Ozone Treatment of Polyester Fabric for Surface Modification

BY

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ABSTRACT

Currently, there is a greater demand for cotton-based goods for the purpose of apparel, including linens for homes and hospitals because of the expanding trend of mothers giving birth in hospitals as a result of hospital infrastructure developments. On the other hand, there is a restricted application of cotton due to a lower potential of supplier raw materials with quality, and a tendency cotton goods for wrinkles after laundering since bed linens, especially those used in hospitals, are usually washable. Hence, to meet social demands, it is preferable to find and use alternative materials. In this paper polyester was used as alternative materials but, it has serious drawback due to its hydrophobic character. The main objective of this study was treated polyester fabric with ozone to make it appropriate for use as bed linen. Ozone treatment reduces the inherent drawbacks in polyester fabric, making it appropriate for use as hospital and residential bed linen. The Polyester fabric was exposed to 50% ozone gas concentrations at different time intervals of 20, 30, 40, and 50 minutes. Using a range of testing devices, changes in the fabric's chemical and physical properties have been analysed in order to assess the effects of these ozone treatments. As the result shows the formation of polar bond were confirmed by FTIR and indicates by increase in wettability and the colour strength of treated dyed Polyester samples. Long-time treatment of ozone provides higher absorbency of fabric with constant percentage of ozone amount.

Keywords: Ozone gas, Surface modification, FITR, Bed sheet, Ozone

INTRODUCTION

For thousands of years, textile goods have been an essential aspect of human life, and the textile industry has contributed significantly to the advancement of human civilization {1). Initially, clothing was made of traditional and conventional textiles used as clothing purpose for protection of man body's from natural external influences such as rain, wind and sun; later, the purpose of these textile products enhanced to multifunctional textiles which were utilized in the medical and healthcare fields, military, sports, and aerospace industries{2,3}. Because of apparels need to be soft, pleasant, long-lasting, and easy to care, the majority of clothing in the world, including bed linens used in hospitals and homes, is made of cotton or blended polyester and cotton materials{4}. Nowadays, the number and quality of nursing care such as bed linens needed by the hospital is high due to the expansion of hospitals and the number of mothers going to the hospital to give birth is increasing. However, the majority of textile goods that produced by textile industry are limited to cotton fabric, which has a lack of suppliers, quality issues brought on by human negligence during cultivation and proper handling, and a propensity to wrinkle (form creases) after laundering{5}. Nevertheless, bed linens, particularly those used in hospitals, must be washable in order to guarantee the clarity, strength, durability, hygienic level, and being standard with certain comfort features and fundamental characteristics{6}. However, the majority of the textile industry particularly in Ethiopia—hasn't tried to develop novel textile materials that could increase patient safety. Therefore, in order to satisfy societal expectations, it is better to identify and employ substitute materials that can enhance the drawbacks of cotton fabric and satisfy the fundamental requirements of bed linens, which are primarily utilized in hospitals and provide significant challenges for the textile industry. Polyester fibres are mostly responsible for achieving these qualities. These fibres surpass the production of natural fibres with a market share of 54.4%. Polyester fabric is widely used in the textile industry due its simple manufacturing process, low cost of manufacturing and has outstanding chemical, physical, and mechanical properties that primary for bed sheets but it has serious drawback due to its hydrophobic character {7}. This hydrophobic character of polyester has an effect on it comfort property during wearing and has limited dye ability character (it is not possible to dye polyester using different dyes except disperse dyes.) Low moisture regain and poor wettability cause a variety of problems both during manufacturing (accumulation of static electricity) and consumer use (clinging to the body, accumulation of fluff and soil). Now a day polyester is the world's leading fibre in manufacturing, so many researches have to be done and this is one the key research areas which improves the hydrophobic character of polyester{13). There is still a great deal of study to be done on improving the hydrophobic properties of polyester fabric through various modification methods. Numerous academic scholars have looked into a number of results and alternative technological developments for polyester fabric surface modification.

Hemen Dave et al. (2013) worked on treatment of a polyester fabric using by non-thermal Plasma Treatment and Its Effect on Coloration Using Natural Dye has been investigated under different operating conditions to improvements in the dye ability of polyester fabrics with natural dyes {1}.

