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Using Ultraviolet Radiation for the Bleaching and Pilling Reduction of Knitted Cotton Fabric

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Abstract
The possibility of the simultaneous bleaching and anti-pilling of cotton fabric using UV radiation on hydrogen peroxide impregnated knitted samples was studied. The effect of a photoinitiator or sensitiser, sodium hydroxide as an activator, sodium silicate as a stabiliser for H_2O_2, and the irradiation time on the samples' whiteness, yellowness, pilling rate and strength loss was investigated. Comparisons of the results with the conventional pad steam process indicate that adequate whiteness can be obtained, while keeping the strength loss within acceptable limits, by padding cotton fabric with pad-steam pad bath components under UV irradiation. In addition, the reduction in pilling tendency is comparable with Biopolished samples on an industrial scale.

Key words: *ultraviolet irradiation, knitted cotton fabric, finishing, bleaching, pilling.*

Introduction

Pilling is a serious defect for textile fabrics which adversely affects the fabric aesthetic, hand, and service life of a garment, and is a major source of fabric attrition [1 - 3], principally for knitted fabrics rather than woven ones. Although knitted fabrics have many advantages, such as higher production rates with lower costs, comfort properties, and soft fabric structure, the pilling problem remains as an objection because of the slack fabric structure. Daily growth in using knitted fabrics, as well as the advent of new man-made fibres and their blends with natural fibres make it necessary to reduce garment pilling [4, 5]. The pilling mechanism has already been described [6, 7] and clarified i.e. the yarn and fabric structure are of great significance for fabric pilling when choosing the right wet treatment, such as dyeing and finishing procedures, which could control the pilling performance.

There are two different ways to minimise pill formation: reducing fuzz density and fuzz formation by fixing fibres more tightly in the yarn and fabric, thereby preventing pill formation; or weakening protruding fibres, resulting in the pills breaking off more easily [8]. Thus a wide variety of techniques have been applied to solve pilling problems. Biopolishing is one of the processes that reduce cellulosic fabric pilling by the latter method. However, due to using Cellulase enzymes in this process, the treated fabric properties are highly dependent on enzymatic hydrolysis conditions; therefore reproducibility on an industrial scale is difficult when reducing the strength loss is crucial [9 - 13]. Hence, finding a new method to weaken surface fibre without significant changes in yarn and fabric strength and properties is important. A study of the literature shows that there have not been many researches about applying UV irradiation to reduce cellulosic fabric pilling. The only paper that used radiation to create anti-pill cotton reported significant strength loss due to the effect of using hydrogen peroxide as a photoinitiator to absorb UV radiation [14]. In our previous paper [15] we evaluated the feasibility of using UV irradiation in the bleaching step of cotton fabric in order to produce anti-pill fabric without adding another finishing step. It was indicated that the total fabric strength loss could be decreased due to the combination of two processes. Moreover, using H_2O_2 as a stabiliser made it possible to improve control conditions in an attempt to diminish unacceptable fabric strength loss. In addition, a novel method of bleaching cotton fabric was obtained. In this paper, due to the more serious pilling problems of knitted fabric, the possibility of using this new method for this type of fabric was studied. Furthermore, the results are compared with those of samples bleached and biopolished on an industrial scale. In this case there is no need to apply cellulase enzymes, which are highly dependent on enzymatic hydrolysis conditions, posing numerous problems for its reproducibility in industry to obtain white and anti-pill knitted cotton goods.

Experimental

Desized and scoured 100% knitted cotton fabric (warp knitting interlock, thickness - 0.7 mm and 228.14 g/m^2), as well as a sample bleached and biopolished on an industrial scale were supplied by the Sabalan Parche Textile Company, Iran. All the chemicals selected were of analytic grade, supplied by the Merck Company. Irradiation of the samples was carried out using a Primarc MPMA tube (575 w, OSRAM) mounted in a sealed cabinet.

