A novel washing algorithm for underarm stain removal

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Abstract. After contacting with human sweat which comprise around 27% sebum, anti-perspirants comprising aluminium chloride or its compounds form a jel-like structure whose solubility in water is very poor. In daily use, this jel-like structure closes sweat pores and hinders wetting of skin by sweat. However, when in contact with garments, they form yellowish stains at the underarm of the garments. These stains are very hard to remove with regular machine washing. In this study, first of all, we focused on understanding and simulating such stain formation on the garments. Two alternative procedures are offered to form jel-like structures. On both procedures, commercially available spray or deo-stick type anti-perspirants, standard acidic and basic sweat solutions and artificial sebum are used to form jel-like structures, and they are applied on fabric in order to get hard stains. Secondly, after simulation of the stain on the fabric, we put our efforts on developing a washing algorithm specifically designed for removal of underarm stains. Eight alternative washing algorithms are offered with varying washing temperature, amounts of detergent, and pre-stain removal procedures. Better algorithm is selected by comparison of Tristimulus Y values after washing.

1. Introduction

Yellowing on armpits occurs due to using deodorants, antiperspirants contributed with sweating and formation of the yellowing in light coloured garments is earlier and causes most of complaints with these garments. Perspiration is a very important way of balancing human body temperature and it is inevitable. 25% of total amount of water loss from human body in daily life is caused by perspiration under usual inactive circumstances. Human perspiration includes many organic compounds such as; water, inorganic salts, ammonia, urea, uric acid, amino-acids, lactic acid and sugar which depend on individual [1]. Human perspiration is usually an odorless body secretion. However, as bacteria multiply on the skin and resolve down these secretions, the resulting by-products may include a strong, unpleasant odor. The quick formation of odor is expected to support the concept that such a mechanism manages via simple bond cleavage as disputed to a complex bacterial action [2,3].

Sebum is a light yellow, oily substance secreted by the sebaceous glands that keep the skin and hair moisturized. Sebum is made up of triglycerides, free fatty acids, wax esters, squalene, cholesterol esters, and cholesterol. The oil on the surface of the skin isn't just made up of sebum, however. It also includes lipids from skin cells, sweat, and environmental matter. The sebaceous glands produce sebum [4-6].

A numerous number of cosmetic products are implemented topically on and around the body on a daily basis, usually multiple times a day, including not just underarm antiperspirant/deodorant products but also body lotions, body sprays, moisturizing creams, breast firming/enhancing creams and sun care products. These products are not washed off but remain on the skin, allowing for repeated
dermal exposure, absorption and deposition into underlying tissues, which may be further increased by abrasions in the skin created by shaving [7,8].

In this study, we have classified underarm products as antiperspirants and deodorants. Antiperspirants are personal hygiene products intended to control sweating and personal stench. Antiperspirants contain fixings that control sweat and personal stench securely and successfully. They are promptly accessible available as splashes (airborne), sticks, creams or roll-ons. A deodorant is a substance connected to the body to counteract personal stench brought on by the bacterial breakdown of sweat in armpits, feet, and different territories of the body. A subgroup of deodorants, antiperspirants, influence smell and counteract sweating by influencing sweat organs. Antiperspirants are normally connected to the underarms, while deodorants may likewise be utilized on feet and different regions as body splashes. In the United States, the Food and Drug Administration groups and controls most deodorants as makeup, however arranges antiperspirants as over-the-counter drugs [9].

Underarm cosmetics are made of a numerous variety of chemicals put for different functional reasons. Alcohol is an ingredient present in some roll-ons, aerosols and gels. The dynamic elements of antiperspirants and deodorants are regularly dissolve in alcohol since it dries rapidly once connected to the skin and gives a quick feeling of coolness. Aluminum salts are the dynamic fixing in antiperspirants. These salts give a sheltered and successful method for controlling sweat [10]. Aluminum zirconium tetrachlorohydrex gly, a typical antiperspirant, can respond with sweat to make yellow stains on clothing [10]. Underarm liners are a contrasting option to antiperspirants that do not leave stains [11].

The main purpose of washing laundry is to clear away soils and micro-organisms from polluted textiles and to manage hygienic and decontaminated textiles to use. Textiles goes through laundering operation that contain soil elimination with special laundering agents, bleaching, disinfecting, neutralizing and rinsing [12].

2. Materials and Method

2.1. Materials

Rexona® Spray, Lady Speed® Stick and Dove® Stick, which are most commonly preferred underarm products, are selected for experimental design for making more stain in the first step that making deodorant stain operation.

Vanish Kosla Oxi Action® stain removal chemical is used for more effective elimination of stains. 15 gr Vanish is used for each stain strip that will be applied pre-stain removal chemical. During the washing process, IEC 60456 standard detergent at IEC standards and OMO® commercial detergent are used. It is calculated that quantity of detergent for 4 kg load is like; 40 + 12 x 4 = 88 g according to IEC 60456 standard. In the IEC detergent, there are 77 % basic detergent, 20 % sodium perborate tetrahydrate as a bleach and 3 % tetraethylenediamine as a bleach activator.

100 % cotton material that most preferred in shirts is used in experiments, and basis weight of this shirting fabric is 147 g/m². For observing the yellowing more explicit, white coloured woven plain fabric is chosen, which has a balanced structure whose densities in warp and weft directions are 27 ends/cm and 24 picks/cm. For obtaining required load in the washing machine, etamine cotton fabrics are used as ballast load.

During the project, Arçelik brand BK 8121 BT model is used, which is seen in Figure 1. Load capacity is 8 kg and there are 2 water intakes. The washing machine gets involved in A+++ energy class, besides provides 40 % more energy save compared to other machines in this class. In the machine, there are multisensor features such as weight, temperature, water amount, wash-off, period and voltage sensors.
Figure 1. Washing machine which is used in this study

Datacolor Model 600 is used to measure yellowing on armpits in Tristimulus Y values. Y tristilumus value measured here was accepted by CIE Nr.15.2 1986 because of pointing out the brightness independent from the colour. Measures are done at D65 sunlight with 10˚ angle.

In this study Thermo Scientific® model Heraeus Oven with 57 litres inside volume is used for drying samples. High temperature environment experimental machine oven, briefly, fitting the term ‘Oven’ has sensitive heat control about all experiments about heat and is used at different sectors for various purposes such as sterilization, drying, dehumidification, cooking. It is provided equal temperature inside the cabin and environment can be set to any temperature between 5-250 °C with sensitivity of ± 1°C.

2.2. Method

In order to simulate stain on underarms, we followed two alternative procedures. For these procedures Rexona® Spray, Lady Speed® Stick and Dove® Stick are used for making deodorant stain on cotton fabrics; Rexona Spray is applied to determined field for 5 seconds from 10 cm distance and both Lady Speed Stick and Dove Stick are spread to the field for 5 tours which are shown in Figure 2.

Figure 2. Applying of the underarm products on the fabric

Acidic and basic sweat solutions are put into separate bottles of 2 liters, then 20 sebum fabrics are put into each bottle to get sebum in the sweat solution, that will be simulate sweat stain on human body much more realistic. Experimental cotton shirt fabrics are subsequently immersed into the acidic and basic sweat solutions to wait for 5 minutes and fabrics are taken out. Wet fabrics are covered with polyethylene bag for an hour at 37 °C. After one hour, fabrics are placed in oven and let dry at 40 °C without polyethylene bag. Lastly, all stained and dried fabrics are washed in wooly 40 program. Then the procedure is repeated until the needed stain is achieved. For the second procedure; nearly all steps are performed in first procedure with a little difference; which is addition of 20 sebum fabrics to the sweat solutions is eliminated and addition of these 20 sebum fabrics is carried out in washing step in
wooly 40 program. With this difference second procedure is repeated until obtaining desired stain on cotton fabrics.