Kamel et al (2010) worked on treatment of a polyester fabric using oxygen gas has been investigated under different operating conditions to improvements in the dye ability of polyester fabrics with disperse dyes and better result was obtained {8}.

Rudakova et al. studied the treatment of polyester fibres with of potassium hydroxide solution that results the hydrolysis occurred and the effect is only in the surface layer {6}.

Ko Sohk Won et al. worked on treatment of polyester fabric with aqueous sodium hydroxide solution causes decrease weight loss and breaking strength but not sufficient treatment {4, 5}.

In general, the above researches and their out puts indicates improvement in coloration after plasma treatment is attributed to the improvement in wettability by incorporation of new active functional groups, modification in surface morphology, as well as structural changes of surface layers. The reduction in crystallinity of polyester surface by non-thermal plasma treatment can result in loosening of the compact structure of PET and hence increase site for diffusion of dyes. The application of ozone gas treatment to polyester was discussed in this work. This process modifies the fibre surface of hydrophobic PET to make it hydrophilic.

When the textile polyester treated with ozone the following properties are improved like ease of soling, static charge build up, tendency to pill and lack of dye receptor sites especially for ionic dyes so, for easy processing and use of variety of dyes for polyester is improved.

Most of the previous research works on chemical and physical modification methods were focussed on the dye ability of polyester fabric by disperse dyes at low temperature and with an ionic dyes using attraction of opposite ionic natures of the fabric and dyes. However, this paper focuses on extensions of the application of polyester fabric to bed sheets by treated by Ozone gas. This is because of the fact that the treated polyester fabric can develop new reactive groups that are responsible for absorbency of water and enhance the dye ability of polyester with dispersing dyes at boiling temperature.

METHODOLOGY

This research has been performed in two consecutive phases. The first phase was modification of polyester fabric with ozone gas treatment and study the chemical & physical properties of treated fabric by identifying the instruments that used for characterized or confirm the changing properties. The second phase was stick on dyeing of polyester fabric with Disperse dyes at boiling temperature and evaluates the treated-dyed fabric and compared with untreated-dyed by conventional dyeing method by considering colour strength, and fastness properties of the dyed fabric.

Materials and Chemicals

100% polyester weaves fabric which has specification of 46picks/inch, 44ends/inch and 130 GSM. For treatment of polyester only ozone gas (o_3) is need but no need any other chemicals. Chemicals used for dyeing were Disperse Blue 19 dyes, Acetic Acid, Dispersing Agent, Caustic Soda, Wetting Agent, Sequestering Agent and Standard Soap for Soaping.

Equipment's and Machinery

Equipment's used for the study Stoves, Scissor, Electronic Balancing, Beakers, PH meters, Pipettes, Infrared Dyeing machine, Mini Dryer, Thermometer, FITR, Colour data 850 spectrophotometer, Auto-Wash, Crock-Meter. Per spirometer and light fastness tester. Universal Tensile Strength tester 3101, Digital Elmendorf tears strength tester and S.D.L Stiffness Tester.

Experimental Works

Ozone treatment of polyester fabric experiments were performed according to general factorial single factor experimental design, using design experts Minitab software Taguchi Design version 19, in the replication of three experiments and the data were analysed using design Taguchi Design version 19, and Microsoft office excel 2010.

Treatment of polyester with Ozone

Commercially 100% polyester fabric was treated with ozone gas at percentage of ozone gas 50%, with time intervals 20, 30.40 and 50 minutes. The ozone treatment of polyester fabrics has dyed with disperse dyes at boiling temperature and compared with the untreated polyester which has been dyed by using a high temperature, high pressure laboratory dyeing machine.

Dyeing procedure

Dyeing of treated and un-treated polyester fabric was carried out in a dye bath containing 1% owf shade and 1 g /l dispersing agent at a liquor ratio of 1:20. The pH of the dye bath was adjusted to 5 as give bellow table. The polyester fabric was introduced into the dye bath at 50°C and the temperature was raised at a rate of 2.5°C min-1 to 100°C and then at a rate of 1.5°C min-1 to 130°C for treated and untreated polyester respectively and the dyeing was continued for 60 minor 1hrs for both samples. All dyeing parameters were the same for both samples except dyeing temperature as shown on table1. Then both dyed samples were rinsed with water and washed in a bath containing 2 g/l non-ionic detergent at a liquor ratio of 1:20 at 50°C for 15 min. Finally, they were rinsed and dried at room temperature.