All samples prior to any treatments were washed to remove any possible impurities which could adversely affect the fabric performance. Washing was performed using a Roaches Dyeing machine (Pyrotec S). The samples were washed at pH 8 - 9 (sodium carbonate) using 0.5 g/l of non-ionic detergent at 100 °C for 30 minutes. The fabrics were then washed off at 35 - 40 °C for 45 minutes, then cooled gradually, and finally rinsed with cold water and air dried without any tension. The liquor ratio was 40:1. The washed samples were treated under different conditions: The first group was padded and then irradiated for 2.5, 5, 10 & 20 minutes. The pad bath (Werner Mathis AG pad) contained the recommended 4 ml/l of hydrogen peroxide (35%), 7 g/l of sodium silicate (72° TW), 5 g/l of sodium hydroxide, and 0.5 g/l of a non-ionic wetting agent. The fabric was padded at room temperature with an impregnation time of 60 seconds and at a wet pick up of 100%. After the irradiation of both sides of the samples, they were washed at boiling point, neutralised using acetic acid and then rinsed.

To compare the conditions mentioned above i.e padding with a bleaching bath, the second group was treated under the same conditions, but neither sodium silicate nor sodium hydroxide were applied,

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and the samples were padded only with hydrogen peroxide as a photoinitiator. Moreover, the control samples were padded with distilled water and similarly treated in order to determine the changes in fabric properties and the effect of H_2O_2 on UV absorption by cotton fabrics. Evaluation of the new treatments in terms of fabric whiteness was studied by bleaching some samples using the well known pad steam method, in which they were saturated with steam for 2.5, 5, 10, and 20 minutes, then washed, neutralised and finally rinsed. As can be seen, the samples were treated under four different conditions:

a) Padding with bleaching solution and then exposure to UV irradiation;
b) Padding with only hydrogen peroxide and then exposure to UV irradiation;
c) Padding with distilled water and then exposure to UV irradiation;
d) Padding with bleaching solution, then steaming, and finally the pad steam process.

The effect of the finishing processes on fabric properties was investigated by measuring the whiteness, yellowness, pilling, and tensile strength. The fabric whiteness and yellowness were measured using a Data Colour reflectance spectrophotometer, Spectraflash model 600+, and the CIE 1982 formula under a D65 illumination source, with a large aperture and 0% UV. The samples were measured in a triple-folded state to make them opaque at 4 points, and an average value was determined.

The pilling rates were studied according to BS 12945-2:2000 using a Martindale Abrasion Tester after a different number of rubs - 125, 500 and 2000. The pilling resistance was determined by comparison with standard pictures in a light cabinet. Furthermore, the pilling rate of the samples was compared with that of a biopolished sample in which cellulase enzymes were used on an industrial scale.

The bursting strengths of the treated and control fabrics were determined. A Mullen LC Hydraulic Burst Tester was employed, and the procedure followed was as prescribed by the ASTM D 3786 – 01 Standard test method. Each test specimen's size was 50 cm². The pressure required to rupture the sample was reported as the bursting strength. Ten bursting strength measurements were made for each sample with a time to burst of 20, and the average value was calculated.

Table 1. *Effect of different treatment conditions on the samples' whiteness.*

Treatment time, min	Type of treatment			
	Pad-irradiation			Pad steam
	Distilled water	Hydrogen peroxide	Bleaching solution	
Untreated	46.5	46.5	46.5	46.8
2.5	51.9	66.6	68.5	70.9
5	56.8	67.1	70.4	71.7
10	55.4	67.4	71.3	72.2
20	57.3	67.8	72.5	72.6

Table 2. *Effect of different treatment conditions on the samples' yellowness.*

Treatment time, min	Type of treatment			
	Pad-irradiation			Pad steam
	Distilled water	Hydrogen peroxide	Bleaching solution	
Untreated	14.90	14.90	14.90	14.90
2.5	13.23	8.51	8.36	7.29
5	11.54	8.34	7.06	6.92
10	11.46	8.05	6.61	6.54
20	11.39	8.15	6.41	6.25

