treatments time, however the mechanical strength of the fabric was compromised to a significant extent. Researcher found that the optimal plasma condition to enhance hydrophobicity without losing tensile strength and weight of fabric was with the pressure range of 0.005–0.3 Torr. However, reducing the treatment time less than 1 min, would lead to low hydrophobic durability in terms of aging and washing cycles. The main reaction for enhancement of hydrophobicity measured by means of contact angle and water absorption time is supported with surface fluorination of the fabric confirmed by X-ray photoelectron analysis.

Lam *et al.* (2010) conducted a study on “Effect of zinc oxide on flame retardant finishing of plasma pre-treated cotton fabric”. An organic phosphorus compound (flame retardant agent, FR), melamine resin (crosslinking agent, CL), phosphoric acid (catalyst, PA) in the presence of ZnO/nano-ZnO co-catalyst was applied to impart flame-retardant properties to plasma pretreated cotton fabrics. It was found that a combined application of plasma pre-treatment and ZnO/nano-ZnO co-catalyst added in the flame-retardant finishing improved the crosslinking process between FR and cotton fabric which, minimized the drawbacks of using acidic flame-retardant chemicals. Both plasma etching effect and effect of acidic FR roughened and wrinkled fabric surface, which is illustrated by the surface morphology of plasma pre-treated cotton specimens subjected to flame-retardant treatment. The FTIR-ATR (Fourier transform infrared–attenuated total reflection) spectra for the plasma-treated cotton showed new peaks about the C=O vibration groups in the carbonyl structure; whereas O–H stretching vibration and COO- stretching vibrations improved the hydrophilicity of the fabric. In addition, the flame retardant fabrics showed some new characteristic peaks in chemical structure, interpreted as carbonyl bands, CH_2 rocking band and CH_3 asymmetric and CH_2 symmetric stretching. Combustibility of FR-CL-PA-ZnO and FR-CL-PA-Nano-ZnO treated fabrics is evaluated by 45^o flammability test. FR-CL-PA-treated specimen showed superior flame-retardancy, which is further improved by the plasma pre-treatment and ZnO/nano-ZnO co-catalyst.

The author concluded that compared to control samples, the flame-retardant-treated cotton specimen exhibited low breaking load and tearing strength and is attributed to the adverse effect of crosslinking agent used; while plasma pre-treatment and ZnO/nano-ZnO co-catalyst may affect the mechanical strength caused by flame-retardant agents.

"A novel approach for functionalization of polyester and cotton textiles with continuous online deposition of plasma polymers" was the study conducted by *et al.* (2011). The chemical and structural nature of hexamethyldisiloxane (HMDSO) plasma polymers deposited on the fabric surface with respect to discharge power. The functional water repellency property imparted to the polyester and cotton fabrics after plasma treatment was assessed by spray test. It was observed that water repellent properties improved after plasma treatment. Moreover, the tensile strength of cotton fabric remained unaffected by the given experimental conditions, whereas that of polyester fabric considerably deteriorated at higher discharge powers.

Kan *et al.* (2011) conducted a study on "Using plasma treatment for enhancing conventional flame-retardant finishing of cotton fabric" with objective to assess the flame retardancy as well retention of inherent properties. The chemical used were reactive organophosphorus chemicals, such as N-methylol dimethylphospho-nopropionamide (FR) used in combination with a melamine resin as crosslinking agent (CL) and phosphoric acid (PA) as the catalyst. After multiple washings, it was found that the catalyst (PA) helped in fixing FR on the surface of the substrate and was stable due to improvement in cross linking; the surface etching by plasma enhanced the bonding between fibre and flame retardant linkages. Flame retardant finish did adversely affect the strength of cotton fabric. In general, tensile strength of fabric highly depends on several factors such as fabric structure, yarn twist and yarn count. Moreover, the reduction of mechanical strength was mainly attributed to strong acidity of finishing bath and high curing temperature which tendered the fabric strength. However, the test sample pre-treated with plasma showed increase in strength. It was concluded that the loss in tensile strength due to flame retardant finish would be compensated by plasma treatment.

Raslan *et al.* (2011) investigated on "Ultraviolet protection, flame retardancy and antibacterial properties of treated polyester fabric using plasma-nano technology". The possibility of using dielectric barrier discharge (DBD) air plasma treatment for fibre surface activation to facilitate deposition of aluminum oxide (Al_2O_3), nano-silver (Ag) and nano-titanium dioxide (TiO_2) on polyester fabric was investigated. Results revealed that Air plasma- Al_2O_3 treatment improved the flame retardancy, Ultraviolet Protection Factor (UPF), the thermal stability and whiteness of polyester fabric; whereas air plasma nano-silver (Ag) positively influenced the antibacterial activity of the fibre, finally the air plasma-nano TiO_2 enhanced the fibre protection against ultraviolet rays.

Udrescu *et al.* (2011) conducted a research on "Water-repellent cotton fabrics by ultraviolet curing and plasma treatment". UV-curing or plasma polymerization of perfluoro-alkylpolyacrylates applied as water emulsion on cotton yielded water-repellent fabrics. The polymerization yields were of the same order as those resulted from thermal curing and high contact angles of water, even at lower add-on. Water repellency was adequately maintained even after repeated washings. The original breathability of cotton was unaffected by the finish applied may be by thermal or UV-curing or by plasma treatment.

Finally it was concluded that, UV-curing and plasma polymerization can be indicated as valid alternative environment friendly methods to confer water-resistant hydro repellency of cotton fabrics.

Tsoi *et al.* (2011) reported on “Using ageing effect for hydrophobic modification of cotton fabric with atmospheric pressure plasma” with an aim to demonstrate a hydrophobic modification of cotton fabric with atmospheric pressure plasma treatment using helium and oxygen as the reactive gas. It was found that helium-oxygen plasma was capable of inducing hydrophobicity to cotton fabric by utilizing the ageing effect. Ageing reversed the surface polarity resulting into formation of hydrophobic aliphatic hydrocarbons; and was confirmed by Fourier Transform Infrared Spectroscopy. The surface hydrophobicity was quantified by measurement of wetting area. Wetted area of plasma-modified cotton was found to be strongly dependent on plasma-induced surface structures and the chemical composition on the fibre surface. The images of Scanning Electron Microscopy revealed that physical morphological alteration due to physical ablation was a crucial factor that contributed to surface hydrophobicity. This work seeks to determine a controlled hydrophobic modification of textile materials through optimization of plasma process based on the Orthogonal Array Testing Strategy (OATS). The optimum process conditions were determined based on the reduction of wetted area of plasma-modified cotton fabrics. Finally, hydrophobicity of plasma-modified cotton fabric was compared with conventional water repellency treatment.

Lam *et al.* (2011) investigated on “Effect of oxygen plasma pretreatment and titanium dioxide overlay coating on flame retardant finished cotton fabrics”. Plasma pre-treatment, using an atmospheric pressure plasma jet (APPJ), was applied to cotton fabrics to enhance material properties, meanwhile retaining inherent advantages of the substrates. An organic phosphorus compound (flame-retardant agent, FR) together with a melamine resin (crosslinking agent, CL) and phosphoric acid (catalyst, PA) were the chemicals selected for the study. Titanium dioxide (TiO_2) or nano-TiO_2 was used as a co-catalyst for cotton fabrics to improve treatment effectiveness and minimize side effects. The surface morphology of plasma pre-treated cotton specimen subjected to flame-retardant treatment showed a rough, thick and wrinkled surface with high deposition of the finishing agent, caused by an etching effect of plasma and attack of acidic FR. Combustibility of FR-CL-PA-TiO_2 and FR-CL-PA-Nano-TiO_2 treated fabrics was evaluated by a 45° flammability test. FR-CL-PA-treated specimen showed superior flame-retardancy, which was further improved by plasma pre-treatment and addition of metal oxide as a co-catalyst. However, the flame retardant-treated cotton specimen had lower breaking load and tearing strength compared to control sample; and is attributed to side effects of the crosslinking agent used; while plasma pre-treated sample showed a reduction in tensile strength may be attributed to adverse effect of flame-retarding agents. Researcher concluded that both plasma pretreatment and metal oxide co-catalyst added in the flame-retardant finishing improved the crosslinking process between FR and cotton fabric, minimizing formation of free formaldehyde and allowing the use of FR in industry.

Kan and Lam (2013) conducted a research on “Low stress mechanical properties of plasma treated fabric subjected to zinc oxide – antimicrobial treatment”. Plasma technology was employed in the study which roughened the surface of the materials, improving the loading of zinc oxides on the surface.

The overall results showed that the plasma-treated specimen had better overall tensile properties after anti-microbial treatment due to enhancement of inter-yarn and inter-fibre friction caused by etching effect of plasma. In addition, pretreatment of cotton fabrics by plasma was employed to improve the loading of chemical reagents as well as to compensate for the loss of mechanical strength.

"Hydrophobic sol-gel finishing for textiles: Improvement by plasma pre-treatment" was the study carried out by Montarsolo *et al.* (2013). The surface of cotton (COT) and polyester (PET) fabrics was modified to create a water-repellent character by depositing a modified silica-based film using the sol-gel technique. TEOS (tetraethoxysilane) based physically modified sols with 2 and 11 % on weight fabric (o.w.f.) of hydrophobic additives were tested. N-propyltrimethoxysilane (C3), hexadecyltrimethoxysilane (C16) and 1H, 1H, 2H, 2H-fluorooctyltriethoxysilane (FOS) were investigated as additives. Furthermore, a low-temperature plasma pre-treatment was adopted to activate the COT and PET fabric surface to improve the sol-gel coating adhesion, resistance to abrasion and fastness to washing stresses. A complete chemical/morphological (Fourier Transform Infrared, X-ray photoelectron spectroscopy, Scanning Electron Microscopy) and physical characterization (abrasion and air permeability test) of treated samples was studied. It was inferred that high values of θ (around 140º) on PET and COT samples were obtained with all additives (C3, C16 and FOS) even at a low concentration (2 %).

Elsisy (2013) presented a study on "Implementation of gas plasma treatment on cotton fabric tailor ability". The primary objective of this research was to examine the effects of fabric finishes on fabric tailor ability in relation to low stress measurements (Fabric Assurance by Simple Testing, "FAST"). Gas plasma finishing was applied to cotton fabric with polymerizing gases *viz.*, air, argon, helium, and nitrogen. Properties of the gas plasma treated samples including low stress mechanical behavior, fabric tailor ability index (performance - % improvement – efficiency), and total fabric-skin comfort value, were evaluated. Fabric Assurance by Simple Testing, "FAST", was employed to evaluate the influence of dry treatment on tested fabrics. The change in the fabric tailor ability parameters of the gas plasma and/or mercerized, or mercerized- plasma treatments were in good agreement with the earlier findings and can be attributed to the amount of air trapped between the yarns and fibres. This study suggested that the gas plasma finishing and/or mercerized - gas plasma processes can influence the final fabric tailor ability properties of cotton fabrics, and further provided information for developing mercerized – gas plasma treated cotton fabric for very high quality fabrics.

Gorjanc *et al.* (2013) conducted a study on "Multifunctional Textiles – Modification by Plasma, Dyeing and Nanoparticles". Research showed that plasma treatment is an effective method to be used in achieving surface changes on the textile material by changing the functional groups and morphology of the fibres. The results of adsorption of different forms of silver nanoparticles on untreated and plasma-treated surfaces of fabrics confirmed the fact that, for nano technological processes, the surface of the material has to be properly prepared. The adsorption of metal nanoparticles on textile materials depends on specific chemical and morphological properties of fibres.

Plasma modification of cotton had a positive influence on the increased adsorption of silver nanoparticles loaded during exhaust dyeing process. It was possible to apply a greater quantity (up to four times) of silver onto plasma modified cotton, from the bath having low concentration of silver nanoparticles. In some cases the plasma treatment did improve the dyeability of cotton. Further it was also revealed that plasma modification did not impair the mechanical properties of textiles. It is possible to induce new and improved characteristics among the textile materials by plasma technology where nano structuring of natural and synthetic fibres is emphasized. The use of plasma treatment for modification of textiles brings many novelties to the textile industry, since plasma technology invariably substitutes or supports the existing technologies, in turn positively influences the economy and ecology of the industrial processes.

Shahidi and Ghoranneviss (2013) investigated on “Effect of plasma pretreatment followed by nanoclay loading on flame retardant properties of cotton fabric”. Researcher studied the effect of plasma treatment with nitrogen gas followed by nanoclay treatment on flame retardancy of cotton fabric. The results showed that Nanoclay is an effective flame retardant for cotton fabrics. The char yield of the sample was treated with nanoclay is 10.20 % and is 5 times more than untreated sample. It was concluded that, N_2 plasma treatment increases flame retardancy of cotton sample. It was observed that, Nitrogen plasma has synergistic effect on nanocaly for flame retardant properties. The char yield value for N_2 plasma/nanoclay treated cotton increase to 12 % after complete burning. The improvement of flame retardancy of the treated samples is attributed to the earlier decomposition of nanoclay to drive the char formation, which could inhibit the transmission of heat, energy and O_2 between flame and cotton fabrics.

Chinnammal and Arunkumar (2014) studied on “Effect of plasma treatment on plain woven cotton fabric” where the bleached and dyed fabrics were treated with oxygen and argon gases. The effect of plasma treatment on absorbency, fabric weight, tensile strength, elongation, thickness, stiffness, crease recovery, abrasion resistance and drape of the fabric were investigated and compared with grey fabric. It was concluded that the oxygen treated bleached cotton fabric exhibit better absorbency than argon treatment; post dyed samples showed less weight gain than pre dyed samples, oxygen treated sample gained less percentage of weight compared to argon treated samples. The treatment timing and stage of dyeing did not show significant effect on fabric weight; there was meagre increase in the cloth thickness among all samples irrespective of gases, treatment time and stage of dyeing. The pre dyed samples exhibited greater stiffness compared to post dyed samples, corresponding to their control samples. There was improvement in crease recovery of the test samples after plasma treatment. However, argon treated samples showed better recovery than oxygen treated. Meanwhile, plasma treatment improved drape quality of the fabric. Oxygen treated samples revealed better drape than argon treated samples, as well post dyed samples exhibited better drapability. Warp tensile strength reduced on plasma treatment and is noticeably when treated with argon. Post dyed samples exhibited relatively less strength loss compared to pre dyed sample. As far as weft tensile strength was considered maximum loss was observed among the samples treated with oxygen than argon treated samples. However, post dyed sample exhibited relatively low strength loss.

The oxygen treated samples exhibited better elongation than argon treated samples. Similarly post dyed sample had better elongation than pre dyed; the samples treated for 40 min exhibited loss in abrasion resistance compared to the samples treated for 20 min *i.e.* greater the treatment time, lesser the abrasion resistance. Plasma treatment with oxygen was found superior to argon gas as the earlier improved the absorbency, drape and air permeability. Nevertheless, as the treatment time increased there was improvement in most of the physical properties. However, the tensile strength decreased with increased exposure to the plasma gas; which indicated that tensile strength and exposure time are inversely proportional.

Kan (2014) carried out a research on "Plasma-assisted titanium dioxide wrinkle resistant treatment of cotton fabric". Researcher worked on optimization of plasma pretreatment for enhancing wrinkle resistant property of cotton fibre which was investigated with the OATS (Orthogonal Array Testing Strategy). The cotton fabric was subjected to the optimum conditions *i.e.*, treatment speed = 15 mm/s; oxygen flow rate = 0.3 ltr/min and jet distance = 5 mm. The order of importance was oxygen flow rate followed by jet distance and treatment speed. Researcher found that plasma pretreatment alone can improve the wrinkle-resistant property of cotton fabric by providing a new pathway for finishing agent to enter into etched fibre surface. Although single plasma pretreatment could improve the wrinkle resistant property when compared with conventional Dimethyloldihydroxyethyleneurea (DMDHEU) treatment; further the post-treatment with 0.2 % TiO_2 could further enhance wrinkle resistant property.

Lam *et al.* (2014) reported on "Objective measurement of hand properties of plasma pre-treated cotton fabrics subjected to flame-retardant finishing catalyzed by zinc oxide". The cotton fabrics were treated with N-methylol dimethylphosphono-propionamide (FR), melamine resin (CL), phosphoric acid catalyst (PA), and ZnO/nano-ZnO co-catalyst to impart flame resistance property. The test samples were exposed to atmospheric pressure plasma jet (APPJ) to enhance the properties by sputtering or etching effect. It was concluded that neutralization of flame-retardant-treated specimens helps minimize side effects of acidic finishing, irrespective of tensile and compression properties. The process also minimizes the shear and bending rigid effect by removing unattached metal oxides from the fabrics and reduction of inter yarn friction.

Palaskar *et al.* (2014) presented a research on "Development of multifunctional cotton fabric using atmospheric pressure plasma and nano-finishing". Multifunctional finishing of cotton fabric was carried out using atmospheric pressure plasma with nano Titanium dioxide (TiO_2)/Silicon dioxide (SiO_2) through pad-dry method. It was observed that, plasma treatment gives better results than the one without plasma application. Further, it could be asserted that TiO_2/SiO_2 and Butanetetracarboxylic acid (BTCA) showed the best wrinkle recovery outcome since polycarboxylic acids would bind the free hydroxyl groups of cellulose, and TiO_2 adds to improvement of the process. One per cent concentration of TiO_2/SiO_2 gives the best results as could be seen from the results of Ultraviolet protection factor, flame retardancy and crease recovery. Results of UPF and CRA revealed that TiO_2 can reduce the effectiveness of BTCA or BTCA can deactivate the TiO_2; therefore it is very important to select the optimum concentration of TiO_2 and BTCA.

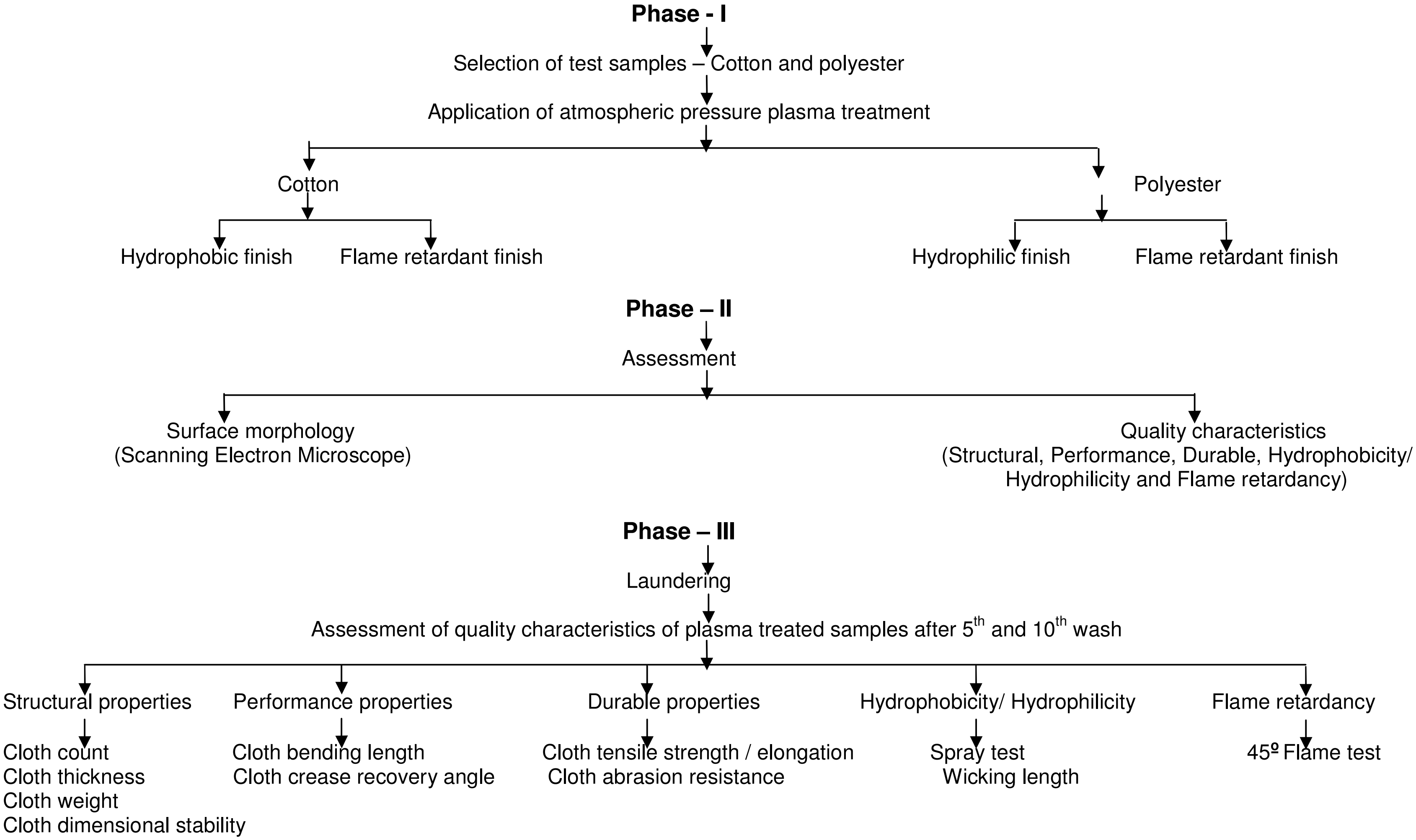
Finally, it is inferred that with the use of plasma technology, required concentration of chemicals can be lowered down by 20–25 %, thus reducing the environmental pollution and providing cost-effective solution to conventional finishing techniques.

Caschera *et al.* (2015) studied on “Flame retardant properties of plasma pre-treated/diamond-like carbon (DLC) coated cotton fabrics”. In the present study superhydrophobic and fire-resistant cotton fabrics were fabricated through a two-step plasma strategy by alternately exposing substrates to H_2 and O_2 plasma pre-treatments and subsequent DLC deposition. Fourier Transform Infrared Spectroscopy analysis revealed that different plasma pre-treatments can impose surface modifications on the chemical structure of cotton, especially in carboxylic and hydroxyl groups, leading to a radical alteration of surface roughness and of the crystalline cellulosic external structure. These changes deeply influence the growth of DLC thin films and the surface properties of cotton fabric because of the combination of a hierarchical structure and surface chemistry, as verified using Field Emission Gun-Scanning Electron Microscopy (FEGSEM) and water contact angle measurements. The effects of both specific gases used in the pre-treatment step and duration of the pre-treatment were analyzed using thermogravimetric analyses. The H_2-pre-treated DLC cottons exhibited good potential as an FR material, showing improved thermal stability compared to untreated cotton, as evidenced by increased ignition time. Moreover, vertical burning tests demonstrated that DLC cotton systems exhibited better flammability resistance.

3. MATERIAL AND METHODS

The present study on ‘Ecofriendly functional finish for textile materials’ is carried out in Dharwad city to find out the possibility of treating cotton and polyester with plasma finish and impact of this finish on the quality characteristics of both the fabrics. The detailed classification of methodology involved in this experimental study is presented under the following headings:

3.1 Selection of test samples
  3.1.1 Criteria set for selection of samples
3.2 Application of atmospheric pressure plasma treatment
  3.2.1 Hydrophobic finish for cotton fabric
  3.2.2 Hydrophilic finish for polyester fabric
  3.2.3 Flame retardant finish for cotton and polyester fabrics
3.3 Analysis of surface morphology of plasma treated cotton and polyester fabrics
3.4 Assessment of quality characteristics of plasma treated cotton and polyester fabrics
  3.4.1 Assessment of structural properties
    3.4.1.1 Cloth count
    3.4.1.2 Cloth thickness
    3.4.1.3 Cloth weight
    3.4.1.4 Cloth dimensional stability
  3.4.2 Assessment of performance properties
    3.4.2.1 Cloth bending length
    3.4.2.2 Cloth crease recovery angle
  3.4.3 Assessment of durable properties
    3.4.3.1 Cloth tensile strength and elongation
    3.4.3.2 Cloth abrasion resistance
  3.4.4 Assessment of cotton for hydrophobicity and polyester for hydrophilicity
    3.4.4.1 Spray test
    3.4.4.2 Wicking length
  3.4.5 Assessment of cotton and polyester fabrics for flame retardancy
    3.4.5.1 Forty five degree (45º) Flame test
3.5 Laundering of plasma treated cotton and polyester fabrics



Research design

3.6 Variables included in the study

3.6.1 Dependent variables

3.6.2 Independent variables

3.7 Statistical tools

3.8 Hypotheses set for the study

3.1 Selection of test samples

The test samples selected for the present study are bleached cotton and polyester fabric

3.1.1 Criteria set for selection of samples

The criteria set for the selection of samples were:

a) The textile materials should be suitable for clothing

b) Two materials shall be selected of which one is natural and another, synthetic to impart special functionalities

3.2 Application of atmospheric pressure plasma treatment

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. The plasma system consists of a set of planar electrodes (top and bottom electrodes) which are placed horizontally facing each other and at least one is covered by dielectric material. The textile fabric to be treated is passed between the gap at the top and bottom electrodes. The inter-electrode gap is adjustable manually depending on the thickness of the fabric. The inlet flow rate of inert or carrier gas to the system can be controlled by the manual flow meters with provision to change the flow rate from 1 to 5 litre per minute (LPM).