Table 1Recipe for polyester dyeing by Disperse dyes

Component	Concentration
Disperse dyes (%)	1%
Dispersing agent	1g/l
Sequestering agent	2g/l
Wetting agent	1g/l
PH	5
Time	1 hrs
Temperature	100^{o}c &130^{o}c

Evaluation method

The dyed treated polyester fabric properties have been evaluated their Wettability, breaking strength, tear strength, wrinkle recovery angle, Stiffness, Colour strength and colour fastness properties. Un treated polyester fabric properties were be evaluated for information and also for comparison with the properties of the fabric treated with ozone gas treatment. The evaluating testing methods for the properties of polyester fabric would be followed the ASTM standards and AATCC Test Methods {9, 11}. All samples have been kept in room temperature for 24 h prior to measurements. Each sample has been measured for five times and the average of the five values has been taken for accuracy.

Wettability measurements

The wettability of the treated polyester fabric was measured according to the standard BS4554:1970{8}. Five tests were measured and then the average value was taken for both samples. The wettability of the treated polyester fabric was measured by water drop absorbency test: Water absorbency test was performed by putting a drop of water using dropper on the fabric surface and visually noting down time for the water absorption.

Air permeability test

The air permeability of the treated polyester fabric has been measured according to the standard ASTMD737 {9}.

Determination of weight loss

The percentage of weight loss was calculated with the following formula:

Weight loss (%) = [(W1 -W2)]/W1 x100. Where, W1 and W2 are the weights of fabric before and after treatment, respectively.

Tensile strength

Tensile strength of the fabric sample was determined by using ASTM D5035-95 standard test method {5}. Universal Strength Tester was used to measure tensile strength of the fabric in the warp and weft way. Fabric sample 100 mm x 150 mm was prepared for both warp and weft direction test separately. The gauge length between the two jaws was adjusted to 75 mm. Then the sample was clamped between the jaws. The specimen was centrally located and the long dimensions were as nearly parallel to the direction of force applied. The tension on the specimen was uniform across the clamped width. The speed was adjusted so then the sample is broken in 20±3 seconds. Then the maximum force used to break the specimen was measured and recorded. The tensile strength of the treated polyester fabric was measured according to ASTM-D 5034 method {14}. The percentage of tensile strength retention was calculated by equation (ii).

% tensile retention = (tensile of treated fabric/ tensile of untreated fabric) *100 --- (ii)

Tearing strength

The tear strength was tested according to ASTM D1423-83 standard method {15}. Tear strength is the capacity of a material to withstand the tearing force required to propagate a tear after its initiation. The test specimen was cut according to the standard template size and the required dimensions are specified in relevant test standards. Tearing strength was tested in the warp and weft direction using Digital Tear Tester with C-Type load. An initial cut about 1cm length was made part way down the centre of a strip and then the two tails thus formed are pulled apart, so that a tear proceeds through the uncut portion of the fabric. The force used to tear the fabric was measured and recorded.

Determination of Flexural Rigidity

The stiffness tester is used for determining the stiffness of a fabric according to BS 3356 BS 9073 part 7 and ASTM D1388{16}. Drapability was checked by measuring the bending length of the sample. Shirley stiffness tester was used for the bending length measurement. The flexural rigidity was calculated using equation:

$G = 1/8 \times W \times L^3$……………………… (1)

Where G is flexural rigidity of fabric, W is the GSM of the fabric and L is the bending length of the fabric.

Testing of colour strength (k/s)

The colour strength (K/S value), of the dyed samples were determined using a spectrophotometer (Hunter Lab Colour) with an illuminate D65 and a 10° observer. The K/S value was calculated by the Kubelka-Munk equation, K/S = (1–R)2 /2R, where R is the reflectance of the dyed sample at the wavelength of maximum absorbance, K is the absorbance, and S is the scattering.

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

Spectrophotometer (Color-Eye 7000A) has been used for measuring colour properties (K/S value and CIE L*a*b* values) of the dyed polyester fabric {10}.