Results and Discussions

The results of measuring the samples' whiteness (***Tables 1*** and ***2***) indicate that during irradiation, the whiteness of samples treated with distilled water remained almost unchanged. The lack of a photoinitiator could be the main reason for this effect, which clarifies that UV irradiation cannot act as a bleaching agent. On the other hand, having a bleaching solution in the pad bath resulted in higher whiteness than that of the padded samples with hydrogen peroxide only. While the oxidant for both was the same, the stabilising effect of sodium silicate in the bleaching bath leads to the slower dissociation of hydrogen peroxide and longer fibre exposure to the bleaching agent. Therefore, after 2.5 minutes the differences between the two series showed an increasing trend. In addition, by creating alkaline pH, sodium hydroxide acted with the whiteness enhancement as an activator, whereas for the other samples, the only activator was UV light.

Comparison of the whiteness properties of samples bleached using irradiation and the pad steam method shows that the samples treated with the new method i.e. irradiation after padding, exhibited acceptable whiteness, which could be due to the possible effect of the energy source and heat transfer. UV irradiation created a hydroxyl radical, which is small and highly reactive. Moreover, the UV energy was transferred by photons [14], which could be more effective than saturated steam.

Evaluation of the samples' yellowness also shows the same trend as the effect of treatments on whiteness with the minimum yellowness for the samples padded with bleaching solution and exposed to UV irradiation. The yellowness of these samples is more or less in the same range as the pad-steam processed samples.

The pilling performances of the fabrics are compared in ***Table 3*** (see page 78). As can be seen, the reduction in the pilling rate of the distilled water treated samples is negligible, except those exposed to UV irradiation for a longer time, which resulted in little improvement in their pilling tendency. In addition, padded samples with hydrogen peroxide showed better performance with maximum pill wear off during longer exposure. Furthermore, the effect of the sensitiser, hydrogen peroxide, in the bleaching bath is much more obvious due to the possible effect of the stabiliser over a longer period of time with hydrogen peroxide on the fabric and subsequent higher effect of UV irradiation on weakening the fabric surface fuzz. Therefore, the apparent pilling is reduced, and pill removal becomes the predominant process. Due to the greater effect of irradiation on the fabric surface [14], the lower pilling rate could be attributed to the decrease in the breaking strength of protruding fibres, which is compatible with the results of other researches [9, 11, 13, 15]. There-

Table 3. Pilling performance of the samples.

Treatment time, min	Type of treatment														
	Pad- Irradiation									Pad steam			Biopolished		
	Bleaching solution			Hydrogen peroxide			Distilled water								
Number of rubs	2000	500	125	2000	500	125	2000	500	125	2000	500	125	2000	500	125
untreated	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3	2-3			
2.5	4-5	4-5	4-5	2-3	2-3	2-3	2-3	2-3	2-3	2-3	3-4	4-5			
5	4-5	4-5	4-5	2-3	3-4	3-4	2-3	2-3	2-3	2-3	3-4	4-5	4-5	4-5	4-5
10	4-5	4-5	4-5	3-4	3-4	4-5	2-3	3-4	3-4	2-3	2-3	3-4			
20	4-5	4-5	4-5	4-5	4-5	4-5	2-3	3-4	3-4	2-3	2-3	3-4			

fore, it can be said that by limited solution penetration in the fabric structure and increasing the dissociation time of hydrogen peroxide via the stabiliser, a reduction in cotton fabric pill tendency, even for a short exposure time, can be achieved. Evidently, with a longer irradiation time of 10 and 20 minutes and after 2000 rubs, a clear fabric surface with no pilling was obtained. Moreover, the results revealed the little effect of pad steam on the samples' pilling. As already mentioned, this effect could be due to the energy source and capability of the substrate to adsorb UV irradiation. If a sample is able to absorb the radiation due to a complete energy transfer of the photon to the substrate [14], the heat transfer of UV radiation in comparison with that of steam will be much higher. Moreover, the surface fuzz and protruding fibres were more affected than those inside the yarns and fabrics - the phenomenon that paved the way to increasing the rate of pill wear off higher than that of pill formation. On the other hand, it was reported that fuzz formation has an exponential curve [6]; therefore removing the formed surface fuzz can reduce the pilling rate of cotton fabric significantly. This mechanism is similar to the way that biopolishing improves cellulosic fabric pilling.