3.2.1 Hydrophobic finish for cotton

The entities of hydrophobic finishing are:

Gas-Helium (l/min) : 5

Power (kW) : 3.5

Treatment time (sec) : 60

Distance between the electrodes (mm) : 1

Monomer : Hexamethyldisiloxane (HMDSO)

Monomer flow rate (ml/min) : 1

Side of treatment : Both sides

3.2.2 Hydrophilic finish for polyester

The entities of hydrophilic finishing are:

Gas-Helium (l/min) : 5
Gas-Oxygen (l/min) : 0.5
Power (kW) : 1.5
Treatment time (sec) : 60
Distance between the electrodes (mm) : 1
Side of treatment : Both sides

3.2.3 Flame retardant finish for cotton and polyester

The cotton and polyester test samples were subjected for plasma treatment by using following entities before further carried for flame retardant finish.

Plasma treatment entities

Gas-Helium (l/min) : 5
Gas-Oxygen (l/min) : 0.5
Power (kW) : 2.5 (cotton) and 1.5 (polyester)
Treatment time (sec) : 30
Distance between the electrodes (mm) : 1
Side of treatment : Both sides

Flame retardant finish

Flame retardant finish was carried out by Pad-Dry-Cure method using following parameters. Right after plasma treatment the fabric was allowed to pass through finishing range consisted of padding mangle and hot air stenter for drying and curing.

Flame retardant - PYROVATEX® CP NEW : 250 gpl
(N-methylol Dimethylphosphonopropionamide)
Cross linking agent - KNITTEX® FEL (melamine resin) : 20 gpl
Drying (temp/min) : 90 ºC/2 min
Curing (temp/min) : 160 ºC/2 min

3.3 Analysis of surface morphology of plasma treated cotton and polyester fabrics

The surface topographical modification of plasma-modified cotton and polyester fabrics were examined at Osmania University, Hyderabad using S-3700N Scanning Electron Microscope, an accelerating voltage of 20 kV and a current of 10 µA at magnification power of 2,500X and 10,000X for assessment up to 20 and 5 micrometer level, respectively.

3.4 Assessment of quality characteristics of plasma treated cotton and polyester fabrics

3.4.1 Assessment of structural properties

It is imperative to consider certain fabric properties while deciding its end use or application. The geometry of the fabric is nothing but its structure; in a woven fabric threads per unit area, cloth thickness and GSM are the three features invariably decide the cloth configuration. These parameters do form a base for the performance, durability and comfort properties of a fabric. Hence, an effort was made to find out the impact of subsequent washes on the structural properties of plasma treated samples.

3.4.1.1 Cloth count

Cloth count in woven textile material is the number of ends and picks per unit area, while the fabric is free from wrinkle and held under no tension. This parameter is determined with the help of pick glass as indicated in BS method 2862:1957 (Booth, 1996). The number of ends and picks in one square inch of the fabric was counted randomly at selected places across the width and along the length of the test specimen. The region nearer to the selvedge was avoided because the spacing of thread is often a little different than in the body of cloth. Further, mean values of ends and picks/inch were calculated.

Number of readings : 10 each for warpway and weftway (1 inch)

Method used : Direct counting of threads per unit area

Instrument used : Magnifying counting device (pick glass)

Test method : BS 2862:1957

3.4.1.2 Cloth thickness

Thickness is the distance between the upper and lower surface of the material measured under a specified pressure, expressed in millimeter (mm). The specimen was tested as directed in BS test method 2544:1954 (Booth, 1996). The test samples were free from folds, crushing or distortion and wrinkles. The specimen was placed on the anvil of the test apparatus, lowered the pressure foot to bring the contact with the opposite side of the material and recorded the thickness in millimeter (mm).

Shape of the anvil : Round

Area of the anvil : 1 cm diameter

Number of readings : 10

Instrument used : Shirley’s thickness tester

Test method : BS 2544:1954

3.4.1.3 Cloth weight per unit area

Fabric weight is expressed as mass per unit area in g/sq mt. The specimen were tested as per IS 1964:2001. A sample of 5 × 5 cm was cut and weighed on electronic weighing balance to determine the weight per square meter (g) (Booth, 1996). Further, warp and weft threads were separated and weighed to calculate respective percentages. The percentage composition of warp and weft was calculated as detailed below:

Weight of 5 × 5 cm sample = a (g)

Weight of warp yarn = b (g)

Weight of weft yarn = c (g)

$$\text{Percent of warp} = \frac{b}{a} \times 100$$

$$\text{Percent of weft} = \frac{c}{a} \times 100$$

Number of readings	: 10
Instrument used	: Electronic weighing balance
Test method	: IS 1964:2001

3.4.1.4 Cloth dimensional stability

Cloth dimensional stability is measured in terms of shrinkage percentage. The fabric sample of 20 × 20 cm was taken and initial length of 15 cm was marked both in warp and weft directions. The test samples were soaked in the soap solution of 1 gpl at room temperature for 30 min, rinsed thoroughly in cold water and dried under shade. The dried samples were pressed gently without stretching. The final distance was measured and change in dimension was expressed in percentage using formula:

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

Where,

Lo – Initial length

La – Final length

Size of specimen	: 15 × 15 cm
Number of readings	: 5 each warpway and weftway

3.4.2 Assessment of performance properties

Performance is the ability of a textile material to serve for its end use. It depends on the behavioral characteristics of fibres, yarns, fabric construction and finish applied, thus indicating its specific application *i.e.* flame retardancy, hydrophilicity, hydrophobicity, biocompatibility, smart and responsive textiles, sensors, *etc.* The various performance properties assessed were cloth bending length and cloth crease recovery angle.

3.4.2.1 Cloth bending length

Fabric stiffness is the resistance of the fabric to bending. Bending length is the length of the fabric that bends under its own weight to a definite extent and equals to half the length of rectangular stripe of fabric that bends under its own weight to an angle of 41.5° .The test samples were tested as directed in BS test method: 3356-1961. Cloth bending length is expressed in centimeters (cm).

A rectangular strip of test sample, 6" × 1" (L × W) was mounted on a horizontal platform in such a way that it over hangs, like a cantilever, and bends on its own weight. Test specimen was cut with the help of template and then both template and test specimen was placed on the platform with the fabric underneath. Both were pushed forward slowly. The test sample starts drooping over the edge of the platform; and the movement of the template was continued until the tip of the specimen viewed in the mirror cuts both index lines. The bending length of both warp and weft samples was measured separately by reading the scale mark opposite a zero line engraved on the side of the platform. Ten readings were recorded by using Shirley's stiffness tester (Booth, 1996).

Size of the specimen : 6" × 1" (L × W)

Number of readings : 10

Name of the instrument : Shirley's stiffness tester

Test method : BS 3356:1961

3.4.2.2 Cloth crease recovery angle

Crease recovery is nothing but allowing the fabric to recover from the crease. The specimen was tested as directed in IS method: 4681-1968 by using Shirley's crease recovery tester. The test samples were cut both warpway and weftway using the template of 2" × 1" (L × W). It was creased by folding in to half and placed under a weight of 2 kg for 5 minutes; and the specimen was transferred on to the fabric clamp using forceps and allowed to recover for 5 minutes. As it recovered, the dial of the instrument was rotated to keep the free edge of the specimen in line with the knife edge; and the recovery angle in degrees was read on the engraved scale. Readings were recorded for both warpway and weftway specimen separately (Booth, 1996).

Size of the specimen : 2" × 1" (L × W)

Weight / load applied : 2 kg

Creasing period : 5 min

Recovery period : 5 min

Number of readings : 5 each warpway and weftway

Instrument used : Shirley's crease recovery tester

Test method : IS 4681:1968

Further, cloth crease recovery angle is determined by using the formula,

$$\text{Cloth crease recovery angle} = \sqrt{\text{Warp way angle}} \times \sqrt{\text{Weft way angle}}$$

3.4.3 Assessment of durable properties

Durability is the ability of a fabric to resist wear and tear through use and performance by some of the power to resist stress of force. The test samples were assessed for its ability to tensile strength, elongation percentage and abrasion resistance, in the present study.

3.4.3.1 Cloth tensile strength and elongation percentage

Tensile strength is the ability of the textile material to resist or rupture induced by external force. It is expressed as force/cross sectional area of the specimen at the time of maximum load. The specimen was tested as directed in ASTM test method: 12616-1989. The method employed to determine the breaking load and elongation of the material is 'strip test' and the instrument is Instron tensile strength tester.

The specimen was gripped between two clamps of the tensile testing machine where upper clamp is non movable and lower is movable. The load was applied longitudinally to the specimen by moving lower clamp until the specimen is ruptured. Values of breaking load of the test specimen were recorded (ISI hand book of Textile Testing).

Size of the specimen : 20 × 5 cm

Number of readings : 05

Test method : Strip test

Load range : 250 kgf

Speed : 300 mm/min

Name of the instrument : Instron tensile strength tester

Test method : ASTM 12616:1989

Elongation percentage

Elongation is the increase in length of the specimen from its initial length expressed in terms of percentage. The distance that material extends under a given force is proportional to its original length; therefore elongation is quoted as strain or percentage extension (Saville, 2004). Strain expresses the elongation as a fraction of the original length.

3.4.3.2 Cloth abrasion resistance

Abrasion is one of the aspects of wear. 'Wear' is the net result of number of agencies which reduce the serviceability of an article. Abrasion is rubbing away the component fibres and yarns on the surface of the fabric (Booth, 1996). The specimens were abraded as directed under IS test method 12673:1989.

The samples were assessed for flat abrasion resistance and tested on Martindale's abrasion tester. Cloth abrasion resistance is expressed in terms of 'cycles'. The end point of measuring the resistance for abrasion was formation of a 'hole'.

Size of the specimen : 13.5 cm (diameter)

Number of readings : 04

Type of abradant : Zero emery paper

Type of abrasion : Multidirectional and flat

Determination of end point : Formation of hole

Name of the instrument : Martindale's abrasion tester

Test method : IS 12673:1989

3.4.4 Assessment of cotton for hydrophobicity and polyester for hydrophilicity

Hydrophobic and hydrophilic materials are defined by the shape of water drop on a flat surface - specifically, the angle between the edge of the droplet and the surface underneath; and is called the contact angle. If the droplet forms a sphere that barely touches the surface, like drop of water on a lotus leaf, where the contact angle is more than 90º, 'obtuse angle' and the surface is hydrophobic, or water-fearing. But if the droplet spreads, wetting a large area of the surface, where the contact angle is less than 90º, 'acute angle' and the surface is considered hydrophilic, or water-loving (*http://news.mit.edu/2013/ hydrophobic-and-hydrophilic-explained-0716*).

3.4.4.1 Spray test

In this test, a small-scale mock rain shower is produced by pouring water through a spray nozzle. The water falls on to the specimen (7.0" × 7.0") which is mounted on a 6" diameter embroidery hoop and fixed at an angle of 45º. The test samples were tested for "water repellency: spray test" as directed in AATCC test method: 22-2005.

To carry out the test, 250 ml of distilled water at 70º F was poured steadily into the funnel, which falls as rain shower onto the test sample (Appendix-I, Fig. 1). After spraying, the sample holder is removed and the frame is tapped six times against a solid object to remove surplus water. The tapping is in two stages, three taps at one point on the frame and then three times at a point diametrically opposite. The assessment of water repellency is expressed in terms of 'spray rating', by observing the fabric surface after the removal of surplus water (Booth, 1996).

The 'spray rating' is recommended by AATCC, along with the chart of photographs against which the appearance of test sample is compared (Appendix-I, Fig. 3). The ratings are as follows:

100 : No sticking or wetting of the upper surface

90 : Slight random sticking or wetting of the upper surface

80 : Wetting of upper surface at spray points

70 : Partial wetting of whole of upper surface

50 : Complete wetting of whole of upper surfaces

0 : Complete wetting of whole of upper and lower surfaces

3.4.4.2 Wicking length

Capillary action (sometimes capillarity, capillary motion, or wicking) is the ability of a liquid to flow in narrow spaces without the assistance of, or even in opposition to external forces like gravity. The effect can be seen in the drawing up of liquids between the hairs of a paint-brush, in a thin tube, in porous materials such as paper and plaster, in some non-porous materials such as sand and liquefied carbon fibre, or in a cell. It occurs because of intermolecular forces between the liquid and surrounding solid surfaces. If the diameter of the tube is sufficiently small, then the combination of surface tension (which is caused by cohesion within the liquid) and adhesive forces between the liquid and container wall act to propel the liquid. (*https://en.wikipedia.org*).

The ability of a fabric to absorb water, especially by 'wicking' or 'capillary action', may be 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 (Booth, 1996). The size of the test sample is 7" × 1" (L × W), cut separately warpway and weftway. Each strip was suspended alongside of a ruler with one inch immersed in the 1 litre of acid dye solution (50 mg Sandol, Rhodine E-2GL), to a hook of 4 g weight to keep the sample straight. The height (length) of rise of liquid in 1, 2 and 5 minutes were observed and recorded.

Size of the specimen : 7" × 1" (L × W)

Number of readings : 4

3.4.5 Assessment of cotton and polyester fabrics for flame retardancy

Flame retardant is a chemical applied to a fabric, or reinforced into the fibre during production, which significantly reduces the flammability of the fabric (*http://www..com/dictionaries/textile.cfm*).

3.4.5.1 Forty five degree (45º) flame test

Ease of ignition and relative ability to sustain the combustion, measures the flammability characteristics of a material was studied by 45º flammability, in terms of seconds. According to the ASTM D1230-94 standards, progressive burning of a fabric at a distance of 127 mm from a flame is deemed to be "failure" of resistance to burning. The speed of flame spread is the time taken by the flame to burn the material (away from the source of ignition), to a distance under specified conditions. A standardized flame of 16 mm flame length was approached to the fabric surface near the lower end for 4 seconds. The Consumer Product Safety Commission (CPSC) has established three classes of fabric, where class I (flame spread time more than 7 seconds) is considered as best and class III (flame spread time less than 4 seconds) is not acceptable (Appendix-II).

Size of the specimen : 6.5" × 2" (L × W)

Number of readings : 5

Flame length : 16 mm

Name of the instrument : MAG Auto flame tester

3.5 Laundering of plasma treated cotton and polyester fabrics

Laundering is another aspect of the study to find out the impact of multiple washes on quality parameters *viz.*, structural, performance, durable and functional properties of treated substrates. The test samples were subjected for a total of 10 washes and the quality parameters were assessed after every 5th wash.

Method of washing	: Hand wash
Concentration of surfactant	: 2 gpl
Number of rinsing	: 3 times
Method of drying	: Shade drying

3.6 Variables included in the study

3.6.1 Dependent variables: The dependent variables included in the present study are cloth tensile strength, elongation percentage and cloth abrasion resistance.

3.6.2 Independent variables: The independent variables included in this study are ends per inch, picks per inch, cloth thickness and cloth weight.

3.7 Statistical tools

Appropriate statistical methods were adopted to analyze the data and infer the results of the findings. The data was analyzed by using the following statistical methods wherever applicable:

- One way ANOVA was used to find out the effect of plasma treatment on quality characteristics of the test samples *i.e.* structural, performance, durable and functional properties
- Co-efficient of determination (R^2) was calculated to know the influence of structural properties on durable properties using the formula:

$$R^2 = \frac{\text{Sum of squares due to multiple regression}}{\text{Total sum of squares}}$$

- To find out the effect of independent variables *viz.*, ends per inch, picks per inch, cloth thickness (mm) and cloth weight (GSM) on dependent variables *viz.*, cloth tensile strength (kgf), elongation (%) and cloth abrasion resistance (cycles), the multiple regression test was applied using the formula:

$$Y = a + b_1 x_1 + b_2 x_2 + \text{--------------} b_n x_n + \epsilon_{ij}$$

$i = 1 \ldots\ldots\ldots n$ and $j = 1 \ldots\ldots\ldots\ldots n$

Where ϵ_{ij} are the errors independently and normally distributed with mean 0 and common variance

$x_1.x_2.$ - --------------------x_n = Independent variables

$b_1.b_2.$ - --------------------b_n = Regression co-efficient

3.8 Hypotheses set for the study

- Plasma treatment alters the inherent characteristics of the cotton and polyester fabrics

- Laundering does not alter the structural, performance, durable and functional properties of the plasma treated fabrics

4. EXPERIMENTAL RESULTS

The results of the present study on 'Ecofriendly functional finish for textile materials' are presented under the following headings:

4.1 Analysis of surface morphology of plasma treated cotton fabric

4.2 Assessment of quality characteristics of plasma treated cotton fabric

4.2.1 Assessment of structural properties of plasma treated cotton fabric

4.2.2 Assessment of performance properties of plasma treated cotton fabric

4.2.3 Assessment of durable properties of plasma treated cotton fabric

4.2.4 Assessment of plasma treated cotton fabric for hydrophobicity

4.2.4.1 Spray test

4.2.4.2 Wicking length

4.3 Analysis of surface morphology of plasma treated polyester fabric

4.4 Assessment of quality characteristics of plasma treated polyester fabric

4.4.1 Assessment of structural properties of plasma treated polyester fabric

4.4.2 Assessment of performance properties of plasma treated polyester fabric

4.4.3 Assessment of durable properties of plasma treated polyester fabric

4.4.4 Assessment of plasma treated polyester fabric for hydrophilicity

4.4.4.1 Spray test

4.4.4.2 Wicking length

4.5 Analysis of surface morphology of post-flame retardant (FR) treated cotton and polyester fabrics

4.6 Assessment of quality characteristics of post-flame retardant (FR) treated cotton and polyester fabrics

4.6.1 Assessment of structural properties of post-flame retardant (FR) treated cotton and polyester fabrics

4.6.2 Assessment of performance properties of post-flame retardant (FR) treated cotton and polyester fabrics

4.6.3 Assessment of durable properties of post-flame retardant (FR) treated cotton and polyester fabrics

4.6.4 Assessment of post-flame retardant (FR) treated cotton and polyester fabrics for flame retardancy

4.6.4.1 Forty five degree (45°) flame test

4.1 Analysis of surface morphology of plasma treated cotton fabric

Plate 1 and 2 display the surface morphologies of untreated and plasma treated cotton, respectively. It is clear from these plates that the untreated substrate showed flat ribbon like structure, smooth surface with convolutions; whereas after plasma treatment with hexamethyldisiloxane (HMDSO) monomer the fibre structure abraded significantly and the surface found to be non-uniform when observed at 20 µm as well as 5 µm.

4.2 Assessment of quality characteristics of plasma treated cotton fabric

The plasma treated cotton fabric was assessed for various quality characteristics *viz.*, structural - cloth count, cloth thickness, GSM and shrinkage percentage; performance - cloth bending length and crease recovery angle; durable- cloth tensile strength and elongation percentage, cloth abrasion resistance; and functional property - hydrophobicity.

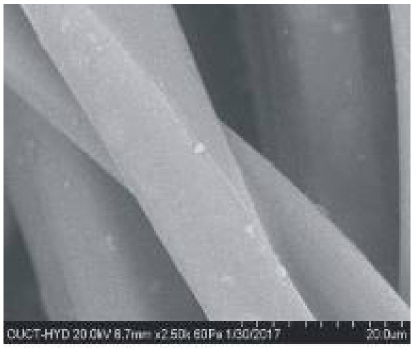
4.2.1 Assessment of structural properties of plasma treated cotton fabric

The impact of plasma treatment on various structural properties *viz.*, cloth count, cloth thickness, GSM and dimensional changes is presented in Table 1; further the effect of washing on these properties is assessed and compared with treated values.

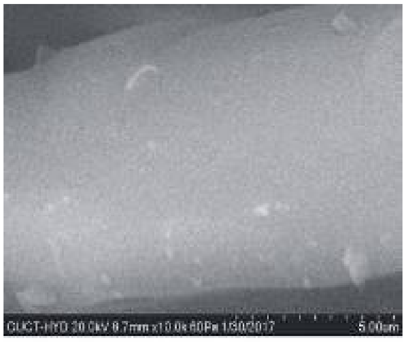
The cloth count indicates the configuration of ends and picks per unit area that also refers to cloth geometry. The ends and picks per inch is 92 and 46 respectively, at control and there was slight increase in thread configuration (warp 93 and weft 47) after plasma treatment. An increase in ends per inch (01.07 %) was observed after 5th wash and there was no alteration in cloth count with respect to pick configuration after multiple washes. This clearly indicates that there was slight increase in ends per inch of plasma treated cotton sample after 5th wash but there after no change in threads per inch after 10th wash.

Cloth thickness is the distance between one surface to its opposite. It is another structural property that influences performance and durability of a fabric that ultimately decides the end use. The thickness of the cloth at control was 00.34 mm and reduced by 05.88 per cent (00.32 mm) after plasma treatment. But a trend of increase is observed after 5th wash and the value remained unchanged after 10th wash (00.35 mm and 09.37 %) and are found to be significant at 1 per cent level of significance.

The weight of the fabric depends on the yarn type, yarn twist, threads per inch, method of fabric construction, mechanical finish and deposition of finishing material on the fabric surface. It is evident from Table 1 that there is decrease in the cloth weight (GSM) after plasma treatment (GSM, 82.88 and 03.54 %) compared to its corresponding control sample (GSM, 85.92). Meanwhile a trend of increase in the GSM of plasma treated sample was observed after 5th and 10th washes (00.67 and 00.96 %, respectively). The change in the value of GSM after plasma treatment and 10th wash is found to be significant at 1 per cent and at 5 per cent level of significance, respectively.

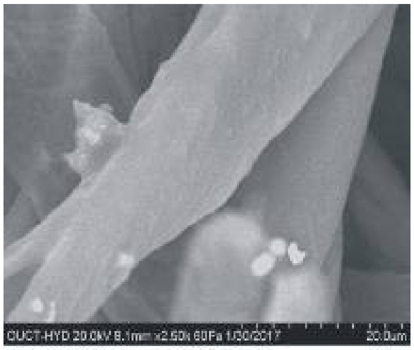


(a) 20 µm

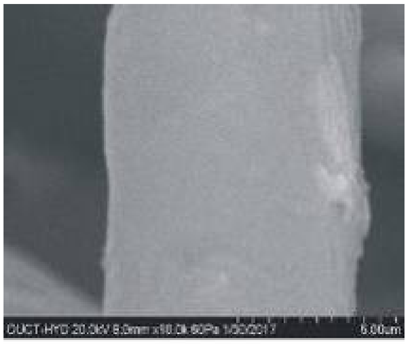


(b) 5 µm

Plate 1: Surface morphology of untreated cotton fabric



(a) 20 µm



(b) 5 µm

Plate 2: Surface morphology of plasma treated cotton fabric

Cloth weight is nothing but the total weight contributed by ends and picks for a measured dimension (square meter). As a part of the assessment, efforts were made to find out the proportion of ends and picks percentage in a measured dimension. And the results revealed that the percentage of ends is almost $^2/_3$ and that of picks is $^1/_3$, not only at control but the proportion remained almost same after plasma treatment and multiple washes, too. Nevertheless, the percentage of ends and picks after plasma treatment is found to be significant at 1 per cent level of significance.

Shrinkage is the linear amount of fabric which contracts either warpway or weftway or both when subjected for wet treatments and this dimensional change is expressed in terms of percentage. The cotton sample is assessed for dimensional stability at control, after plasma treatment and multiple washes of plasma treated samples to infer the consistency of plasma finish; and the results are presented in Table 1. In general it is found that the warpway shrinkage percentage is greater than weftway. Maximum warpway shrinkage is observed at control (02.54 %), followed by plasma treated sample (02.27 %) and multiple washes (01.60 % at 5th and 10th washes). The percentage shrinkage values were significant at 5 per cent (after plasma treatment) and highly significant at 1 per cent (5th and 10th washes) level of significance. Whereas, the weftway shrinkage was 00.80 per cent at control and decreased after plasma treatment (00.67 %). But there was no change in the weftway dimension after 5th and 10th washes. However, the weftway shrinkage observed in the plasma treated sample was found to be significant at 1 per cent level of significance.

4.2.2 Assessment of performance properties of plasma treated cotton fabric

The stiffness of a fabric is defined as its resistance to bending. It is learnt from Table 2 that the warpway bending length was longer (02.36 cm) than its corresponding weftway length (01.95 cm), at control. However, a decrease in warpway (01.78 cm) and weftway bending lengths (01.18 cm) was observed after plasma treatment. This reduction in bending length in both the directions is found to be significant at 1 per cent level of significance. Meanwhile, there was no effect of washing on the decrease percentage in the bending length of treated fabric, which is evident from this table.

Crease recovery angle is one of the performance properties directly supports the bending length of that fabric and indicates the level of softness and pliability of a fabric. The value of crease recovery angle of the test sample presented in Table 2 indicates that the warpway recovery angle (64º) is lower than its corresponding weftway recovery (76º), at control. After plasma treatment an increase in recovery angle of both warp (72º) and weft (80º) is noticed, however the percentage increase is higher in warpway (12.50 %) than weftway (05.26 %). Further, a slight increase in the crease recovery angle is observed both warpway (09.72 and 11.11 %) and weftway (16.25 and 17.50 %) after 5th and 10th washes, respectively. Cloth crease recovery is the combined effect of recovery angles of both warp and weft yarns. It is evident that after plasma treatment, the recovery angle of cotton fabric is relaxed; nevertheless the angle was further improved after 5th wash but remained almost unchanged after 10th wash.