To analyze the sufficiency of staining after every staining process Tristimulus Y values was measured and compared to raw fabric colour value, so at the 4th repeat staining process was adequate and it was stopped. Tristimulus Y values before washing is measured by Datacolor Model 600 Spectrophotometer.

After producing sweat stained samples, they are washed in eight different washing algorithms that are created by Design of Experiment (DOE) which are shown in Table 1. Variables of a full-factorial experimental design are temperature (40-60 °C), detergent (IEC and OMO®) and pre-treatment process (applied or not).

<table>
<thead>
<tr>
<th>Profile</th>
<th>Temperature (°C)</th>
<th>Detergent</th>
<th>Pre-treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>IEC</td>
<td>NO</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>IEC</td>
<td>NO</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>OMO</td>
<td>NO</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>OMO</td>
<td>NO</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>IEC</td>
<td>APPLIED</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>IEC</td>
<td>APPLIED</td>
</tr>
<tr>
<td>7</td>
<td>40</td>
<td>OMO</td>
<td>APPLIED</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>OMO</td>
<td>APPLIED</td>
</tr>
</tbody>
</table>

The baby protect plus program was chosen while washing procedure. The operation was held by heat, pre-stain removal chemistry and detergent variable and constant variable such as water and machine period. The heat is 40 and 60 celcius centigrade, Vanish Kosla Oxi Action is used like pre-stain removal and IEC60456 coded standard detergent and OMO is used as detergent. 15 gr pre-stain removal chemistry is dropped stain strips that contains deodorant. It is put into the machine for washing operation after 15 minutes. Eight profiles were worked starting of these chosen parameters and three stain strips was used for each profile. In Baby Protect Plus program, water is 109 litres and period is 1200 rpm as constant values. Total washing time is 220 minutes. At the end of washing operation colour values of each profiles was measured and was observed how is the removal of stains, then the most suitable washing instruction was determined for these situations.

After washing previously produced stained samples, Tristimulus Y values of these samples are measured by Datacolor 600. In washing machine plants, for evaluating some performance of washing algorithms, Tristimulus Y values are used according to IEC 60456 washing standard. During loading the fabrics to washing machine IEC 60456 standard is also used. Quantity of complementary fabrics to complete the total loading of 4 kg, cotton fabrics are used in the experiments. While loading the machine to share these loads equally 7 complementary fabrics and 1 cotton stained fabric was loaded three times respectively.

By calculating stain removal percentage, which is related with before and after Tristimulus values, we comment on efficiency of algorithms on cleaning; stain removal formula (1) can be found in IEC 60456 washing standard and shown below.

\[
\text{Stain Removal (\%)} = \frac{\left( \frac{\text{Tristimulus Y value of unsoled fabric before washing}}{\text{Tristimulus Y value of soiled fabric before washing}} \right) \times \left( \frac{\text{Tristimulus Y value of soiled fabric after washing}}{\text{Tristimulus Y value of unsoled fabric after washing}} \right)}{\left( \frac{\text{Tristimulus Y value of soiled fabric after washing}}{\text{Tristimulus Y value of unsoled fabric after washing}} \right)} \times 100
\]

MiniTab® Statistical Analysis software is used to evaluate test results and ANOVA is performed.
3. Results and Discussion
Analysis related with this study was performed by Minitab® ANOVA. When the effect of parameters on stain removal of Rexona spray is considered, it is seen from Figure 3, that commercial laundry detergent, namely OMO, has a positive effect on stain removal that is provided by ingredients of commercial detergent. Because, commercial detergents include enzymes, whitening agents, alkalis, etc. which are enhancing removing of the stain from surface of the fabric. Effect of temperature on stain removal is found as expected that, algorithms with higher temperature resulted with more efficient Rexona stain removal. Application of pre-treatment agent before laundering, which is another parameter of experimental design, showed the most significant stain removal percentage due to high amount of bleaching agent in its composition.

Contrary to Rexona deodorant stain removal, commercial detergent has no significant effect on removal of Dove stick stain. IEC (standard detergent) and OMO (commercial detergent) have nearly same stain removal results. High temperature in algorithms provides better stain removal with a small difference, which is negligible. Application of pre-treatment in laundering of Dove stick stain has a negative effect for stain removal probably due to fixation of stain as a result of interaction between pre-treatment chemical and Dove stain.
It is apparent that non-surfactant ingredients of the commercial detergent are affected by the oxidation power of pre-treatment chemical which results in a slight decrease for the overall washing performance of commercial detergent. Moreover, removal of Lady Speed stick stain is examined and it is seen from Figure 5 that higher temperature in algorithms mostly results in better stain removal. The slight difference between performances at 40 C and 60 C for OMO® may be attributed to the difference of enzyme activities at related temperatures.

![Figure 5: Interaction of parameters on stain removal of Lady](image)

According to these results, higher temperature in washing process, in other words, 60 °C is more effective on removal of stains. Moreover, using of commercial detergent (OMO®) has a positive effect on removal of stains; because of containing higher amount of bleaching agent. Pre-treatment agent used in this study also has a significant effect on removal of stains, which can be seen in Figure 3. For Rexona Spray stain, removal of stain is about 110 % without using pre-treatment agent, which increases dramatically as high as 135 % when using pre-treatment agent. On the stain made by Rexona® Spray by applying pre-stain removal chemical 25 % more efficient cleaning is provided.

4. Conclusion
According to results of algorithms created with parameters of temperature, detergent type, application of pre-treatment process; it is found that temperature has no significant effect on stain removal, a suitable temperature can be selected related with care label. Application of pre-treatment agent obviously has a beneficial effect on removal of underarm stains, presence of high volume of bleaching agents in Vanish improves removal of stains. However, results show that interaction of pre-treatment agent with commercial detergent may result in a limited stain removal performance.

Acknowledgment
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References


[9] Cosmetics Q&A Personal care products U.S. Food and Drug Administration


Study of the stretching force of the needle's thread in the work with woollen textiles

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Abstract. The presented paper deals with examining the thread tension force while working with woolen textile materials. The thread’s tension force is a main characteristic of a quality stitch. Its analysis and definition is characterized by the creation of a computer-integrated measuring system to determine the thread’s tension force. A statistical method (double-factor disperse analysis) is used to analyze and evaluate the fact how the factors:
- F1 – surface mass of processed woolen textile materials,
- F2 – the number of layers on the thread's influence the deviation from the maximal value of the thread’s tension force.

1. Introduction
The stretching force of the needle thread is a major factor affecting the quality of the stitch line in the sewing industry.

The analysis of the nature and technological features of the process of stitching formation [6,8,9,11] shows that there are numerous factors influencing the stretching force of the needle thread.

The impact of some of them on the stretching of the upper thread has been the subject of study by several elite world famous companies [8,11].

In our country, on the stretching force of the needle thread, the influence of the factors has been studied: number of concatenated layers of under dynamic operating conditions [1] and the fibrous composition of the textile material under static operating conditions [3] through the application of two – factors and multi – factors dispersion analysis for linen fabrics under dynamic operating conditions [2, 4], etc.

The increasing variety of textile requires continuous experimentation to establish the optimal values of the tension of the needle thread for the textile material in question, which will be treated according to the specific characteristics of the sewing process.

More thorough study of this problem is further motivated by the created computer-integrated measuring system for determining the stretching force of the needle thread [10].

