INVESTIGATION OF EFFECTS OF REPEATED LAUNDERING ON THE COTTON KNITTED FABRICS WITH BIOPOLISHING TREATMENT

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Abstract
This work was concerned with effects of repeated laundering on the cotton knitted fabrics with biopolishing treatment. 100% cotton single jersey fabrics were subjected to the laundering process in a domestic washing machine following 10 and 20 times. Afterwards, thickness, stiffness, weights and CIELab color coordinates of these fabrics were investigated. In order to determine the effect of enzyme concentration and laundry cycles on some fabric properties Design Expert 6.0.1 analysis of variance (ANOVA) with F values of significance level of $\alpha = 0.05$ were used. It was determined the effect of factors and their interactions on selected fabric properties. With respect to the experimental results, rising laundering increased the fabric thickness, stiffness and weights and colorimetric values of the fabrics were also influenced. Additionally, it was indicated that, the effect of the enzyme concentration (%) on these fabric properties was meaningful and rising bioenzyme concentration decreased the fabric thickness, stiffness and weights but increased color differences value.
Key words: Knitted fabric, Cellulase enzyme, Biopolishing, Repeated laundering, Statistical analysis.

1. Introduction

Laundering is required for many textile goods, but it cases lead to deteriorations of fabric performance. During laundering, the fabric is subjected to complex thermal, mechanical and physical actions in both wet and dry conditions. Most textile products must be able to withstand a reasonable number of laundering cycles. For shirts, the average life expectancy is approximately 30 to 40 launderings [1]. Also, for hygienic reasons garments need to be washed, so they should be durable against washing [2].

Enzyme treatments have become one of the most commonly used wet processing techniques in the industry. Enzyme technology has been applied to improve handle, appearance and other surface characteristics of cotton and cotton blends. Hydrolysis of cellulose with cellulase is useful for biopolishing cotton fabrics [3].

The interest aroused by using enzymes to produce specific surface effects on cellulosic substrates has grown in the last few years. With the help of an enzymatic process, fibrillation can be fully eliminated or reduced at will, leading to better softness, increased volume, and a peach-skin handle. In this manner, the use of cellulase enzymes for controlled elimination of fibrils from the fiber surface in a process known as biopolishing [4, 5]. Biopolishing is a finishing process in which a fabric is treated with an enzyme to impart properties such as anti-pilling, softness and smoothness. This concept was initially developed in Japan where the first experiments were performed on cotton woven fabrics using cellulases. Improved properties were obtained without using traditional chemical treatments [6].

Enzymes offer advantages over traditional chemical means for these processes including case of use and handling, biodegradability, and other “environmentally-friendly” characteristics [7].

In this study, the effects of repeated laundering on the knitted fabrics which were applicated the enzymes with different concentrations (%) in pretreatment process were investigated. Afterwards, thickness, stiffness, weights and CIELab color coordinates of these fabrics were investigated.

2. Materials and method

We produced 100 % cotton single jersey structure on Orizio circular knitting machine with Ne 30/1 yarns (28 gauge, 32" diameter, 2760 total needle count, with a positive yarn feeding system), since they are widely used. Also, used cellulase enzyme is a concentrate enzyme and can be dissolve in water easily. Its operating range is pH 5-6 [8]. Production of knitted fabrics and enzyme process were done under the industrial conditions. The prevent to different machines impact on the fabrics, all of the treatments were carried out on the same jet machine. Enzymes with three different concentrations (0.6%, 0.8%, 1.0%) were applicated to the fabrics in pretreatment process and the successive dyeing and finishing process were carried out in a standard way using a liquor ratio of 20:1, 50ºC temperature (Table 1).

