EFFECT OF SELF-CLEANING TREATMENT ON SOME PHYSICO-MECHANICAL PROPERTIES OF WOVEN POLYESTER AND POLYESTER/COTTON BLEND FABRICS

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ABSTRACT

Self-cleaning textiles have recently received much attention due to their convenience of less soiling, and thus less laundering. TiO_2 NPs is used to impart textile material self-cleaning characteristics. When TiO_2NPs is coated on textile polymers, its inherent photo-catalytic activity decomposes the polymeric textile materials, as well as the contaminants. Fabric material and its weaving construction are expected factors that able to mitigate the deterioration of mechanical strength of the treated fabrics under the photocatalytic activity of TiO_2NPs. The present work aims at investigating the effect of self-cleaning treatment on some physico-mechanical properties of woven polyester and polyester/cotton blend fabrics. Three kind of woven constructions were chosen namely, Plain 1/1, Twill 4/4 and Satin 4, each one were weaved using two types of picks number 24 and 36 picks/cm. Self-cleaning treatments of polyester (PES) and polyester/cotton blend fabrics was carried out using TiO_2NPs with binder and realized under the effect of direct sunlight. The fabrics were monitored for physico-mechanical properties and self-cleaning efficacy after the exposure to sunlight. Results obtained indicated that, at the same weaving construction and fabric types, the fabric tensile strength, elongation at break and surface roughness after self-cleaning treatments is higher than before treatment. Moreover, at the same weaving construction, 100% PES fabrics show the highest tensile strength and elongation at break as well as surface roughness compared with PES/cotton blend. It is further observed that, at the same fabric material and picks number, Plain 1/1 weave construction give higher tensile strength compared with Twill 4/4 and Satin-4 meanwhile, the surface roughness of the three weaving construction show the following order: Plain 1/1 > Twill 4/4 > Satin 4.

Keywords: Cotton Fabric, Nano-Titanium Dioxide, Self-Cleaning, Polyester, Weaving Construction

I. INTRODUCTION

Self-cleaning textiles have recently received much attention due to their convenience of less soiling, and thus less laundering. Methods applied for achieving self-cleaning textiles depends on fabricating textile surface by the lotus effect and applying photocatalytic materials **[1–3]**. Among the catalytic materials, titanium dioxide nanoparticles (TiO_2 NPs) is widely used due to its characteristics of non-toxicity, chemical stability, high photocatalytic activity, low cost and durability against washing **[4]**. The lotus effect can be achieved by imparting nano to micro scale of rough structures to a hydrophobic surface for easy removal of contaminants **[1, 2]**.

TiO_2 NPs catalyst, when subjected to irradiation with photons of energy equal to or higher than its band gap, generates electron-hole pairs, which can induce the formation of reactive oxygen species that lead to oxidation processes for degradation of contaminants **[5 – 7]**.

TiO_2 NPs coated textiles demonstrate self-cleaning performance since TiO_2 NPs have the ability to decompose organic compounds by photocatalytic activity. Since TiO_2 is a semiconductor, a photon of ultraviolet light, which exceeds the band gap energy, can lift an electron from the valence band of the mineral into the empty "conduction band", where electrons can flow and carry a current. In this process, two mobile charges are produced: the electron in the conduction band and the hole left behind in the valence band, which behaves much like a positively charged particle. These two charges, can interact with H_2O and O_2 molecules at the surface of the titania, producing superoxide radical anions (O_2^-) and hydroxyl radicals ($OH^·$)– highly reactive chemicals that can then convert organic compounds to carbon dioxide and water **[8 - 15]**.

TiO_2NPs impart textile fabrics simultaneously trilateral properties namely, antibacterial, UV protective and self-cleaning properties. Taking into account ever growing consumer demands, the fact that small amount of TiO_2 NPs provides desirable effects as well as simple synthesis and application procedures, it becomes clear why such multifunctional textile materials are of interest for textile industry **[15 - 18]**.

The problematic issues are primarily related to, the fate of fibers impregnated with TiO_2NPs exposed to longer UV irradiation i.e., their integrity and possible degradation due to the contact with photocatalyst has not been monitored yet.

The chemical finishing of polyester fabrics is mainly intended to overcome some of its inherent drawbacks such as soiling tendency **[19]**.