Table 1. Effect of laundering on structural properties of plasma treated cotton fabric

Sl. No	Cotton samples	Structural properties							
		Cloth count (threads per inch)		Cloth thickness (mm)	Cloth weight (GSM)			Cloth shrinkage (%)	
		Warp	Weft		GSM	Warp (%)	Weft (%)	Warpway	Weftway
1	Untreated	92	46	00.34	85.92	65.37	34.63	02.54	00.80
2	Treated (hydrophobicity)	93** (01.08)	47** (02.17)	00.32** (05.88)	82.88** (03.54)	66.50**	33.50**	02.27*	00.67**
3	5th wash	94** (01.07)	47 (00.00)	00.35** (09.37)	83.44 (00.67)	66.50	33.50	01.60**	00.67
4	10th wash	94** (01.07)	47 (00.00)	00.35** (09.37)	83.68* (00.96)	66.50	33.50	01.60**	00.67

Figures in parenthesis indicate percentages

*- Significant at 5 % level of significance

**- Significant at 1 % level of significance

ANOVA TABLE								
S.Em. ±	0.283	0.252	0.002	0.486	0.420	0.382	00.155	00.067
C.D. (5 %)	0.256	0.229	0.002	0.652	0.564	0.515	00.208	00.089
C.D. (1 %)	0.344	0.307	0.003	0.899	0.777	0.713	00.287	00.123
C.V. %	0.960	1.718	2.637	1.296	1.421	2.525	17.398	21.295

S.Em. ± = Standard error mean

C.D. = Critical difference

C.V. % = Co-efficient of variance

Table 2. Effect of laundering on performance properties of plasma treated cotton fabric

Sl. No	Cotton samples	Performance properties				
		Cloth bending length (cm)		Cloth crease recovery angle (degree)		
		Warpway	Weftway	Warpway	Weftway	Cloth recovery
1	Untreated	02.36	01.95	64	76	70
2	Treated (hydrophobicity)	01.78** (24.57)	01.18** (39.48)	72** (12.50)	80** (05.26)	76** (08.57)
3	5th wash	01.78 (00.00)	01.10** (06.78)	79** (09.72)	93** (16.25)	86** (13.16)
4	10th wash	01.78 (0.00)	01.10** (06.78)	80** (11.11)	94** (17.50)	87** (14.47)

Figures in parenthesis indicate percentages **- Significant at 1 % level of significance

ANOVA TABLE					
S.Em. ±	0.044	0.032	1.078	1.232	0.636
C.D. (5 %)	0.053	0.038	1.423	1.652	0.853
C.D. (1 %)	0.073	0.052	1.941	2.277	1.175
C.V. %	5.658	5.889	3.268	3.213	1.785

S.Em. ± = Standard error mean C.D. = Critical difference C.V. % = Co-efficient of variance

4.2.3 Assessment of durable properties of plasma treated cotton fabric

The tensile strength is the fundamental ability to resist strain or rupture induced by tension. Table 3 and Fig. 1 depicts that plasma treated sample showed higher warpway and weftway tensile strength (23.70 kgf and 10.45 kgf) compared to their corresponding control samples (22.62 kgf and 09.40 kgf), respectively. However, on 5th and 10th washes, there was a descending order in the tensile strength of both, warpway (00.72 % and 01.22 %) and weftway (02.87 % and 04.49 %), respectively was observed when compared to plasma treated samples.

The breaking load and elongation percentage are directly proportional and supportive. It is evident from Table 3 and Fig. 1 that after plasma treatment, the elongation percentage of cotton fabric enhanced significantly in both directions *i.e.* warpway (08.88) and weftway (06.88), compared to control sample (07.85 and 05.86), respectively. However, the warpway elongation is found to be higher than the corresponding weftway elongation. There was slight reduction observed in warpway (07.99 and 08.78 %) and weftway (02.76 to 05.38 %) elongation after 5th and 10th wash, respectively compared to plasma treated cotton sample.

The increase in tensile strength (breaking load) and elongation of treated sample and decrease in both tensile strength and elongation after subsequent washes were found to be significant at 1 per cent level of significance.

Cloth abrasion resistance is the wearing away of any part of material by rubbing against another surface. Table 3 displays the result of abrasion resistance of control and treated cotton fabric as well as after 5th and 10th wash. It is clear from this Table that, there was reduction in the abrasion resistance after plasma treatment (44.55 %). Further a trend of gradual decrease in the values is observed after 5th (10.71 %) and 10th (21.43 %) washes compared to treated samples, and the values are significant at 1 per cent level of significance.

4.2.3.1 Influence of ends per inch, picks per inch, cloth thickness and GSM on tensile strength of plasma treated cotton fabric

Table 4 elicits the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway as well as weftway tensile strength of plasma treated cotton samples.

It is apparent from this Table that the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway tensile strength was non-significant at control, treated and 5th wash. But the ends per inch influenced the warpway tensile strength of plasma treated cotton fabric negatively and is found to be significant at 1 per cent level of significance after 10th wash. Similarly, picks per inch did influence negatively on warpway tensile strength on 10th wash, but found to be significant at 5 per cent level of significance. Moreover, it was also evident that influence of cloth thickness was positive whereas influence of GSM was negative on warpway tensile strength of treated fabric after 10th wash and both values were found to be significant at 1 per cent level of significance. The R^2 value of plasma treated cotton fabric after 10th wash was found to be 0.91 *i.e.* the influence is 91.00 per cent.

Table 3. Effect of laundering on durable properties of plasma treated cotton fabric

Sl. No	Cotton samples	Durable properties				
		Cloth tensile strength (kgf)		Elongation (%)		Cloth abrasion resistance (cycles)
		Warpway	Weftway	Warpway	Weftway	
1	Untreated	22.62	09.40	07.85	05.86	101
2	Treated (hydrophobicity)	23.70** (04.77)	10.45** (11.17)	08.88** (13.12)	06.88** (17.41)	56** (44.55)
3	5th wash	23.53** (00.72)	10.15** (02.87)	08.17** (07.99)	06.69** (02.76)	50** (10.71)
4	10th wash	23.41** (01.22)	09.98** (04.49)	08.10** (08.78)	06.51** (05.38)	44** (21.43)

Figures in parenthesis indicate percentages **- Significant at 1 % level of significance

ANOVA TABLE					
S.Em. ±	0.029	0.020	0.008	0.008	1.466
C.D. (5 %)	0.045	0.032	0.012	0.013	2.259
C.D. (1 %)	0.063	0.045	0.017	0.019	3.167
C.V. %	0.253	0.418	0.197	0.274	4.669

S.Em. ± = Standard error mean C.D. = Critical difference C.V. % = Co-efficient of variance

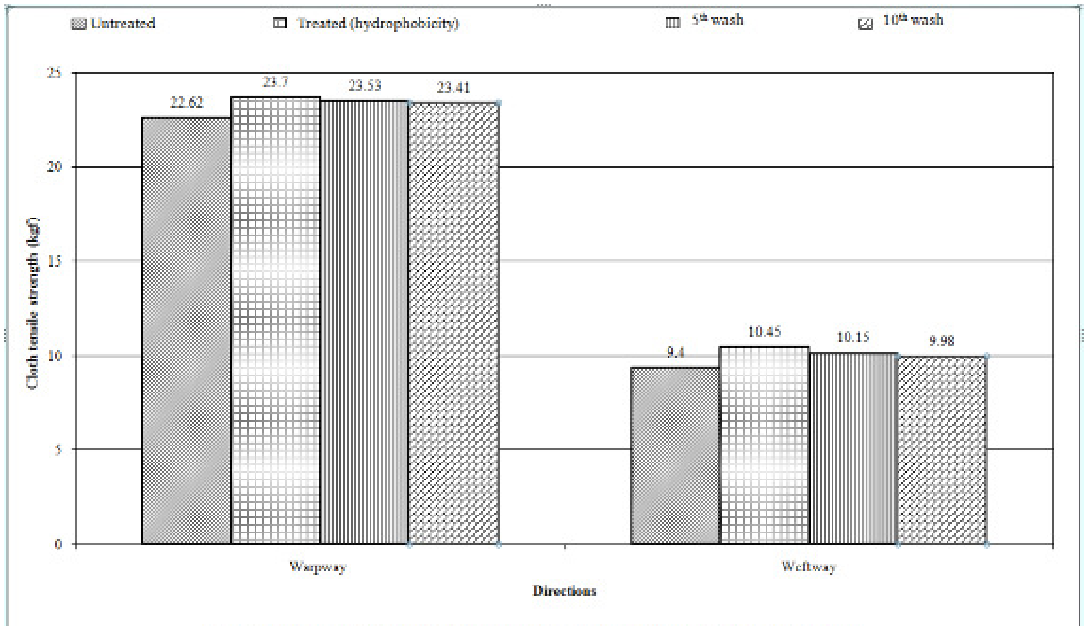


Fig. 1a. Cloth tensile strength and elongation percentage of plasma treated cotton fabric

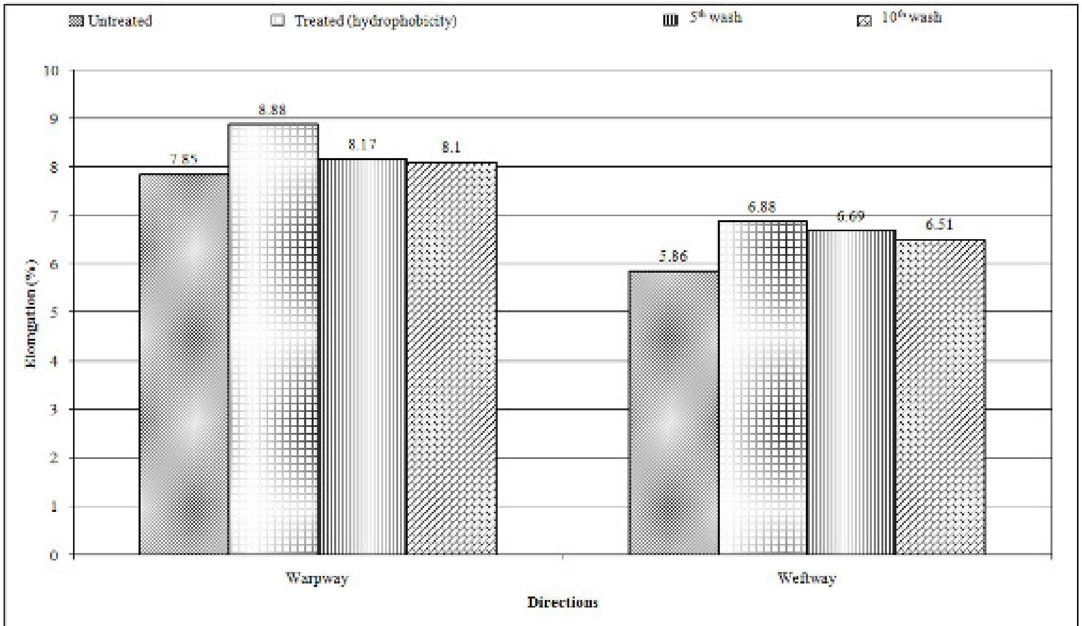


Fig. 1b. Cloth tensile strength and elongation percentage of plasma treated cotton fabric

Fig. 1. Cloth tensile strength and elongation percentage of plasma treated cotton fabric

From the same Table, it is observed that the influence of ends per inch, picks per inch, cloth thickness and GSM on weftway tensile strength was non-significant at control, treated, 5th wash and 10th wash. The R^2 values of all the variables (X_1, X_2, X_3 and X_4) were found to be minimum *i.e.* 0.25, 0.34, 0.14 and 0.15, respectively.

4.2.3.2 Influence of ends per inch, picks per inch, cloth thickness and GSM on elongation percentage of plasma treated cotton fabric

Table 5 depicts the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway as well as weftway elongation percentage of plasma treated cotton fabric.

It is evident from Table 5 that influence of picks per inch, cloth thickness and GSM on warpway elongation was found to be non-significant at control, treated, 5th and 10th washes. Though, the influence of ends per inch on warpway tensile strength at control was negative but found to be significant at 5 per cent level of significance with 0.56 R^2 value.

However, influence of ends per inch, picks per inch, cloth thickness and GSM on weftway elongation percentage also found to be non-significant at treated, 5th and 10th washes except the GSM which showed negative influence on weftway elongation at control and was found significant at 5 per cent level of significance. The R^2 value was 0.86 *i.e.* influence of GSM is 86.00 per cent.

4.2.3.3 Influence of ends per inch, picks per inch, cloth thickness and GSM on abrasion resistance of plasma treated cotton fabric

Table 6 reveals about the influence of ends per inch, picks per inch, cloth thickness and GSM on cloth abrasion resistance of plasma treated cotton fabric.

From this Table it was found that the influence of ends per inch, picks per inch, cloth thickness and GSM on cloth abrasion resistance was found to be non-significant at control, treated, 5th and 10th washes. However, the corresponding R^2 values of all the variables (X_1, X_2, X_3 and X_4) were found to be 0.15, 0.23, 0.41 and 0.31, respectively.

4.2.4 Assessment of plasma treated cotton fabric for hydrophobicity

4.2.4.1 Spray test

The spray test may be adapted to any textile fabric to assess the level of water repellency. This test measures the resistance of fabrics to wetting by water. It is especially suitable for measuring the water repellent efficacy of finishes applied to fabric. The various factors attribute to ‘resistance to wetting’ or ‘water-repellency’ are the type of fibre, yarn, method of construction and finish on the fabric.

After spraying and tapping the hoop as indicated in the methodology, the test sample is compared with the ‘Standard Spray Test Ratings Chart’ for wet and spotted pattern. The face of the test sample is assigned a rating corresponding to the nearest level on the rating chart. The individual rating is the result of plasma treated cotton sample subjected to multiple washes, is presented in Table 7.

Table 4. Influence of ends per inch, picks per inch, cloth thickness and GSM on cloth tensile strength of plasma treated cotton fabric

Sl. No	Cotton samples	Variables	Cloth tensile strength (kgf)					
			Warpway			Weftway		
			Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test
1	Untreated	X_1	0.002	0.004	0.60^{NS}	-0.02	0.02	-0.96^{NS}
		X_2	0.01	0.007	1.87^{NS}	-0.0007	0.05	-0.01^{NS}
		X_3	-0.36	0.54	-0.66^{NS}	-2.86	3.61	-0.79^{NS}
		X_4	-0.004	0.004	-1.09^{NS}	0.02	0.02	0.94^{NS}
		R^2	0.50			0.25		
2	Treated (hydrophobicity)	X_1	0.05	0.06	0.88^{NS}	0.005	0.004	1.17^{NS}
		X_2	-0.01	0.04	-0.35^{NS}	-0.003	0.003	-1.06^{NS}
		X_3	-3.44	3.52	-0.97^{NS}	-0.01	0.24	-0.07^{NS}
		X_4	0.02	0.02	0.93^{NS}	0.002	0.002	1.05^{NS}
		R^2	0.35			0.34		
3	5th wash	X_1	0.0007	0.01	0.05^{NS}	-0.001	0.007	-0.17^{NS}
		X_2	0.004	0.009	0.47^{NS}	0.001	0.006	0.23^{NS}
		X_3	0.98	0.69	1.41^{NS}	0.35	0.44	0.79^{NS}
		X_4	0.01	0.03	0.57^{NS}	-0.0003	0.02	-0.01^{NS}
		R^2	0.38			0.14		
4	10th wash	X_1	-0.01	0.004	-3.81**	-0.006	0.01	-0.49^{NS}
		X_2	-0.005	0.001	-2.76*	0.001	0.006	0.20^{NS}
		X_3	2.07	0.31	6.56**	-0.02	0.96	-0.02^{NS}
		X_4	-0.25	0.05	-4.54**	0.05	0.16	0.30^{NS}
		R^2	0.91			0.15		

X_1 = Ends per inch
X_2 = Picks per inch
X_3 = Cloth thickness
X_4 = Cloth GSM
NS – Non-significant
R^2 – Co-efficient of determination
*- Significant at 5 % level of significance
**- Significant at 1 % level of significance

Table 5. Influence of ends per inch, picks per inch, cloth thickness and GSM on elongation percentage of plasma treated cotton fabric

Sl. No	Cotton samples	Variables	Elongation (%)					
			Warpway			Weftway		
			Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test
1	Untreated	X_1	-0.01	0.006	-2.49*	-0.005	0.002	-1.93^{NS}
		X_2	-0.01	0.01	-1.11^{NS}	0.005	0.004	1.07^{NS}
		X_3	-0.74	0.76	-0.97^{NS}	0.39	0.34	1.15^{NS}
		X_4	0.006	0.005	1.14^{NS}	-0.006	0.002	-2.64*
		R^2	0.56			0.86		
2	Treated (hydrophobicity)	X_1	0.004	0.009	0.51^{NS}	0.008	0.004	1.98^{NS}
		X_2	-0.006	0.006	-0.89^{NS}	-0.004	0.002	-1.62^{NS}
		X_3	-0.25	0.49	-0.51^{NS}	0.02	0.21	0.13^{NS}
		X_4	0.002	0.004	0.62^{NS}	0.002	0.001	1.21^{NS}
		R^2	0.25			0.51		
3	5th wash	X_1	-0.01	0.01	-1.28^{NS}	0.004	0.01	0.32^{NS}
		X_2	-0.01	0.01	-1.23^{NS}	0.006	0.01	0.62^{NS}
		X_3	0.11	0.86	0.13^{NS}	1.25	0.72	1.73^{NS}
		X_4	-0.02	0.04	-0.68^{NS}	0.04	0.03	1.12^{NS}
		R^2	0.33			0.53		
4	10th wash	X_1	0.007	0.006	1.17^{NS}	-0.02	0.01	-1.61^{NS}
		X_2	-0.0006	0.002	-0.24^{NS}	0.005	0.007	0.69^{NS}
		X_3	-0.45	0.45	-1.00^{NS}	0.92	1.25	0.73^{NS}
		X_4	0.12	0.08	1.53^{NS}	-0.19	0.22	-0.88^{NS}
		R^2	0.39			0.45		

X_1 = Ends per inch
X_2 = Picks per inch
X_3 = Cloth thickness
X_4 = Cloth GSM
NS – Non-significant
R^2 – Co-efficient of determination
*- Significant at 5 % level of significance

Table 6. Influence of ends per inch, picks per inch, cloth thickness and GSM on cloth abrasion resistance of plasma treated cotton fabric

Sl. No	Cloth abrasion resistance (cycles)				
	Cotton samples	**Variables**	**Co-efficient**	**Standard error**	**t-test**
1	Untreated	X_1	1.11	1.80	0.61^{NS}
		X_2	2.54	3.20	0.79^{NS}
		X_3	-26.21	228.23	-0.11^{NS}
		X_4	-0.54	1.72	-0.31^{NS}
		R^2	0.15		
2	Treated (hydrophobicity)	X_1	-0.55	1.98	-0.28^{NS}
		X_2	1.7	1.44	1.17^{NS}
		X_3	-12.87	104.78	-0.12^{NS}
		X_4	0.10	0.87	0.12^{NS}
		R^2	0.23		
3	5th wash	X_1	-0.37	0.41	-0.90^{NS}
		X_2	0.21	0.34	0.62^{NS}
		X_3	8.69	23.97	0.36^{NS}
		X_4	-2.08	1.18	-1.75^{NS}
		R^2	0.41		
4	10th wash	X_1	-1.64	1.36	-1.20^{NS}
		X_2	0.09	0.61	0.15^{NS}
		X_3	84.24	97.94	0.86^{NS}
		X_4	-19.21	17.28	-1.11^{NS}
		R^2	0.31		

X_1 = Ends per inch

X_2 = Picks per inch

X_3 = Cloth thickness

X_4 = Cloth GSM

R^2 – Co-efficient of determination

NS – Non-significant

Table 7. Effect of laundering on water repellency of plasma treated cotton fabric

Sl. No	Cotton samples	Spray test (ratings)
1	Untreated	Zero
2	Treated (hydrophobicity)	100
3	5th wash	70
4	10th wash	70 to 50

Ratings as per AATCC:

100 : No sticking or wetting of upper surface (ISO 5)
90 : Slight random sticking or wetting of upper surface (ISO 4)
80 : Wetting of upper surface at spray points (ISO 3)
70 : Partial wetting of whole of upper surface (ISO 2)
50 : Complete wetting of whole of upper surface (ISO 1)
0 : Complete wetting of whole of upper and lower surfaces (0)

This table clearly indicates that the control sample has rating as ‘zero’ and that of plasma treated cotton as 100 (ISO 5). The impact of multiple washes on plasma treated cotton sample indicated a reduction in the rating level *i.e.* from 100 to 70 (ISO 2) and from 70 to 50 (ISO 2 to ISO 1), respectively after 5th and 10th washes.

4.2.4.2 Wicking length

Wicking, simply means the capillary movement of moisture within fabric structure. Wicking can only occur when a liquid wets the fibre assembled within the capillary space between them.

The wicking length of control, plasma treated cotton fabric and the treated samples after 5th and 10th wash is presented in Table 8. The wicking of test samples is measured at 1, 2 and 5 minutes and the comparison is made between control and treated samples; and further assessed the impact of multiple washes on the wicking length of treated samples.

In general a trend of increase in wicking length is observed with increase in duration. The warpway wicking length (03.00 cm) of control sample is higher than its corresponding weftway length (02.30 cm) at 1 minute duration and this trend remained same at 2 and 5 min durations.

The plasma treated sample indicated that there was absolutely no wicking, irrespective of the time duration, hence the wicking length is indicated as ‘zero’ cm.

The assessment of wicking length of plasma treated sample after 5th wash showed slight wicking both warpway and weftway (00.90 cm and 01.30 cm, respectively) at 1 min duration. Meanwhile a trend of increase in wicking after 2 min (01.90 cm and 02.00 cm, respectively) and 5 min (03.10 cm and 03.20 cm, respectively) is also observed. However, this increase in wicking length of plasma treated sample after 5th wash is remarkably shorter than its corresponding control values at 1, 2 and 5 min duration.

On the other hand the warpway and weftway wicking length of plasma treated sample after 10th wash was almost same as that of 5th wash, irrespective of the time duration *i.e.* 01.00 cm and 01.30 cm, respectively at 1 min, 02.00 cm and 02.10 cm, respectively at 2 min and 03.20 cm and 03.30 cm, respectively at 5 min. Nevertheless, there was not much difference in the warpway and weftway wicking length of plasma treated samples after 5th and 10th washes where as a great deal of difference in wicking lengths were observed with control sample.

4.3 Analysis of surface morphology of plasma treated polyester fabric

The Scanning Electron Microscope (SEM) reveals about the morphology of untreated polyester fabric and the change over in the plasma treated test sample which is presented in Plate 3 and 4, respectively.

It is evident from Plate 4 that formation of microgrooves in the oxygen plasma treated polyester fibre is more obvious compared to the uniform structure of untreated sample (Plate 3).

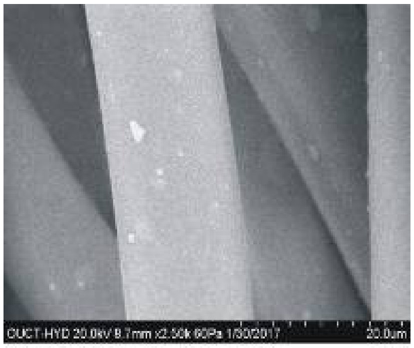
Table 8. Effect of laundering on wicking length of plasma treated cotton fabric

Sl. No	Cotton samples	Wicking length (cm)					
		1 minute		2 minute		5 minute	
		Warpway	Weftway	Warpway	Weftway	Warpway	Weftway
1	Untreated	03.00	02.30	04.10	02.70	05.60	04.00
2	Treated (hydrophobicity)	00.00**	00.00**	00.00**	00.00**	00.00**	00.00**
3	5th wash	00.90**	01.30**	01.90**	02.00**	03.10**	03.20**
4	10th wash	01.00**	01.30**	02.00**	02.10**	03.20**	03.30**

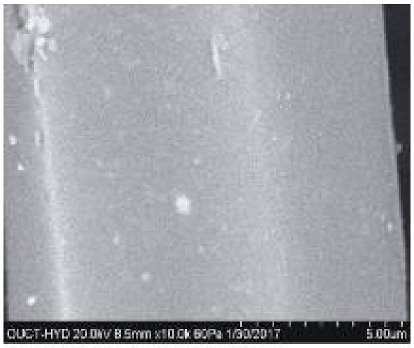
**- Significant at 1 % level of significance

ANOVA TABLE						
S.Em. ±	0.028	0.034	0.047	0.052	0.068	0.037
C.D. (5 %)	0.054	0.064	0.088	0.099	0.129	0.070
C.D. (1 %)	0.079	0.094	0.129	0.144	0.188	0.102
C.V. %	4.054	4.925	4.065	5.343	4.023	2.459

S.Em. ± = Standard error mean C.D. = Critical difference C.V. % = Co-efficient of variance

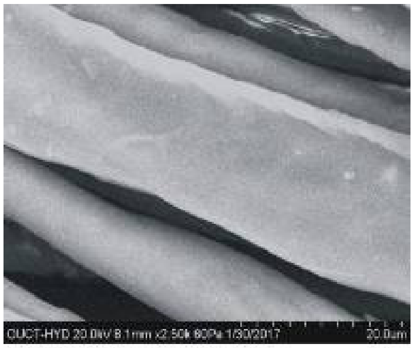


(a) 20 μm

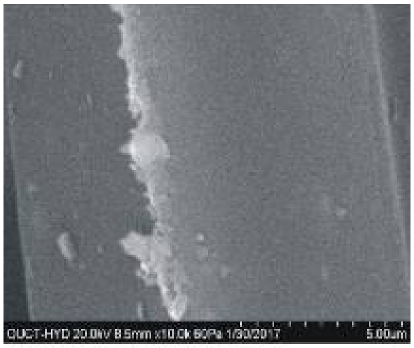


(b) 5 μm

Plate 3: Surface morphology of untreated polyester fabric



(a) 20 μm



(b) 5 μm

Plate 4: Surface morphology of plasma treated polyester fabric

4.4 Assessment of quality characteristics of plasma treated polyester fabric

Similar to cotton test sample, the plasma treated polyester fabric was assessed for various quality characteristics *viz.*, structural - cloth count, cloth thickness, GSM and shrinkage percentage; performance - cloth bending length and crease recovery angle; durable- cloth tensile strength and elongation percentage, cloth abrasion resistance; and functional property - hydrophilicity, too.