Colour fastness properties

The colour fastness of dyed polyester fabric has been tested according to ESISO standard methods. The specific tests have been ES ISO 105-X12: 2018 standards for colour fastness to rubbing, ES ISO 105 C06: 2018 method for colour fastness to washing, ISO 105-E04 for colour fastness to perspiration, and ISO 105-BO2 for colour fastness to light (xenon lamp).The colour fastness properties to washing, and rubbing samples were evaluated.

Testing of Rubbing Fastness

Rubbing fastness was tested according to ES ISO 105-X12: 2018 standard. A specimen of 22cm X 8cm was prepared which is equivalent to the size of the plate of the crock meter. Two specimens were taken-one for dry state and one for wet state for one sample. A rubbing cloth 5cm x 5cm was prepared and one rubbing cloth is wet out with water for wet rubbing. The specimen was mounted on the base board of the crock meter, putting the long direction of the specimen parallel to truck of rubbing. The white rubbing cloth was mounted flat over the end of the peg on the crock-meter and holds it by means of the spring clip provided. The finger was rest on the specimen ensuring that the spring clip is not in contact with the test specimen. The specimen was then rub back and forth over a straight truck for 10 complete cycles at a rate of 1 second for each cycle. Finally, the white rubbing test cloth was removed and the degree of staining on the undyed fabric was evaluated with grey scales.

Testing of Washing Fastness

ES ISO 105 C06: 2018 method was followed for wash fastness. A specimen of 10 X4 cm was sandwiched between a cotton fabric and polyester fabric and sewn along all four sides to from a composite specimen. Washing solution containing 5gpl soap and 2gpl sodium carbonate was taken in the launder -O- meter with a liquor ratio of 1:20. The specimen was treated for 45 minutes at 60^{o}C at the speed of 22 revolutions per minute. The specimen was removed and rinsed in running water without applying friction in cold water. The stitch was opened on three sides and dried in room temperature. The change in colour and degree of staining was evaluated using geometric grey scales.

Testing of Light Fastness

Light fastness was tested according to ES ISO 105 B02:2015 standard. A fabric sample which is cut and half of its part is exposed and half of its part is covered was mounted in a frame together with a standard blue scale reference fabric and it was placed in a testing chamber. This blue scale wool fabric consisting of eight darks to light blue shades used to record the colour change of a fabric. The test sample is exposed to a continuous light of xenon-arc lump at a radiant of 5 for about 72 hours. The change was compared with the original unexposed sample, which is assessed by blue scales 1-8.

Testing of Perspiration Fastness

Perspiration fastness was tested according to ISO 105F10 standard. Specimens of 40×100 mm were attached to same size of multi fibre to form a composite fabric. The composite fabric was wetted in acidic and basic solutions and placed between acrylic-resin plates under a pressure of 12.5 kPa separately. The test devices containing the composite specimens were placed in the oven for 4 h at 37°C ± 2 °C. The change in colour of each specimen and the staining of the adjacent fabrics were assessed and compared with on the grey scales.

RESULT AND DISCUSSION

In this paper characteristics of untreated, treated and dyed polyester fabric quality were like absorbency, weight loss, and Tensile and tear strength. Washing fastness, both wet and dry rubbing fastness, perspiration, stiffness/s value and degree of staining were evaluated. In this study, the effect of ozone treatment and duration of treatment were investigated. The polyester fabric was treated 50% ozone concentration at various time interval and the treated samples were assessed for colour strength, stiffness, fastness properties and physical properties.

FTIR analysis

The chemical modifications induced by ozone treatment of the polyester fabric were determined by an FTIR analysis. Like a fingerprint no two unique molecular structures produce the same infrared spectrum.