Although ultraviolet rays are present virtually everywhere, there a certainly many factors affecting the intensity of the rays and its accessibility inside the fabrics which should have a direct impact on the efficiency of self-cleaning reactions of TiO_2NPs. This has been investigate in our previous work published recently **[4]**. The important results obtained from that work showed that, the highest degree of self-cleaning properties was observed with satin-4 weaving construction, whereas plain 1/1 weaving construction verifies the least degree of self-cleaning. Twill 4/4 weaving construction verifies intermediate values. It is was also observed that, at the same weaving construction, increasing the picks number from 24 to 36 pick/cm leads to decrement in degree of self-cleaning properties of the fabrics. Moreover, at the same picks number and weaving construction, 100 % PES fabrics treated with TiO_2NPs achieve highest self-cleaning properties compared with PES/cotton blend fabric **[4]**.

When TiO_2 is coated on textile polymers, the photo-catalysis and the resulting oxidation may decompose the polymeric textile materials, as well as the contaminants **[12]**. Fabric material and its weaving construction as well as existence of addition polymer (as binder in this study) are expected factors that able to mitigate the deterioration of mechanical strength of the treated fabrics from the photocatalytic activity of TiO_2.

With this in mind and in continuation to our previous work, the present work aims at investigating the effect of self-cleaning treatment on some physico-mechanical properties of woven polyester and polyester/cotton blend fabrics. We have built our investigation onto polyester fabrics and its blends with cotton due to its inherent soiling tendency compared with other natural fibres. Self-cleaning treatments of polyester (PES) and polyester/cotton blend fabrics was carried out using TiO_2NPs with binder and realized under the effect of direct sunlight. For this end, the PES and its blend with cotton in different weaving construction were treated with TiO_2NPs then monitored for physico-mechanical properties and self-cleaning efficacy after the exposure to sunlight.

II. EXPERIMENTAL

2.1 Materials

Titanium dioxide nanoparticles (TiO_2 NPs) in anatase form was supplied by Aldrich Chemical Company, USA. It has the following crystal structure, tetragonal, a = 0.3785 nm, c = 0.9514 nm) from literatures it has band gap = 3.2 eV which is equivalent to a wavelength of 388 nm **[20]**.

Prtofix® Binder 83 – Acrylic based copolymers, self-crosslinking – were of technical grade chemicals- supplied from Clariant Chemicals (India) Limited.

2.2 Weaving Machine

The samples were produced using Jacquard-weaving machine from Estopli Electronic, Italy. The machine has the following specifications:

Number of Hooks in Jacquard machine = 3072Hook

Number of actual hook design = 2560 Hook

Machine speed 290 Picks/min

Fabric width without selvage = 142 cm

Number of warp set = 72 end/cm

Reed count = 9 dent/cm

Reeding (number of yarn/dent) = 8 yarn/ dent

2.3 Fabrics Specifications

Table I shows the specification of the produced fabrics and its weaving construction. 100 % PES yarns were used in warp direction whereas different ratios of PES and cotton yarns in the weft direction were performed. According to the capacity of machine used, and weaving construction chosen; the maximum picks number in cm could achieved is 36 pick/cm. and 24 picks/cm.

2.3 Treatment of the Fabrics with TiO_2 NPs

The produced fabrics were cut into swatch (30×30 cm). The swatches were immersed in the solution containing TiO_2 (2 wt.-%) and Prtofix® Binder 83 (1 wt.-%) for 5 min. The fabrics were then squeezed using laboratory padding machine to wet pick up of 100% then dried at 80°C for 5 min and curing at 140°C for 3 min.

Table I: Fabric Specifications (Type of Warp Yarns is 100 % PES)

No	Weft material	Weft Blending Ratio	Picks number (pick/cm)	Weaving Structure
1	Cotton	100	36	Plain 1/1
2	PES/Cotton	50/50		
3	PES	100		
4	Cotton	100	24	
5	PES/Cotton	50/50		
6	PES	100		
7	Cotton	100	36	Twill 4/4
8	PES/Cotton	50/50		
9	PES	100		
10	Cotton	100	24	
11	PES/Cotton	50/50		
12	PES	100		
13	Cotton	100	36	Satin 4
14	PES/Cotton	50/50		
15	PES	100		
16	Cotton	100	24	
17	PES/Cotton	50/50		
18	PES	100		

2.4 Testing and Analysis

Laboratory tests on the produced samples were carried out at the standard conditions for textiles with an air temperature (20 ±2°C) and relative humidity of air (65 ± 5 %) according to the American Society of Testing Materials (ASTM).