4.4.1 Assessment of structural properties of plasma treated polyester fabric

The impact of plasma treatment on various structural properties *viz.*, cloth count, cloth thickness, GSM and dimensional changes is presented in Table 9. Further the effect of washing on these properties is assessed and compared with the values of plasma treated sample.

Cloth count in woven textile is the number of ends and picks per unit area and is determined by the yarn count and compactness of the weave. The ends and picks per inch of polyester fabric is 80 and 45, respectively at control and remained unchanged even after plasma treatment. But on 5th wash, there was increase in both, ends/inch (01.25 %) and picks/inch (02.22 %) which remained constant even after 10th wash and the values were highly significant at both the levels of washes.

Cloth thickness is the distance between upper and lower layers of the fabric measured in mm. It is generally expected that thicker the fabric, longer it takes to wear and tear. Thick fabrics however are not always convenient because of their bulkiness and stiffness. It is observed from this Table that plasma treated test sample showed highly significant decrease in cloth thickness *i.e.* 04.00 per cent, when compared to control values. However, on subsequent washings there is no change in the thickness of treated sample.

A perusal from Table 9, it is observed that there is significant loss in cloth weight after plasma treatment (01.73 %) compared to its corresponding control value (50.80 g/m^2). Though a trend of decrease in the GSM of plasma treated sample is observed after 5th and 10th washes (49.36 g/m^2, 01.12 % and 49.20 g/m^2, 1.44 %, respectively) but the values are found to be non-significant. Meanwhile, a general trend of greater percentage of warp contribution *i.e.* almost $^2/_3$ and $^1/_3$ contribution by weft is found among the control and plasma treated samples. The proportion of warp and weft in the plasma treated sample remained unchanged, even after 5th and 10th washes. Further, it is evident that the warp percentage of treated samples did reduce by 04.00 per cent (62.38 g/m^2) compared to control (66.14 g/m^2); whereas, weft percentage showed an ascending value. And this change is found to be highly significant at 1 per cent level of significance. On washing, there is slight difference in values which is found to be non-significant compared to the values of treated sample.

The shrinkage percentage of plasma treated polyester sample (each 00.67 % for both warpway and weftway) is found to be significantly lower than the corresponding yarn direction (each 00.80 %) of control sample. But on washing, there is no alteration in the consolidation of either ends or picks per inch of treated samples.

Table 9. Effect of laundering on structural properties of plasma treated polyester fabric

Sl. No	Polyester samples	Structural properties							
		Cloth count (threads per inch)		Cloth thickness (mm)	Cloth weight (GSM)			Cloth shrinkage (%)	
		Warp	Weft		GSM	Warp (%)	Weft (%)	Warpway	Weftway
1	Untreated	80	45	00.25	50.80	66.14	33.86	00.80	00.80
2	Treated (hydrophilicity)	80 (00.00)	45 (00.00)	00.24** (04.00)	49.92 (01.73)	62.38**	37.62**	00.67**	00.67**
3	5th wash	81** (01.25)	46** (02.22)	00.24 (00.00)	49.36 (01.12)	62.35	37.65	00.67	00.67
4	10th wash	81** (01.25)	46** (02.22)	00.24 (00.00)	49.20 (01.44)	62.35	37.65	00.67	00.67

Figures in parenthesis indicate percentages

*- Significant at 1 % level of significance

ANOVA TABLE								
S.Em. ±	0.343	0.236	0.002	0.738	1.040	0.711	0.067	0.067
C.D. (5 %)	0.311	0.214	0.002	0.990	1.395	0.953	0.089	0.089
C.D. (1 %)	0.417	0.287	0.003	1.364	1.922	1.313	0.123	0.123
C.V. %	1.355	1.650	3.279	3.316	3.675	4.334	21.295	21.295

S.Em. ± = Standard error mean

C.D. = Critical difference

C.V. % = Co-efficient of variance

4.4.2 Assessment of performance properties of plasma treated polyester fabric

Stiffness is a special property of fabric to keep standing without any support. It is a key factor in the study of handle and drape of fabric. However, crease recovery indicates the ability of fabric to go back to its original position after creasing.

From Table 10, it is clear that the plasma treated test samples became relatively soft and pliable, which is evident from the reduction in the bending path of both warp (02.07 cm) and weft (01.68 cm) samples compared to the corresponding direction of control sample *i.e.* 02.15 cm and 01.70 cm, respectively. Further on subsequent washes this trend of reduction is observed and these values are highly significant at 1 per cent level of significance.

It is learnt from the same Table, that the warpway crease recovery angle was lower (114º) than its corresponding weftway crease recovery angle (120º) at control. However, the significant increase in warpway (118º) and weftway angle (133º) was observed after plasma treatment at 1 per cent level of significance. Further, this trend of increase in the crease recovery angle is observed both warpway (02.54 % and 05.08 %) and weftway (01.50 % and 03.00 %) after 5th and 10th washes, respectively. Cloth crease recovery is the resultant of warp and weft recovery angle; and the values are found to be highly significant not only after plasma treatment but also after subsequent washes *i.e.* 5th and 10th washes.

4.4.3 Assessment of durable properties of plasma treated polyester fabric

The tensile strength depends upon the fibre content of the fabric and its inherent properties like type of yarn (single, play, filament *etc.*), yarn number, yarn crimp, thread per inch, cloth cover and compactness of the weave. Further, the strength of its component fibres does determine the ultimate strength of the fabric.

It is evident from Table 11 and Fig. 2 that the warpway tensile strength of the fabric, before and after plasma treatment as well as multiple washes is higher than its corresponding weftway strength. However, the tensile strength of plasma treated polyester fabric in both directions *i.e.* warpway (32.91) and weftway (14.99) was found to be higher compared to its control values (31.42 and 14.20, respectively). Moreover, a trend of decrease in warpway (03.43 % to 03.71 %) and weftway (01.20 % to 01.26 %) tensile strength was observed after 5th to 10th wash respectively, when compared to plasma treated sample.

Similarly, cloth elongation percentage of plasma treated sample enhanced in both warpway (03.54 %) and weftway (03.94 %) compared to control polyester. However, a trend of decrease in elongation percentage was found on multiple washes *i.e.* 01.30 to 01.47 per cent in warp direction and 01.74 to 02.05 per cent in weft direction from 5th to 10th washes respectively, when compared with the values of treated sample, (Table 11 and Fig. 2).

The change in values of cloth tensile strength and elongation percentage after plasma treatment and number of washes is found to be significant at 1 per cent level of significance.

Table 10. Effect of laundering on performance properties of plasma treated polyester fabric

Sl. No.	Polyester samples	Performance properties				
		Cloth bending length (cm)		Cloth crease recovery angle (degree)		
		Warpway	Weftway	Warpway	Weftway	Cloth recovery
1	Untreated	02.15	01.70	114	120	117
2	Treated (hydrophilicity)	02.07** (03.72)	01.68* (01.17)	118** (03.50)	133** (10.83)	125** (06.83)
3	5th wash	02.01** (02.89)	01.20** (28.57)	121* (02.54)	135 (01.50)	127** (01.60)
4	10th wash	01.63** (21.25)	01.17** (30.35)	124** (05.08)	137* (03.00)	130** (04.00)

Figures in parenthesis indicate percentages

*- Significant at 5% level of significance

**- Significant at 1% level of significance

ANOVA TABLE					
S.Em. ±	0.020	0.013	1.704	2.185	0.977
C.D. (5 %)	0.024	0.016	2.285	2.929	1.310
C.D. (1 %)	0.033	0.022	3.148	4.036	1.805
C.V. %	2.542	2.289	3.195	3.718	1.747

S.Em. ± = Standard error mean

C.D. = Critical difference

C.V. % = Co-efficient of variance

Table 11. Effect of laundering on durable properties of plasma treated polyester fabric

Sl. No.	Polyester samples	Durable properties				
		Cloth tensile strength (kgf)		Elongation (%)		Cloth abrasion resistance (cycles)
		Warpway	Weftway	Warpway	Weftway	
1	Untreated	31.42	14.20	16.37	12.69	65
2	Treated (hydrophilicity)	32.91** (04.74)	14.99** (05.56)	16.95** (03.54)	13.19** (03.94)	64** (01.54)
3	5th wash	31.78** (03.43)	14.81** (01.20)	16.73** (01.30)	12.96** (01.74)	63** (01.56)
4	10th wash	31.69** (03.71)	14.80** (01.26)	16.70** (01.47)	12.92** (02.05)	38** (40.63)

Figures in parenthesis indicate percentages

**- Significant at 1% level of significance

ANOVA TABLE					
S.Em. ±	0.011	0.015	0.040	0.071	0.426
C.D. (5 %)	0.018	0.023	0.062	0.109	0.657
C.D. (1 %)	0.025	0.033	0.087	0.153	0.922
C.V. %	0.074	0.211	0.483	1.097	1.483

S.Em. ± = Standard error mean

C.D. = Critical difference

C.V. % = Co-efficient of variance

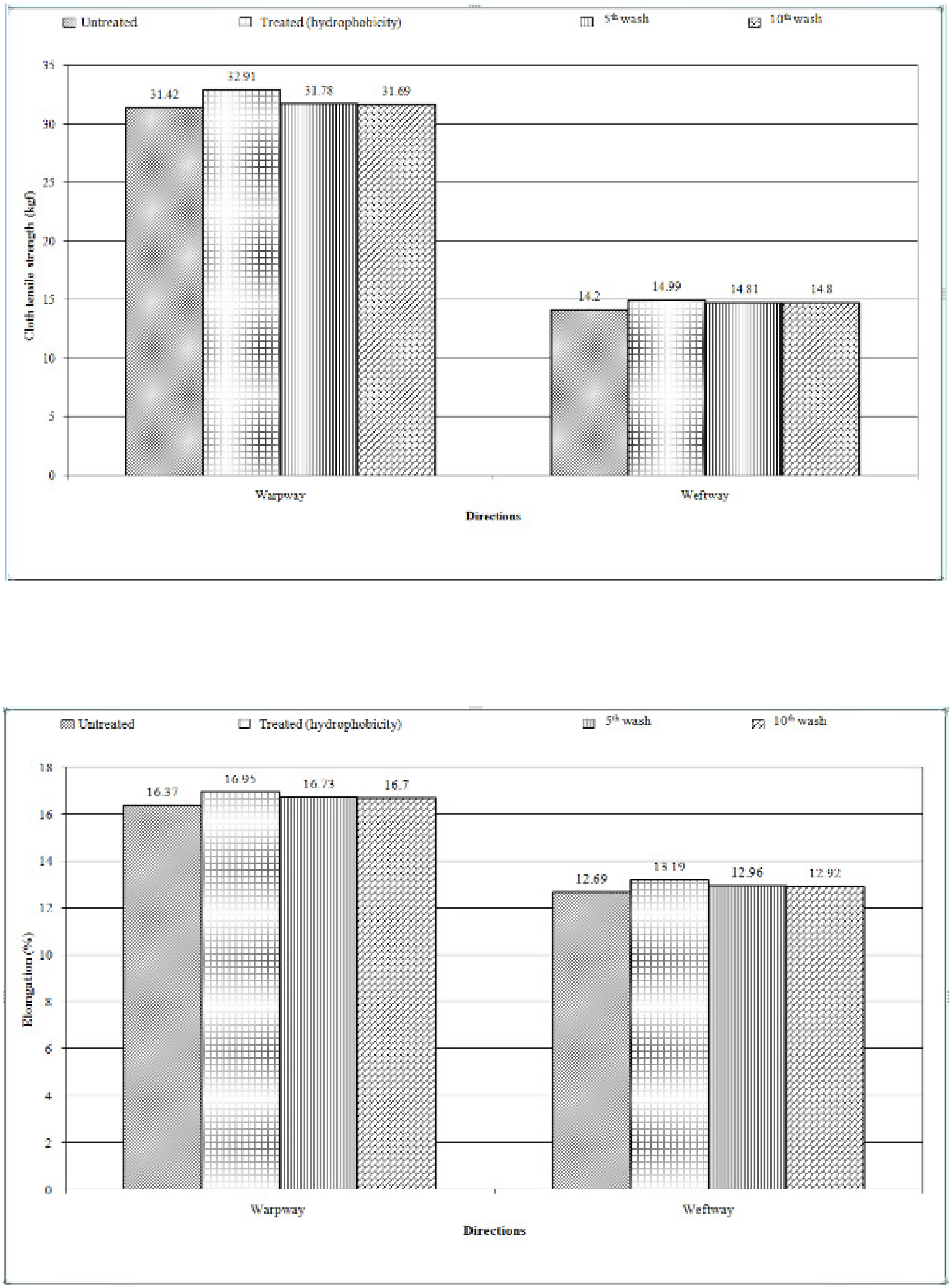


Fig. 2. Cloth tensile strength and elongation percentage of plasma treated

Abrasion resistance refers to the ability of a material to resist surface wear caused by flat, flex and edge rubbing. Table 11 displays the results of cloth abrasion resistance values for flat rubbing of plasma treated as well as washed polyester samples. It is clear from this that after plasma treatment the resistance values of polyester fabric reduced significantly. Further the resistance level of plasma treated samples reduced on multiple washes, too. The number of cycles which determine the level of abrasion resistance is reduced from 65 cycles (control) to 64 cycles (treated); from 64 cycles (treated) to 63 cycles (after 5th wash) and from 64 cycles (treated) to 38 cycles (after 10th wash) and are found to be highly significant at 1 per cent level of significance.

4.4.3.1 Influence of ends per inch, picks per inch, cloth thickness and GSM on tensile strength of plasma treated polyester fabric

Table 12 reveals the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway and weftway tensile strength of plasma treated polyester samples. It is clear from this Table that the ends per inch, picks per inch, cloth thickness and GSM did not show significant influence on the warpway tensile strength at control, treated, 5th and 10th washes.

But, a negative influence of cloth thickness and positive influence of picks per inch on weftway tensile strength of treated sample at 5th and 10th washes respectively was found to be significant at 1 per cent level of significance. The R^2 values were found to be 0.79 and 0.75 respectively, *i.e.* the influence is 79.00 and 75.00 per cent.

4.4.3.2 Influence of ends per inch, picks per inch, cloth thickness and GSM on elongation percentage of plasma treated polyester fabric

Table 13 displays the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway and weftway elongation percentage of plasma treated polyester fabric.

It is observed from this Table that ends per inch and GSM did not influence the corresponding warpway elongation percentage of untreated fabric but picks per inch and cloth thickness did influence the elongation percentage of untreated fabric positively and found to be significant at 5 per cent level of significance with 0.78 R^2 value. Further, the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway elongation percentage of treated sample and after 5th and 10th washes was found to be non-significant.

It is also evident from the same table that the influence of ends per inch, picks per inch, cloth thickness and GSM on weftway elongation percentage at control, treated, 5th and 10th washes appeared to be non-significant.

4.4.3.3 Influence of ends per inch, picks per inch, cloth thickness and GSM on abrasion resistance of plasma treated polyester fabric

Table 14 depicts the influence of ends per inch, picks per inch, cloth thickness and GSM on cloth abrasion resistance of plasma treated polyester fabric.

It is evident from Table that there was negative influence of picks per inch (cloth count weft) and cloth thickness on cloth abrasion resistance of polyester fabric at control and was found to be significant at 5 per cent level of significance.

Table 12. Influence of ends per inch, picks per inch, cloth thickness and GSM on cloth tensile strength of plasma treated polyester fabric

Sl. No	Polyester samples	Variables	Cloth tensile strength (kgf)					
			Warpway			Weftway		
			Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test
1	Untreated	X_1	-0.01	0.007	-1.90^{NS}	-0.01	0.007	-1.73^{NS}
		X_2	0.01	0.01	1.52^{NS}	0.007	0.01	0.73^{NS}
		X_3	1.90	1.28	1.48^{NS}	1.17	1.26	0.92^{NS}
		X_4	-0.002	0.004	-0.61^{NS}	0.0003	0.004	0.07^{NS}
		R^2	0.55			0.43		
2	Treated (hydrophilicity)	X_1	0.01	0.01	1.08^{NS}	0.001	0.005	0.25^{NS}
		X_2	-0.01	0.01	-1.04^{NS}	0.006	0.007	0.87^{NS}
		X_3	-0.55	1.23	-0.45^{NS}	0.34	0.67	0.51^{NS}
		X_4	-0.001	0.005	-0.37^{NS}	-0.0004	0.002	-0.17^{NS}
		R^2	0.33			0.19		
3	5th wash	X_1	-0.007	0.006	-1.05^{NS}	0.003	0.006	0.52^{NS}
		X_2	-0.0003	0.01	-0.03^{NS}	-0.01	0.01	-1.50^{NS}
		X_3	0.72	1.13	0.63^{NS}	-4.25	1.10	-3.86**
		X_4	0.001	0.004	0.24^{NS}	0.005	0.004	1.30^{NS}
		R^2	0.24			0.79		
4	10th wash	X_1	-0.01	0.02	-0.75^{NS}	0.007	0.02	0.34^{NS}
		X_2	-0.007	0.02	-0.37^{NS}	0.07	0.01	3.68**
		X_3	1.59	1.57	1.01^{NS}	-1.15	1.47	-0.78^{NS}
		X_4	0.01	0.02	0.40^{NS}	-0.005	0.02	-0.20^{NS}
		R^2	0.28			0.75		

X_1 = Ends per inch
X_2 = Picks per inch
X_3 = Cloth thickness
X_4 = Cloth GSM
NS – Non-significant
R^2 – Co-efficient of determination
**- Significant at 1 % level of significance

Table 13. Influence of ends per inch, picks per inch, cloth thickness and GSM on elongation percentage of plasma treated polyester fabric

Sl. No	Polyester samples	Variables	Elongation (%)					
			Warpway			Weftway		
			Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test
1	Untreated	X_1	-0.009	0.01	-0.76^{NS}	0.01	0.03	0.30^{NS}
		X_2	0.04	0.01	2.51*	0.03	0.05	0.60^{NS}
		X_3	5.66	2.17	2.60*	3.63	6.09	0.59^{NS}
		X_4	-0.006	0.007	-0.91^{NS}	-0.02	0.02	-1.32^{NS}
		R^2	0.78			0.52		
2	Treated (hydrophilicity)	X_1	-0.009	0.02	-0.38^{NS}	0.02	0.02	0.90^{NS}
		X_2	-0.01	0.03	-0.38^{NS}	-0.02	0.03	-0.50^{NS}
		X_3	-0.12	3.04	-0.04^{NS}	-0.34	3.59	-0.09^{NS}
		X_4	-0.001	0.01	-0.09^{NS}	-0.003	0.01	-0.27^{NS}
		R^2	0.07			0.20		
3	5th wash	X_1	-0.01	0.03	-0.38^{NS}	0.03	0.04	0.79^{NS}
		X_2	0.04	0.07	0.57^{NS}	-0.02	0.08	-0.30^{NS}
		X_3	9.74	6.72	1.44^{NS}	-10.07	8.13	-1.23^{NS}
		X_4	-0.03	0.02	-1.30^{NS}	0.01	0.03	0.64^{NS}
		R^2	0.39			0.25		
4	10th wash	X_1	-0.04	0.05	-0.85^{NS}	-0.07	0.19	-0.37^{NS}
		X_2	0.01	0.04	0.36^{NS}	0.01	0.18	0.08^{NS}
		X_3	5.72	3.57	1.60^{NS}	-5.83	13.89	-0.41^{NS}
		X_4	0.01	0.06	0.24^{NS}	0.13	0.24	0.58^{NS}
		R^2	0.51			0.18		

X_1 = Ends per inch

X_2 = Picks per inch

X_3 = Cloth thickness

X_4 = Cloth GSM

NS – Non-significant

R^2 – Co-efficient of determination

*- Significant at 5 % level of significance

Table 14. Influence of ends per inch, picks per inch, cloth thickness and GSM on cloth abrasion resistance of plasma treated polyester fabric

Sl. No	Cloth abrasion resistance (cycles)				
	Polyester samples	**Variables**	**Co-efficient**	**Standard error**	**t-test**
1	Untreated	X_1	0.53	0.24	2.16^{NS}
		X_2	-0.83	0.35	-2.32*
		X_3	-112.33	42.04	-2.67*
		X_4	-0.06	0.14	-0.47^{NS}
		R^2	0.60		
2	Treated (hydrophilicity)	X_1	-0.20	0.30	-0.64^{NS}
		X_2	0.57	0.41	1.38^{NS}
		X_3	-3.82	37.12	-0.10^{NS}
		X_4	0.06	0.15	0.40^{NS}
		R^2	0.38		
3	5th wash	X_1	-0.09	0.19	-0.48^{NS}
		X_2	0.21	0.36	0.60^{NS}
		X_3	34.09	32.9	1.03^{NS}
		X_4	-0.12	0.12	-1.00^{NS}
		R^2	0.25		
4	10th wash	X_1	-0.48	0.58	-0.83^{NS}
		X_2	-0.02	0.55	-0.04^{NS}
		X_3	116.21	41.6	2.79*
		X_4	0.81	0.71	1.12^{NS}
		R^2	0.67		

X_1 = Ends per inch

X_2 = Picks per inch

X_3 = Cloth thickness

X_4 = Cloth GSM

NS – Non-significant

R^2 – Co-efficient of determination

*- Significant at 5 % level of significance

Further, it was observed that there was influence of GSM on cloth abrasion resistance of treated polyester fabric after 10th wash and is significant at 5 per cent level of significance.

The R^2 value of control and plasma treated sample after 10th wash were found to be 0.60 and 0.67 respectively. In other words, 0.60 and 0.67 per cent of variation in cloth abrasion resistance (dependent variable) is explained by picks per inch and cloth thickness (independent variables) at control and after 10th wash, respectively.

4.4.4 Assessment of plasma treated polyester fabric for hydrophilicity

4.4.4.1 Spray test

Table 15 depicts about water repellency of test sample both at control and treated level and impact of multiple washings on the level of water repellency. The untreated polyester sample showed a rating of 80, which clearly reads as ‘wetting of upper surface at spray points’. But on plasma treatment the rating came down to zero (0), indicating ‘complete wetting of whole upper and lower surface’ of the test sample. Though on multiple washes the rating raised from zero to 50 however, was much lower than the value at control *i.e.* 80. On the whole, it may be stated that the spray test ratings did fall from 80 to zero and gradually elevated again on multiple washes.

4.4.4.2 Wicking length

The ability of fabric to absorb water, especially by a wicking or capillary action, may be observed by timing the rate at which water climbs up a narrow strip of fabric suspended vertically with its lower end clipped into water. The wicking length of polyester test sample at control, on plasma treatment, after 5th and 10th washes is presented in Table 16. It is evident from this Table that the wicking of control sample was absolutely ‘zero’ when observed after 1, 2 and 5 minutes, both in warp and weft directions. But there was wicking in the plasma treated polyester fabric both warpway and weftway, observed right from 1 minute and gradually the level of wicking length increased with increase in time *i.e.* 02.80 cm and 03.50 cm (1 min), 03.60 cm and 04.70 cm (2 min) and 05.30 cm and 06.10 cm (5 min), respectively. However, the wicking was greater in weftway than warpway. As well the wicking speed in the first minute is faster and there after the length of spread gradually slowed down. In other words, the intensity of wicking did not rise proportionately with increase in time.

4.5 Analysis of surface morphology of post-flame retardant (FR) treated cotton and polyester fabrics

Plate 1 and 5 reveals about the surface characteristics of untreated and plasma treated flame retardant cotton fabric; whereas Plate 2 and 6 displays the alteration in surface topography of untreated and plasma treated flame retardant polyester fabric.

It is evident from Plate 5 and 6 that the surface morphology of both cotton and polyester fibres changed significantly after plasma treatment followed by flame retardant finish compared to the morphology of their respective control samples.