In modern sewing companies the maximum force of the upper thread stretching is adjusted manually from the disc brake, based on experience and the insight of the machine operator or the technician.
Thus in the factories were created conditions for the influence of the subjective factor on the quality and the productivity in the process of stitching formation.

The application of the statistical methods for research and analysis at the study of the stretching force of the needle thread places on a scientific basis these studies and it is essential for ignoring the influence of the subjective factors.

Overall, the sewing industry, especially in large-scale production, it is necessary to carry out many preliminary studies to refine the nature and the size of the stretching force of the upper thread in the specific technological conditions of work, which will be processed the textiles.

Of particular interest is the study of the attribute stretching force of the needle thread in the variation of two or more factors under dynamic operating conditions of the sewing machine, and by applying a variance analysis.

For this purpose, in the preliminary studies [1, 4] two-factor analysis of variance has been applied, as were examined respectively - cotton type fabrics (97% Cotton + 3% elastane) and linen fabrics, and in the research [2] a multi-factor dispersion analysis has been applied for linen fabrics.

By several observations on the fashion trends in terms of the fibrous composition of textile materials that were hot for the season autumn-winter 2016-17, we can summarize that prevailed the fabrics with wool and woolen type fibrous compositions.

2. Discussion and analysis
In light of the above, the objective of this work is by using of the statistical method of analysis and evaluation (two-factor disperse analysis), to establish whether it is essential, individually and jointly, the impact of factors:

- \( F_A \) – surface mass of the textile material;
- \( F_B \) - number of layers in the treated package of textile materials

on the variation of the stretching force of the needle thread for woven woolen fabrics.

2.1. Conditions to execute the experiment
The total stretching force of the needle thread during the conducting of the experiments is reported by means of a computer-integrated information measuring system [10].

The system includes the following modules:

- Modified capacitive sensor Rothschild, with integrated transformer capacity in pulse-width modulation, created on the basis of specialized integrated circuit UTI (Universal transducer interface) – Smartek;
- Converter UTI thresholds the signal with an interval of ~ 3 m Sec;
- Controller based on microprocessors Microchip - PIC 16F628. Created a program that uses the measurement results of pulse-width modulation them transferred to a package of data for communication protocol. Protocol for communication with the PC is built through communication interface - rs 232 at a frequency of exchange 19,200 bod/Sec;
- PC – saves the received data automatically, and created software is able to configure the duration of the measurement;
- By means of MS-Office, Excel is carried out the further processing of the obtained results.

The conditions for implementing the process stitching formation during the experiments are:

- Measurements for each experiment were performed under dynamic conditions;
- Sewing machine for stitch line of subclass 301 - JUKI (Japan);
- Step of stitch line - \( T = 3 \) mm;
- Selection of a sewing needle - BDS recommends ad for bonding of textile materials with the same fibrous content and structural features of double-layer package to use certain thicknesses of needles, and for three - and a multilayer package, respectively thicker needles. Therefore, attempts in which joining 2 layers of the textile materials a sewing needle № 75 was selected,
and for the experiments where 4 layers of textile material were jointed is selected sewing needle № 85;

- Sewing thread for the realization of experiments - thread with a composition 100% Cotton, trading № 50;
- For each experiment the thread stretching guide ha stop be adjusted in advance, so that the intertwining of the upper and lower thread to become the middle of the textile materials to be joined;
- Measurement starts from the upper dead point of the needle, maintaining a constant speed of rotation of the main shaft in 30 seconds;
- The nature of variation in the stretching force of the needle thread in time is given in Figure 1, it has been a representative sample of the recording of the measuring system of the tensile strength for 10 seconds;
- The rotational speed of the main shaft is determined by the number of amplitudes, Figure 1 by unit of time – second;

![Figure 1](image_url)

**Figure 1.** Variation of the stretching force of the needle thread in time

- The measuring system is calibrated so that the results of the measurement of the stretching force is in gram-force [gf]. This requires additional conversion of the research results as follows: $1 \text{ gf} = 9.80665 \times 10^{-3} \text{N} = 0.98 \text{ cN}$;
Textile materials with which the experiments were conducted are: Fabric One - 100% wool, surface mass 180 g/m², warp threads with Nm 52/2, weft threads Nm 52/2, warp density based on 127 threads/dm, weft density – 204 picks/dm; Fabric Two - 100% wool, surface mass 194 g/m², warp threads with Nm 52/2, weft threads Nm 37/1, warp density based on 175 threads/dm, weft density 263 picks/dm; Fabric Three - 100% wool, surface mass 207 g/m², warp threads with Nm 52/2, weft threads Nm 37/1, warp density based on 266 threads/dm, weft density 270 picks/dm.

When carrying out the two-factor analysis of variance, the values of variants of the factors \( F_A \) and \( F_B \) are: \( F_{A1} = 180 \text{ g/m}^2; F_{A2} = 194 \text{ g/m}^2; F_{A3} = 207 \text{ g/m}^2; F_{B1} = 2 \text{ layers}; F_{B2} = 4 \text{ layers}. \)

2.2. Experimental results

To assess the significant impact of both factors \( F_A \) and \( F_B \) (individually and jointly) on the stretching force of the needle thread is considered two-factor complex \( F_A - F_B \) where:

\[ X \text{ [cN]} \] - value of the maximum tensile force of the needle thread recorded in each trial is determined as an average value of the maximum values of the tensile strength obtained for 30 seconds;

\( m = 3 \) – repetitions number for each of the combinations of variations of factors;
\( a = 3 \) – factor \( F_A \) variants number;
\( b = 2 \) – factor \( F_B \) variants number;
\( \bar{X} \) - general average, \( N \) – total number of tests, \( N = abm = 18 \)

\[
\bar{X} = \frac{\sum_{i=1}^{N} X_{i}}{N} = 163.06 \text{ cN} \quad (1)
\]

\[
M_B = \frac{\sum X_B}{ma} \quad \text{- mean values by factor } F_B \quad (2)
\]

\[
H_A = \frac{\sum X_A}{mb} \quad \text{- mean values by factor } F_A \quad (3)
\]

\[
M_{AB} = \frac{\sum X_{AB}}{m} \quad \text{- average for a subset} \quad (4)
\]

After conducting the tests and the calculations by equations (1), (2), (3), (4) the following results are obtained:

\[
M_{A1B1} = 171.17 \text{cN}; \quad M_{A2B1} = 168.3 \text{cN}; \quad M_{A3B1} = 165.5 \text{cN}
\]

\[
M_{A1B2} = 161.5 \text{cN}; \quad M_{A2B2} = 157.8 \text{cN} \quad M_{A3B2} = 154.7 \text{cN}
\]

\[
Q_i = mb\sum \left( H_A - \bar{X} \right)^2 \quad (5)
\]

\[
Q_c = ma\sum \left( M_B - \bar{X} \right)^2 \quad (6)
\]

\[
Q_{ic} = m\sum \left[ (M_{AB} - \bar{X}) - (H_A - \bar{X}) - (M_B - \bar{X}) \right]^2 \quad (7)
\]

\[
Q_z = \sum \left( X_{AB} - M_{AB} \right)^2 \quad \text{- internal group variation} \quad (8)
\]

The degrees of freedom are defined as follows:

\[
f_A = a - 1; \quad f_B = b - 1; \quad f_{AB} = (a - 1)(b - 1) \quad (9)
\]

\[
f_Z = abm - ab; \quad f = abm - 1 \quad (10)
\]
2.3. Discussion of the experimental results.
Statistical processing of the experimental results on the algorithm of formulas (1 ÷ 10) gives the components of the dispersion, which are summarized in the Table. 1.