2.4.1 Surface Roughness

Surface roughness was monitored according to JIS 94 standard, using surface roughness measuring instrument, SE 1700a made in Japan. Values recorded in (μm) unit and represent the average of 5 reading.

2.4.2 Tensile Strength and Elongation at Break

Fabric tensile strength (kg.f) and elongation at break (%) was determined according to ASTM standard test method **[21]**.

2.4.3 Evaluation of Self-Cleaning Properties [22]

Self cleaning of the treated fabrics were assist using standardized method termed as Stain Degradation Assessment (SDA) method, developed for the quantitative evaluation of self-c1eaning efficiency of the finished fabric **[22]**. The method involves (i) a standardized staining procedure to apply a uniform stain on the fabric, (ii) instrumental evaluation of photo-degradation of stain in terms of *K/S* using a template to reduce error, and (iii) analysis of *KlS* values to evaluate stain degradation in percentage.

i) Preparation of Textile Swatches

Untreated and treated fabrics were cut into swatches of 5 cm x5 cm. Two sets of test specimens were prepared. One set was for assessment after exposure to the UV light and the other set was for assessment without exposure and its comparison with the exposed specimen. The fabric swatches were ironed to obtain a flat and smooth surface. The specimen was sandwiched between two layers of non-absorbing paper while ironing to avoid direct contact with the hot iron surface.

ii) Stain Application

Dilute solution of methylene blue dye at concentration of 0.1% (wt. %) in distilled water was prepared. The fabrics were stained using us 5 mL dye solution. The samples were then dried on a non-absorbing surface with the stained side up.

iii) Exposure of Stained Samples to Direct Sunlight

Stained samples were exposed to direct sunlight for 24 h at ambient conditions.

iv) Analysis of Stain Degradation

K/S values of the stained specimens before and after the exposure to sunlight were determined using Color-Eye 3100 Spectrophotometer from SDL Inter.

v) Calculation of Stain Degradation

The % decrease in *K/S* (*which represent the degree of self cleaning by photo-degradation of the fabrics)* was then calculated at each of the five positions of the specimen by taking *K/S* before and after the exposure of specimen to sunlight for specific time duration. The % decrease in *K/S* for each position was calculated using the following formula **[22]**:

$$\textit{Degree of self cleaning by photodegradation} = \%\ \textit{decrease in } K/S = \frac{(K/S)\textit{stained and unexposed} - (K/S)\ \textit{exposed}}{(K/S)\ \textit{stained and unexposed}} \times 100$$

Where:

(K/S) unexposed = *K/S* of stained specimen before exposure

(K/S) exposed = *K/S* of stained specimen after exposure to sunlight

III. RESULTS AND DISCUSSION

3.1 Self-Cleaning Properties of PES and PES/Cotton Blend Fabrics Treated with TiO_2 vise-a-vise Untreated Fabrics

Two kinds of yarn materials, namely PES and cotton, were chosen to form fabrics with three different blending ratios. For each blending ratio three kind of weaving construction and picks number were exploit. Specifications of the produced fabrics are set out in Table I. A part of each sample was treated with TiO_2 NPs and monitored for self-cleaning properties as detailed in the experimental section. Results obtained are set out in Table II. It is clear from table II that, the highest degree of self-cleaning properties was observed with satin-4 weaving construction, whereas plain 1/1 weaving construction verifies the least degree of self-cleaning. It is further noted that, 100 % PES fabrics treated with TiO_2NPs achieve highest self-cleaning properties compared with PES/cotton blend fabric.

3.2 Change in Tensile Strength of the Fabrics After Self-Cleaning Treatment

Figure 1 shows the effect of self-cleaning treatments on the tensile strength of PES and PES/cotton blend fabrics after self-cleaning treatments. The results obtained with those similar fabrics before treatments are also presented in the same figure for comparison. It should be noted here that, the tensile strength of the treated fabrics were monitored after exposure to sun light for 24 h. Three kind of woven construction were chosen namely, Plain 1/1, Twill 4/4 and Satin 4 keeping the picks number constant and equal 24 picks/cm. The results of Figure 1 depicts the following:

i) At the same weaving construction and fabric types, the fabric tensile strength after self-cleaning treatments is higher than before treatment. This was observed with all three substrates under investigation. This may be attributed to the performance of the binder used in the self-cleaning treatment. The binder (which is a polymeric materials based on self-crosslinking acrylic based copolymers) imparts the fabric two functions. The first is extra strength and the second is protective action to the fabrics material against the oxidation action of TiO_2 NP in presence of sunlight.