In addition, comparison of the effect of the new method on knitted fabric pilling with comparable biopolished samples, with a pilling rate of 4-5, reveals a satisfactory reduction in the level of cotton fabric pilling for the method suggested due to the same anti-pilling mechanism. As a result, through the application of this new method, there is no necessity of using cellulose enzymes in an additional finishing step to remove surface fuzz and reduce the pilling tendency.

The main objective of applying UV radiation in textile finishing is limiting fabric strength loss. As shown in ***Figure 1***, similar to the statistical studies of the results of ANOVA tests, the strength loss of distilled water treated samples is not statistically significant, except for the irradiated sample after 20 minutes, the reason for which could be related to the lack of an initiator to absorb the UV radiation. The tensile strength of the hydrogen peroxide treated sample after 2.5 minutes of irradiation is in the same range as the control sample, while the other samples show statistically significant differences. In addition, using a bleaching bath with a stabiliser decreased the strength loss, hence UV radiation did not statistically change the strength of the irradiated samples after 2.5, 5, and 10 minutes. However, 20 minutes of radiation resulted in higher strength loss, which placed this sample in a different statistical group. Samples bleached for 2.5 and 5 minutes using the conventional pad-steam method did not show any significant difference as compared with the untreated control fabric, which after 10 and 20 minutes of treatment is in a different statistical group.

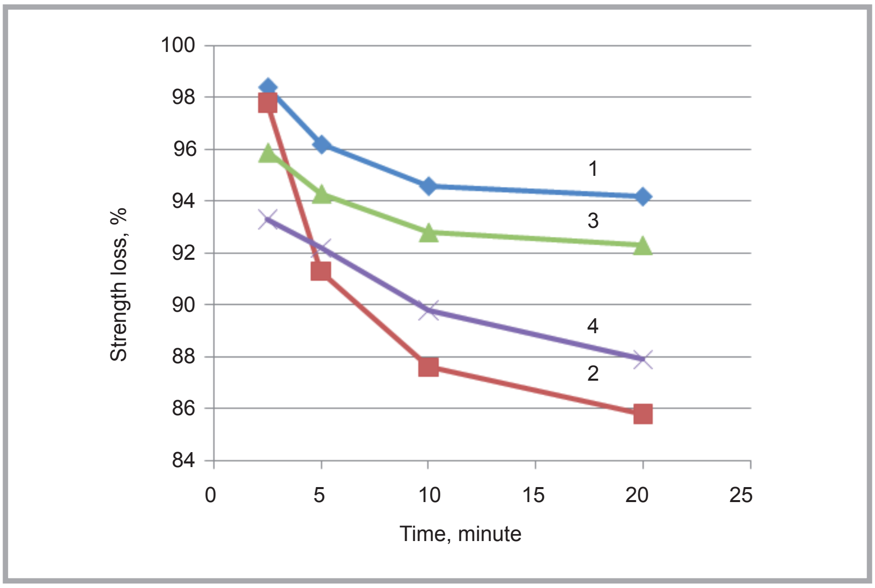

Figure 1. *Strength loss of the treated samples under different conditions; 1 - distilled water, 2 - hydrogen peroxide, 3 - bleachinh solution, 4 - pad steam.*

Conclusions

The application of UV radiation on hydrogen peroxide impregnated knitted cotton fabric created the new possibility of having a single process for bleaching and simultaneous anti-pilling without adding a new process to finishing procedure. By using the solution of a bleaching bath in the conventional pad-steam method and then UV radiation, this not only achieved fabric whiteness of the same level as with the normal bleaching process, but the strength loss due to radiation and the photoinitiator, hydrogen peroxide, also decreased to less than 10% of that of the untreated control sample, with a notable reduction in fabric pilling propensity. In addition, the new method enhances the pilling performance so much that there is no necessity of using cellulose enzymes and biopolishing to improve fabric appearance.

It seems possible that using different concentrations of the bleaching agent and UV power can pave the way for a new continuous process which is more acceptable for the textile industry.

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