Table 1. Components of dispersion

<table>
<thead>
<tr>
<th>Sum of squares of deviations</th>
<th>Degrees of freedom</th>
<th>Dispersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between the of groups factor F_A ( Q_i = 104.43 )</td>
<td>( f_i = 2 )</td>
<td>( S_A^2 = \frac{Q_i}{f_A} = 52.22 )</td>
</tr>
<tr>
<td>Between the groups of factor F_B ( Q_c = 496.17 )</td>
<td>( f_c = 1 )</td>
<td>( S_B^2 = \frac{Q_c}{f_B} = 496.17 )</td>
</tr>
<tr>
<td>Between the groups of interaction F_A and F_B ( Q_{ic} = 1.893 )</td>
<td>( f_{ic} = 2 )</td>
<td>( S_{AB}^2 = \frac{Q_{ic}}{f_{AB}} = 0.947 )</td>
</tr>
<tr>
<td>Internal group ( Q_z = 3.67 )</td>
<td>( f_d = 12 )</td>
<td>( S_Z^2 = \frac{Q_z}{f_Z} = 0.307 )</td>
</tr>
</tbody>
</table>

The resulting dispersions were evaluated using the criteria of Fisher. For this purpose, identify the relevant account and tabular values of F - criteria:

\[
F_{RA} = \frac{S_A^2}{S_Z^2} = 170.1 \quad (11)
\]

\[
F_{RB} = \frac{S_B^2}{S_Z^2} = 1616.19 \quad (12)
\]

\[
F_{RAB} = \frac{S_{AB}^2}{S_Z^2} = 3.08 \quad (13)
\]

\[
F_{TA} \begin{cases} 
  f_2 = abm - ab \\
  r = 0.01 
\end{cases} = 6.93 \quad (14)
\]

\[
F_{TB} \begin{cases} 
  f_2 = abm - ab \\
  r = 0.01 
\end{cases} = 9.33 \quad (15)
\]

\[
F_{TAB} \begin{cases} 
  f_2 = (a-1)(b-1) \\
  r = 0.01 
\end{cases} = 6.93 \quad (16)
\]

A comparison of expected values obtained with tabular values the criterion of Fisher at the chosen significance level \( r = 0.01 \) leads to the following conclusions:

- The surface mass of the joint woolen fabrics (F_A) substantially affects the results of the measured stretching force of the needle thread.
The number of layers of processed fabrics package (FВ) also substantially affects the measured stretching force of the upper thread.

Combined mutual influence of both factors (FА and FВ) had no statistically significant impact on the stretching force of the needle thread at the selected level of significance.

3. Conclusion

Experimental measurements of the stretching force of the needle thread under dynamic conditions of joining wool fabrics were made using advanced computer-integrated measuring system.

The actual values of the stretching force of the needle thread X [cN] are obtained by varying the two factors.

Two – factors analysis of variance establishes the importance of the factors: FA – surface mass of the textile materials to be joined and FB – number of layers of the processed package on the maximum value of the stretching force of the needle thread.

The applied dispersion analysis proves that the individual effects of the factors FA and FB on the stretching force of the needle thread is statistically significant until their joint effect is negligible.

The results are scientifically - applied character and can be used in making fast and accurate decisions in response to specific technological problems.

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[8] Brochures and manuals for servicing the machines of companies: Juki, Textima, Pfaff, Omnitex, Brother, Rimoldi


FR Performance of New Fire-off on PET/CO blend fabrics

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Abstract. This paper represents the investigation on flame retardancy performance and durability of polyester/cotton (P/C) fabrics treated with a novel halogen/formaldehyde free, P-N synergetic FR finishing agent called New Fire-off. 100 % Cotton, 100 % Polyester and three different blend P/C fabrics were chosen in this study. Fabric samples were treated with New Fire-off through pad-dry-cure process. Flammability and thermal properties of the treated samples with New Fire-off were tested according to relevant ISO standard and procedures. The obtained results showed that this new finishing formulation is a good char-forming agent. However, further studies are required to achieve washing durability for the P/C blends.

1. Introduction
The natural and synthetic fibre blends are so popular than using pure fibre alone, as a consequence of combining good properties of blended each fibres. Polyester/Cotton (P/C) blends are widely used in home textiles, clothing and knitwear due to their high strength, excellent wearing resistance, good hygroscopicity, and high air permeability properties [1]. Fire retardancy is one of the essential properties for these blends. Polyester fibre (thermoplastic) shrinks at its melting point and run away from the fire while cotton fibre becomes char form. If a blend of these cotton and polyester is burned, the molten polyester generally tends to wick on cotton char and this result the 'scaffolding effect' [2].

Halogenated flame retardant systems are popular and widely used in FR coating and finishing formulations. However their use is being restricted due to environmental problems [3]. Similarly, the phosphorus-nitrogen (P-N) FR systems, Fyrol 76, Fyroltex HP, Pyrovatex CP New, and Proban shows a good N-P synergism for P/C, but these methods have a formaldehyde-released problem [4-8]. Over the past years, there has been an increasing trend in the flame retardance community to develop flame retardant coating systems or finishes for textiles with a major focus on phosphorus based, halogen and/or formaldehyde-free systems [3, 9].

In our previous work, a novel halogen-and formaldehyde free, P-N synergetic FR finishing agent called Fire-off (PVA (PR)-P-DCDA) had been synthesized by polyvinyl alcohol (PVA), hydrophilic polyester resin (PR), phosphoric acid and dicyandiamide (DCDA). Then, Fire-off was applied to 100% cotton, 100% polyester and 50/50% P/C fabrics via pad-dry-thermosol process. A durable flame retardancy (FR) achieved with Fire-off for 100% Polyester fabrics up to 20 domestic laundering cycles. However P/C fabrics were not durable against washing. In order to improve FR efficiency and washing durability of P/C fabrics, the amount of P % content of the polymer was increased and obtained chemical was called New Fire-off.
In this study, FR performance of New Fire-off on P/C fabrics with different blend ratios was investigated and assessed in terms of the durability against home laundering.

2. Experimental

2.1. Materials
The fabrics used were cotton, polyester and C/P blends (Table 1) supplied from BJ Textile, Erdem Textile and Zorlu Textile companies.

As a FR chemical, PVA (PR)-P-DCDA with 1.83% of increase in P content (New Fire-off) was prepared in Eksoy Chemical Company.

Table 1. Fabrics used in the study.

<table>
<thead>
<tr>
<th>No</th>
<th>Fabric Type</th>
<th>Fabric Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% P knitted</td>
<td>132 g/m²</td>
</tr>
<tr>
<td>2</td>
<td>60/40% P/C knitted</td>
<td>392 g/m²</td>
</tr>
<tr>
<td>3</td>
<td>30/70% P/C knitted</td>
<td>365 g/m²</td>
</tr>
<tr>
<td>4</td>
<td>50/50 % P/C woven</td>
<td>185 g/m²</td>
</tr>
<tr>
<td>5</td>
<td>100% C woven</td>
<td>112 g/m²</td>
</tr>
</tbody>
</table>

2.2. Fabric Treatment and Home Laundering Procedures
All fabric samples were firstly immersed in 400 g/L New Fire-off bath at room temperature to give ~100% pick-up regulated by padding. After two-dips and two-nips, they were dried at 100°C for 3 min, and then cured at 180°C for 3 min. The calculated add-on of FR was between 25-40 %.

After curing, the treated fabrics were subjected to a different number of laundering/drying cycles according to ISO 6330/4G Test Method -2012 Textiles - Domestic washing and drying procedures for textile testing for durability assessment.