ii) At the same weaving construction, 100% PES fabrics show the highest tensile strength compared with PES/cotton blend. By increasing the proportion of cotton yarn in the weft direction from 50/50 to 100 %, the tensile strength of the fabrics decreased. This was observed whatever the fabric treated or not but with certainty that tensile strength values were higher after self-cleaning treatments. The tensile strength of the fabrics whether treated or not follows the order: 100 % PES > PES/cotton (constructed from 100 % yarn in warp direction and 50/50 PES/cotton yarn in weft direction) > PES/cotton (constructed from 100 % PES yarn in warp direction and 100 % cotton yarn in weft direction).

iii) It is further observed from Figure 1 that, at the same fabric material and picks number, Plain 1/1 weave construction give higher tensile strength compared with Twill 4/4 and Satin-4. Plain weave is the simplest and most important of all weave interlacing, in which alternating warp yarns are present on both sides of the fabric. The plain weave repeats on two ends and two picks, i.e. the first end passes over the first pick and under the second pick whilst the second end reverses this sequence. Therefore, in plain weave structure, higher number of yarns interlacing is account for the higher tensile strength compared with Twill 4/4 and Satin-4 **[23 - 25]**.

Figure 2 shows the results when the fabrics were constructed using 36 picks/cm instead of 24 pick/cm. The results of Figure 2 were exactly similar that obtained previously in Figure 1 and can be explained on similar bases.

Figure 3 shows the change in tensile strength of the fabrics with weaving construction plain 1/1, and picks number of 24 and 36 picks/cm after self-cleaning treatment. The tensile strength of the fabric having 36 picks/cm is higher than similar fabric having 24 picks/cm. This is rather logical since by increasing the number of picks the number of yarn interlacing increased and the tensile strength increased. This findings were observed irrespective to fabric types. However, close examination of the results in Table II and Figure 3 show that, fabric constructed using 24 picks/cm exhibited higher self-cleaning efficacy compared with similar fabrics weaved using 36 picks/cm.

Table II. Self-Cleaning Properties of PES and PES/cotton Blend Fabrics Before and After Treatment with TiO_2

No	Weft material	Weft Blending Ratio	Picks no /cm	Weaving Structure	Degree of self-cleaning (%)	
					Untreated	Treated
1	Cotton	100	36	Plain 1/1	3	81
2	PES/Cotton	50/50			3	83
3	PES	100			3.2	85
4	Cotton	100	24		3.2	82
5	PES/Cotton	50/50			3.5	84
6	PES	100			3.5	87
7	Cotton	100	36	Twill 4/4	3.1	83
8	PES/Cotton	50/50			3.2	84
9	PES	100			3.5	86
10	Cotton	100	24		2.7	85
11	PES/Cotton	50/50			2.7	86
12	PES	100			3.2	88
13	Cotton	100	36	Satin 4	2.2	83
14	PES/Cotton	50/50			*2.5*	84
15	PES	100			2.5	89
16	Cotton	100	24		3	88
17	PES/Cotton	50/50			3	89
18	PES	100			3.1	90

[1]Untreated mean bleached untreated fabric and stained then exposed to sunlight for 24 h

[2]Treated mean fabrics treated with TiO_2 NPs and stained then exposed to sunlight for 24 h

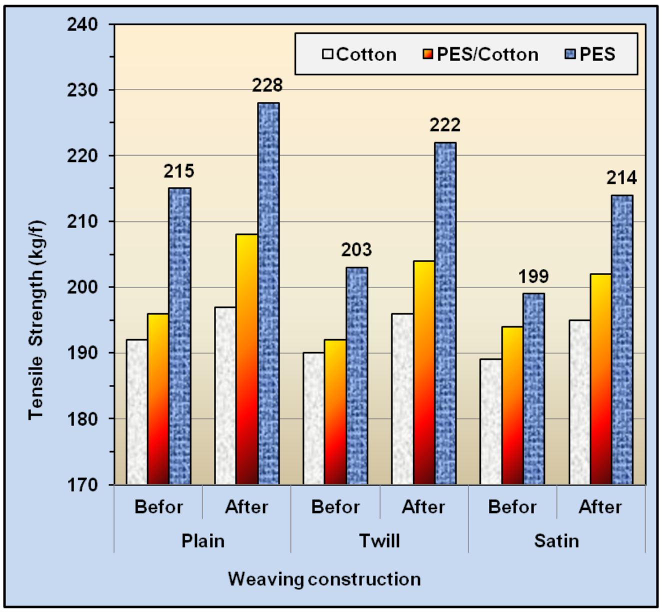

Figure 1: Change in Tensile Strength of the Fabrics having Different Weaving Construction and Constant Pick Number (24 Picks/cm) Before and After Self-Cleaning Treatment

