EFFECT OF WEAVING CONSTRUCTION AND BLENDING RATIO ON SELF-CLEANING PROPERTIES OF POLYESTER AND POLYESTER/COTTON BLEND FABRICS TREATED WITH TiO_2 NANOPARTICLES

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ABSTRACT

Self-cleaning finishing of polyester fabrics (PES) with TiO_2 NPs aims at overcome its inherent soiling tendency compared with other natural fibres. However, although sunlight rays are present virtually everywhere, there are 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 PES fabric treated with TiO_2 NPs. In this work the effect of weaving construction of PES fabrics and its blend with cotton yarn that verify higher self-cleaning efficacy after treatment with TiO_2 NPs was investigated. For this regard, two kinds of yarn materials were chosen to form fabrics with three different blending ratios. For each blending ratio three kind of weaving construction and picks number were exploit. The samples were treated with TiO_2 NPs and monitored for self-cleaning properties. Results obtained shows 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 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. It is further noted that, at the same picks number and weaving construction, 100 % PES fabrics treated with TiO_2NPs achieve highest self-cleaning properties

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

I. INTRODUCTION

Recently, the research interest for the use of nanotechnology in the textile industry has increased rapidly. This is mainly because textile fabrics are some of the best platforms for deploying nanotechnology. Fibers make optimal substrates where a large surface area is present for a given weight or volume of the fabric.

Although enormous progress in this field has been already made, nanotechnologies still pose many questions and challenges including their industrial scale implementation that would enable commercial manufacturing of nanomaterials and corresponding products, environmental, safety and health concern, as well as optimization of treatment parameters **[1 – 4]**.

A large number (more than thousand) of labeled commercial products (electronic, automotive, medical, cosmetics, optics, etc.) contain different nanoparticles (NPs) **[1, 2, 5, 6]**. Ag NPs are currently the most commonly used nano-engineered material due to their outstanding antimicrobial activity **[1]**. However, the potentials of metal oxide nanoparticles, in particular TiO_2 NPs, offer broader application **[7, 8]**. This photocatalyst can be efficiently utilized for self-cleaning of surfaces **[9–11]**, water and air purification **[12 – 16]**, anti-fogging surfaces **[17, 18]**, photovoltaics **[19 – 22]**, etc.

Finishing of textile materials with Ag, TiO_2 and ZnO NPs became the focus of many research groups worldwide during the last decade. The interest for TiO_2 NPs immobilization onto textile materials is continually growing due to their extraordinary photocatalytic activity, non-toxicity, high availability, biocompatibility, and low price **[34, 35]**.

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 **[36]**.

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. Recently two published review papers focused on the functionalization of different textile materials with TiO_2 NPs **[36]**.

Unlike metals, which possess a continuum of electronic states, TiO_2 as a semiconductor has a band structure. Such structure is characterized by the existence of energy gap that extends from the top of the occupied valence band to the bottom of the unoccupied conduction band **[36 - 38]**.

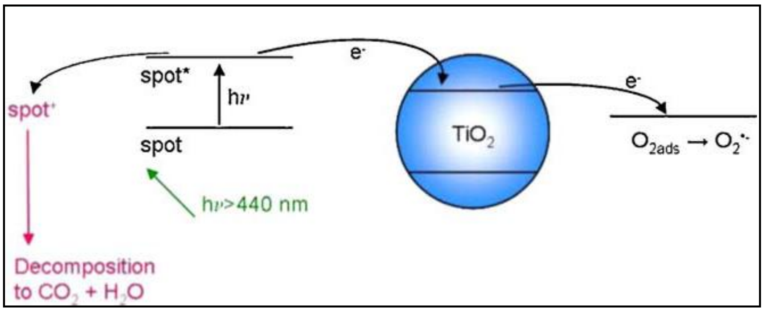

Figure 1: Scheme of The Self-Cleaning Mechanism of Wine Pigments on Tio$_2$-Cotton/Polyester Pretreated Fabrics Under Sunlight [36 - 38].