Table 15. Effect of laundering on water repellency of plasma treated polyester fabric

Sl. No	Polyester samples	Spray test (ratings)
1	Untreated	80
2	Treated (hydrophilicity)	0
3	5th wash	50
4	10th wash	50

Ratings as per AATCC:

100 : No sticking or wetting of upper surface (ISO 5)
90 : Slight random sticking or wetting of upper surface (ISO 4)
80 : Wetting of upper surface at spray points (ISO 3)
70 : Partial wetting of whole of upper surface (ISO 2)
50 : Complete wetting of whole of upper surface (ISO 1)
0 : Complete wetting of whole of upper and lower surfaces (0)

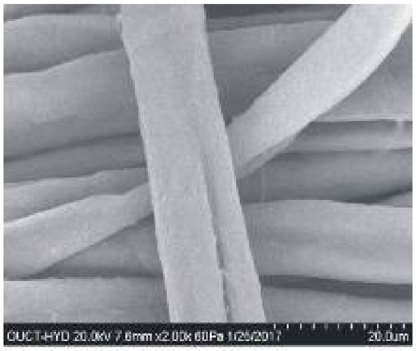
Table 16. Effect of laundering on wicking length of plasma treated polyester fabric

Sl. No	Polyester samples	Wicking length (cm)					
		1 minute		2 minute		5 minute	
		Warpway	Weftway	Warpway	Weftway	Warpway	Weftway
1	Untreated	00.00	00.00	00.00	00.00	00.00	00.00
2	Treated (hydrophilicity)	02.80**	03.50**	03.60**	04.70**	05.30**	06.10**
3	5th wash	04.70**	04.90**	06.50**	06.80**	08.50**	08.80**
4	10th wash	04.60**	04.60**	06.10**	05.80**	08.10**	07.90**

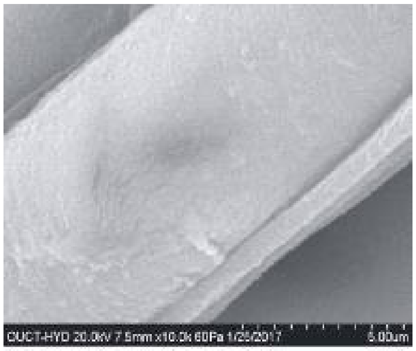
**- Significant at 1 % level of significance

ANOVA TABLE						
S.Em. ±	0.091	0.095	0.028	0.102	0.170	0.144
C.D. (5 %)	0.171	0.180	0.054	0.192	0.321	0.272
C.D. (1 %)	0.250	0.262	0.079	0.280	0.467	0.396
C.V. %	5.241	5.063	1.237	4.120	5.411	4.409

S.Em. ± = Standard error mean C.D. = Critical difference C.V. % = Co-efficient of variance

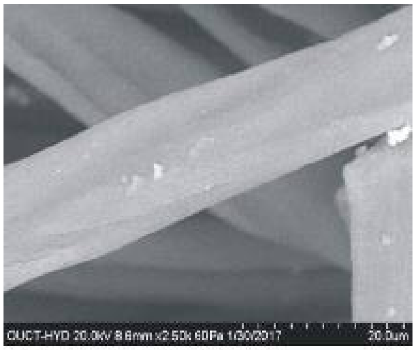


(a) 20 μm

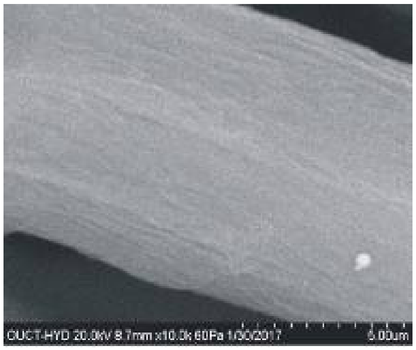


(b) 5 μm

Plate 5: Surface morphology of post-flame retardant (FR) treated cotton fabric



(a) 20 μm



(b) 5 μm

Plate 6: Surface morphology of post-flame retardant (FR) treated polyester fabric

The treated fibres showed microroughness on the surface structure irrespective of entirely different inherent surface characteristics of cotton and polyester fibres.

4.6 Assessment of quality characteristics of post-flame retardant (FR) treated cotton and polyester fabrics

The post-FR treated cotton and polyester fabrics was assessed for various quality characteristics *viz.*, structural- cloth count, cloth thickness, GSM and shrinkage percentage; performance- cloth bending length and crease recovery angle; durable- cloth tensile strength and elongation percentage, cloth abrasion resistance; and functional property - flame retardancy, as that of cotton and polyester fabrics.

4.6.1 Assessment of structural properties of post-flame retardant (FR) treated cotton and polyester fabrics

The influence of plasma treatment on various structural properties *viz.*, cloth count, cloth thickness, GSM and shrinkage percentage is displayed in Table 17; further the effect of multiple washings on these properties is assessed and compared with the values of plasma treated sample.

Cloth count of the woven textile is the number of ends and picks per unit length and was calculated while the fabric is under zero tension and free from folds and wrinkles. Cloth count is influenced by the respective yarn density and fabric set. The ends and picks per inch of cotton and polyester is 92:46 and 80:45, respectively at control but the number increased after plasma treatment followed by flame retardancy finish, and is significant at 1 per cent level of significance; and becomes 93:47 for cotton and 81:46 for polyester. Further, there was increase in the ends and picks per inch of cotton after 5th wash from 01.08 per cent to 02.15 per cent and 02.17 per cent to 02.12 per cent, respectively but remained unchanged thereafter. Whereas there is no change in the cloth count of polyester fabric on subsequent washes.

Cloth thickness is the distance between upper and lower surface of the material, measured under the specified pressure. It is evident from Table 17 that thickness of cotton and polyester fabrics at control was 00.33 mm and 00.25 mm, respectively; which was increased by 00.37 mm (cotton 12.12 %) and 00.28 mm (polyester 12.00 %), after flame retardant finish. Meanwhile, the thickness reduced after 5th wash (cotton 02.70 % and polyester 07.14 %) and the values were highly significant at 1 per cent level of significance. However, it is evident from this Table that further washings did not influence the thickness of both the fabrics, any more.

The findings of cloth weight revealed that there was remarkable increment in GSM of treated cotton and polyester fabrics, from 85.92 g/m^2 to 98.40 g/m^2 and 50.80 g/m^2 to 86.16 g/m^2, respectively. And this increase in GSM is highly significant at 1 per cent level of significance. Further, on 5th and 10th washes, the GSM of cotton fabric reduced by 00.89 and 01.38 per cent but however was higher than control values. Similarly, the GSM of polyester fabric did reduce by 31.68 per cent and 38.07 per cent after 5th and 10th washes, respectively.

Table 17. Effect of laundering on structural properties of post-flame retardant (FR) treated cotton and polyester fabrics

Sl. No.	Samples	Structural properties							
		Cloth count (threads per inch)		Cloth thickness (mm)	Cloth weight (GSM)			Cloth shrinkage (%)	
		Warp	Weft		GSM	Warp (%)	Weft (%)	Warpway	Weftway
	Cotton								
1	Untreated	92	46	00.33	85.92	65.37	34.63	02.54	00.80
2	Treated (Plasma + FR)	93** (01.08)	47** (02.17)	00.37** (12.12)	98.40** (14.53)	64.54	34.46	02.41*	00.67**
3	5th wash	95** (02.15)	48** (02.12)	00.36** (02.70)	97.52 (00.89)	64.51	35.49	01.34**	00.67
4	10th wash	95** (02.15)	48** (02.12)	00.36** (02.70)	97.04* (01.38)	64.50	35.50	01.34**	00.67
	Polyester								
5	Untreated	80	45	00.25	50.80	66.14	33.86	00.80	00.80
6	Treated (Plasma + FR)	81** (01.25)	46** (02.22)	00.28** (12.00)	86.16** (69.60)	65.95	34.05	00.67**	00.67**
7	5th wash	81 (00.00)	46 (00.00)	00.26** (07.14)	58.86** (31.68)	65.93	34.07	00.67	00.67
8	10th wash	81 (00.00)	46 (00.00)	00.26** (07.14)	53.36** (38.07)	65.92	34.08	00.67	00.67

Figures in parenthesis indicate percentages

*- Significant at 5% level of significance

**- Significant at 1% level of significance

Contd...

ANOVA TABLE

	Cloth count (threads per inch)		Cloth thickness (mm)	Cloth weight (GSM)			Cloth shrinkage (%)	
	Warp	**Weft**		**GSM**	**Warp (%)**	**Weft (%)**	**Warpway**	**Weftway**
Cotton								
S.Em. ±	0.142	0.171	0.002	0.874	0.962	0.964	0.086	0.067
C.D. (5 %)	0.129	0.155	0.002	1.173	1.290	1.292	0.115	0.089
C.D. (1 %)	0.173	0.208	0.003	1.616	1.777	1.780	0.159	0.123
C.V. %	0.479	1.142	2.559	2.065	3.323	6.112	10.127	21.295
Polyester								
S.Em. ±	0.368	0.259	0.003	0.984	1.147	0.723	0.067	0.067
C.D. (5 %)	0.334	0.235	0.002	1.320	1.539	0.969	0.089	0.089
C.D. (1 %)	0.448	0.315	0.003	1.819	2.120	1.335	0.123	0.123
C.V. %	1.444	1.788	3.618	3.534	3.890	4.752	21.295	21.295

S.Em. + = Standard error mean

C.D. = Critical difference

CV% = Co-efficient of variance

Further, it is evident from this Table that the contribution of ends is almost $^2/_3$ among the test samples at different levels *i.e.* control, treated and washed samples.

Contraction in the direction of warp and weft refers to 'fabric shrinkage'. Shrinkage above 5 per cent in either direction *i.e.* warp and weft is considered excess and stated as "not desirable". Table 17 displays about the cloth shrinkage of both cotton and polyester fabrics after flame retardant finish. The general observation from this Table is that the warpway shrinkage is greater than its corresponding weftway shrinkage in cotton fabric; whereas the percentage shrinkage of warp and weft yarns in polyester fabric is same. Nevertheless, the shrinkage of control samples (cotton 02.54 % and 00.80 %; Polyester each 00.80 %) was highest compared to other stages of testing. A descending trend of shrinkage is observed in cotton fabric which attained stability after 5th wash. On the contrary, the polyester fabric did not show any shrinkage after plasma treatment (each 00.67 %) *i.e.* the fabric attained dimensional stability after plasma treatment.

4.6.2 Assessment of performance properties of post-flame retardant (FR) treated cotton and polyester fabrics

Cloth bending length is the property of the fabric that depends on the energy required to produce a given bending deformation under its own weight. The construction features affecting the stiffness of a cloth is mainly its nature of fibre, yarn type, yarn count, fabric geometry, cloth weight, cloth thickness and finish applied.

It is evident from Table 18 that the warpway bending path of both cotton and polyester fabric was higher than the respective weftway bending. It is interesting to note that the plasma treated cotton shows decrease in bending length in both warp (02.33 cm) and weft (01.93 cm) compared to the corresponding control values (02.37 cm and 01.95 cm), respectively. This trend of decrease in warpway bending length was observed on 5th and 10th washes (01.95 cm and 01.73 cm, respectively); whereas weftway bending length reduced significantly after 5th wash and further remained unchanged.

On the other hand, polyester fabric showed significant reduction in warpway (05.58 %) and weftway bending length (22.35 %) after plasma treatment. Later, on subsequent washes the values of bending length in both the directions gradually reduced and the values found to be highly significant at 1 per cent level of significance when compared with the values of treated samples.

Crease resistance is that property of the fabric which causes it to recover from folding, deformations that normally occur during its use. The recovery will depend on the time, varying for different fabrics from an instantaneous recovery to a slow disappearance of the crease. All textile materials used in clothing must be flexible and capable of being creased and folded to conform to figure and be comfortable to the wearer. The effect of plasma treatment on crease recovery is narrated in Table 18. It is presented in this Table that the warpway recovery angle is lower than its corresponding weftway angle in both cotton and polyester fabrics, at control. After plasma treatment an increase in recovery angle in both the directions among both the test samples was noticed.

Table 18. Effect of laundering on performance properties of post-flame retardant (FR) treated cotton and polyester fabrics

Sl. No	Samples	Performance properties				
		Cloth bending length (cm)		Cloth crease recovery angle (degree)		
		Warpway	Weftway	Warpway	Weftway	Cloth recovery
	Cotton					
1	Untreated	02.37	01.95	64	76	70
2	Treated (Plasma + FR)	02.33 (01.69)	01.93 (01.03)	82** (28.13)	97** (27.63)	89** (27.14)
3	5th wash	01.95** (16.31)	01.18** (38.86)	79** (03.66)	93** (04.12)	86** (03.37)
4	10th wash	01.73** (25.75)	01.18** (38.86)	68** (17.07)	85** (12.37)	79** (11.24)
	Polyester					
5	Untreated	02.15	01.70	114	120	117
6	Treated (Plasma + FR)	02.03** (05.58)	01.32** (22.35)	115 (00.88)	127** (05.83)	121** (03.42)
7	5th wash	01.78** (12.32)	01.27** (03.79)	110** (04.35)	116** (08.66)	113** (06.61)
8	10th wash	01.73** (14.78)	01.18** (10.61)	105** (08.69)	113** (11.02)	110** (09.09)

Figures in parenthesis indicate percentages

**- Significant at 1 % level of significance

Contd...

ANOVA TABLE

	Cloth bending length (cm)		Cloth crease recovery angle (degree)		
	Warpway	**Weftway**	**Warpway**	**Weftway**	**Cloth recovery**
Cotton					
S.Em. ±	0.040	0.029	0.678	0.891	1.028
C.D. (5 %)	0.048	0.035	0.909	1.195	1.378
C.D. (1 %)	0.066	0.048	1.252	1.647	1.899
C.V. %	4.711	4.637	2.073	2.275	2.842
Polyester					
S.Em. ±	0.041	0.015	2.619	2.736	1.321
C.D. (5 %)	0.050	0.019	3.511	3.669	1.771
C.D. (1 %)	0.068	0.025	4.838	5.055	2.440
C.V. %	5.323	2.833	5.271	5.131	2.565

S.Em. ± = Standard error mean

C.D. = Critical difference

C.V. % = Co-efficient of variance

However, the percentage increase in cotton fabric is higher in warpway (28.13 %) than the corresponding weftway (27.63 %). On the contrary, the weftway recovery percentage (05.83 %) of polyester fabric seems to be higher than the respective warpway recovery (00.88 %), after plasma treatment. But further, significant decrease in the crease recovery angle is observed both warpway (03.66 % and 17.07 %) and weftway (04.12 % and 12.37 %) in cotton fabric; similarly in polyester fabric too, *i.e.* warpway (04.35 % and 08.69 %) and weftway (08.66 %) and 11.02 %) after 5th and 10th washes, respectively in comparison to the respective treated samples. Nevertheless, the cloth crease recovery values of both cotton and polyester fabrics enhanced significantly after plasma treatment (27.14 % and 03.42 %) respectively. But on multiple washes, there was fall in the respective values however these recovery values were found to be significant at 1 per cent level of significance.

4.6.3 Assessment of durable properties of post-flame retardant (FR) treated cotton and polyester fabrics

Effect of laundering on durable properties of FR treated cotton and polyester fabrics is presented in Table 19. It is evident from this Table that the tensile strength and elongation percentage of both cotton and polyester fabric is maximum at control but correspondingly decreased after FR treatment and multiple washes. The warpway and weftway tensile strength of cotton treated fabric was reduced by 03.18 per cent and 05.43 per cent, respectively when compared to its control values (Fig. 3). Meanwhile, a trend of meagre reduction of 00.23 and 01.01 per cent was noticed after 5th wash in warpway and weftway tensile strength, respectively; but finally there was consistency in the strength. It is true that elongation percentage positively supports its corresponding tensile strength. It is evident from Table 19 that there was decrease in the elongation among treated (warp 08.15 % and weft 15.02 %) sample, after 5th wash (warp 01.53 % and weft 00.60 %) and after 10th wash (warp 01.53 % and weft 01.00 %).

Similarly, the evidence on impact of FR finish and multiple washes of plasma treated polyester sample is also presented in Table 19 and Fig. 4. It is very clear from this Table that the weftway tensile strength in general is lower than its warpway strength; so also the percentage elongation, as that of cotton sample.

The reduction in tensile strength of polyester fabric after FR treatment in warpway was 01.59 per cent and that of weftway, 02.54 per cent. However, multiple washes did not affect adversely the tensile strength, in totality. And eventually, though the elongation of treated polyester was reduced by 01.71 per cent (warpway) and 06.15 per cent (weftway) but, however the washings did not show any remarkable reduction. At the end of 10th wash, the decrease in elongation was 00.68 and 00.76 percentages in warp and weft directions.

Abrasion is simply an aspect of wear, tear and is the rubbing away of the component fibres and yarns in a fabric. In general, weakening of the fabric structure is a direct consequence of the break down. The life of any fabric is depends on its resistance to abrasion. The abrasion resistance of the test sample is presented in Table 19. It is clear from this Table that, maximum resistance for abrasion is found in control samples of both cotton and polyester fabric (101 and 65 cycles), respectively.

Table 19. Effect of laundering on durable properties of post-flame retardant (FR) treated cotton and polyester fabrics

Sl. No.	Samples	Durable properties				
		Cloth tensile strength (kgf)		Elongation (%)		Cloth abrasion resistance (cycles)
		Warpway	Weftway	Warpway	Weftway	
	Cotton					
1	Untreated	22.62	09.40	07.85	05.86	101
2	Treated (Plasma + FR)	21.90** (03.18)	08.89** (05.43)	07.21** (08.15)	04.98** (15.02)	55** (45.54)
3	5th wash	21.85** (00.23)	08.80** (01.01)	07.10 (01.53)	04.95 (00.60)	42** (23.64)
4	10th wash	21.82** (00.37)	08.79** (01.12)	07.10 (01.53)	04.93 (01.00)	28** (49.09)
	Polyester					
5	Untreated	31.42	14.20	16.37	12.69	65
6	Treated (Plasma + FR)	30.92** (01.59)	13.84** (02.54)	16.09** (01.71)	11.91** (06.15)	43** (33.85)
7	5th wash	30.89* (00.09)	13.83 (00.07)	16.00 (00.55)	11.87 (00.34)	41 (04.65)
8	10th wash	30.85** (00.23)	13.81 (00.22)	15.98 (00.68)	11.82 (00.76)	40* (06.98)

Figures in parenthesis indicate percentages

*- Significant at 5% level of significance

**- Significant at 1% level of significance

Contd...

ANOVA TABLE					
	Cloth tensile strength (kgf)		Elongation (%)		Cloth abrasion resistance (cycles)
	Warpway	Weftway	Warpway	Weftway	
Cotton					
S.Em. ±	0.017	0.037	0.090	0.173	2.615
C.D. (5 %)	0.026	0.057	0.139	0.267	4.028
C.D. (1 %)	0.036	0.080	0.195	0.374	5.648
C.V. %	0.154	0.828	2.470	6.692	9.246
Polyester					
S.Em. ±	0.018	0.020	0.086	0.174	1.905
C.D. (5 %)	0.029	0.031	0.133	0.269	2.935
C.D. (1 %)	0.040	0.044	0.186	0.377	4.115
C.V. %	0.122	0.296	1.073	2.892	8.032

S.Em. ± = Standard error mean C.D. = Critical difference CV% = Co-efficient of variance

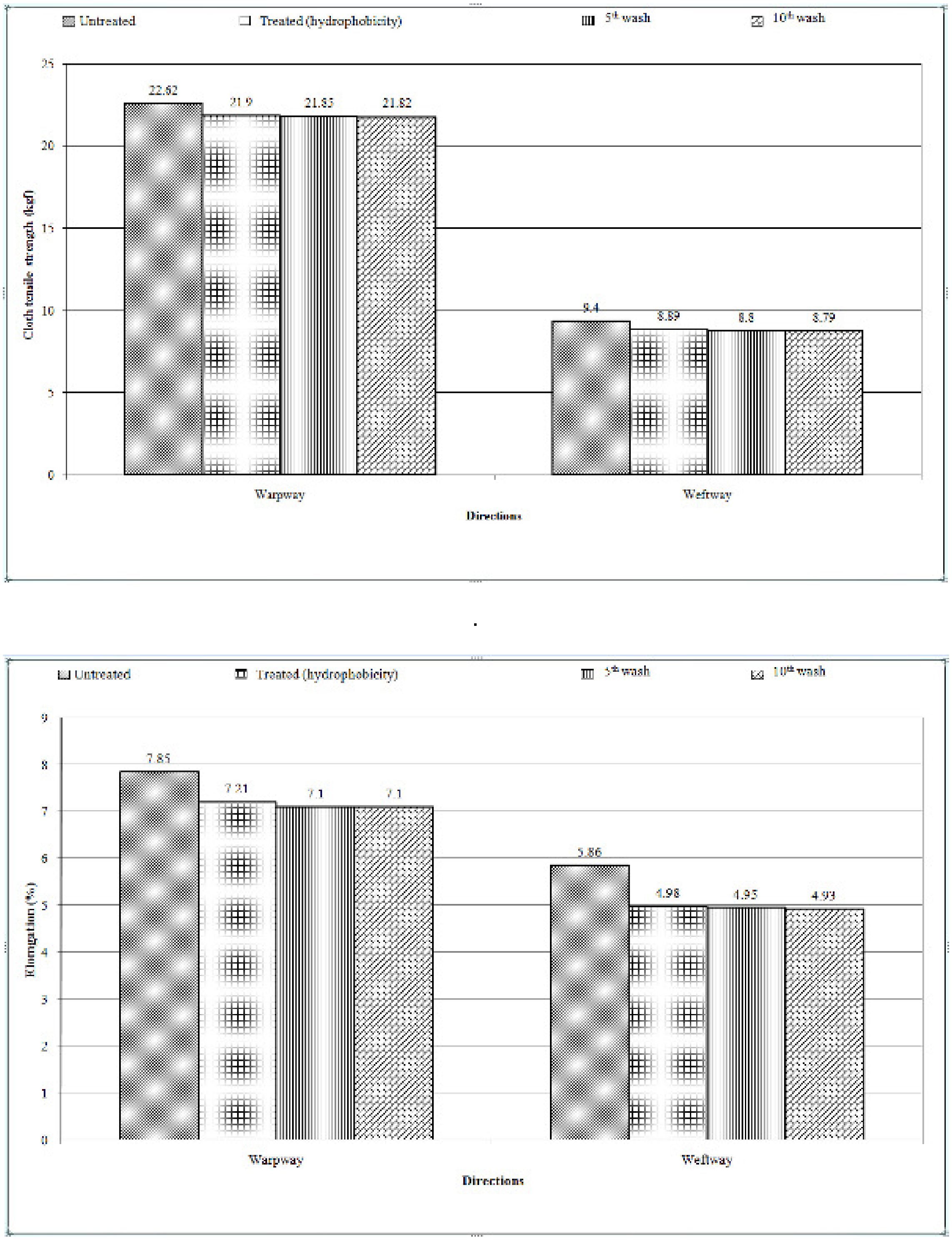


Fig. 3: Cloth tensile strength and elongation percentage of post-flame retardant (FR) treated cotton fabric

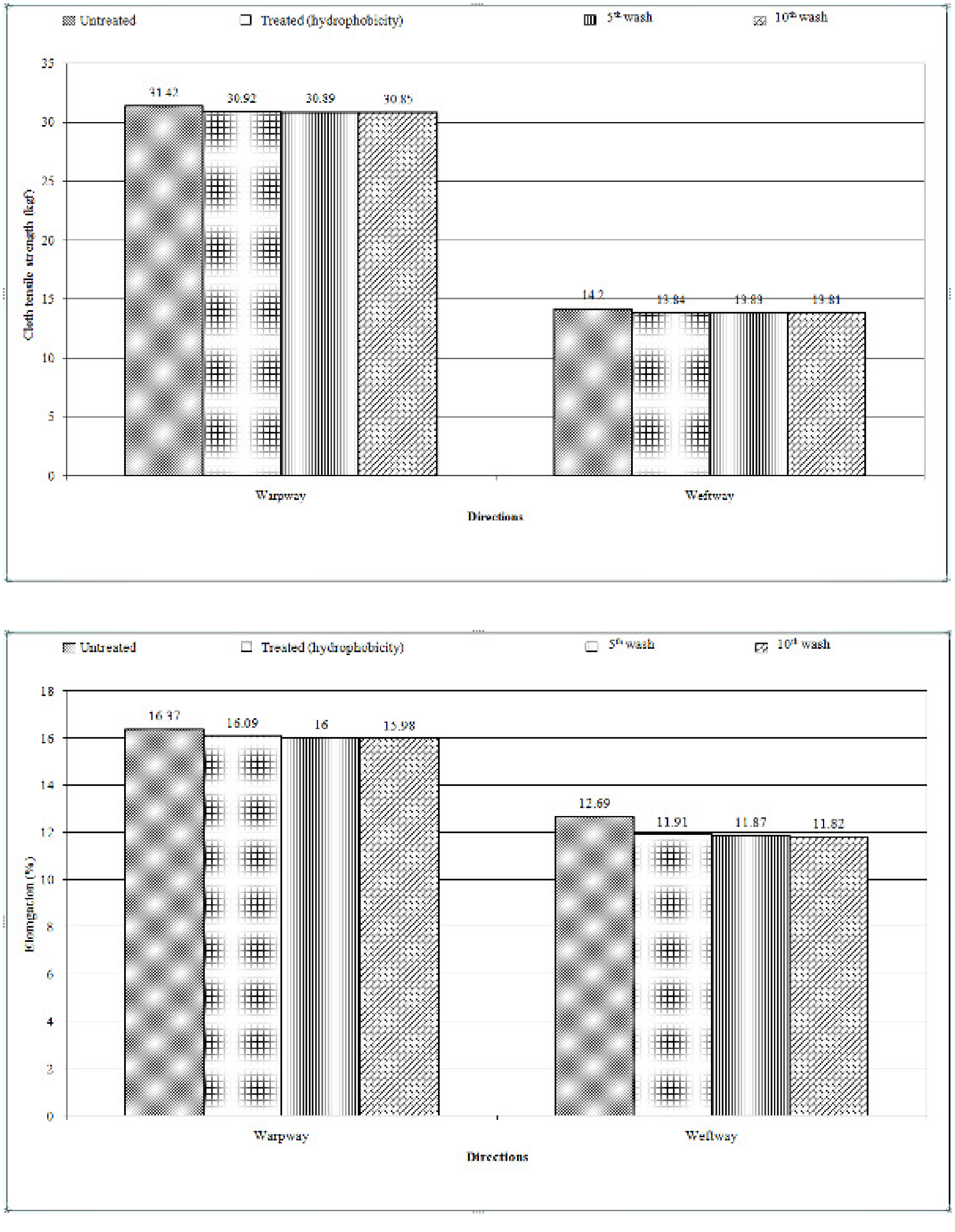


Fig. 4: Cloth tensile strength and elongation percentage of post-flame retardant (FR) treated polyester fabric

After FR treatment the test sample could be worn off at much lower cycles. In other words it may be stated that the abrasion resistance reduced by 45.54 per cent in cotton and 33.85 in polyester. Meanwhile, the values of reduction in abrasion resistance of both post FR treated samples were highly significant at 1 per cent level of significance. However, the multiple washes adversely affected the resistance of cotton fabric for abrasion, as indicated at 5th (23.64 %) and 10th (49.09 %) washes. On the contrary laundering did not affect the abrasion resistance of treated polyester fabric, severely *i.e.* 04.65 and 06.98 per cent after 5th and 10th washes.