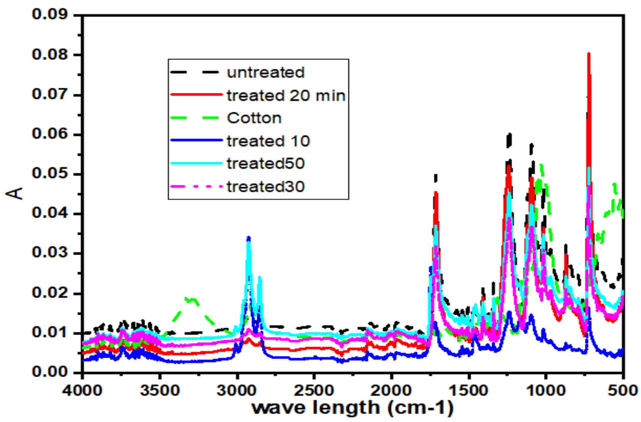

Figure 1: FTIR results of treated untreated

As shown on figure the high peaks from around 1714cm-1 indicate the original signals, such as characteristics spectra of stretching vibration band of C=O at around 1730 cm-1 and C-O-C stretching vibration band at around 1097 to 1300 cm-1. All these peaks confirm the existence of ester linkages. As shown on the figure the FTIR spectra obtained for the treated at30 ,40 and 50 minutes ozone-treated polyester fabrics has a new sharp absorption band with peak intensity at 2925.1 cm−1 and 2853.7 cm−1, characteristic of –C–OH groups, was observed, which revealed the presence of additional hydroxyl groups.

Effect of time on the wettability of the polyester fabric

As the result shows the wettability of the polyester fabric was strongly enhanced by ozone treatment gases compared with that of the untreated polyester fabric. The water absorbency of polyester fabric is determined by its polymer structure and morphological structure. When the surface of the fabric is altered by ozone treatment its water absorbency increases highly but decreasing its strength due to the polymer chains is broken because of the ozone gases treatment. The following (Table2) indicates the absorbency behaviour of different polyester fabric samples treated with ozone gas at different treatment time. The untreated polyester fabric sample has been used as a control sample for comparisons. The test technique was used to measure the water absorbency of the polyester fabric by measuring the time it takes a drop of water placed on the fabric surface to be completely absorbed into the fabric.

Table2: Effect of treatment time on the wettability of the fabric

Treatment time (min)	Time (Min: Sec. Micro sec) at different Drop places				average	
0	05:00.52	4:20.08	05:04.26	04:35.44	5:06.22	5:04
20	01:20.40	01:16.01	01:19.03	01:21.06	1:20.05	1:36.55
30	00:26.85	00:24.32	00:26.54	00:28.14	00:22.15	00:25.50
40	00:22.56	00:28.26	00:20.78	00:24.66	00:22.29	00:23.55
50	00:22.12	00:20.97	00:23.45	00:18.26	00:22.31	00:21.42

As the result shows the wettability of the polyester fabric was strongly enhanced by ozone treatment gases compared with that of the untreated polyester fabric.

Effect of ozone treatment on weight loss of polyester fabric

Almost all the sample on ozone treatment of polyester indicates weight loss. However, the extent of weight loss varies depending on the duration of the treatment. In the present research work the treatment of polyester was carried out using 50% concentration of ozone for 20 minutes, 30 minutes, 40 minutes and 50 minutes. It was observed that the ozone treatment of PET fabrics leads to a loss in weight of the fabrics.

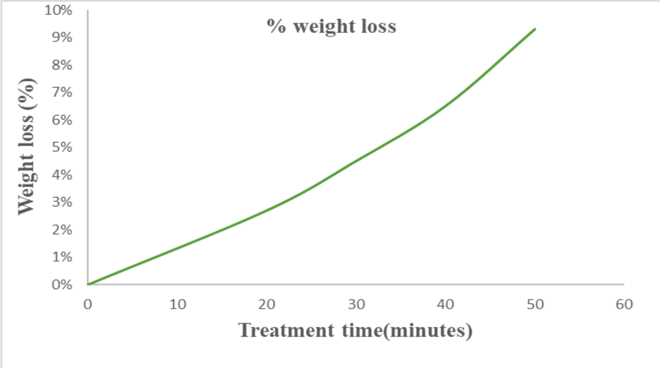

Figure 2: Effect of ozone treatment on weight loss

As the result indicates, when the treatment time increase the weight loss also increase.

In the present study the ozone treatment of polyester was carried out using 50% ozone amount for 50 minutes were observed higher weight loss as compared to other samples that was untreated and treated fabric at 20minutes, 30minutes and 40 minutes.

Effect of Ozone treatment on Fabric Physical Property

Tensile strength

Tensile strength of the fabric sample was determined by using ASTM D5035-95 standard test method to determine the maximum force and elongation at maximum force of test specimens. Universal Strength Tester was used to measure tensile strength of the fabric in the warp and weft way. Fabric sample 100 mm x 150 mm was prepared for both warp and weft direction test separately. The gauge length between the two jaws was adjusted to 75 mm. Then the sample was clamped between the jaws. The specimen was centrally located and the long dimensions were as nearly parallel to the direction of force applied. The tension on the specimen was uniform across the clamped width. The speed was adjusted so then the sample is broken in average 25±3 seconds. Then the maximum force used to break the specimen was measured and recorded.