Table 1. Pretreatment, enzyme and dyeing recipes of the samples

Process	Application recipe	Agents
Pretreatment	0,5 g 0,5 g 1,0 g 3,0 g 2,0 g 0,5 g 0,8 g 1,0 g	Wetting agent Degreasing agent Degreasing agent Caustic soda Peroxide Heavy metal complexing agent Enzymatic peroxide Acid
Enzyme (%)	**0,6 / 0,8 / 1,0**	**Enzyme (Biopolishing)**
Preparing	1,0 g	Heavy metal complexing agent
Dyeing	1,034 % 3,940 % 0,804 % 80,0 g 20,0 g	Everzol Yellow 3RS H/C 150% Everzol Red ED Everzol Red ED-4B Soduim sulphite Soda
Washing	1,20 g 0,75 g 0,10 g 0,75 g 0,10 g	Acid Fastness improving Acid Fastness improving Acid
Finishing	6,0 %	Softener

Laundering process

The laundering was carried out under conditions similar to what the fabrics were expected in home laundering. After the enzyme treatments, fabrics were washed in a household washing machine at 40ºC for 1 hour with water containing household detergent. After washing, they were briefly hydroextracted and dried on a flat surface in conditioned atmosphere for one week. Used detergent is one of the most popular detergents on the market. It contained, less than 5% nonionic surfactants, oxygen-based bleaching agents, 15-30% phosphate, enzyme and perfume. According to the Table 1 and number of the repeated laundering cycles, we totally obtained 9 different samples (Table 2). The samples were washed separately in different numbers of washing cycles: 0, 10 and 20 cycles.

Table 2. Laundering applications

Sample no	Process	
	Application of enzyme (%) in pretreatment	Laundering cycles
1	0,6	Unwashed
2	0,6	10
3	0,6	20
4	0,8	Unwashed
5	0,8	10
6	0,8	20
7	1,0	Unwashed
8	1,0	10
9	1,0	20

At every stage, measurements were taken as follows: thickness (TS 7128 EN ISO 5084), stiffness (ASTM D 4032-94), weight (TS 251) and colorimetric measurement (CIELab 2000 formulation) [9-11].

Results and discussions

The tests and evaluations performed are expressed as follows.

The evaluations of the thickness results

Some properties of fabrics like keeping warm and bulkiness, are depends on the thickness of the fabrics. Since thick and porous fabrics contain more air, form a thicker layer between human body and surrounding and make the heat transfer difficult, they keep warmer [12].
The determination of the thickness of fabric consist of precise measurement of the distance between two plane parallel plates when they are separated by the fabric, with a known arbitrary pressure between the plates being applied and maintained [13]. Each sample is subjected to test 10 times and results are noted in mm. The gained results are shown in Figure 1.

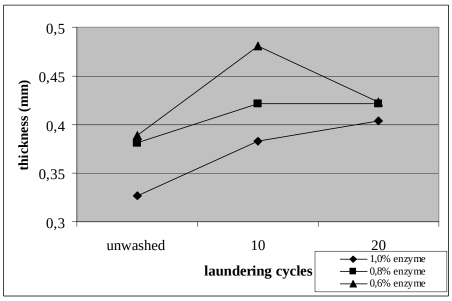


Figure 1. The values of the fabric thickness

By examining the Figure 1, we can see that; the thickness of the fabrics is generally increased by laundry process. The maximum increase in thickness is seen at the end of 10^{th} laundry cycle. It is determined that; the increase in thickness at the end of 20^{th} laundry cycle is lower than the increase at the end of 10^{th} cycle. Lau *et al.* (2002) states that, after a few laundry processes, the thickness of the knitted fabrics increases significantly [2]. Although at the end of 20^{th} laundry cycle, a small amount of thickness reduction is observed in the fabric treated with 0.6% cellulose, the thickness of the final fabric is higher than the unwashed fabric.
In order to determine the effect of enzyme concentration and laundry cycles on fabric thickness, Design Expert 6.0.1 analysis of variance (ANOVA) with F values of significance level of α= 0.05 are performed (Table 3 and Figure 2). The factors have significant effects on the examined outputs, if the p value is smaller than 0.05 (5%)

Table 3. Results of the analysis of variance (ANOVA) for thickness values

Source	**Sum of squares**	**Degrees of freedom**	**Mean square**	**F value**	**p value**
Model	0.14	8	0.017	193.48	<0.0001
A	0.066	2	0.033	365.86	<0.0001
B	0.054	2	0.027	300.14	<0.0001
AB	0.020	4	4.877E-003	53.96	<0.0001
Pure error	7.320E-003	81	9.037E-005		
Cor total	0.15	89			
R-squared: 0.95					