When the fabric treated with TiO_2 NPs irradiated with light of energy greater than or equal to its band gap energy, self-cleaning and anti-microbial effect can best be illustrated in three steps:

1) Photo-excited TiO_2 produces electron-hole pairs which migrate to the surface of the TiO_2

2) The photo-generated holes in TiO_2 react with adsorbed H_2O or OH^- to produce highly reactive hydroxyl radicals, hydrogen peroxide at the catalyst/water interface. Electrons can then react with oxygen vacancies to form superoxide ions.

3) The highly active oxygen species generated can then oxidize organic compounds or cells adsorbed on the TiO_2 surface, which results in the death of microorganisms and self-cleaning effect.

When the stain gets illuminated with visible light, the excited electron from organic molecule of stain is injected into conduction band of TiO_2NPs. On the other hand, the electrons from the conduction band of TiO_2 NPs reduce oxygen generating very reactive superoxide radicals which along with the other extreme reactive radicals (HO_2•−, OH•, RO•,

RO_2•) degrade the stain. In addition, excited pigment of the organic compound (R•) could be directly degraded by photo-induced holes (hVB^+) (Fig. 1) **[36-39]**.

The chemical finishing of polyester fabrics is mainly intended to overcome some of its inherent drawbacks such as soiling tendency **[40]**. 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 actually evoked the aim of the present work, which aims at investigating the effect of weaving construction and blending ratio on self-cleaning properties of cotton/polyester 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.

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 **[41, 42]**.

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.

2.4 Testing and Analysis

2.4.1 Evaluation of Self-Cleaning Properties [43]

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 **[43]**. The method involves (i) a standardized staining procedure to apply a uniform stain on the fabric, (ii) instrumental evaluation of photodegradation 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

A 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 4, 8, 16 and 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 **[43]**:

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

Where:

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

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

Table I: Fabric specifications (type of warp yarns is 100 % PES)

No	Weft material	Weft Blending Ratio	Picks number /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		

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

The relative amounts of direct sunlight penetrating the fabrics construction and react with TiO_2 NPs to produce active oxygen species that able to decompose the stain depend on many factors. The latter include the fibre type, and fabric construction.

The aim of the present work is to study the optimum weaving construction of PES fabrics and its blend with cotton yarn that verify best self cleaning efficacy for the fabrics after treatment with TiO_2 NPs. For this regard, two kinds of yarn materials were chosen to form a 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 should be noted here that, values of K/S of untreated and stained fabrics were recorded in the table after 24 h exposure time only, whereas changes in K/S values of treat fabric were recorded after 4, 8. 16 and 24 h

3.2 Effect of Number of Picks Number and Weaving Construction on Degree of Self-Cleaning of the Produced Fabrics

Table II and Figure 2 show the effect of weaving construction and number of picks of PES/cotton blend fabric constructed using 100 % cotton yarns in weft direction and 100 % PES yarns in warp direction then treated with TiO_2 NPs on degree of self-cleaning after 24 h exposure to sunlight. It is seen from Table II and Figure 2 that:

i) At the same picks number, 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.

ii) 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.

Satin-4 is a basic weaving structure, in which the yarn crossover or interlacing points are spaced as evenly and widely as possible and in which the yarn crossover points lying between the visible crossover points are more or less covered by yarns lying on the surface (floats) **[44, 46]**. Satin waving construction has the highest float characteristics compared with other two weaving construction used in this study, namely Twill 4/4 and plain 1/1. This higher float characteristic in satin construction permit the penetration of direct sunlight to interact with TiO_2 NPs and therefore increases the degree of self-cleaning and stain removal.

The same results were obtained with those fabrics constructed from PES yarns in warp direction and using 50/50 cotton/PES yarns in weft direction (Table II and Figure 3) as well as those fabrics constructed for 100 % PES yarns in weft and warp direction (Table II and Figure 4). Both fabric shows highest self-cleaning properties when they constructed using Satin-4 weaving pattern and 24 picks/cm.