4.6.3.1 Influence of ends per inch, picks per inch, cloth thickness and GSM on tensile strength of post-flame retardant (FR) treated cotton and polyester fabrics

Table 20 reveals about the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway and weftway tensile strength of post-flame retardant (FR) treated cotton and polyester fabrics.

It is apparent from Table 20 that influence of ends per inch, picks per inch, cloth thickness and GSM on warpway tensile strength of post-flame retardant (FR) treated cotton found to be non-significant at all stages of testing *i.e.* at control, after plasma treatment, 5th and 10th washes. It is also clear from same Table that the ends per inch and picks per inch, influenced negatively and positively the weftway tensile strength at control and the values are significant at 5 per cent level of significance. A negative impact of picks per inch at 5 per cent level of significance and GSM 1 per cent level of significance is observed on weftway tensile strength of FR treated fabric. The cloth thickness and GSM negatively influenced the weftway tensile strength after 5th and 10th washes but found to be non-significant.

Meanwhile, it is evident from the same Table that the ends per inch and picks per inch did influence the tensile strength of polyester fabric at control and found to be significant at 5 per cent level of significance. But, cloth thickness positively influenced the warpway tensile strength and the values are highly significant with 0.69 R^2 value. The warpway strength of plasma treated polyester fabric was negatively influenced by ends per inch, and is highly significant; whereas picks per inch positively influenced at 5 per cent level of significance. Similarly, there was significant influence of ends per inch (negative) on the warpway tensile strength after 5th wash.

Meanwhile, ends per inch and cloth thickness did influence the weftway tensile strength of FR treated polyester fabric, positively and negatively at 5 per cent and 1 per cent level, respectively after 10th wash; with 0.75 R^2 value *i.e.* the influence is 75.00 per cent. Though there was influence of ends and picks per inch, cloth thickness and GSM on the weftway tensile strength of FR treated polyester at different levels, but found to be significant.

4.6.3.2 Influence of ends per inch, picks per inch, cloth thickness and GSM on elongation percentage post-flame retardant (FR) treated cotton and polyester fabrics

Table 21 indicates the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway and weftway elongation percentage of post-flame retardant (FR) treated cotton and polyester fabrics.

Table 20. Influence of ends per inch, picks per inch, cloth thickness and GSM on cloth tensile strength of post-flame retardant (FR) treated cotton and polyester fabrics

Samples	Variables	Cloth tensile strength (kgf)											
		Cotton						Polyester					
		Warpway			Weftway			Warpway			Weftway		
		Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test
Untreated	X_1	-0.01	0.01	-1.04^{NS}	-0.11	0.04	-2.49*	-0.02	0.006	-3.12*	-0.01	0.007	-1.73^{NS}
	X_2	0.01	0.006	2.18^{NS}	0.07	0.02	2.73*	0.02	0.009	2.56*	0.007	0.01	0.73^{NS}
	X_3	-0.44	0.43	-1.01^{NS}	-1.26	1.83	-0.69^{NS}	3.78	1.15	3.27**	1.17	1.26	0.92^{NS}
	X_4	-0.002	0.003	-0.60^{NS}	0.03	0.01	2.07^{NS}	0.004	0.004	1.11^{NS}	0.0003	0.004	0.07^{NS}
	R^2	0.56			0.73			0.69			0.43		
Treated (Plasma + FR)	X_1	0.001	0.02	0.03^{NS}	-0.01	0.03	-0.36^{NS}	-0.04	0.009	-5.15**	-0.002	0.01	-0.13^{NS}
	X_2	0.04	0.02	1.54^{NS}	-0.11	0.03	-3.01*	0.02	0.01	2.52*	0.0006	0.02	0.02^{NS}
	X_3	-1.11	2.92	-0.38^{NS}	8.02	3.68	2.17^{NS}	-2.49	0.90	-2.76*	-1.89	1.91	-0.98^{NS}
	X_4	-0.001	0.006	-0.27^{NS}	-0.02	0.007	-3.30**	0.00009	0.002	0.04^{NS}	-0.001	0.005	-0.33^{NS}
	R^2	0.44			0.77			0.87			0.21		
5th wash	X_1	0.05	0.02	2.18^{NS}	0.01	0.05	0.28^{NS}	-0.04	0.01	-2.32*	0.03	0.01	1.62^{NS}
	X_2	-0.03	0.02	-1.47^{NS}	0.06	0.05	1.15^{NS}	0.03	0.02	1.78^{NS}	0.01	0.02	0.52^{NS}
	X_3	-0.65	0.79	-0.82^{NS}	-0.18	1.87	-0.10^{NS}	2.58	1.57	1.64^{NS}	1.92	1.66	1.15^{NS}
	X_4	0.007	0.007	1.12^{NS}	-0.005	0.01	-0.34^{NS}	-0.008	0.01	-0.41^{NS}	0.01	0.02	0.91^{NS}
	R^2	0.85			0.37			0.60			0.57		
10th wash	X_1	-0.04	0.02	-1.71^{NS}	0.02	0.06	0.36^{NS}	-0.009	0.004	-2.10^{NS}	0.02	0.009	2.32*
	X_2	-0.009	0.01	-0.47^{NS}	0.10	0.04	2.15^{NS}	0.002	0.006	0.35^{NS}	-0.01	0.01	-0.93^{NS}
	X_3	1.99	2.30	0.86^{NS}	-2.89	5.90	-0.49^{NS}	0.91	0.68	1.33^{NS}	-4.63	1.35	-3.43**
	X_4	0.005	0.004	1.07^{NS}	-0.01	0.01	-1.13^{NS}	-0.00009	0.002	-0.03^{NS}	-0.004	0.004	-0.85^{NS}
	R^2	0.48			0.49			0.53			0.75		

X_1 = Ends per inch
X_3 = Cloth thickness
NS – Non-significant
*- Significant at 5 % level of significance
X_2 = Picks per inch
X_4 = Cloth GSM
R^2 – Co-efficient of determination
**- Highly significant at 1 % level of significance

Table 21. Influence of ends per inch, picks per inch, cloth thickness and GSM on elongation percentage of post-flame retardant (FR) treated cotton and polyester fabrics

Samples	Variables	Elongation (%)											
		Cotton						Polyester					
		Warpway			Weftway			Warpway			Weftway		
		Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test
Untreated	X_1	0.009	0.02	0.38^{NS}	-0.007	0.01	-0.46^{NS}	-0.03	0.01	-2.21^{NS}	-0.02	0.03	-0.71^{NS}
	X_2	-0.0002	0.01	-0.02^{NS}	0.004	0.009	0.52^{NS}	0.05	0.02	2.24^{NS}	0.06	0.05	1.16^{NS}
	X_3	0.24	0.95	0.25^{NS}	0.85	0.61	1.38^{NS}	9.46	2.94	3.21*	12.35	6.78	1.81^{NS}
	X_4	-0.0008	0.008	-0.11^{NS}	-0.001	0.005	-0.20^{NS}	0.001	0.01	0.10^{NS}	0.001	0.02	0.08^{NS}
	R^2	0.05			0.32			0.68			0.50		
Treated (Plasma + FR)	X_1	0.06	0.23	0.28^{NS}	-0.006	0.21	-0.02^{NS}	-0.12	0.08	-1.49^{NS}	0.20	0.26	0.75^{NS}
	X_2	-0.0007	0.24	-0.003^{NS}	0.004	0.21	0.02^{NS}	-0.001	0.09	-0.01^{NS}	-0.10	0.31	-0.32^{NS}
	X_3	28.39	23.99	1.18^{NS}	-27.38	21.45	-1.27^{NS}	-2.06	7.99	-0.25^{NS}	-10.94	26.16	-0.41^{NS}
	X_4	-0.004	0.05	-0.09^{NS}	0.01	0.04	0.36^{NS}	-0.01	0.02	-0.68^{NS}	0.04	0.06	0.68^{NS}
	R^2	0.26			0.28			0.35			0.22		
5th wash	X_1	-0.08	0.16	-0.52^{NS}	0.68	0.53	1.29^{NS}	-0.04	0.10	-0.45^{NS}	0.15	0.15	0.96^{NS}
	X_2	0.09	0.16	0.56^{NS}	-0.10	0.51	-0.19^{NS}	0.05	0.12	0.44^{NS}	0.10	0.18	0.60^{NS}
	X_3	4.82	5.33	0.90^{NS}	-9.06	17.32	-0.52^{NS}	4.42	9.07	0.48^{NS}	6.68	13.65	0.48^{NS}
	X_4	-0.05	0.04	-1.10^{NS}	0.09	0.15	0.61^{NS}	0.01	0.11	0.11^{NS}	0.13	0.17	0.79^{NS}
	R^2	0.50			0.59			0.07			0.28		
10th wash	X_1	-0.01	0.17	-0.09^{NS}	-0.22	0.15	-1.45^{NS}	0.08	0.04	1.99^{NS}	-0.14	0.08	-1.70^{NS}
	X_2	0.11	0.13	0.80^{NS}	-0.06	0.11	-0.55^{NS}	-0.03	0.06	-0.53^{NS}	0.05	0.12	0.45^{NS}
	X_3	-1.66	16.55	-0.10^{NS}	11.02	14.34	0.76^{NS}	-10.56	6.53	-1.61^{NS}	12.90	11.94	1.08^{NS}
	X_4	-0.004	0.03	-0.12^{NS}	0.02	0.03	0.89^{NS}	0.005	0.02	0.25^{NS}	-0.02	0.04	-0.66^{NS}
	R^2	0.11			0.41			0.55			0.47		

X_1 = Ends per inch

X_2 = Picks per inch

X_3 = Cloth thickness

X_4 = Cloth GSM

NS – Non-significant

R^2 – Co-efficient of determination

*- Significant at 5 % level of significance

It is inferred from this Table that the influence of ends per inch, picks per inch, cloth thickness and GSM on warpway and weftway elongation of cotton fabric was observed to be non-significant at control, treated, 5th and 10th washes *i.e.* there was no influence of independent variables *viz.,* ends per inch, picks per inch, cloth thickness and GSM on dependent variables *i.e.* warpway as well as weftway elongation percentage.

Moreover, the influence of cloth count and GSM on warpway and weftway elongation percentage of FR treated polyester fabric was found to be non-significant at control, treated, 5th and 10th washes, except the influence of cloth thickness on warpway elongation percentage of polyester fabric was positive and significant at 5 per cent level of significance; the R^2 value was found to be 0.68 *i.e.* the influence is 68.00 per cent.

4.6.3.3 Influence of ends per inch, picks per inch, cloth thickness and GSM on abrasion resistance post-flame retardant (FR) treated cotton and polyester fabrics

Table 22 narrates about the influence of cloth count (warp and weft), cloth thickness and GSM on cloth abrasion resistance of post-flame retardant (FR) treated cotton and polyester fabrics.

From this Table it is observed that the ends per inch and picks per inch did influence the abrasion resistance of untreated cotton fabric, negatively and positively, respectively and is significant at 5 per cent level of significance, with 0.75 R^2 value, *i.e.* the influence to be 75.00 per cent. Meanwhile, the picks per inch exhibited negative influence on abrasion resistance of treated cotton fabric after 10th washes and is highly significant, with R^2 value to be 0.75. On the contrary the influence of all the independent variables on dependent variable is found to be non-significant.

Similarly the independent variables like ends per inch, picks per inch, cloth thickness and GSM did influence the dependent variable (abrasion resistance) of polyester fabric at control, post-FR treated, 5th and 10th washes is found to be non-significant.

4.6.4 Assessment of post-flame retardant (FR) treated cotton and polyester fabrics for flame retardancy

4.6.4.1 Forty five degree (45º) flame test

Flame retardants are a key component in reducing the adverse effect of fires on people, property and the environment. Flame retardants are added or treated potentially flammable textile materials by means of chemical finishing that can prevent the ignition and propagation of fire by small flames, often causing the degradation of textiles at lower temperatures through the process of dehydration.

It is apparent from Table 23 that the post-FR treated cotton and polyester test samples did not ignite in presence of flame but did show slight char/melt length (3 cm and 2 cm); when compared to their control sample (each 15 cm) with burning time of 6 and 7 seconds respectively. After 5th wash, both the test samples showed a longer burning time *i.e.* cotton, 21 seconds and polyester, 19 seconds which is much greater than control sample. In other words, it may be stated that greater the time, better is the flame retardancy.

Table 22. Influence of ends per inch, picks per inch, cloth thickness and GSM on cloth abrasion resistance of post-flame retardant (FR) treated cotton and polyester fabrics

Sl. No.	Samples	Variables	Cloth abrasion resistance (cycles)					
			Cotton			Polyester		
			Co-efficient	Standard error	t-test	Co-efficient	Standard error	t-test
1	Untreated	X_1	-7.31	2.56	-2.84*	0.26	0.27	0.95^{NS}
		X_2	4.41	1.50	2.93*	-0.61	0.46	-1.32^{NS}
		X_3	-112.96	98.88	-1.14^{NS}	-83.45	56.56	-1.47^{NS}
		X_4	0.98	0.83	1.18^{NS}	-0.02	0.18	-0.15^{NS}
		R^2	0.75			0.34		
2	Treated (Plasma + FR)	X_1	-4.78	5.14	-0.92^{NS}	1.76	2.57	0.68^{NS}
		X_2	6.46	5.19	1.24^{NS}	-3.35	3.06	-1.09^{NS}
		X_3	-655.12	514.66	-1.27^{NS}	402.39	251.51	1.59^{NS}
		X_4	0.25	1.11	0.23^{NS}	-0.56	0.66	-0.85^{NS}
		R^2	0.52			0.53		
3	5th wash	X_1	-2.18	7.45	-0.29^{NS}	0.10	0.67	0.15^{NS}
		X_2	-1.99	7.28	-0.27^{NS}	-0.97	0.78	-1.24^{NS}
		X_3	-207.08	243.01	-0.85^{NS}	-52.59	58.95	-0.89^{NS}
		X_4	1.49	2.16	0.69^{NS}	0.01	0.74	0.01^{NS}
		R^2	0.15			0.27		
4	10th wash	X_1	-1.14	1.08	-1.05^{NS}	0.14	0.17	0.82^{NS}
		X_2	-3.21	0.85	-3.77**	-0.48	0.25	-1.89^{NS}
		X_3	15.67	102.63	0.15^{NS}	10.66	24.67	0.43^{NS}
		X_4	0.36	0.21	1.66^{NS}	0.01	0.08	0.21^{NS}
		R^2	0.75			0.51		

X_1 = Cloth count warp
X_3 = Cloth thickness
NS – Non-significant
*- Significant at 5 % level of significance
X_2 = Cloth count weft
X_4 = Cloth GSM
R^2 – Co-efficient of determination
**- Highly significant at 1 % level of significance

Table 23. Effect of laundering on flame retardancy of post-flame retardant (FR) treated cotton and polyester fabrics

Sl. No.	Samples	Flame retardancy		
		Burning time (sec)	Char/melt length (cm)	Class
	Cotton			
1	Untreated	6	15.00	II
2	Treated (Plasma + FR)	DNI	03.00	I
3	5th wash	21	10.00	I
4	10th wash	20	11.00	I
	Polyester			
5	Untreated	7	15.00	II
6	Treated (Plasma + FR)	DNI	02.00	I
7	5th wash	19	10.00	I
8	10th wash	17	10.00	I

DNI - Did not ignite

According to Consumer Product Safety Commission (CPSC):

Class I : Fabric burning time more than 7 seconds
Class II : Fabric burning time between 4 - 7 seconds
Class III : Fabric burning time less than 4 seconds

Although, the burning time of both test samples reduced after 10th wash (cotton, 20 seconds and polyester, 17 seconds) was much encouraging, compared to control sample. Further it was observed that, there was increase in the char length of FR treated cotton sample and found to be 10 cm and 11 cm after 5th and 10th washes. Similarly, the melt length of polyester did enhance and read as each 10 cm after 5th and 10th washes.

5. DISCUSSION

The results of the present study on ‘Ecofriendly functional finish for textile materials’ are discussed under the following headings:

- 5.1 Analysis of surface morphology of plasma treated cotton fabric
- 5.2 Assessment of quality characteristics of plasma treated cotton fabric
  - 5.2.1 Assessment of structural properties of plasma treated cotton fabric
  - 5.2.2 Assessment of performance properties of plasma treated cotton fabric
  - 5.2.3 Assessment of durable properties of plasma treated cotton fabric
  - 5.2.4 Assessment of plasma treated cotton fabric for hydrophobicity
    - 5.2.4.1 Spray test
    - 5.2.4.2 Wicking length
- 5.3 Analysis of surface morphology of plasma treated polyester fabric
- 5.4 Assessment of quality characteristics of plasma treated polyester fabric
  - 5.4.1 Assessment of structural properties of plasma treated polyester fabric
  - 5.4.2 Assessment of performance properties of plasma treated polyester fabric
  - 5.4.3 Assessment of durable properties of plasma treated polyester fabric
  - 5.4.4 Assessment of plasma treated polyester fabric for hydrophilicity
    - 5.4.4.1 Spray test
    - 5.4.4.2 Wicking length
- 5.5 Analysis of surface morphology of post-flame retardant (FR) treated cotton and polyester fabrics
- 5.6 Assessment of quality characteristics of post-flame retardant (FR) treated cotton and polyester fabrics
  - 5.6.1 Assessment of structural properties of post-flame retardant (FR) treated cotton and polyester fabrics
  - 5.6.2 Assessment of performance properties of post-flame retardant (FR) treated cotton and polyester fabrics
  - 5.6.3 Assessment of durable properties of post-flame retardant (FR) treated cotton and polyester fabrics
  - 5.6.4 Assessment of post-flame retardant (FR) treated cotton and polyester fabrics for flame retardancy
    - 5.6.4.1 Forty five degree (45º) flame test

5.1 Analysis of surface morphology of plasma treated cotton fabric

Alteration in surface topography of cotton fabric after plasma treatment to induce hydrophobicity is clearly evident from Plate 2 when compared with untreated sample presented in Plate 1. The smooth surface of cotton has changed to rough texture on plasma treatment and is due to physical abrasion; which is a predominant reaction of plasma that induced a distinct surface morphology to the substrate. The action of helium gas in ablation / surface etching proposed to be the prime factor contributing to the surface hydrophobicity (Tsoi *et al.,* 2011). Moreover, a thin layer of monomer (HMDSO) covers the entire fibre and characterized by a globular structure somewhat similar to bumping structure of lotus leaf (Twardowski *et al*., 2012).

5.2 Assessment of quality characteristics of plasma treated cotton fabric

The plasma treated cotton fabric was assessed for various quality characteristics *viz*., structural - cloth count, cloth thickness, GSM and shrinkage percentage; performance - cloth bending length and crease recovery angle; durable- cloth tensile strength and elongation percentage, cloth abrasion resistance; and functional property - hydrophobicity.

5.2.1 Assessment of structural properties of plasma treated cotton fabric

Effect of laundering on structural properties *i.e.* cloth count, cloth thickness, cloth weight and shrinkage percentage of plasma treated cotton sample is presented in Table 1. It is essential to understand that all the entities of fabric geometry are dependent on each other; and any change in one entity invariably influences the other entity may be positively or negatively, ultimately that brings change in the behavior of the fabric.

Threads per unit inch is nothing but the cloth count, clearly indicates that ends/inch is almost the double of picks/inch and therefore the percentage of warp is $^{2}/_{3}$ in comparison to weft, $^{1}/_{3}$ in a known dimension of test samples. However, there was not much variation (increase) in the ends and picks per inch of plasma treated sample. This is mainly due to the fact that, plasma is a dry finish which does not involve any kind of liquid application. In fact cotton does shrink when come in contact with water, due to relaxation, which is evident through 5th and 10th washes. There was slight increase in the ends/inch (01.07 %) after 5th wash may be due to relaxation of warp yarns during laundering. However, there was no change in cloth count after 10th wash which indicates that the fabric has attained dimensional stability by 5th wash and further laundering has not lead to any more shrinkage. In fact quicker the dimensional stability better is the fabric performance.

Cloth thickness in a woven fabric is total thickness of warp and weft at intersections. The fabric thickness was higher at control and reduced after plasma treatment (05.88 %), due to etching phenomenon of fabric surface which involves removal of thin upper layer as well as some parts of amorphous region during treatment.

The protruding fibres were completely etched, thus leading to thinning of the fabric. But the plasma treated fabric was post treated with the monomer hexamethyldisiloxane (HMDSO) to induce hydrophobicity to cotton fabric, which lead to slight increase in the thickness and this may be attributed to the layer of monomer formed during hydrophobic finishing as well as progressive consolidation of yarns due to shrinkage. These results are supported by Chinnammal and Arunkumar (2014) who displayed that there was slight increase in the thickness among all the post dyed samples irrespective of gases, treatment time and stage of dyeing.

It is evident from Table 1 that the GSM is maximum at control but reduced after plasma treatment (03.54 %) and this loss of weight is due to etching of fabric surface; and this result is supported by decrease in the values of cloth thickness presented in the same Table. In other words, it may be stated that cloth thickness and corresponding GSM are directly proportional.

Maximum shrinkage both warpway and weftway is observed at control and is called 'relaxation shrinkage' where the cotton yarns held at tension while weaving tend to relax when come in contact with water. This being the initial shrinkage, is always greater than progressive shrinkage. A decreasing trend in warpway shrinkage indicates gradual attainment of dimensional stability. In fact the fabric attained weftway dimensional stability at an early stage *i.e.* before laundering compared to warpway stability. And this is mainly due to warp yarns which are held at greater tension than weft yarns while weaving.

Hence, the null hypothesis set for the study that laundering does not alter the structural properties of plasma treated fabrics is rejected, since, ends per inch, cloth thickness, GSM and cloth shrinkage altered significantly on subsequent washes.

5.2.2 Assessment of performance properties of plasma treated cotton fabric

Bending length of the fabric is one of the important performance properties describes the pliability and hand feel characteristics. There is reduction in the bending path of the treated sample in both the directions, which may be due to change in the morphology of the fabric due to etching, removal of the size from the fabric, reduction in the thickness and corresponding GSM. These results are supported by the study conducted by Chinnammal and Arunkumar (2014) who indicated that post dyed samples were soft and pliable compared to pre dyed samples. In other words the atmospheric pressure plasma treatment has reduced the stiffness of the cotton fabric.

The values of crease recovery angle presented in Table 2 clearly indicated that the angle of recovery was relaxed after plasma treatment and is mainly due to etching of the surface and partial removal of size present on the cloth surface if any by 'cleaning of the surface'. Due to combined effect of 'etching' and 'cleaning', the test sample showed an improvement in recovery angle. In other words plasma treatment improved the resiliency of the cotton fabric, one of the most desirable comfort features.

While assessing the impact of laundering on plasma treated test sample, it is found that there was further improvement in the recovery angle both warpway and weftway and ultimately cloth recovery angle and these results are supported by the bending length values of corresponding yarn directions.

In fact cloth stiffness and cloth crease recovery angle are inversely proportional *i.e.* greater the bending length lower is the recovery angle. Meanwhile, the structural properties of the test sample (Table 1) influenced the performance properties; *i.e.* the gradual decrease in cloth thickness and GSM after 5th and 10th washes contributed to attain greater resiliency of plasma treated fabrics. These results are supported by the study conducted by Chinnammal and Arunkumar (2014) on “Effect of plasma treatment on plain woven cotton fabric” where cloth thickness and GSM are directly and cloth stiffness is inversely influence the recovery angle of the cotton fabric.

Therefore, the null hypothesis set for the study that plasma treatment alters the inherent characteristics of cotton fabric is rejected. Since, it does not alter the inherent properties of cotton fabric except the morphology of the fibre, (substrate).

5.2.3 Assessment of durable properties of plasma treated cotton fabric

The tensile strength and elongation percentage of plasma treated cotton samples presented in Table 3 indicated to be higher compared to control sample. This may be due to the frictional properties of fibres because of plasma sputtering action. This result is in line with the study conducted by Kan and Lam (2013) who stated that the increase in cotton strength after plasma treatment is due to enhancement of inter yarn and inter fibre friction caused by etching effect of plasma. Further on washing, both tensile strength and elongation declined due to removal of amorphous region during plasma treatment. Cotton is a fibre which gains strength when wet due to improvement in alignment of its long polymer in amorphous region, but impact of plasma on the amorphous region declined its property to get strengthen on washing. Therefore, influence of cloth count, cloth thickness and GSM found to be significant on tensile strength after 10th wash. Hence, the null hypothesis set for the study laundering does not alter the durable property of plasma treated fabrics is rejected.

A perusal of Table 3 showed a decreasing trend of cloth abrasion resistance of plasma treated cotton on multiple washes compared to control. This reduction may be basically due to complete removal of impurities, protruding ends from fabric surface not only during treatment as well as while washings. Karahan *et al.* (2009) revealed that hairiness of both wool and cotton fabric was significantly reduced by air and argon plasma treatments.

This result is also supported by the study conducted by Bhat *et al.* (2011) where it was clearly indicated that the protruding fibres become fragile due to etching and thus easily breakable.

Hence, the null hypothesis set for the study that laundering does not alter the durable properties of plasma treated fabrics is rejected as the treated cotton show significant reduction in abrasion resistance on subsequent washings.