Abbreviations
A: Laundering cycle (Unwashed, 10, 20)
B: Enzyme concentration (0.6%, 0.8%, 1.0%)

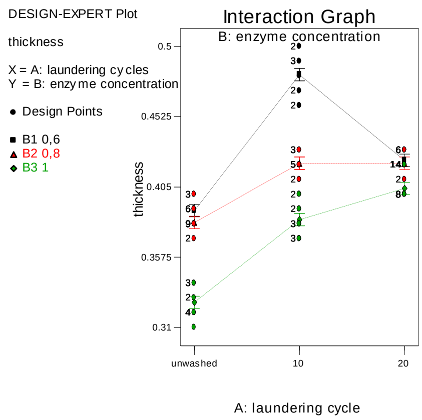


Figure 2. Interaction graph for AxB

As can be seen from Table 3 and Figure 2, laundry cycle (A) and enzyme concentration (B) have an important effect on fabric thickness. Also it can be said that; interaction between A and B has an effect on the fabric thickness. R^2 value of the model is determined as 0.95. Interaction between A and B has an effect on fabric thickness, because the effect of laundry cycle (A) on the fabric thickness depends on enzyme concentration (B). Fabric thickness increases with the increasing laundry cycles but increasing enzyme concentration decreases the fabric thickness (Figure 2).

The evaluation of the stiffness results

Since fibre, yarn, fabric and finishing processes have an effect on fabric stiffness, it is assumed that, repeated laundering and enzyme processes have an effect on fabric stiffness too. ASTM D 4032-94 standard was used in stiffness measurements and results are noted in kg. Also it can be said that as the value increased, the stiffness increased. Figure 3 shows the test results.

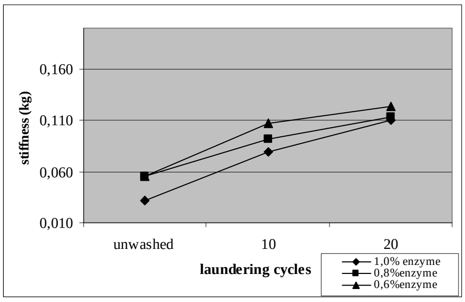


Figure 3. Change of the fabric stiffness

Figure 3 shows that, as the laundry cycles increases, fabric stiffness is also increases. The tightening and deformation of the fabric, resultant of repeated laundry increases the fabric stiffness. The maximum increase in stiffness is seen at the end of 10^{th} laundry cycle. As mentioned by Lau *et al.* (2002) as the laundry cycle increases, the stiffness of the fabric increases [2]. The reason of this increase can be explained by the fabric shrinkage and decreased effect of the softening agent. It is observed that increasing enzyme concentration has a positive effect on fabric softness. The statistical evaluations for fabric stiffness are shown in Table 4 and Figure 4.

Table 4. Results of the analysis of variance (ANOVA) for stiffness values

Source	Sum of squares	Degrees of freedom	Mean square	F value	p value
Model	0.012	8	1.469E-003	36.38	<0.0001
A	0.011	2	5.397E-003	133.63	<0.0001
B	4.751E-004	2	2.376E-004	5.88	0.0232
AB	4.849E-004	4	1.212E-004	3.00	0.0788
Pure error	3.635E-004	9	4.039E-005		
Cor total	0.012	17			
R-squared: 0.97					

Abbreviations
A: Laundering cycle (Unwashed, 10, 20)
B: Enzyme concentration (0.6%, 0.8%, 1.0%)

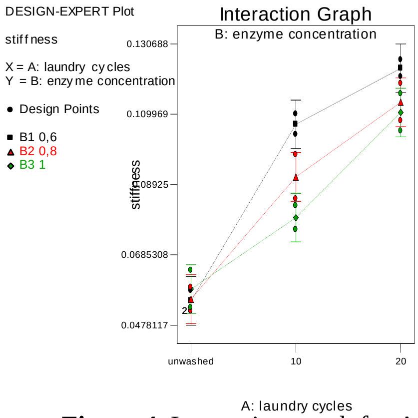


Figure 4. Interaction graph for AxB

As can be seen from Table 4 and Figure 4, laundry cycles and enzyme concentration have an effect on fabric stiffness but interaction between A and B has no effect statistically on fabric stiffness. R^2 value of the model is determined as 0.97.