2.3. Flammability and Thermal Properties Evaluation of the Treated Fabrics
The vertical burning test (Figure 1) including flame application time, ignition time, and char length/width was conducted according to ISO 6940:2006 entitled "Textile fabrics - Burning behaviour - Determination of ease of ignition of vertically oriented specimens to evaluate FR properties of the finished fabrics. Also, LOI test was carried out according to BS 4589-2.

Figure 1. Vertical Flammability Test
20x5 cm lengthwise specimens were prepared and left for 24 hours condition. The conditioned specimens were then mounted in a suitable clamp and placed in a standard cabinet that allows 2 mm/second airflow, and the bottom edge of the fabric was exposed to a standard flame for 1 second to its ignition time under controlled conditions. Treated fabrics were subjected to flame for only 20 seconds.

Thermal properties of treated fabrics were also investigated through thermal gravimetric analysis (TGA) and differential thermal analysis (DTA).

3. Results and Discussion

3.1. Vertical Flammability Test and LOI Results

All treated fabrics passed the vertical flammability test. After 20 s of flame exposure to the specimens, they were not ignited and did not show after-glow. Test results are exhibited on Table 2, including char length/width and mass loss %.

Table 2. Vertical flammability test results of treated fabrics.

<table>
<thead>
<tr>
<th>No</th>
<th>Fabric Type</th>
<th>Fabric Density</th>
<th>Time to flame subjection</th>
<th>Mass loss %</th>
<th>Char length/width</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% P knitted</td>
<td>132 g/m²</td>
<td>20 s</td>
<td>6.96</td>
<td>8.3 / 2.3 cm</td>
</tr>
<tr>
<td>2</td>
<td>60/40% P/C knitted</td>
<td>392 g/m²</td>
<td>20 s</td>
<td>2.78</td>
<td>8.7 / 1.9 cm</td>
</tr>
<tr>
<td>3</td>
<td>30/70% P/C knitted</td>
<td>365 g/m²</td>
<td>20 s</td>
<td>3.63</td>
<td>9 / 2.1 cm</td>
</tr>
<tr>
<td>4</td>
<td>50/50% P/C woven</td>
<td>185 g/m²</td>
<td>20 s</td>
<td>4.98</td>
<td>10 / 1.9 cm</td>
</tr>
<tr>
<td>5</td>
<td>100% C woven</td>
<td>112 g/m²</td>
<td>20 s</td>
<td>10.34</td>
<td>11.8 / 2.5 cm</td>
</tr>
</tbody>
</table>

As seen from the table, 100 % cotton fabric has the highest value in mass loss % and char length/width value among other fabric samples while 60/40% P/C fabric has lowest values. If FR performance of P/C fabrics were compared, 60/40% P/C has better values in terms of mass loss and char length. It is well known that fabrics density is strongly related to FR performance. 60/40% P/C has also an advantage of heavier weight as well as higher polyester ratio. By comparing 100 % cotton and 100 % polyester, it is obviously seen that New Fire-off treatment have better FR results in polyester fabrics than cotton fabrics. Therefore, it could be said that there is also a direct relation between FR performance and polyester ratio of treated fabrics.

Flammability of the fabrics after laundering cycles of 5, 10, 15 and 20 were also evaluated in term of FR properties against washing. The results are listed on Table 3. It was observed that 100 % cotton fabric burns rapidly while C/P blends extinguish themselves and burn very slowly. As it is seen from the table that ignition times almost did not changed after 5 washing cycles. So, fabrics lost most of their FR performance in 1-5 cycles.

Table 3. Vertical flammability test results after home washing.

<table>
<thead>
<tr>
<th>No</th>
<th>Fabric Type</th>
<th>Fabric Density</th>
<th>Ignition time after 5 washing cycles</th>
<th>Ignition time after 10 washing cycles</th>
<th>Ignition time after 15 washing cycles</th>
<th>Ignition time after 20 washing cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% P knitted</td>
<td>132 g/m²</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>60/40% P/C knitted</td>
<td>392 g/m²</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>30/70% P/C knitted</td>
<td>365 g/m²</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>50/50% P/C woven</td>
<td>185 g/m²</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>100% C woven</td>
<td>112 g/m²</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>
LOI values of treated and untreated fabrics are given in Table 4. FR treatments with Fire-off on polyester and P/C blends lead an increase in LOI values from 18-19 to 26-27.

Table 4. LOI test results of untreated and treated C/P fabrics.

<table>
<thead>
<tr>
<th>No</th>
<th>Fabric Type</th>
<th>Fabric Density</th>
<th>LOI of untreated fabric</th>
<th>LOI of treated fabric</th>
<th>LOI after 5 wash</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% P knitted</td>
<td>132 g/m²</td>
<td>19-20</td>
<td>26.5-27</td>
<td>ND</td>
</tr>
<tr>
<td>2</td>
<td>60/40% P/C knitted</td>
<td>392 g/m²</td>
<td>19</td>
<td>26.5-27</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>30/70% P/C knitted</td>
<td>365 g/m²</td>
<td>19</td>
<td>26.5-27</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>50/50 % P/C woven</td>
<td>185 g/m²</td>
<td>18-19</td>
<td>25.5-26</td>
<td>20-21</td>
</tr>
<tr>
<td>5</td>
<td>100% C woven</td>
<td>112 g/m²</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

*ND: Not detected

3.2. Thermogravimetric and Differential Thermal Analysis of Treated Fabrics
Thermal changes of treated P/C fabrics are shown in Figure 2, and collected numerical datas are given in Table 5.

a) 100% P knitted

b) 60/40% P/C knitted
c) 30/70% P/C knitted

d) 50/50% P/C woven

e) 100% C woven

Figure 2. TGA/DTA of treated fabrics with New Fire-off.
Table 5. Collected datas from TGA/DTA graphs of treated fabrics

<table>
<thead>
<tr>
<th>No</th>
<th>Fabric Type</th>
<th>T_d 0.05 / T_d 0.5 (°C)</th>
<th>T_g / T_m (°C)</th>
<th>ΔH_m (uV.s/mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100% Polyester</td>
<td>55.8 / 296</td>
<td>70.7 / 267.3</td>
<td>6.45</td>
</tr>
<tr>
<td>2</td>
<td>60/40% P/C</td>
<td>109.2 / 394.8</td>
<td>66.9 / 246.3</td>
<td>10.61</td>
</tr>
<tr>
<td>3</td>
<td>30/70% P/C</td>
<td>67.1 / 368.9</td>
<td>68.2 / 286.5</td>
<td>14.93</td>
</tr>
<tr>
<td>4</td>
<td>50/50% P/C</td>
<td>82.1 / 399.1</td>
<td>65.6 / 246.2</td>
<td>7.13</td>
</tr>
<tr>
<td>5</td>
<td>100% Cotton</td>
<td>68.8 / 304.9</td>
<td>64.3 / 306</td>
<td>-33.00</td>
</tr>
</tbody>
</table>

It is clearly seen from the Table 5 that T_m and ΔH_m values of 30/70% P/C fabrics are highest among the other fabrics, which can be attributed to high flame retardancy with increased char formation. Although 60/40% P/C and 50/50% P/C have very similar T_g / T_m and T_d 0.5 (°C) values, ΔH_m value of 60/40% P/C is higher than 50/50% P/C. It indicated that 60/40% P/C fabric has better flame retardancy than 50/50% P/C.

4. Conclusion and Directions for Further Study
In this study, FR properties and durability performance of 100 % C, 100 % P and P/C fabrics treated with New Fire-off were investigated. Results showed that FR were successfully rendered the all fabrics with New Fire-off. As fabrics consisted of higher ratio polyester demonstrated better FR properties, New Fire-off is more effective on the polyester part of the blends. However, all fabrics lost most of their FR properties between 1-5 home washing. So, durability against washing still needs to be improved for all the fabrics.