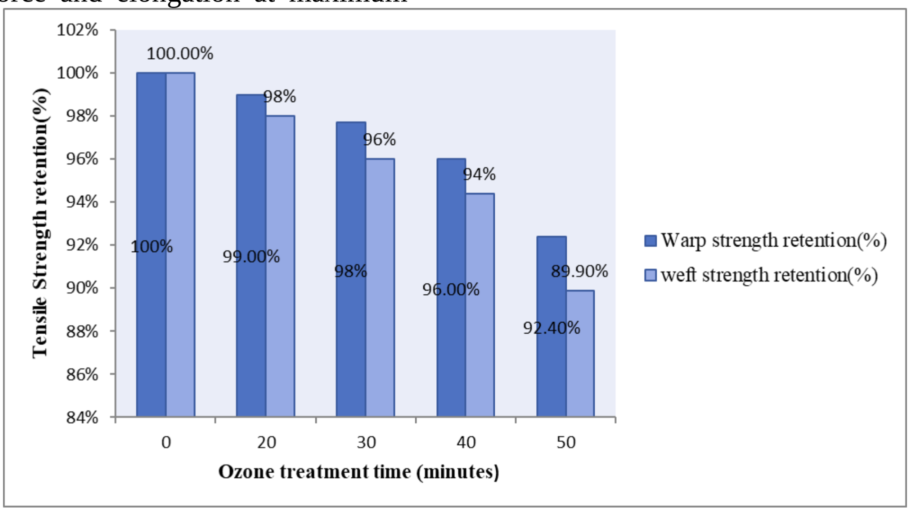

Figure 3: Effect of treatment time on tensile strength

The percentage of tensile strength retention of treated polyester fabric as compared to un treated polyester fabric is 99%, 98%, 96%, 92.4 in warp direction and 98%, 96%, 94%, 89.9% in weft direction for the treatment time of 20minutes, 30minutes ,40 minutes and 50 minutes respectively.

Tear Strength

In this method tear strength measurement covers all the force which helps to propagate a single-rip tear starting from a cut in the polyester fabric and using a falling pendulum type apparatus. Both warp and weft directions of all the samples were tested. The tear strength of treated polyester samples (warp-wise and weft-wise) decreased as the ozone treatment time of polyester increase. In all samples the tear strength of sample fabrics in warp direction was higher than weft directions.

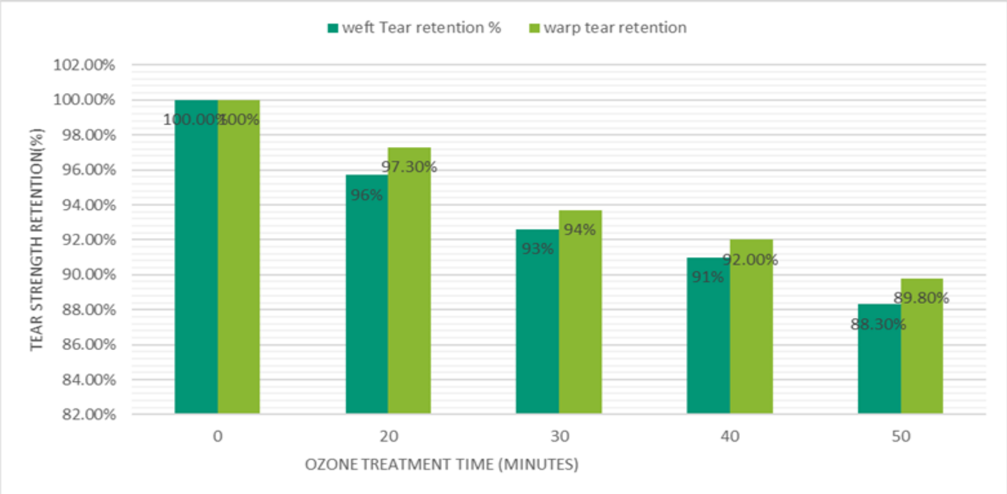

Figure 4: Effect of time on tear strength

The percentage of tear strength retention of treated polyester fabric as compared to un treated polyester fabric is 97.3%, 94%, 92%, 89.8 in warp direction and 96%, 93%, 91%, 88.3% in weft direction for the treatment time of 20minutes, 30minutes ,40 minutes and 50 minutes respectively.