The evaluation of the weight results

TS 251 standard was used in weight measurements and each of the samples are measured 5 times. Figure 5 shows the test results.

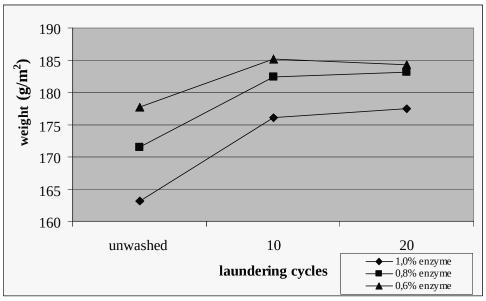


Figure 5. The values of fabric weight

According to the test results, the increasing enzyme concentration decreases the fabric weight. Cellulase enzyme in biopolishing treatment has an effect on pills, and these pills leaves from the fabrics at the end of washing process. A small amount of weight reduction can be observed as a result of leaving of these pills. At the end of 20th laundry process, the minimum weight is determined in the sample treated by 1.0% enzyme. Ozdil *et al.* (2003) determined the weight reduction on the samples treated by enzyme and stated that; especially the samples treated 2 times by enzyme have more weight reduction [14]. Korlu *et al.* (2008) states that; if the fabric is waited wet after enzymatic process, a small amount of increase in weight is seen and the same amount of increase is also seen in course density. So the reason of the increase in weight is described by dimensional changes of the fabric [15]. A similar situation can also be seen in Mavruz and Ogulata (2007) [16]. A small amount of weight reduction can be seen as a result of leaving of the pills from the fabric surface. But in the knitted fabrics, since they have a flexible structure, fibres expand in wet processes and dimensional changes occur and weight can be increased. At the end of repeated laundry, an increase in fabric weight can be seen. Chemical and mechanical conditions in laundry process, provides shrinkage and as a result of this an increase in weight can be observed. The maximum increase in weight is seen at the end of 10th laundry cycle.

The results of the statistical evaluations to determine the effect of enzyme concentration and laundry cycle on fabric weight are shown in Table 5 and Figure 6.

Table 5. Results of the analysis of variance (ANOVA) for weight values

Source	Sum of squares	Degrees of freedom	Mean square	F value	p value
Model	2009.99	8	251.25	68.14	<0.0001
A	1123.91	2	561.95	152.40	<0.0001
B	803.95	2	401.98	109.02	<0.0001
AB	82.13	4	20.53	5.57	0.0014
Pure error	132.74	36	3.69		
Cor total	2142.73	44			
R-squared: 0.94					

Abbreviations
A: Laundering cycle (Unwashed, 10, 20)
B: Enzyme concentration (0.6%, 0.8%, 1.0%)