Further studies could focus on modifications of the synthesis of Fire-off and using cross linkers for the cotton part of the blends to increase FR properties and durability.

References

Acknowledgments
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Effect of pigment concentration on fastness and color values of thermal and UV curable pigment printing

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Abstract. In the current study, it is aimed to determine the effect of pigment concentration on fastness and colour values of thermal and ultraviolet (UV) curable pigment printing on synthetic leather. For this purpose, thermal curable solvent-based and UV curable water-based formulations were prepared with different pigment concentrations (3, 5 and 7%) separately and applied by screen printing technique using a screen printing machine. Samples printed with solvent-based formulations were thermally cured and samples printed with water-based formulations were cured using a UV curing machine equipped with gallium and mercury (Ga/Hg) lamps at room temperature. The crock fastness values of samples printed with solvent-based formulations showed that increase in pigment concentration was not effective on both dry and wet crock fastness values. On the other hand, in samples printed with UV curable water-based formulations, dry crock fastness was improved and evaluated as very good for all pigment concentrations. However, increasing the pigment concentration affected the wet crock fastness values adversely and lower values were observed. As the energy level increased for each irradiation source, the fastness values were improved. In comparison with samples printed with solvent-based formulations, samples printed with UV curable water-based formulations yielded higher K/S values at all pigment concentrations. The results suggested that, higher K/S values can be obtained in samples printed with UV curable water-based formulations at a lower pigment concentration compared to samples printed with solvent-based formulations.

1. Introduction
Pigment printing has been widely used in textile printing industry. This is due to the fact that it is applicable to all fiber and fiber blends with easy application and fixation methods [1, 2]. During fixation processes, in order to bind the pigments onto the textile surfaces via binders, dry air at high temperature is used in conventional thermal curing technique, in that, there is no need for complicated equipment and after wash treatment [3-6]. Despite its high energy consumption and cost, conventional thermal curing technique has still been used in textile finishing processes such as coating and pigment printing. Although the pigment printing has been commonly applied in textile industry, the UV curing technique has been rarely used or investigated. Due to its low energy consumption, space saving, short start-up period, fast and reliable curing, UV-curing technology has been utilized in many other industrial applications [2, 7]. Classical thermally curable solvent-based, water-based or powder
coatings consume high energy and particularly, solvent-based systems contain a high amount of organic solvent. On the other hand, UV curable formulations contain very low amount of volatile organic compounds (VOCs) than those of thermal curable. In addition, UV curable formulations contain almost no harmful substances causing air pollution and therefore are accepted as environmentally-friendly. Along with mentioned advantages, UV cured films offer improved abrasion and solvent resistance, and good bonding. In UV curing, the photo initiators release radicals when they are induced by irradiation. This initiates the polymerization of the binder which leads to a crosslinked network of polymers. Irradiation sources can be mercury (Hg) and gallium (Ga) lamps. Particularly, medium pressure Hg lamps provide high power and emission which is absorbed by most of the photoinitiators, whereas Ga lamp is usually used for deep curing. The pigments in UV curable coatings affect the curing behavior of the film, since they scatter or absorb the UV light [10].

Screen printing is a versatile printing technique since it is applied onto various types of substrates such as paper, plastics, textiles, etc. with different size and thickness [11]. In this study, for the first time, pigment printing on a polyurethane based synthetic leather using a water based UV curable polyurethane acrylate binder will be applied by screen printing technique. The study will focus on the effect of different pigment concentrations on fastness and color values of thermally and UV cured printed samples. The results will show the potential use of water based UV curable formulations as an alternative to traditionally applied solvent-based thermal curable formulations in printing on polyurethane based synthetic leather.

2. Experimental

2.1. Materials
Polyurethane (PU) based synthetic leather samples (Flokser Tekstil, Turkey) with a mass of 545 g/m², were used as they are supplied. PU (Dincerler Tekstil, Turkey), dimethylformamide (DMF) (Kimetsan, Turkey) and toluene (Tekkim, Turkey) were used for the preparation of the solvent-based thermal curable pastes. In the preparation of UV curable water based printing pastes, a flexible, water based PV acrylate binder was used as the binder and photoinitiators will be applied by screen printing technique. The study will focus on the effect of different pigment concentrations on fastness and color values of thermally and UV cured printed samples. The results will show the potential use of water based UV curable formulations as an alternative to traditionally applied solvent-based thermal curable formulations in printing on polyurethane based synthetic leather.

2.2. Method

2.2.1. Preparing of solvent-based and water based printing pastes. Thermal curable solvent-based and UV curable water-based formulations were prepared with different pigment concentrations (3%, 5% and 7%) separately and applied by screen printing technique using a flat screen printing machine (Rapid Tag, ASPE) and a screen having mesh number of 62. Solvent-based pastes were prepared according to a commercial formulation as given in Table 1. The viscosity and pH of the solvent-based paste was measured as 6.8 and 1600 cP (at 30 rpm with spindle 3) respectively. The samples were cured at 150 °C for 120 s.
In the preparation of water-based printing pastes, aliphatic PU acrylate resin (Laromer® UA 9059) was used as the binder. Bisacyl phosphine (Irganox® 819 DW) and α-hydroxyketone (Irgacure® 500) were used as the photoinitiators, which are responsible for initiating the polymerization through formation of free radicals during UV curing, were used. In addition to binder and photoinitiators, pigment, wetting agent, defoamer, deionized water and ammonia solution (NH₄OH) were used in the formulation. The pH and the viscosity of the printing paste were adjusted to 8.0 - 9.0 and 20.000 - 25.000 cP (at 20 rpm, with spindle 6), respectively. The formulation of UV curable water based printing pastes were prepared as given in Table 2. Samples printed with UV curable water based pastes were cured at room temperature using a UV curing machine (Raycon®), equipped with Ga and Hg lamps and a conveyor belt with an adjustable speed. UV curing of printed samples was conducted at 3 energy levels (60, 90 and 120 W/cm) at a belt speed of 10 m/min under different UV lamp combinations (Hg, Ga, GaHg, GaGaHg). Total applied energy amount was determined with a UV-Integrator Type D radiometer. The applied energy and the UV lamp combinations are given in Table 3.

### Table 1. Solvent-based printing formulation.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solvent-based PU binder</td>
<td>50</td>
</tr>
<tr>
<td>DMF</td>
<td>25</td>
</tr>
<tr>
<td>Toluene</td>
<td>25</td>
</tr>
<tr>
<td>Pigment (Irgazin® Red K 3840)</td>
<td>3%, 5% and 7%</td>
</tr>
</tbody>
</table>

### Table 2. Water-based printing formulation.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Quantity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deionized water</td>
<td>26</td>
</tr>
<tr>
<td>Binder (Laromer® UA 9059)</td>
<td>66</td>
</tr>
<tr>
<td>Photoinitiator (Irgacure® 500)</td>
<td>1.8</td>
</tr>
<tr>
<td>Photoinitiator (Irgacure® 819 DW)</td>
<td>1.8</td>
</tr>
<tr>
<td>Pigment (Irgazin® Red K 3840)</td>
<td>3, 5 and 7</td>
</tr>
<tr>
<td>Thickener (Orgal® P 460)</td>
<td>2.63</td>
</tr>
<tr>
<td>Wetting agent</td>
<td>0.49</td>
</tr>
<tr>
<td>Defoamer</td>
<td>0.1</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0.33</td>
</tr>
</tbody>
</table>
Table 3. UV lamp combinations and amount of total applied energy.