Before = before self-cleaning treatment

After = after self-cleaning treatment and exposure to sunlight for 24 h.

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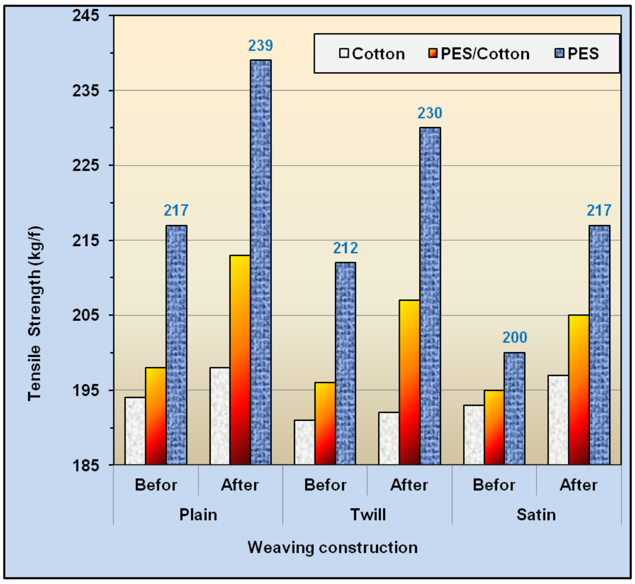

Figure 2: Change in Tensile Strength of the Fabrics Having Different Weaving Construction and Constant Pick Number (36 Picks/Cm) Before and After Self-Cleaning Treatment.

Before = before self-cleaning treatment

After = after self-cleaning treatment and exposure to sunlight for 24 h.

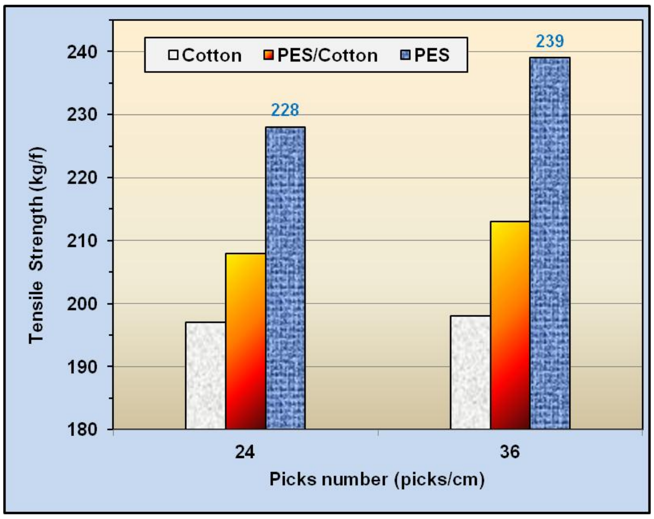

Figure 3: Change in Tensile Strength of the Fabrics Weaved Using Plain 1/1 Weaving Construction, and Picks Number of 24 and 36 Picks/Cm After Self-Cleaning Treatment

3.2 Change in Elongation at Break of the Fabrics After Self-Cleaning Treatment

Figures 4, 5 show the effect of self-cleaning treatments on the elongation at break of PES and PES/cotton blend fabrics weaved using 24 picks/cm (Figure 4) and 36 picks/cm (Figure 5) after self-cleaning treatments. The results obtained with similar fabrics before treatments are also presented in the same Figures for comparison. The results of Figures 4, 5 make it evident that:

i) At the same weaving construction and fabric types, the elongation at break after self-cleaning treatments is higher than before treatment. This was observed with all three substrates under investigation. This may be attributed to the binder used in the self-cleaning treatment which is a polymeric materials based on self-crosslinking acrylic based copolymers.

ii) At the same weaving construction, 100% PES fabrics show the highest elongation at break compared with PES/cotton blend. By increasing the proportion of cotton yarn in the weft direction from 50/50 to 100 %, the elongation at break of the fabrics decreased. This was observed whatever the fabric treated or not but with certainty that values of elongation at break were higher after self-cleaning treatments.

iii) It is further observed from Figures 4 ,5 that, at the same fabric material and picks number, values of elongation at break show no specific trends among the three weaving constructions used in this study.