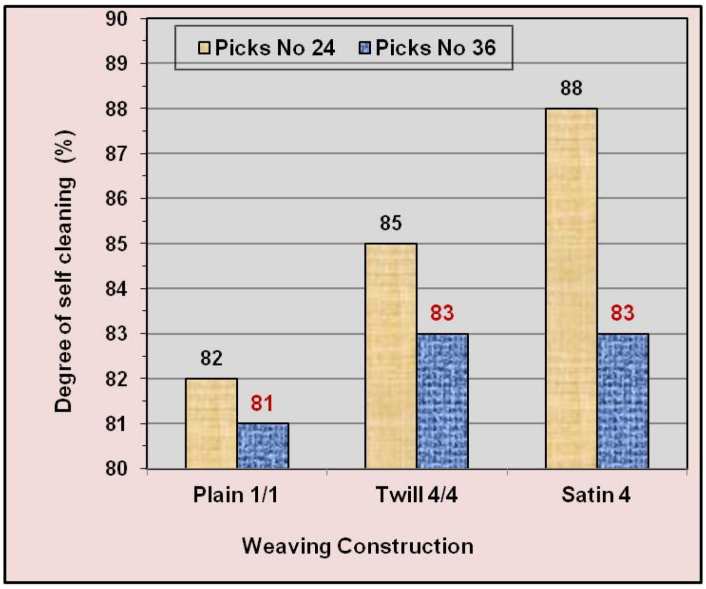

Figure 2: Effect of weaving construction and number of picks of PES/cotton blend fabric (constructed using 100 % cotton yarns in weft direction and 100 % PES yarns in warp direction) treated with TiO_2 NPs on degree of self-cleaning after 24 h exposure to sunlight

Table II. Self-Cleaning Properties of PES and PES/Cotton Blend Fabrics Treated with Tio_2 in Comparison with the Untreated Fabrics

No	Weft material	Weft Blending Ratio	Picks no /cm	Weaving Structure	Change in K/S (%) with exposure time				
					Untreated	Fabrics Treated with TiO_2 NPs			
					24 h	4 h	8 h	16 h	24 h
1	Cotton	100	36	Plain 1/1	3	77	80	80.7	81
2	PES/Cotton	50/50			3	80.7	82	82.7	83
3	PES	100			3.2	83	83.9	84	85
4	Cotton	100	24		3.2	78.1	80.3	81	82
5	PES/Cotton	50/50			3.5	81	83	83.9	84
6	PES	100			3.5	83.5	83.5	85	87
7	Cotton	100	36	Twill 4/4	3.1	78.4	79.8	80	83
8	PES/Cotton	50/50			3.2	82.3	83.2	83	84
9	PES	100			3.5	82.5	84	85	86
10	Cotton	100	24		2.7	83	83.8	83.9	85
11	PES/Cotton	50/50			2.7	83	83.9	84	86
12	PES	100			3.2	87.4	88.2	87	88
13	Cotton	100	36	Satin 4	2.2	80	81	82	83
14	PES/Cotton	50/50			*2.5*	80	82.3	83	84
15	PES	100			2.5	87	88.3	88.3	89
16	Cotton	100	24		3	84	86	86	88
17	PES/Cotton	50/50			3	84	86	87	89
18	PES	100			3.1	86.5	89	89.1	90