<table>
<thead>
<tr>
<th>Lamp source</th>
<th>Hg</th>
<th>Ga</th>
<th>GaHg</th>
<th>GaGaHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy level (W/cm)</td>
<td>60</td>
<td>90</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>Applied energy (mj/cm$^2$)</td>
<td>186</td>
<td>287</td>
<td>497</td>
<td>288</td>
</tr>
</tbody>
</table>

The crock fastness tests were performed according to ISO 105-X12 Textiles-Tests for Colour Fastness standard in a James H. Heal crockmeter. The color parameters of the printed samples were evaluated with X-Rite Color i5 spectrophotometer. The crock fastness and colour values of water-based UV cured and solvent-based thermal cured printed samples were compared.

3. Results and Discussion

3.1. Crock fastness and color values of printed samples with solvent-based thermal cured formulations

The synthetic leather samples printed with solvent-based thermal cured (at 150 °C for 120 s) formulations are shown in Figure 1. Their dry and wet crock fastness results are shown in Table 4.

![Photographic images of printed synthetic leather samples](image)

**Figure 1.** Photographic images of printed synthetic leather samples (SB: solvent-based paste, P: pigment).

Table 4. Crock fastness results (SB: solvent-based, P: pigment)

<table>
<thead>
<tr>
<th>Sample</th>
<th>SB (P3%)</th>
<th>SB (P5%)</th>
<th>SB (P7%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Wet</td>
<td>3/4</td>
<td>3/4</td>
<td>3/4</td>
</tr>
</tbody>
</table>

The crock fastness values of samples were evaluated as 3 and 3/4. The results suggested that the increase in pigment concentration was not effective on both the dry and wet crock fastness values. The color measurement test results of the printed samples are shown in Table 5.
According to the color measurement results, with the increase in pigment concentration, $L^*$ (lightness-darkness) value decreased while $a^*$ (redness-greenness) value increased and $b^*$ (yellowness-blueness) value decreased. Moreover, K/S (color strength) value increased with increased pigment concentration. The maximum K/S value of 10.61 was obtained for 7% pigment concentration.

Table 5. Color values of printed samples at 500 nm (SB: solvent-based, P: pigment)

<table>
<thead>
<tr>
<th>Sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>K/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB (P3%)</td>
<td>44.56</td>
<td>53.58</td>
<td>33.35</td>
<td>10.33</td>
</tr>
<tr>
<td>SB (P5%)</td>
<td>44.48</td>
<td>53.88</td>
<td>33.03</td>
<td>10.58</td>
</tr>
<tr>
<td>SB (P7%)</td>
<td>43.76</td>
<td>54.84</td>
<td>32.65</td>
<td>10.61</td>
</tr>
</tbody>
</table>

3.2. Crock fastness and color values of printed samples with water-based UV curable formulations
Photographic images of the UV cured printed synthetic leather samples with pigment concentration of 3% are shown in Figure 2. The wet crock fastness results are given in Table 6. Dry crock fastness was evaluated as 4/5 for all pigment concentrations. Increasing the pigment concentration affected the wet crock fastness values adversely and lowered the values to 1/2. However, as the energy level increased for each irradiation source, the fastness values improved. These results can be explained by the fact that at higher concentrations, pigment in the formulation absorb more UV-light, competing and consequently hindering the formation of the free radicals which are responsible for polymerization reaction of the binder [2, 12]. Thus the curing level of the binder decreases which leads to poor fixation of the pigments on the synthetic leather surface. The highest wet fastness values (3, 3/4) were obtained at a pigment concentration of 3%.

Figure 2. Photographic images of synthetic leather samples printed with UV curable water-based formulation having a pigment concentration of 3%.
Table 6. The wet crock fastness test results (WB: water-based, P: pigment).

<table>
<thead>
<tr>
<th>Lamp source</th>
<th>Hg</th>
<th>Ga</th>
<th>GaHg</th>
<th>GaGaHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy level (W/cm)</td>
<td>60</td>
<td>90</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>186</td>
<td>287</td>
<td>497</td>
<td>288</td>
<td>439</td>
</tr>
<tr>
<td>Applied energy (mj/cm²)</td>
<td>1/2</td>
<td>2/3</td>
<td>3/4</td>
<td>2/3</td>
</tr>
<tr>
<td>WB (P3%)</td>
<td>2</td>
<td>2/3</td>
<td>3/4</td>
<td>2/3</td>
</tr>
<tr>
<td>WB (P5%)</td>
<td>1/2</td>
<td>2/3</td>
<td>3</td>
<td>2/3</td>
</tr>
<tr>
<td>WB (P7%)</td>
<td>1/2</td>
<td>2</td>
<td>2/3</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 7. Color values of printed samples at 500 nm (WB: water-based, P: pigment)

<table>
<thead>
<tr>
<th>Lamp source</th>
<th>Hg</th>
<th>Ga</th>
<th>GaHg</th>
<th>GaGaHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy level (W/cm)</td>
<td>60</td>
<td>90</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>Applied energy (mj/cm²)</td>
<td>186</td>
<td>287</td>
<td>497</td>
<td>288</td>
</tr>
<tr>
<td>L*</td>
<td>44.62</td>
<td>44.72</td>
<td>44.79</td>
<td>44.67</td>
</tr>
<tr>
<td>WB (P3%)</td>
<td>43.62</td>
<td>44.06</td>
<td>43.87</td>
<td>43.78</td>
</tr>
<tr>
<td>WB (P5%)</td>
<td>43.64</td>
<td>43.54</td>
<td>43.69</td>
<td>43.48</td>
</tr>
<tr>
<td>WB (P7%)</td>
<td>53.25</td>
<td>53.21</td>
<td>53.52</td>
<td>53.41</td>
</tr>
<tr>
<td>a*</td>
<td>53.92</td>
<td>53.94</td>
<td>54.13</td>
<td>54.02</td>
</tr>
<tr>
<td>b*</td>
<td>54.95</td>
<td>54.76</td>
<td>54.7</td>
<td>54.96</td>
</tr>
<tr>
<td>K/S</td>
<td>10.62</td>
<td>10.72</td>
<td>10.84</td>
<td>10.67</td>
</tr>
<tr>
<td>WB (P3%)</td>
<td>10.77</td>
<td>10.8</td>
<td>10.91</td>
<td>10.84</td>
</tr>
<tr>
<td>WB (P7%)</td>
<td>11.06</td>
<td>11.21</td>
<td>11.35</td>
<td>11.02</td>
</tr>
</tbody>
</table>
Color values of printed samples for different pigments concentrations (3, 5, 7%) are shown in Table 7. Similar to the results obtained with thermal cured solvent-based samples, with the increase in pigment concentration the value of $L^*$ decreased, while the value of $a^*$ increased and the value of $b^*$ decreased. Moreover, $K/S$ values increased with the increase in pigment concentration. In case of single or combined use of Ga and Hg lamps, $K/S$ values increased as the total amount of applied energy increased during curing. This trend was not observed for $L^*a^*b^*$ values.

4. Conclusion
In comparison with solvent-based thermal cured samples, the water-based UV cured samples yielded higher $K/S$ values at all pigment concentrations. In samples printed with thermal cured solvent-based formulations, maximum $K/S$ value of 10.61 was obtained in 7% pigment concentration, whereas maximum $K/S$ value at the same pigment concentration was measured as 11.94 for samples printed with water-based UV curable formulations at high energy levels under UV lamp combinations. In addition, the maximum $K/S$ value obtained at 7% pigment concentration in solvent-based formulation could be achieved with only 3% pigment concentration with water-based formulation. The increase in pigment concentration led to a decrease in $L^*$ values in both water and solvent-based formulations.