Figure 6 shows the change in elongation at break of the fabrics with weaving construction Satin 4, and picks number of 24 and 36 picks/cm after self-cleaning treatment. The elongation at break of the fabric having 24 picks/cm is higher than similar fabric having 36 picks/cm.

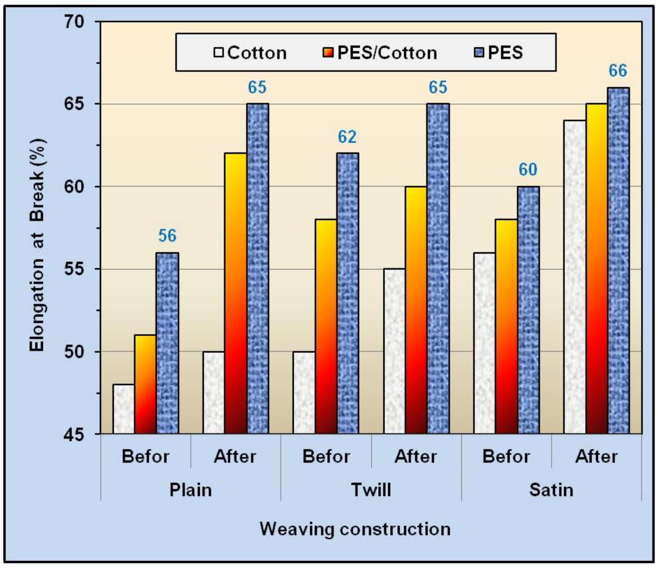

Figure 4: Change In Elongation at Break of the Fabrics Having Different Weaving Construction and Constant Pick Number (24 Picks/Cm) Before and After Self-Cleaning Treatment

Before = before self-cleaning treatment

After = after self-cleaning treatment and exposure to sunlight for 24 h.

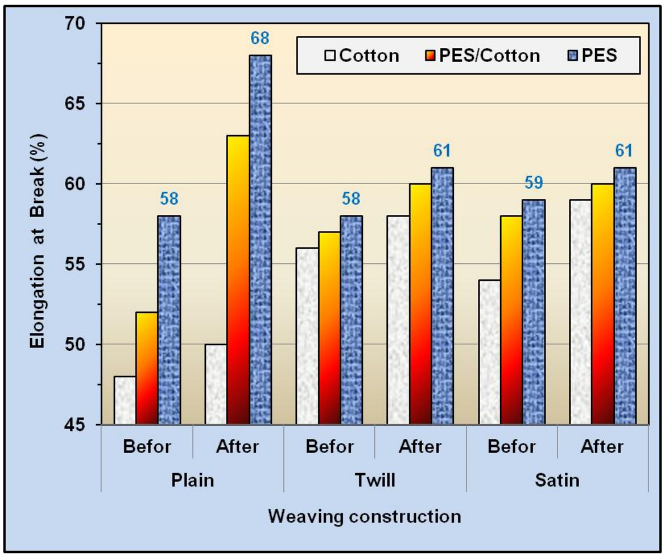

Figure 4: Change In Elongation at Break of The Fabrics Having Different Weaving Construction and Constant Pick Number (36 Picks/Cm) Before and After Self-Cleaning Treatment

Before = before self-cleaning treatment

After = after self-cleaning treatment and exposure to sunlight for 24 h.