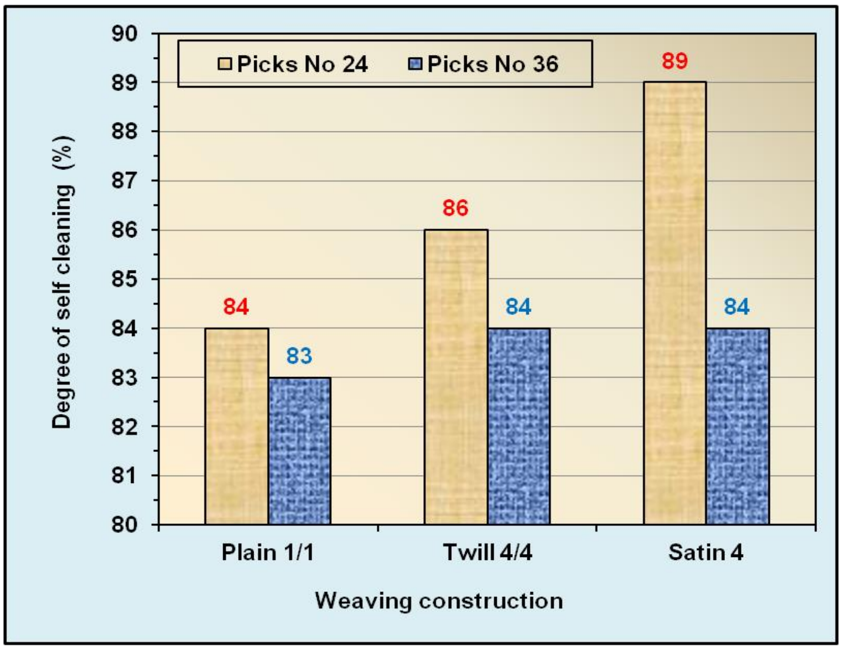

Figure 3: Effect Of Weaving Construction And Number Of Picks Of PES/Cotton Blend Fabric (Constructed Using 50/50 Cotton/PES Yarns In Weft Direction And 100 % PES Yarns In Warp Direction) Treated With Tio_2 Nps On Degree Of Self-Cleaning After 24 H Exposure To Sunlight

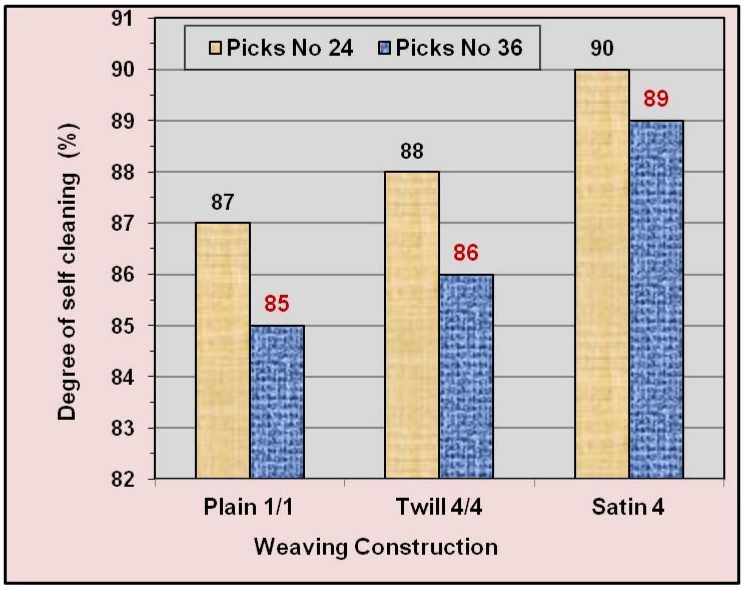

Figure 4: Effect Of Weaving Construction And Number Of Picks Of PES Fabric (Constructed Using 100 % PES Yarns In Weft And Warp Direction) And Treated With Tio_2 Nps On Degree Of Self-Cleaning After 24 H Exposure To Sunlight

3.3 Effect of Yarn Type and Weaving Construction of The Fabrics Treated with Tio_2 Nps On Degree of Self-Cleaning

Table II and Figure 5, 6 show the effect of yarn type and weaving construction of the fabrics treated with TiO_2NPs on degree of self-cleaning at constant picks number (24, 36 picks/cm respectively). It is seen from Figure 5, 6 and Table II that:

a) At the same picks number and weaving construction, 100 % PES fabrics treated with TiO_2NPs achieve highest self-cleaning properties. For example, about 90 % of stain were removed after 24 h exposure to sunlight when the fabric construction was Satin-4. PES/cotton blend fabric shows lower degree of self-cleaning at the same weaving construction and picks number.

b) At the same fabric type Satin-4 weaving construction shows higher degree of self-cleaning.