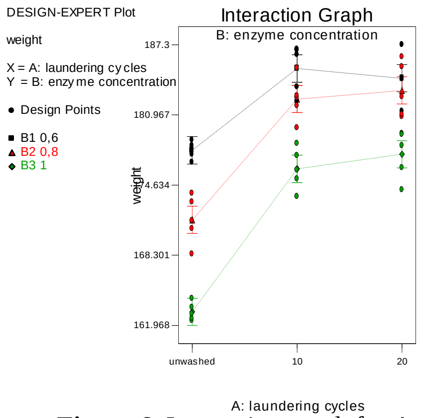
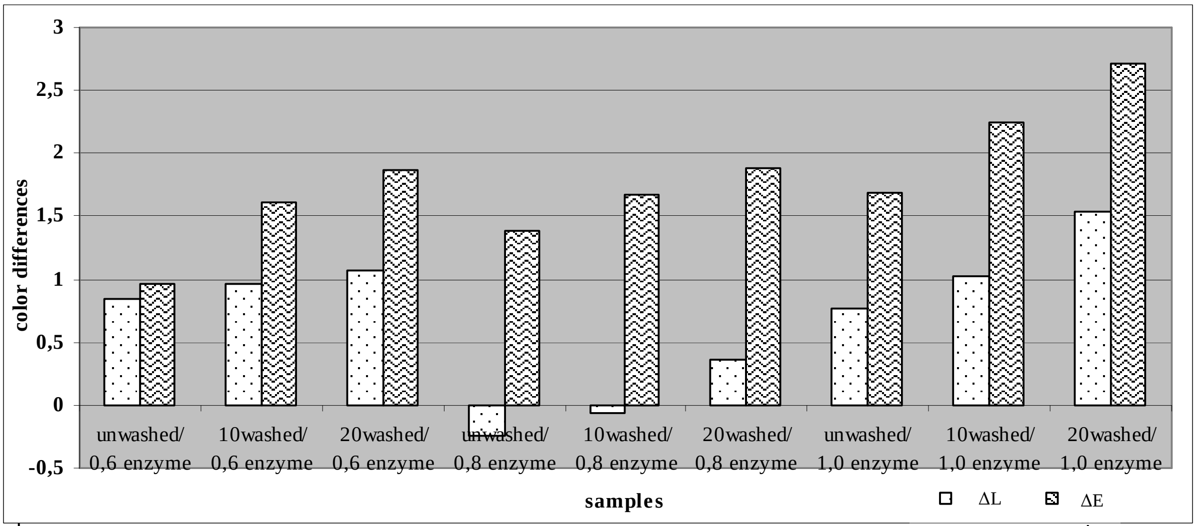


Figure 6. Interaction graph for AxB

When Table 5 and Figure 6 are examined, it is seen that, enzyme concentration, laundry cycle, and interaction between them have an effect on fabric weight at a significance level of α= 0.05. R^2 value of the model is determined as 0.94.

Color measurement

The color values of the sample fabrics are measured to determine the color differences of enzyme treated fabrics. In the measurements Minolta Spectrophotometer with D 65 light source was used. Non enzyme treated & unwashed fabric is referenced and according to this reference, the color differences of the other fabrics are determined by the formula (ΔE) CIELab 2000. If ΔE value is under 1, this means, the color is different from the reference color and it can not be acceptable. The result of investigations can be seen from Figure 7.



ΔE: Total color differences, ΔL: Lightness/darkness (+=lighter, -=darker) [17]

Figure 7. Result of color value of sample fabrics

When the Figure 7 is investigated; since ΔE values of all samples are over 1, it can be said that, the color value of enzyme treated and washed samples are very different from the reference sample. At the same level of laundry cycles, it is seen that, as the enzyme concentration increased, ΔE value is also increased, so the color difference is increased. At the same level of enzyme concentration, as the laundry cycle is increased, color difference is also increased. As the Ozdil *et al.* (2003) stated that; this is most probably because of the difference in light reflection together with yarn surface modification [14]. Also Kretzschmar *et al.* (2007) conducted that enzymatic processes have an effect on color efficiency [18].
According to the ΔL values, as the laundry cycle is increased, it is seen that color is lighter. Because of the detergent and laundry conditions, it is difficult to keep the fabric color same.

Conclusions

The results of the experimental studies carried out are summarized as follows.

- As the laundry cycle is increased, the fabric thickness is increased. The tightening and fabric relaxation, resultant of repeated laundry, increases the fabric stiffness and thickness. The reason of the thickness reduction with the increase in enzyme concentration can be expressed as follows. Biopolishing consist of a cellulase enzyme treatment to give a partial hydrolysis of cotton; so some deformations occur in the fabric.
- It is determined that cellulase enzyme has a negative effect on fabric stiffness. As the enzyme concentration increased, as a result of special modification provided by enzyme on the fibre surface, the value of softness is also increased.
- Since cellulase enzyme decreases the amount of pilling on the surface of the fabric, as the cellulase concentration increased, fabric weight is decreased. Also since the laundry cycle affects the fabric structure (wales per cm and courses per cm), increases the fabric weight.
- According to the results of the spectrophotometer, the colors of the samples treated by enzyme are different from the reference sample. Since cellulase enzyme provides a surface having more clearly and smooth. It causes a color change. Also repeated laundry affected the fabric color and as the laundry cycle is increased, the fabric color become lighter.

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