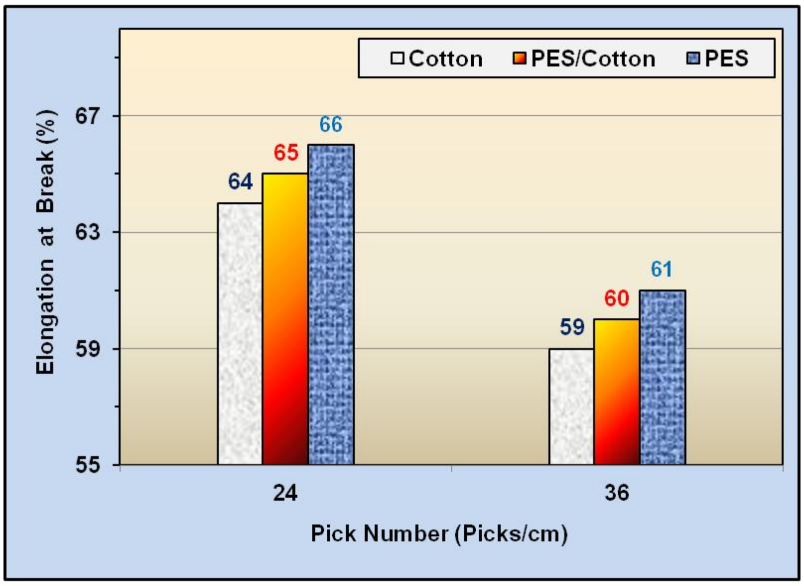

Figure 3: Change in Elongation at Break of The Fabrics Weaved Using Satin 4 Weaving Construction, and Picks Number of 24 And 36 Picks/Cm After Self-Cleaning Treatment

3.2 Change in Surface Roughness of the Fabrics After Self-Cleaning Treatment

Figures 7, 8 show the effect of self-cleaning treatments on the surface roughness of PES and PES/cotton blend fabrics weaved using 24 picks/cm (Figure 7) and 36 picks/cm (Figure 8) after self-cleaning treatments. Values of surface roughness of similar fabrics before treatments are also present in the same Figures for comparison. The results of Figure 7, 8 can be interpreted as follows:

i) At the same weaving construction and fabric types, the surface roughness after self-cleaning treatments is higher than before treatment. This was observed with all three substrates under investigation. This may be attributed to the oxidation action of TiO_2 NP during self-cleaning process.

ii) At the same picks number and weaving construction, 100% PES fabrics shows the highest surface roughness compared with PES/cotton blend. By increasing the proportion of cotton yarn in the weft direction from 50/50 to 100 %, the surface roughness of the fabrics decreased (which mean that the fabrics tend to be softer). This was observed whatever the fabric treated or not but with certainty that values of surface roughness were higher after self-cleaning treatments.

iii) It is further observed from Figures 7, 8 that, at the same fabric material and picks number, the surface roughness of the three weaving construction show the following order: Plain 1/1 > Twill 4/4 > Satin 4. Higher number of yarns interlacing is account for the higher surface roughness compared with Twill 4/4 and Satin-4 **[23 - 25]**.

Figure 9 shows the change in surface roughness of the fabrics with weaving construction Plain 1/1, and picks number of 24 and 36 picks/cm after self-cleaning treatment. The surface roughness of the fabric having 36 picks/cm is higher than similar fabric having 24 picks/cm.

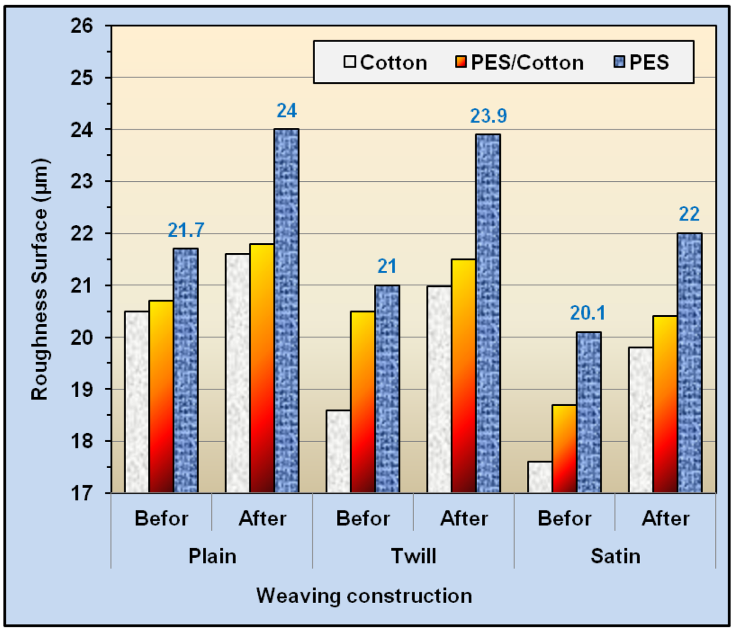

Figure 7: Change in Surface Roughness of the Fabrics Having Different Weaving Construction and Constant Pick Number (24 Picks/Cm) Before and After Self-Cleaning Treatment

Before = before self-cleaning treatment

After = after self-cleaning treatment and exposure to sunlight for 24 h.