5.2.4 Assessment of plasma treated cotton fabric for hydrophobicity

5.2.4.1 Spray test

The impact of laundering on water repellency of plasma treated cotton fabric and control sample is presented in Table 7, which gives a clear picture about treated and untreated test samples. Cotton basically is hydrophilic in nature and absorbs moisture readily when come in contact with.

And this is proved by the spray test rating scale which reads as ‘zero’ *i.e.* ‘complete wetting of upper and lower surface’. On the contrary the plasma treated cotton was rated as 100 which expresses as ‘No sticking or wetting of upper surface’; this clearly indicates that the treated sample has acquired a new dimension of ‘water repellency’. However, the level of water repellency gradually reduced after multiple washes and is indicated as 70 after 5th wash *i.e.* ‘partial wetting of whole of upper surface’ and 70 to 50 after 10th wash *i.e.* somewhat ‘partial to complete wetting of upper surface’. This indicates that, the level of water repellency gradually reduced after multiple washes; in other words there is shift from ‘water repellency’ to ‘partial hydrophilicity’ on subsequent washes. Therefore, it may be stated that though plasma finish followed by monomer treatment did turn the cotton from hydrophilicity to water repellency and this change over is not permanent. Furthermore, the plasma treatment does not change the inherent inbuilt bulk characteristics of cotton but the change is restricted to morphology only. These results are supported by the study conducted by Tsoi *et al.* (2011) that physical morphological alteration is a crucial function that contributes to surface hydrophobicity of the substrate. Hence, the null hypothesis set for the study that plasma treatment alters the inherent characteristics of cotton fabric is rejected.

5.2.4.2 Wicking length

Vertical wicking test method is used to evaluate the ability of vertically aligned fabric specimen to transport liquid along and/or through them, and is applicable for woven, knitted and nonwoven fabrics.

From Table 8, it is evident that the wicking length is maximum at control in both warpway and weftway directions compared to plasma treated samples after 5th and 10th washes. This clearly indicates that the contact angle between water and surface is less than 90º hence, it may be inferred that the fabric is hydrophilic, because the water is attracted to the surface and spreads out. In a fibre this may progress to wicking which is driven by capillary action or capillarity. Capillary forces drive the liquid in capillary spaces thus develops greater affinity between the liquid and the surface and the liquid attempts to spread across the surface. Capillary rise in a fabric can be considered as the effect of capillary rise between the yarns within a fabric and is termed macro-capillary; the capillary rise between the fibres within a yarn may be termed as micro-capillary; and both contribute to capillary rise in the fabric. Capillary wicking is spontaneous and relies on the presence of a porous material and a wettable surface.

The plasma treated sample exhibited a total hydrophobic nature by expressing wicking length as ‘zero’. And these results are supported by the values of ‘Spray Test Rating Scale’ presented in Table 7, where the rating of plasma treated cotton fabric was 100, meant ‘No sticking or wetting of upper surface’. Hydrophobicity can be expressed in terms of contact angle, which is greater than 90º (obtuse angle).

Zhang *et al.* (2003) stated that a post treatment at a high temperature was conducive to enhance the hydrophobicity and the recovery of water-repellency after multiple washes is possible, mainly due to some physical and chemical changes in the fabric after plasma treatment.

Since, the low temperature plasma treatment was the method adopted in the present study there is possibility of reversible hydrophilicity of plasma treated cotton fabric to some extent after multiple washes, was evident. And this fact is proved by the wicking length of plasma treated cotton sample after 5th and 10th washes. Though there is slight wicking due to capillary forces the length is much shorter than the wicking length of control sample, which indicates that the treated sample have retained the property of water-repellency, if not hydrophobicity.

5.3 Analysis of surface morphology of plasma treated polyester fabric

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

It is evident from Plate 4 that oxygen plasma is efficient to convert hydrophobic polyester into hydrophilic due to its sputtering action on the surface of the substrate. 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 treatment but also in the subsequent process of washings. Thus, resulting 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).

5.4 Assessment of quality characteristics of plasma treated polyester fabric

The plasma treated polyester fabric was assessed for various quality characteristics *viz.*, structural - cloth count, cloth thickness, GSM and shrinkage percentage; performance- cloth bending length and crease recovery angle; durable- cloth tensile strength and elongation percentage, cloth abrasion resistance; and functional property -hydrophilicity.

5.4.1 Assessment of structural properties of plasma treated polyester fabric

It is apparent from Table 9, that the ends per inch of the test sample is greater than picks per inch, which indicates that the compact alignment of warp yarns, compared to weft. However, there was no variation in the ends and picks per inch of plasma treated sample and is mainly due to the fact that plasma is a dry treatment, which does not involve any water application; further polyester has very little affinity towards water absorption. But oxygen plasma application implies attachment of more number of polar groups into the etched fibre surface. Therefore, on washing the polyester fabric was able to shrink which lead to increase in the cloth count. Nevertheless, by the end of 10th wash, the test sample had attained dimensional stability, expressing its inherent performance property. Hence, the null hypothesis set for the study that laundering does not alter the structural properties of plasma treated fabrics is rejected.

Cloth thickness was found to be higher in the untreated sample (00.25 mm) which reduced about 04.00 per cent after oxygen plasma treatment. This may be because of the electron and ion bombardment on the fibre surface that leads to etching phenomenon. It occurs by direct removal of a very thin layer, as well as by the indirect method of ions with the molecules of material (Bhat *et al.,* 2011). Thus the results of present study is in contrast with the study conducted by Chinnammal and Arunkumar (2014) which displayed that there is light increase in thickness in all plasma treated samples irrespective of gases, timing and stage of dyeing (Table 9).

It is evident from Table 9, that after plasma treatment the GSM of polyester fabric reduced by 01.73 per cent compared to control. 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 9 showed a trend of shrinkage both warpway and weftway at control, may 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. Whereas after plasma treatment there was no shrinkage, which clearly indicated that plasma treated sample exhibited good dimensional stability. But there was an increase in the threads per unit length (cloth count) after 5th wash and is mainly due to cloth shrinkage of treated sample. This is the evidence of hydrophilicity of polyester fabric induced by plasma treatment. However, these values are found to be significant at 1 per cent level of significance. Hence, the null hypothesis set for the study that laundering does not alter the structural properties of plasma treated fabrics is rejected, *i.e.* the structural properties *viz*., cloth count, GSM and cloth shrinkage of plasma treated polyester fabric were altered to some extent after multiple washes.

5.4.2 Assessment of performance properties of plasma treated polyester fabric

Table 10 narrates about the reduction in bending length of test sample after plasma treatment and further reduced on multiple washes. It may be stated that the polyester fabric at control, exhibited longer bending path compared to treated and washed samples. In other words longer the bending path, stiffer the fabric is. Due to etching of fibre surface the fabric became more soft, pliable and resilient. These results are supported by the study conducted by Chinnammal and Arunkumar (2014) who stated that pre dyed samples had greater stiffness 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. Oxygen plasma treated sample showed increase in crease recovery angle.

The rough surface of polyester fabric developed due to plasma treatment created more contact points within the fibres and yarns microscopically, resulting into enhanced inter-yarn and inter-fibre friction. 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.

5.4.3 Assessment of durable properties of plasma treated polyester fabric

The values of tensile strength and elongation percentage of plasma treated polyester fabric displayed in Table 11 were higher compared to the corresponding control sample. 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 roughening effect created 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. In fact, the tensile strength of polyester fabric remains unaltered, when wet due to its inherent property. But, when the plasma treated samples were subjected to multiple washings, there was degradation in both tensile strength and elongation percentage basically due to the introduction of polar groups to make the fabric hydrophilic. During this action there was thickness loss and was attributed to dehairing. Further, loss in cloth thickness negatively influenced the tensile strength and elongation. Therefore, the influence of cloth thickness and picks per inch on weft tensile strength of plasma treated polyester found to be significant after 5th and 10th washes, respectively.

Hence, the null hypothesis set for the study that laundering does not alter the durable properties of plasma treated fabrics is rejected *i.e.* laundering does affect the durable properties of plasma treated polyester fabric.

Abrasion is the physical destruction of fibres, yarns and fabric resulting from rubbing of textile surface over other surface. It is observed from Table 11 that oxygen plasma treated polyester sample showed low abrasion resistance value (64 cycles) compared to untreated sample (65 cycles). This may be due to direct removal of very thin layer of substrate by etching process which reduced the percentage of projected and protruded fibres that were fragile. Further due to dehairing, there was reduction in cloth thickness as well GSM. Thinner the fabric, lower the abrasion resistance and vice-versa. Karahan *et al.* (2009) also stated that due to physical alterations of fabric surface, there was reduction in the abrasion resistance.

On laundering, the treated sample showed a gradual reduction in abrasion resistance value. This may be attributed to further wear and tear of surface fibres, a common phenomenon observed after multiple washings. However, the resistance for abrasion was less by only one cycle in plasma treated sample compared to control. In fact both the values may be considered as same since the values expressed the inbuilt strength of polyester fabric. Therefore, the null hypothesis set for the study that plasma treatment alters the inherent characteristics of polyester fabric is rejected.

5.4.4 Assessment of plasma treated polyester fabric for hydrophilicity

5.4.4.1 Spray test

Hydrophobicity of fabric is the property to repel water from its surface. It is evident from Table 15 that the untreated polyester fabric showed spray test rating of 80 which means the fabric was wet at spray points. But after plasma treatment the polyester fabric was completely wet from both upper and lower surface, indicating it to be hydrophilic. The hydrophobicity of polyester fabric was converted to hydrophilicity, which may be due to surface modification, etching, creation of rough and grooved surface, better inter spaces between fibres and yarns and favorable surface morphology for moisture to seep into. After multiple washes, the level of hydrophilicity did not remain at 'zero' but slightly reverted one step towards hydrophobicity *i.e.* spray test rating - 50 which indicates 'complete wetting of whole of upper surface'. However both 'zero' and '50' ratings indicate hydrophilicity with different levels of wetting. These results are in line with the study conducted by Joshi *et al*. (2015) who stated that oxygen plasma treated sample shows greater spreading of water on the fabric when subjected to spray testing.

5.4.4.2 Wicking length

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.

It is revealed from Table 16 that, oxygen plasma treated polyester 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 up to 5th wash and there after declined. This reveals that up to 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.

5.5 Analysis of surface morphology of post-flame retardant (FR) treated cotton and polyester fabrics

Plate 1 and 3 showed the morphological structure of the untreated cotton and polyester at 20 and 5 µm level. On one hand, cotton fibre showed a twisted ribbon-like structure caused by spiraling of cellulose fibrils. Conversely on the other hand, polyester fibre observed with smooth tube like structure. But after plasma treatment the morphology of both the fibres changed due to etching thus creating surface roughness. Formation of continuous microcracks and pores parallel to fibre axis and fibre surface was severely eroded. Moreover, high deposition of finishing agents, resulting from application of FR finish, slightly acid in nature could be observed on the thickened and wrinkled fibre surface (Lam *et al.*, 2011).

5.6 Assessment of quality characteristics of post-flame retardant (FR) treated cotton and polyester fabrics

The post-flame retardant (FR) treated cotton and polyester fabrics was assessed for various quality characteristics *viz.*, structural - cloth count, cloth thickness, GSM and shrinkage percentage; performance - cloth bending length and crease recovery angle; durable - cloth tensile strength and elongation percentage, cloth abrasion resistance; and functional property - flame retardancy.

5.6.1 Assessment of structural properties of post-flame retardant (FR) treated cotton and polyester fabrics

Various structural properties of test samples like cloth count, cloth thickness, cloth weight and cloth dimensional stability of plasma treated cotton and polyester fabrics were assessed after flame retardant finish and the values were compared with that of control samples. Further, treated test samples were subjected to multiple washes and assessed as well as compared after 5th and 10th washes with treated one.

Among the structural properties the most focal feature is threads per unit area synonymously referred to cloth count, comprises of ends and picks per inch. These threads provide basic/foundation structure to the cloth that ultimately decides its end use on the basis of GSM and thickness. It is noted that after plasma treatment followed by flame retardancy finish ends and picks of both the fabrics increased in number which is mainly due to relaxation shrinkage and alteration of fibre topography. The sputtering action of plasma led to formation of microgrooves on the surface of fibre irrespective of their specific inherent characteristics. Moreover, fixation of flame retarding agent onto these grooves altered the overall morphology and structure of fibres, thus enhanced the cloth count of both cotton and polyester fabrics significantly. Helium along with oxygen plasma added more number of polar groups because of which cloth count of cotton again increased after 5th wash and thereafter remained constant. Whereas ends and picks per inch of polyester fabric remained unaltered even after subsequent washes. This opponent behavioral change of cotton and polyester on subsequent washes is basically due to the opposite inherent properties.

Therefore, the modification is restricted only to the upper most layer of the substrate and did not affect their respective bulk properties (Sparavigna, 2008). Hence, the null hypothesis set for the study that plasma treatment alters the inherent characteristics of cotton and polyester is rejected.

As far as cloth thickness was considered a remarkable increase in thickness of both the fabrics is noticed over control after plasma treatment followed by flame retardancy finish. This is mainly due to the deposition of FR agent on the abraded region of fibre surface. However, up to five washings, there was possibility of release of FR agent to some extent that ultimately leads to the reduction in cloth thickness values of both test samples. This may be apprehended that some per cent of FR agent was superficially held on the fabric surface during padding mangle and was released from the substrate during multiple washes. However, further laundering did not show any thickness loss which indicated the sustainability of FR finishing. These results are in line with the study conducted by Kan *et al.* (2011) where it was stated that FR coating was able to react directly with fabric through its N-methylol group to form a cross linked polymeric network with the bonding being highly resistant to hydrolysis during multiple home washings.

As there is increase in the yarn density as well as cloth thickness on post FR treatment, the GSM of the cotton and polyester test samples automatically got elevated. The GSM of control increased remarkably on post FR finishing and is mainly due to increase in yarn density and deposition of FR agent on the etched fibre surface, formed due to sputtering action of highly ionized plasma. However, on washing the GSM values were reduced corresponding to the values of cloth thickness. The results were supported by Bhat *et al.* (2011) where it was stated that the amount of material deposited, gradually increased the weight of fabric, during plasma treatment.

In general the warpway shrinkage was relatively greater than weftway. It is evident from Table 17 that maximum shrinkage was observed in both cotton and polyester at control, which further gradually reduced to maximum and attained the stability. This is because the first shrinkage that occurs is referred to as relaxation shrinkage where the warp yarns relax from the tension held during weaving process. The first shrinkage is always maximum; thereafter the shrinkage if any is always in less percentage and is progressive, hence termed as progressive consolidation which finally leads to dimensional stability. Due to different inherent properties of cotton and polyester fabrics the rate of shrinkage varied. Moreover, these results are supported with the corresponding values of thread per inch *i.e.* cloth count of respective fabrics (Table 17).

Hence, the null hypothesis set for the study that laundering does not alter the structural properties of plasma treated fabrics is rejected *i.e.* there is change in the threads per unit area, cloth thickness, cloth GSM and shrinkage percentage of plasma treated fabrics after plasma and FR finishing.

5.6.2 Assessment of performance properties of post-flame retardant (FR) treated cotton and polyester fabrics

On post fire retardant finish there is not much alteration in the bending length values of the test samples.

The cloth stiffness reduced due to the sputtering action of plasma and deposition of flame retarding material into the microgrooves induced some percentage of stiffness on to the fabrics. This result is in line with the study conducted by Chinnammal and Arunkumar (2014) who stated that all the plain woven treated samples have greater stiffness than their originals except the post dyed samples. Moreover, during washing there is possibility of removal of some percentage of FR agents that probably reduced the cloth stiffness of the treated fabrics irrespective of their original bulk properties, thus making the test samples soft and pliable to some extent. Further, these results are also supported by the study conducted by Lam *et al*. (2014) who reported that increased inter yarn friction due to the etching action of plasma enhances the stiffness of fabrics subjected to flame retardant treatment.

Cloth crease recovery is complimentary to cloth bending length and describes the resiliency of the test samples. The results indicated in Table 18, clearly showed that after post FR treatment, the crease recovery angle of both cotton and polyester fabrics increased but on multiple washes, the values fall down. It means the level of stiffness reduced on washing, making the test samples more pliable. This may be due to presence of FR agent within the abraded fibre area, that in turn would probably restricted the molecular movement of fibre (Palaskar *et al*., 2014).

Further, these results are also supported by the study conducted by Kan (2014), which indicated that etching effect on fabric surface caused by plasma treatment provides a new pathway for the FR finishing agent to enter in to the fibre resulting in increasing the wrinkle recovery angle.

Therefore, on multiple washes the degradation or removal of FR agent, decreases the crease recovery angle of the respective fabrics. Hence, the null hypothesis set for the study that laundering does not alter the performance properties of the plasma treated fabrics is rejected, *i.e.* the post-FR treated test samples *viz*., cotton and polyester irrespective of their specific inherent properties showed a continuous trend of decrease in stiffness and improvement in resiliency.

5.6.3 Assessment of durable properties of post-flame retardant (FR) treated cotton and polyester fabrics

Durable properties of FR treated cotton and polyester fabrics displayed in Table 19. It is evident from this Table that the tensile strength and elongation percentage both in warpway and weftway directions of cotton and polyester fabrics reduced significantly after plasma treatment.

These results are supported by the study conducted by Lam *et al.* (2011) where it is mentioned that though roughening effect of plasma creates more contact points in fibres microscopically resulting in increased inter-yarn and inter-fibre friction; but when plasma treatment is followed by flame retardant finishing, the cross linking agent (CL) used to bind FR-agent to fibre surface, reduces the strength of textile fabrics. Moreover, drop in breaking load is also attributed to acidity of FR finishing agent; therefore neutralizing the flame-retardant-treated textile specimen with alkali is indispensable.

On subsequent washing there was a trend of slight reduction in tensile strength and elongation percentage was observed but is found to be significant for both the fabrics except weftway tensile strength of polyester fabric. This meagre reduction may be due to degradation of FR agent to some extent.

Moreover, the picks per inch and cloth GSM did influence the weftway tensile strength of cotton fabric and is found to be significant. On the contrary there was influence of cloth count and cloth thickness on plasma treated polyester fabric as well the laundered test samples and the values are found to be significant.

Abrasion resistance is one of the fabric properties that determine the level of durability. The unit for expressing cloth abrasion is 'cycles' *i.e.* higher the number of cycles greater the resistance is. It is noted from Table 19 that, after plasma treatment abrasion resistance of cotton and polyester fabric reduced significantly due to reduction in the fabric hairiness performed by plasma etching action which makes the fibre more fragile (Karahan *et al.*, 2009). Moreover, plasma finishing followed by pad-dry-cure and stentering, made the fabric flat and smoother. Washing of FR treated fabrics further reduced its resistance power may be because of more distortion in fibre structure. Abrasion resistance is found to be high in cotton than polyester because of their contrasting bulk properties. Therefore, the null hypothesis set for the study that plasma treatment alters the inherent characteristics of cotton and polyester fabrics is rejected.

5.6.4 Assessment of post-flame retardant (FR) treated cotton and polyester fabrics for flame retardancy

5.6.4.1 Forty five degree (45º) flame test

A progressive burning of a fabric at a distance of 127 mm from a flame is deemed to be "burn time", and at less than 7 seconds, is termed as failure of resistance to burning under specified conditions. Consumer Product Safety Commission (CPSC) has established three classes of fabric, where class I is considered as best and class III, as not acceptable (ASTM D1230-94).

Table 23 presents the burning time and char/melt length of plasma treated cotton and polyester finished with flame retardancy. It is clear from this Table that both cotton and polyester untreated test samples easily catch fire within 6 and 7 seconds, respectively with char/melt length of each 15.00 cm, and finally degraded due to very high combustible inherent property. In general, the flame spread on a microscopically raised fabric surface is more rapid than on a smooth fabric surface. In fact, the plasma treatment followed by flame retardant finish did remove the surface fibrils of both the test samples thus, making it smooth and in turn reduced the velocity of burning speed. Hence, elevated the level of test samples from class II to class I. In fact, after FR finish the test samples did not ignite which clearly indicated that the post FR finished fabrics were highly resistant to fire. Moreover, on subsequent washes, the time taken to burn the FR treated samples reduced from DNI to 21 and from 21 to 20 (cotton); DNI to 19 and from 19 to 17 (polyester) seconds compared to the corresponding untreated samples. This phenomenon may be due to the etching effect on the fabric surface caused by plasma treatment.

The helium-oxygen plasma removes all the contaminations from the fibre surface and thus may avoid interference of bonding between respective fibres and FR-CL linkages (Kaplan, 2004).

The etching effect reduces the weak boundary layers and increases the surface area. Thus, allowing greater number of FR molecules to get attached. The attachment of FR molecules ultimately improved the performance of flame retardancy. In addition, the oxygen plasma introduces more polar groups that in turn enhanced the wettability of cotton as well as polyester fibres which may also positively influenced the flame-retardancy of plasma treated samples. But on subsequent washes, degradation of FR-agent from the etched surface to some extent probably reduced the level of flame retardancy, thus making the fabric slightly flammable. However, parallelly these test samples belonged to class I category as the burning time was more than 7 seconds.

Hence, the hypothesis set for the study that laundering does not alter the functional properties of the plasma treated fabrics is accepted.

6. SUMMARY AND CONCLUSIONS

The present study entitled ‘Ecofriendly functional finish for textile materials’ was carried out in the University of Agricultural Sciences, Dharwad, during the year 2015-2017 with the objectives to explore the possibility of treating cotton and polyester fabrics with plasma finish, to study the surface morphology and assess the impact of plasma finish on quality characteristics of both the test samples. Further the test samples were assessed for hydrophobicity (cotton), hydrophilicity (polyester) and flame retardancy of both cotton and polyester fabrics. Washing was another aspect of experimental procedure where the test samples were subjected for 10 washes and its influence was assessed after every 5th wash. Plasma treatment is a dry treatment since does not use water as in case of conventional processing where huge amount of water is used and later would be released as effluent; hence considered as ecofriendly process. In plasma treatment a specific gas performs special role when accompanied by additional agent and alters the surface topography of textile substrate in turn induce special functionality. The present investigation comprised of assessment of surface morphology and quality characteristics of plasma treated cotton and polyester fabrics before and after subsequent washes.