Flexural Rigidity

The effect of ozone treatment time on flexural rigidity (bending stiffness) of the polyester fabric was investigated and compared in both warp and weft direction measurements. It shows that these durations of treatment have significant effect on the flexural rigidity of polyester fabrics. The flexural rigidity of treated samples increases as compared to the control samples. This may be because of the increased stiffness.

Table 3: Effect of ozone treatment on bending length

Treatment time (min)	Bending Length (cm)		Flexural Rigidity (mg-cm)		
	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Overall (Warp + weft
0	2.5	2.3	25.39	19.77	22.58
20	2.34	2.02	20.8	13.44	17.12
30	1.31	1.45	4.95	3.65	4.3
40	1.27	1.26	3.33	3.25	3.29
50	1.23	1.2	3.02	2.8	2.91

Air Permeability

Air permeability is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material. Air permeability is expressed as the quantity of air in cm3 passing per second through a cm2 of the fabric. It was observed from the result that the fabrics treated with ozone for long time (50minuet) enhance the air permeability in polyester fabrics. From the table it is seen that in all three-samples air permeability increases as the Ozone treatment time increases. This shows as the treatment time increase the air permeability values are much higher than that of the untreated fabric.

Table 4: Air Permeability (CM3/ Second /Cm2) test

Treatment time (min)	Air Permeability (CM3/ Second /Cm2)
0	32.38
20	38.24
30	45.22
40	53.43
50	69.15

Effect of ozone treatment on colour strength dyed fabric

Table 5: Effect of ozone treatment on color strength dyed fabric

Treatment time (min)	Color strength of the dyed fabric			
	Color strength (%)		K/s	K/s
	Before washing	After washing	Before washing	After washing
0/standard	100%	93.42%	5.32	4.87
20	93%	87.87%	4.53	4.42
30	97%	92.6%	4.81	4.62
40	118.44%	117.53%	5.48	5.31
50	144.47%	143.89%	6.04	5.92

Colour fastness properties

All treated samples were subjected to various colour fastness testing such as light, washing, and perspiration and crocking and the results are reported in the following table. The polyester treated sample at various time, their colourfastness properties were evaluated. For comparison the colour changes of the untreated samples also evaluated and considered as control sample. All samples have very well to excellent fastness properties with respect to rubbing fastness, light fastness, washing and Perspiration fastness of the ozone treated samples.

Table 6: Fastness property of the polyester fabric

Treatment time(minuet)	Types of dyes	Color fastness property of the polyester fabric			
		Washing	Rubbing fastness	Perspiration	Light

		fastness	Dry	wet	Acidic	alkaline	fastness
0 /standard	Disperse Blue 19	4/5	5	4	5	4-5	5
20	Disperse Blue 19	4/5	5	4	4	4/5	6
30	Disperse Blue 19	4/5	5	4	4/5	5	6
40	Disperse Blue 19	4/5	5	4/5	4/5	5	5/6
50	Disperse Blue 19	4/5	5	4/5	4/5	5	5/6

CONCLUSION

In this work, ozone treatment process has shown a significant chemical and physical change on polyester fabric that make the fabric hydrophilic and to improve its comfort characteristics. From this study it can be concluded that the ozone treatment has beneficial effects on fabric properties namely water absorption, water vapour transmission, air permeability and dye ability rate. Long-time treatment of ozone provides higher absorbency of fabric with constant percentage of ozone amount.

The results of surface modification of polyester fabric can be summarized as follows:

Chemical modification with ozone brought a weight loss of polyester fabric and it affects the strength above the optimum value.

As the duration of treatment increases the formation of polar groups also increase, and the weight loss also increases almost linearly.

This could be concluded that the treatment facilitates the deterioration of ester linkage in polyester chain which cause tensile strength and tear strength decreased.

Water absorbency test, sinking time test and colour strength measurement all these indicates there was an increase in wettability/absorbency of treated Polyester.

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