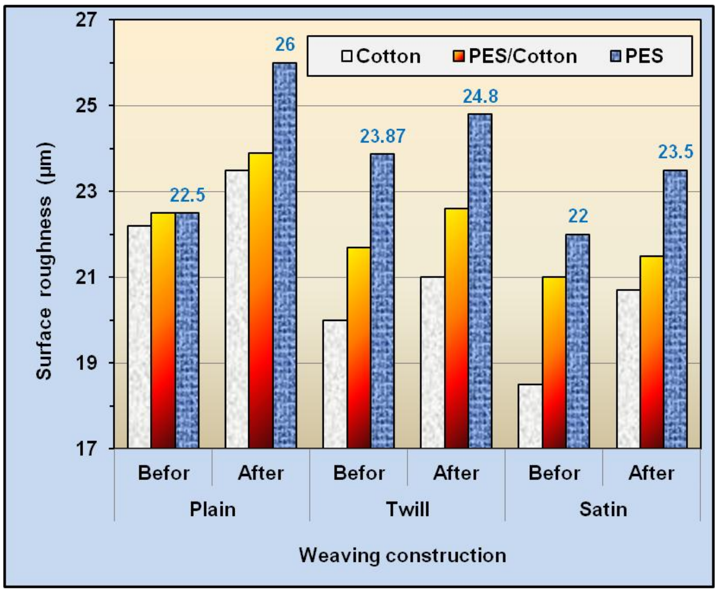

Figure 8: Change in Surface Roughness of the Fabrics Having Different Weaving Construction and Constant Pick Number (36 Picks/Cm) Before and After Self-Cleaning Treatment

Before = before self-cleaning treatment

After = after self-cleaning treatment and exposure to sunlight for 24 h.

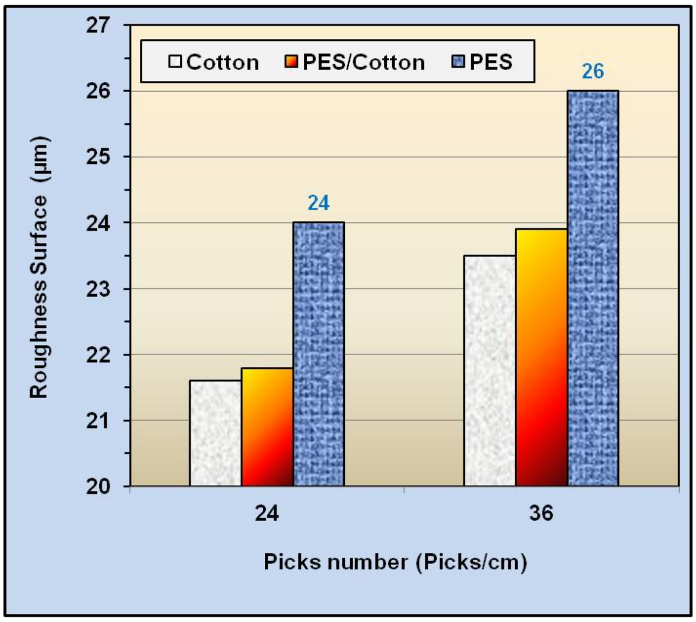

Figure 9: Change in Surface Roughness of the Fabrics Weaved Using Plain 1/1 Weaving Construction, and Picks Number of 24 and 36 Picks/Cm After Self-Cleaning Treatment

IV. CONCLUSION

The results indicated that, weaving constructions and the type of fabric materials have influence on the ultimate physico-mechanical properties of the fabric after self-cleaning treatments. The fabric tensile strength, elongation at break and surface roughness after self-cleaning treatments is higher than before treatment. Moreover, at the same weaving construction, 100% PES fabrics show the highest tensile strength and elongation at break as well as surface roughness compared with PES/cotton blend. It is further observed that, at the same fabric material and picks number, Plain 1/1 weave construction give higher tensile strength compared with Twill 4/4 and Satin-4 meanwhile, the surface roughness of the three weaving construction show the following order: Plain 1/1 > Twill 4/4 > Satin 4. The surface roughness of the fabric having 36 picks/cm is higher than similar fabric having 24 picks/cm

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