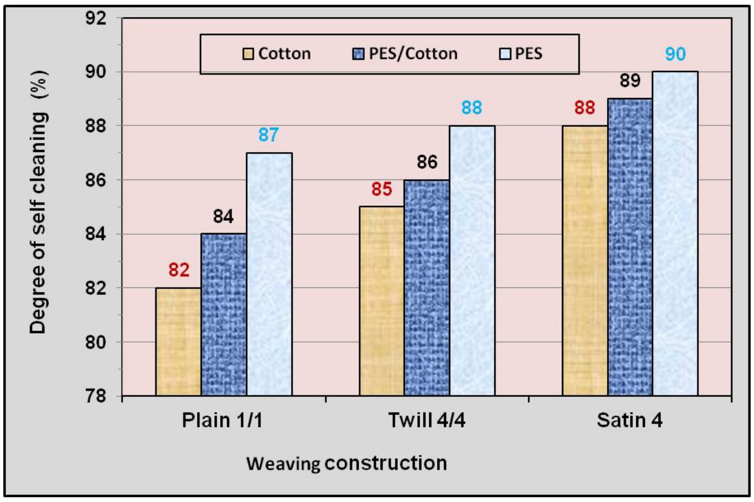

Figure 5: Effect of Yarn Type and Weaving Construction of the Fabrics Treated with Tio_2 Nps on Degree of Self-Cleaning After 24 H Exposure to Sunlight. Number of Picks = 24 Picks /Cm

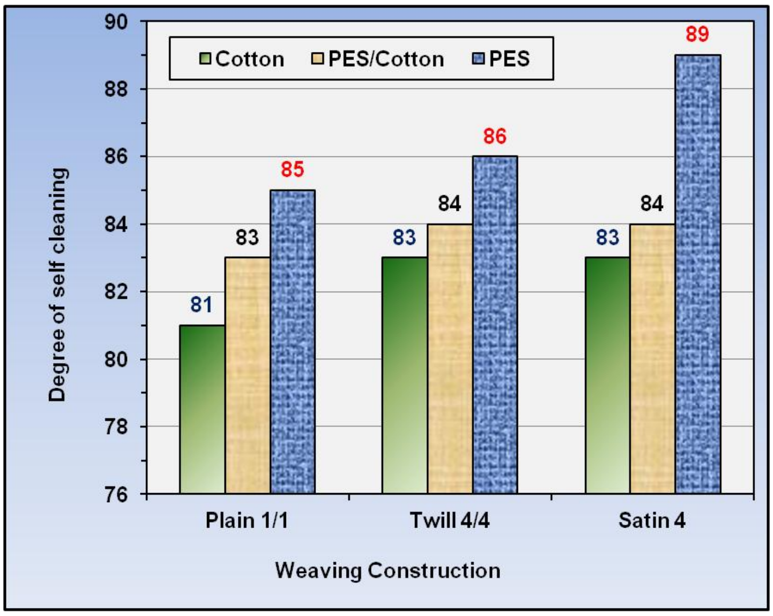

Figure 6: Effect of Yarn Type and Weaving Construction of the Fabrics Treated with Tio_2nps on Degree of Self-Cleaning After 24 H Exposure to Sunlight. Number of Picks = 36 Picks/Cm

IV. CONCLUSION

The effect of weaving construction of PES fabrics and its blend with cotton yarn that verify best self-cleaning efficacy for the fabrics after treatment with TiO_2 NPs was investigated. For this regard, two kinds of yarn materials were chosen to form a fabrics with three different blending ratios. For each blending ratio three kind of weaving construction and picks number were exploit. The samples were treated with TiO_2 NPs and monitored for self-cleaning properties. Results obtained shows 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 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. It is further noted that, 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.

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