The outcomes of the experimental study are summarized below:

Analysis of surface morphology of plasma treated cotton fabric

- Helium plasma treatment along with monomer (HMDSO) significantly altered the surface morphology of cotton fabric
- On plasma treatment the hydrophilicity of cotton transformed into hydrophobicity due to modification of smooth surface to globular structure

Assessment of structural properties of plasma treated cotton fabric

- Plasma treatment did not alter the cloth count remarkably
- The thickness of the plasma treated cotton fabric reduced due to etching of the fabric surface and lead to decrease in the corresponding GSM
- The relaxation shrinkage was greater than the progressive shrinkage at different stages of assessment
- The test sample attained dimensional stability after plasma treatment, thus there was no effect of multiple washes on the dimension

Assessment of performance properties of plasma treated cotton fabric

- The atmospheric plasma treatment reduced the stiffness and increased the crease recovery angle of cotton fabric, and the values are highly significant at 1 per cent level of significance
- The multiple washes further reduced the cloth stiffness and improved the resiliency and hand-feel of the test sample, which indicates that plasma treatment did not affect the inherent characteristics of cotton fabric

Assessment of durable properties of plasma treated cotton fabric

- Plasma treatment increased the tensile strength and elongation percentage of cotton fabric. But on washing, it declined due to removal of amorphous region caused by sputtering action of plasma
- There is significant influence of ends per inch, picks per inch, cloth thickness and GSM on warpway tensile strength of plasma treated cotton fabric, after 10th wash. Whereas the influence of structural properties on elongation percentage was found to be non significant not only after plasma treatment but also on subsequent washes
- Removal of upper thin layer of fabric surface due to sputtering action of plasma reduced the resistance for abrasion of treated substrate. A trend of reduction in abrasion was further observed after multiple washes
- Influence of structural properties *viz.,* ends per inch, picks per inch, cloth thickness and GSM on abrasion resistance of treated samples found to be non-significant

Assessment of plasma treated cotton fabric for hydrophobicity

Spray test

- The plasma treatment along with monomer fixation imparted hydrophobicity to cotton fabric
- However, the sustainability of hydrophobicity is not permanent but reduced to some extent on multiple washes
- Plasma finish did change the morphology of cotton fibre but not the inherent properties
- Plasma etching results into more micro rough surface that is filled with air. Organic surface contaminants visible to naked eye shall be removed by plasma treatment and this either increases or decreases the wettability. And therefore ensures any type of printing, painting since the coating remains on the surface of the substrate
- Dry etching modifies surfaces with the most reliable and environmentally friendly option
- Hydrophobic cotton fabric does behave like soil and stain resistant
- It is possible to reduce the hydrophilicity of cotton fabric by reducing the wettability

Wicking length

- The control sample exhibited good wicking rise compared to treated sample
- There was absolutely ‘No wicking’ in the plasma treated cotton fabric indicating induced hydrophobicity in cotton fabric
- The induced hydrophobicity is attributed to change in the fabric topography or fabric surface
- The multiple washes imparted water repellency in the treated sample by reducing the level of induced hydrophobicity

- The plasma treated cotton samples did not revert back to hydrophilicity on multiple washes hence; plasma treatment is a sustainable finish to remarkable extent

Analysis of surface morphology of plasma treated polyester fabric

- Oxygen plasma treatment abrades the fibre surface completely
- Addition of polar groups on the abraded region converts hydrophobicity of polyester into hydrophilicity

Assessment of structural properties of plasma treated polyester fabric

- Oxygen plasma treatment did not alter the cloth count of polyester fabric
- On multiple washes there was significant increase in threads per inch and is mainly due to shrinkage
- Etching and cleaning of surface significantly reduced (1 % level of significance) the cloth thickness
- Loss in cloth thickness lead to loss in GSM after plasma treatment
- Plasma treated polyester fabric shrunk and is mainly due to formation of amorphous region (15-35 %) in the fibre axis and its capacity to absorb 00.40 per cent moisture
- Shrinkage resulted into increase in ends and picks per inch

Assessment of performance properties of plasma treated polyester fabric

- The control sample exhibited maximum stiffness compared to plasma treated and washed samples
- On oxygen plasma treatment the fabric became soft and pliable
- The cloth harshness is reduced due to etching, cleaning of fibre surface as well as dehairing
- Reduction in cloth thickness and GSM directly influenced the cloth bending length at control and after plasma treatment
- In general, the weftway recovery angle was higher than its corresponding warpway recovery and is supported with resultant bending length values
- On plasma treatment the test sample has become resilient
- Multiple washing, further improved the resiliency and hand-feel of plasma treated samples

Assessment of durable properties of plasma treated polyester fabric

- The tensile strength and elongation of polyester fabric enhanced significantly after plasma treatment when compared to control values
- But on washing there was decline in the values of tensile strength and elongation of plasma treated samples due to more sterilization and dehairing

- There was negative influence of cloth thickness and positive influence of picks per inch on the weftway tensile strength of treated polyester fabric after 5th and 10th washes, respectively and was found to be highly significant
- The picks per inch and cloth thickness influenced the tensile strength of untreated fabric positively at 5 per cent level of significance
- The multiple washes affected negatively the tensile strength and corresponding elongation values due to dehairing and thickness loss
- The polyester fabric becomes hydrophilic due to introduction of polar groups
- Laundering does affect the durable properties of plasma treated fabric
- The abrasion resistance of polyester fabric was relatively higher at control than treated when subjected for multiple washes
- Oxygen plasma treatment modified the topography of test sample
- The reduction in cloth thickness and GSM lead to low resistance for flat abrasion
- Etching, dehairing and cleaning, adversely affected abrasion resistance when subjected to subsequent washes

Assessment of plasma treated polyester fabric for hydrophilicity

Spray test

- Oxygen plasma treatment modified hydrophobicity of polyester fabric into hydrophilicity
- On contact with water along agitation (washing) the treated sample may tend to revert back to its inherent behavior but not wholly
- The modified topography of polyester sample was not cent per cent sustainable for multiple washes; but expected to relax and release the tension when come in contact water
- There was little flare towards hydrophobicity, indicated through elevation in the spray test rating from zero to 50

Wicking length

- The untreated polyester sample was cent per cent hydrophobic with ‘zero’ wicking length
- The absorption of moisture was through capillary action in plasma treated polyester fabric
- The capillary action was higher in the beginning of the experiment but the speed gradually decreased with increase in time duration of 2 and 5 min
- An increasing trend of wicking was observed up to 5th wash but a small fall was found after 10th wash, may be due to attainment of saturation by 5th wash itself
- Oxygen plasma finish modifies the hydrophobicity of polyester into hydrophilicity, an important feature contributes to wear comfort

- Oxygen plasma is the most common gas used for cleaning and plasma surface modification. Oxygen is used in high frequency plasma cleaner that ensures cent per cent removal of organic matter
- The development of static charges could be reduced to a greater extent by inducing hydrophilicity in polyester fabric

Analysis of surface morphology of post-flame retardant (FR) treated cotton and polyester fabrics

- Plasma treatment followed by flame retardant finish significantly altered the surface topography of both cotton and polyester fibres
- Due to surface erosion there was formation of micro cracks and pores all along the fibre axis
- Post FR finish induced flame retardancy of greater level among both cotton and polyester fabrics

Assessment of structural properties of post-flame retardant (FR) treated cotton and polyester fabrics

- A slight increase in cloth count of both the test samples after plasma treatment was observed. But on multiple washings, the threads per unit area increased remarkably in cotton fabric whereas the numericals in polyester remained unchanged due to their different inherent characteristics
- Deposition of flame retarding agent on microgrooves of cotton and polyester fibre surface and consolidation of yarns due to shrinkage, increased the cloth thickness and the correspondingly GSM. But on multiple washes there was drop in the values and is due to release of superficially held FR agent from the fabric surface to some extent
- The relaxation shrinkage was maximum at control; but the percentage of progressive shrinkage gradually reduced on multiple washes
- After plasma treatment shrinkage percentage of both fabrics reduced significantly in both the directions *i.e.* warp as well as in weft
- The polyester fabric attained the dimension stability at much earlier stage of treatment compared to cotton fabric and is attributed to the respective inherent characteristics

Assessment of performance properties of post-flame retardant (FR) treated cotton and polyester fabrics

- A certain level of reduction in the values of stiffness of cotton and polyester test samples on post-FR finish is due to deposition of FR agent on the surface of respective fibres
- On subsequent number of washes, the cloth stiffness of both the test samples *viz.,* cotton and polyester reduced, due to removal of FR agent present of the surface of the substrate, thus making the fabric flexible

- Cloth crease recovery angle of both the test samples after FR finishing enhanced compared to control samples. But on multiple washes, there was decrease in the recovery angle; however these values were highly significant at 1 per cent level of significance

- The cloth stiffness and cloth crease recovery angle are inversely proportional yet supportive to each other *i.e.* greater the stiffness lower the recovery and vice versa

Assessment of durable properties of post-flame retardant (FR) treated cotton and polyester fabrics

- Plasma treatment followed by flame retardancy (FR) finishing reduced the tensile strength and elongation of cotton as well as polyester samples

- On washing, a meager percentage of reduction in tensile strength and elongation was noticed compared to the corresponding treated samples

- Influence of picks per inch and GSM on weftway tensile strength of cotton found to be significant at 5 per cent and highly significant at 1 per cent level of significance, respectively

- Influence of cloth count and cloth thickness on tensile strength of plasma treated polyester as well as laundered sample was significant

- Sterilization of both cotton and polyester during helium-oxygen plasma treatment followed by flame retardant (FR) finishing significantly reduced the abrasion resistance of both the test samples

Assessment of post-flame retardant (FR) treated cotton and polyester fabrics for flame retardancy

Forty five degree (45º) flame test

- The untreated test samples could ignite and propagate flame at very low burning time *i.e.* cotton, 6 seconds and polyester, 7 seconds whereas char/melt length of both test samples was 15 cm and categorized as class II

- Class II: The textiles have an average time of flame spread in the test of 4-7 seconds, in which the base fabric is ignited, charred or melted

- The plasma treated cotton and polyester fabrics finished with flame retardancy ‘Did Not Ignite’ when approached with flame and the length of char/melt was ignorable. Thus, categorized as class I

- The treated test samples did burn after 5th and 10th wash but took long time to burn, much higher than the time specified for class I *i.e.* 7 seconds. Hence, still categorized under class I

- The length of char or melt length of treated sample was relatively lower than the length of char/melt length of untreated sample

Implications and recommendations

The present investigation entitled ‘Ecofriendly functional finish for textile materials’ has provided information on the modifications of surface topography of plasma treated cotton and polyester fabrics as well as their quality characteristics *viz.*, structural, performance, durable and functional properties of plasma treated fabrics on subsequent washes has been emphasized. The plasma treatment found to be very efficient and effective in inducing multiple functionalities by converting the fibre morphology through etching, cleaning and sputtering phenomenon.

Application of helium gas along with hexamethyldisiloxane (HMSO) monomer modified the hydrophilicity of cotton into hydrophobicity thus, making the fabric stain resistant. On the other hand, oxygen plasma converted the hydrophobic polyester into hydrophilic by adding number of polar groups in the polymer structure thus, making polyester fabric more comfortable to the wearer. Nevertheless, the chances of development of static charges on hydrophilic polyester fabric could be reduced to a greater extent.

The high tendency of combustibility and the inherent nature of propagation of flame are reduced to a greater extent by subjecting to helium-oxygen plasma treated test samples to flame retardant (FR) finish using N-methylol Dimethylphosphono-propionamide.

The plasma treatment modified the morphology of cotton and polyester fabrics without altering the inherent bulk properties.

The hydrophobicity of cotton, the hydrophilicity of polyester, flame retardancy of both cotton and polyester test samples reverted back to some extent when subjected to multiple washes. However, the reverted values were higher than the respective control values.

In other words, plasma treatment induced special functional properties in cotton and polyester fabrics by modifying the respective surface morphology, at the same time protecting their inherent bulk properties.

The independent variables *viz.*, ends per inch (X_1), picks per inch (X_2), cloth thickness (X_3) and GSM (X_4) majorly influenced tensile strength (kgf) of plasma treated cotton (hydrophobicity) and polyester (hydrophilicity) fabrics on subsequent washes. Similarly, the independent variables did influence the tensile strength of post FR treated cotton and polyester fabrics. Abrasion was another dependent variable of hydrophilic polyester and post FR treated cotton fabric, which were influenced by X_3 and X_2 respectively, after 10th wash.

Recommendations

Plasma treated hydrophobic cotton fabric is recommended for

- Gloves in pathology and chemical laboraties, catering and fast food centers, food serving counters, beauty parlours *etc.*
- Bibs for children, senior citizens and patients
- Nappies for children

- Table runners in the restaurants, cafeteria, food courts *etc.*

Plasma treated hydrophilic polyester fabric is recommended for

- Sportswear: T-shirts, caps, short pants *etc.*
- Children's sleep wear
- School uniforms for nursery kids
- Home textiles: pillow covers, bed linen of children

Post FR treated cotton and polyester fabrics is recommended for

- Kitchen aprons and dusters
- Industrial uses *viz.,* welding clothes
- Lab coats

Suggestions for further study

- Effect of plasma treatment on quality characteristics of protein fabrics
- Implication of plasma treatment to induce antimicrobial activity on cellulosic fabrics
- Development of plasma treated UV protective textiles
- Impact of nano finish on plasma surfaces (antibacterial finish)
- Feasibility of plasma technologies in fibre-reinforced composites (to enhance mechanical properties)
- Impact of plasma finish on oil and soil repellency
- Plasma treatment for disposable medical textiles (gloves, bandages, gowns, caps *etc.*)

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APPENDIX-I

Water Repellency: Spray Test (AATCC Test Method 22-2005)

Purpose and Scope

This test method is applicable to any textile fabric, which may or may not have been given a water repellent finish. It measures the resistance of fabrics to wetting by water. The results obtained with this test method depend on the resistance to wetting or water repellency of the fibers, yarns and finishes on the fabric, and upon the construction of the fabric.

Principle

Water sprayed against the taut surface of a test specimen under controlled conditions produces a wetted pattern whose size depends on the repellency of the fabric. Evaluation is accomplished by comparing the wetted pattern with pictures on a standard chart.

Apparatus and Materials

1. AATCC spray tester
2. Graduated cylinder, 250 ml
3. Water (distilled)
4. Stopwatch

Test specimens

Three test specimens 180.0 × 180.0 mm (7.0" × 7.0") are needed and should be conditioned at 65 ± 2 % relative humidity and 21 ± 1℃ (70 ± 2 ℉) for a minimum of 4 hrs before testing. Where possible, each specimen should contain different groups of lengthwise and width wise yarns.

Procedure

a. Calibrate the apparatus by pouring 250 ml of distilled water at 27 ± 1 ℃ (80 ± 2 ℉) into the funnel of the tester and measure the time required for the funnel to empty.

b. The spray time must be between 25-30 sec, otherwise the nozzle should be checked to see if the holes are enlarged or blocked.

c. Fasten the test specimen securely in the 152.4 mm (6.0") diameter hoop so that the face of the fabric specimen will be exposed to the water spray. The surface of the specimen should be smooth and without wrinkles.

d. Place the hoop on the stand of the tester with the fabric uppermost in such a position that the center of the spray pattern coincides with the center of the hoop.

e. In the case of twills, gabardines, piques or fabrics with similar ribbed construction, place the hoop on the stand in such a way that the fabric is oriented in the same direction as it will be used in the end product.

f. Pour 250 ml of distilled water at 27 ± 1 °C (80 ± 2 °F) into the funnel of the tester and allow it to spray onto the test specimen for 25-30 sec.

g. Avoid touching the funnel with the graduated cylinder while pouring the distilled water. Movement of the funnel will alter the spray disposition on the specimen.

h. Take the hoop by the bottom edge and tap the opposite edge firmly once against a solid object with the fabric facing the object, then rotate the hoop 180° and tap once more on the point previously held.

i. Repeat steps 8.2 through 8.5 for all three specimens.

Evaluation and report

a. Immediately after tapping, compare the wet or spotted pattern with the rating chart. Rate the face of the specimen. Each test specimen is assigned a rating corresponding to the nearest level on the rating chart.

b. Intermediate ratings can be used for ratings of 50 or higher

c. In rating loosely woven or porous fabrics, such as voile, any passage of water through the openings of the fabric is disregarded.

d. Report the individual rating results for each test specimen. Do not average the results.

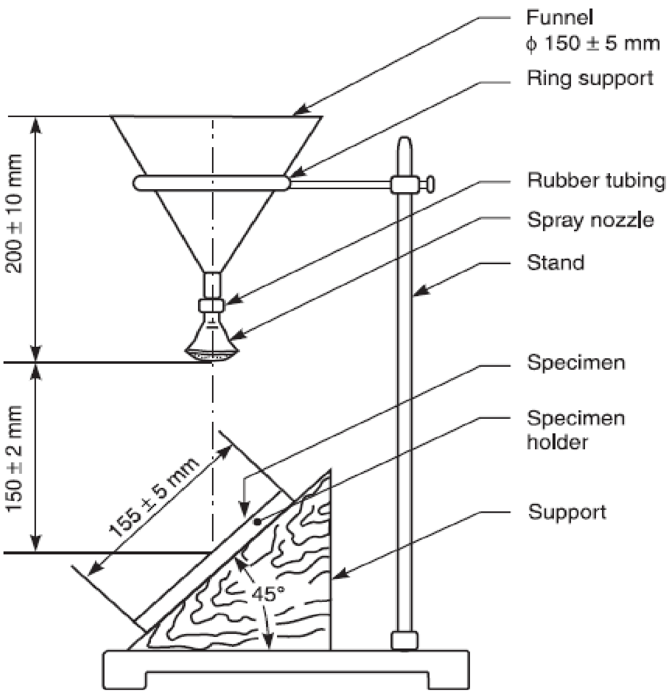


Fig. 1. Details of AATCC spray tester

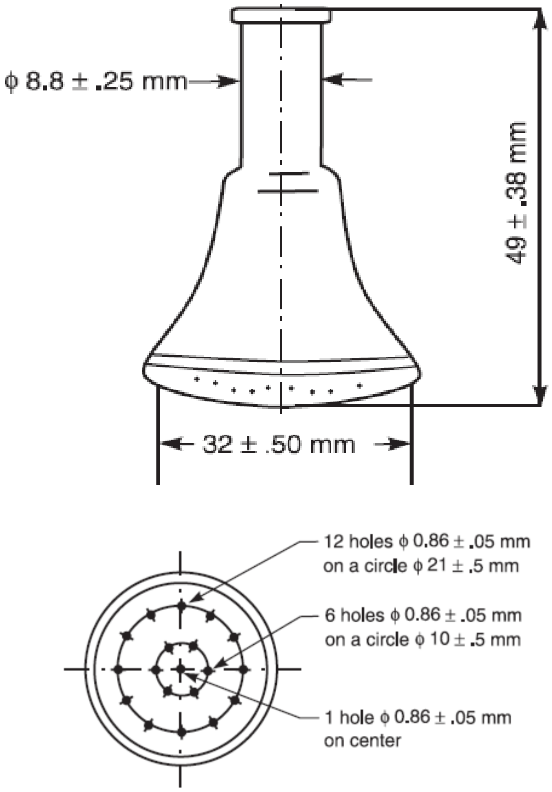


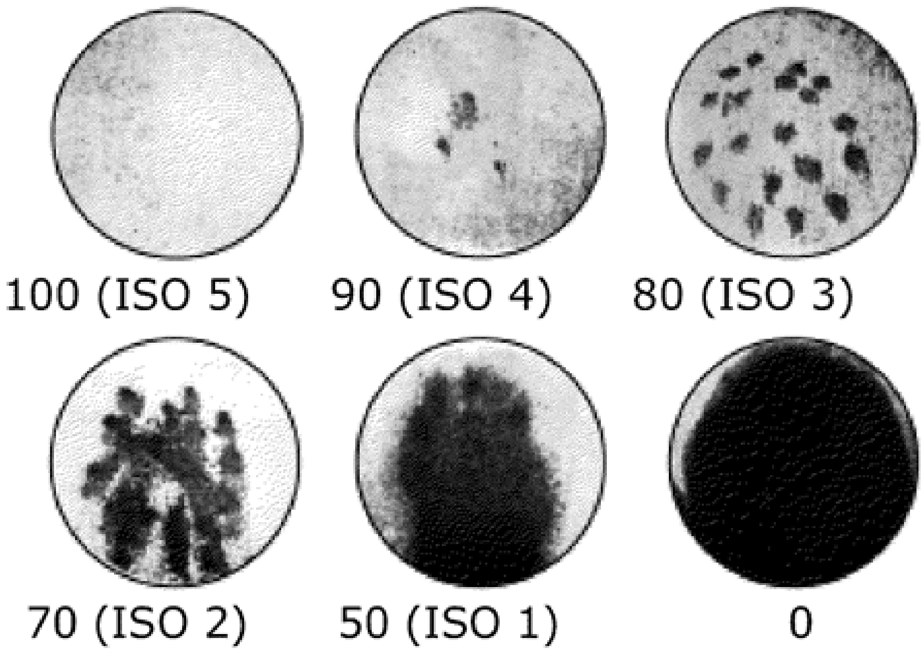
Fig. 2. Details of nozzle for spray tester

Spray test parameters

“Water Repellency : Spray Test”

AATCC Test Method 22 – 2005

STANDARD SPRAY TEST RATINGS



100 – NO STICKING OR WETTING OF UPPER SURFACE

90 – SLIGHT RANDOM STICKING OR WETTING OF UPPER SURFACE

80 – WETTING OF UPPER SURFACE AT SPRAY POINTS

70 – PARTIAL WETTING OF WHOLE OF UPPER SURFACE

50 – COMPLETE WETTING OF WHOLE OF UPPER SURFACE

0 – COMPLETE WETTING OF WHOLE UPPER AND LOWER SURFACES

Fig. 3. Spray test rating chart

APPENDIX-II

Flammability: 45º Flame Test (ASTM D1230-94)

What this test is used for:

This test is used to measure and describe the properties of natural or synthetic fabrics in response to heat and flame under controlled lab conditions. Most any textile material can be evaluated using this test with the following exceptions: children's sleepwear, protective clothing, hats/gloves, footwear, and interlining fabrics. Two factors are measured:

1. Ease of ignition (how fast the sample catches on fire).
2. Flame spread time (the time it takes for the flame to spread a certain distance).

How this test works:

Samples are mounted in a frame and held in a special apparatus at an angle of 45º. A standardized flame is applied to the surface near the lower end for specified amount of time. The flame travels up the length of the fabric to a trigger string, which drops a weight to stop the timer when burned through. The time required for the flame travel the length of the fabric and break the trigger string is recorded, as well as the fabric's physical reaction(s) at the ignition point.

Scientific Testing Requirements:

1. Condition according to ASTM D1776-98
2. 45º Flammability Tester
3. Pre-cut fabric sample(s)
4. Sample frame with four clips
5. Brushing device (for piled or napped fabrics only)
6. 50/3 mercerized sewing thread

Procedure:

Sample Preparation

1. a) Launderable / Dry-cleanable Fabrics: Cut 12, 6.5" x 2" samples (per group)

    - 6 from the original fabric: (3 in warp direction - 3 in weft direction)
    - 6 from the laundered / dry-cleaned fabric: (3 in warp direction - 3 in weft direction)

    b) Non-Launderable / Non-Dry-cleanable Fabrics: Cut 6, 6.5" x 2" samples (per group) (3 in warp direction - 3 in weft direction)

2. All fabrics are oven dried for 30 min at 105 ºC

3. All fabrics should then be placed in desiccator for at least 15 min before testing

4. Secure samples into frame using two clips on each side

5. Piled or napped fabric should be brushed at this time with brushing device to raise the surface fibers

Preparing the Flammability Tester

1. Main power switch is OFF (left side of front panel).

2. Timer is set at zero.

3. Move rack to right, using lever arm located in front panel. Place sample holder in instrument sample rack so that the longest frame is on top.

4. Using the lever, slide the rack to the left until the sample comes in contact with the L – shaped locating arm. The burner tip now remains 5/16" away from the face of the specimen.

6. Fill the glass U – shaped manometer with water to a convenient level (located on the left side of the chamber).

7. Stop cord of 50/3 mercerized cotton sewing thread is threaded through instrument.

Performing the Test

1. Turn ON main power switch.

2. Select time of Auto Impingement (1, 5, 10 sec, or manual). For the purpose of this class we will use the time of 5 sec.

3. Press start button. Impingement is automatic and the flame is applied for a period of 5 sec.

4. Timer will start automatically. Starting upon application of the flame and ending when the weight is released by the burning of the stop cord.

5. Record results

6. When testing is done, switch power OFF. Turn off gas supply.

Results:

Calculations

1. Calculate the arithmetic mean flame-spread time of the six (or twelve) specimens. Add all the times together and then divide by six (or twelve).

2. If the mean time is less than 3.5 seconds, or any of the specimens do not burn, test six (or twelve) additional specimens.

3. Calculate the arithmetic mean flame-spread time for all six (or twelve) specimens. Add all six (or twelve) specimens together and divide by six (or twelve).

4. The time of flame spread is the average time for all the specimens of that sample material tested.

Interpretation of results

The following three classes are used by the Consumer Product Safety Commission to interpret results for a similar test:

Class I: These textiles are considered by the trade to be generally acceptable for apparel and are limited to the following:

1. Textiles that do not have a raised fiber surface but have an average time of flame spread in the test of 3.5 seconds or more.
2. Textiles having a raised fiber surface that have an average time of flame spread in the test of more than 7 seconds or that burn with a surface flash (in less than 7 seconds) in which the base fabric is not affected by the flame.
3. Textiles for which no specimen ignites.

Class II: These textiles are considered by the trade to have flammability characteristics for apparel intermediate between Class I and Class III fabrics are limited to the following:

1. Textiles having a raised fiber surface that have an average time of flame spread in the test of 4 to 7 seconds and in which the base fabric is ignited, charred or melted.

Class III: These textiles are considered by the trade to be unsuitable for apparel and are limited to the following:

1. Textiles that do not have a raised fiber surface that have an average time of flame spread in the test of less than 3.5 seconds.
2. Textiles having a raised fiber surface that have an average time of flame spread in the test of less than 4 seconds in which the base is ignited, charred, or melted.

Report:

1. Report that the specimens were tested as directed in ASTM Test Method D1230.
2. Describe the materials or products tested and the method of sampling used.
3. Report the average time in seconds of flame spread for the fabric specimens that did ignite. If no specimens ignite, report DNI (did not ignite).
4. For raised surface fabrics, report the number of fabric specimens for which the base fabric ignited, charred, or melted.
5. Report the number of specimens tested of each fabric.
6. Determine the classification of each fabric as defined above.
7. If fabric was laundered, report the information for the laundered samples and the non-laundered samples separately.

ECOFRIENDLY FUNCTIONAL FINISH FOR TEXTILE MATERIALS

ARCHANA BAHUGUNA **2017** **DR. SHAILAJA D. NAIK**
MAJOR ADVISOR

ABSTRACT

Study on the possibility of treating cotton and polyester fabrics with plasma finish, surface morphology assessment and impact of washing on quality characteristics of plasma finished test samples was carried out during 2015-17 at Department of Textile and Apparel Designing, College of Rural Home Science, University of Agricultural Sciences, Dharwad. Cotton was exposed to helium-oxygen along with hexamethyldisiloxane (HMDSO) monomer to introduce hydrophobicity and O_2 gas to bring hydrophilicity in polyester. Flame retardancy was induced with He-O_2 plasma treatment followed by flame retardant finish applying PYROVATEX® CP NEW (FR) and KNITTEX® FEL (melamine resin).

Major alterations in fibre morphology observed were globular structure in cotton, abraded surface in polyester and microcracks in both, indicated bringing in hydrophobicity, hydrophilicity and flame retardancy, respectively. Furthermore, treated samples were subjected to 10 hand washings and evaluated for structural, performance, durable and functional properties after every 5th wash. Irrespective of the gases, improvement in softness, pliability, resiliency, dimensional stability, tensile strength and elongation percentage of test samples was due to sputtering, etching and cleaning action of plasma treatment. He-O_2 plasma along with HMDSO monomer efficiently formulated cotton completely into hydrophobic (0 to 100 ratings) and hydrophilicity in polyester (80 to 0 ratings) by addition of more number of polar groups on oxygen plasma treatment. Similarly, increase in cloth count (1-2 %), thickness (12 %), corresponding GSM (14 % in cotton and 69 % in polyester) observed in post FR treated fabrics was due to deposition of FR agent into the micro-grooves formed due to plasma.

Multiple washes showed alterations in values of hydrophobicity (100 to 50 ratings), hydrophilicity (0 to 50 ratings) and flame retardancy (DNI to 17-20 sec) but displayed greater influence of finish than control. Thus indicating efficiency of plasma treatment inducing a trend of water repellency, water absorption and flame resistance.