Crock fastness results showed that, for all pigment concentrations, dry crock fastness value of 3 was obtained with solvent-based thermal cured formulations. On the other hand, for water-based UV curable formulations dry crock fastness values of 4/5 were obtained. Dry crock fastness values were not affected by the lamp combinations or increase in applied total energy. These results showed that samples printed with water-based UV curable formulations had better dry crock fastness than samples printed with solvent-based thermal cured formulations.

Wet crock fastness value of 3/4 was obtained with solvent-based thermal cured formulations for all pigment concentrations. Wet crock fastness results of water-based formulations indicated that, increase in pigment concentration led to a decrease in fastness values. However, as the energy level increased, an improvement in fastness values was observed for each combination of lamps. The highest wet crock fastness value of 3/4 was observed at high energy levels. In order to improve the wet crock fastness values, curing should be applied at higher energy levels for UV curable formulations. According to the results, since GaGaHg combination yielded the same fastness values with GaHg combination, at 3% pigment concentration, the use of GaHg combination is suggested for curing of water-based formulations for energy efficiency.

Acknowledgment
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References


The arrangement of the fibers in the yarn and effect on its strength

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Abstract. This article presents the results of research on the deformation changes in the initial moments of loading and unloading of conversional ring and compact yarns samples with a special strain gauge device. It was revealed that compact yarn in the initial load moment is deformed slowly doubled (4 seconds) compared to the conversional ring yarn. At the moment of unloading, on the contrary, the deformation of the compact yarn occurs rapidly (2 seconds), and the compact yarn in which a fiber foredeck regularly deformed quickly (1 second). A comparative study of resistance to stretching of the conversional ring and compact yarn based on Kelvin model was done. As a result, it has been found that the instant and long elastic module of compact yarn are slightly higher than conversional ring yarn with similar module, and the viscosity parameter which characterizes the decrease of the modulus of elasticity is lower compare with it.

1. Introduction

The yarn deformation takes an important place in spinning on demand level due to its strengths and quality. When the yarn and fibres are operated through technological process or within the exploitation period, they deformate and change because of different mechanic influences (drawing, lying, folding or pressing). It is known that, when the yarn is spanned or twisted, mostly and mainly the fibres located along the sides of the cross section are stretched. When the yarn is spanned or twisted, the fibres at the center of the cross section are less affected. It is very important to apply certain methods to activate the center fibers within the spinning as well. And that’s why the influence of spinning triangle upon the yarn structure and features has been studied well [1–4]. Position state of fibres within the spinning triangle has been specified by the experts of ROTORCRAFT Company. Therefore, the spinning triangle determines the state of fiber in yarn. The tension of fibres located alongside in transversal part is high, and the fibre tension decreases towards the center part. Taking into consideration this condition, and due to the reason that the fibres have different tensions, the yarn structure also varies. So, the fibre structure is unsmooth and its resistance against extension forces is low. Yarn deformation has been studied with the aim to prove this state in practice.

2. Theoretical part

For analysing such processes, we rely on Creep Theory suggested by Y.N.Rabotnov and others. According to this theory, one-side yarn deformation under the influence of stable force due to time is determined by the following theorem.

\[
\frac{d}{a} = A\sigma^a \quad (1)
\]
thus \( A, \alpha \) – the values determined through testing.

The correlation between deformation \( \varepsilon \) and yarn length \( l \) is expressed as following:

\[
\varepsilon = \ln \frac{l}{l_0}, \quad l_0 \quad \text{– the initial length of yarn.}
\]

To express the strain through deformation we apply to mass conservation law. If the yarn keeps and preserves its density, then

\[
F = F_0 l_0
\]

Thus, \( F_0, F, l \) – the values of yarn surface length at initial and optional time. Using the equation, we find the strain \( \sigma \) value

\[
\sigma = \frac{F}{F_0} = \frac{F}{F_0 l_0} = \frac{\varepsilon}{l_0} (2)
\]

here, \( P_0 \) – the external force applied on the yarn (3) and using the equation (2) we change the equation (1) as following:

\[
1 = A_0 (\frac{l}{l_0})^N
\]

We find this equation by integration, where \( l = l_0, \quad l = 0 \)

\[
\left[ (\frac{l}{l_0})^N \right] = \left[ \frac{1}{1 - A_0 t_0} \right]^\frac{1}{\alpha}
\]

thus, \( A_\alpha = A_0 l_0^N \alpha \)

we find \( \varepsilon \) using formula (2)

\[
\varepsilon = -\frac{1}{\alpha} \ln (1 - A_0 t)
\]

If in formula (4) \( t_0 = 1, \quad \alpha = \frac{1}{l_0} \), then deformation increases unlimitedly. In this case the external forces prevent the integrality of yarn and causes its breakage. The parameters \( \alpha \) and \( A_0 \) can be found by testing. For this, we accept \( \varepsilon \) as deformation and the values of \( \varepsilon \) as \( t = t_i, \quad i = 1,2,\ldots,n \). Therefore, we compose the functional \( (\alpha = \frac{1}{l_0}) \) as:

\[
S = \sum_{i=1}^{n} [\varepsilon_i - \alpha \ln (1 - A_0 t_i)]^2
\]

and find the minimum at \( \alpha_0 \) and \( A_0 \) values. For this, we equate the differential \( \frac{\partial S}{\partial \alpha}, \frac{\partial S}{\partial A_0} \) derivative to zero and find:

\[
\alpha_0 \sum_{i=1}^{n} \ln^2 (1 - A_0 t_i) - \sum_{i=1}^{n} \varepsilon_i \ln (1 - A_0 t_i) = 0 \quad \alpha_0 \sum_{i=1}^{n} \frac{t_i \ln (1 - A_0 t_i)}{1 - A_0 t_i} - \sum_{i=1}^{n} \frac{\varepsilon_i t_i}{1 - A_0 t_i} = 0
\]

We find \( \alpha_0 \) from the first equation, put it on the second one, and get the equation in relation to \( A_0 \).
The formula (4) is effective until the creeping process is over. The test results show that the yarn’s deformation, under the influences of forces, extends for a certain time, then slows down and practically does not change. In this case, when the creeping process is over, we can observe rheological properties which change slowly. At this time the deformation changing due to time, in simple cases, can be determined by Kelvin-Voigt equation. If deformation is as \( \varepsilon = \varepsilon(t) \), then due to this formula we get the following expression:

\[
\varepsilon_i = A_0 \left[ \frac{1 - \beta \varepsilon(t-1)}{(1 - A_0 t_n)} \right] + \varepsilon(t_n) \quad (5)
\]

thus, \( \beta \) – unchangeable number, the deformation is found through the value \( t \to \infty \) on the base of testing \( \varepsilon_n \).

\[
\beta = \frac{A_0}{\alpha [\varepsilon(t) - \varepsilon(t_n)] (1 - A_0 t_n)}
\]

The formula (5) can be changed as:

\[
\varepsilon_i = [\varepsilon(t) - \varepsilon(t_n)] \left[ 1 - I^{-\beta(t-t_n)} \right] + \varepsilon(t_n)
\]

3. Experimental

Standard methods were used to determine the yarn structure. Yarn samples to be tested on this purpose were kept in air conditioned area within 24 hours and after that the linear density, durability and spinnability of each sample was determined. The changes in structures of 50 cm-length snips were observed in compact and conventional yarns spanned at different values of hasp rotation frequency (13000 min-1 and 17000 min-1) as well as in two types of spinnability, namely (740 b/m and 860 b/m). The yarn breakage was observed and registered when a certain load was applied. When a load of 210 kg was suspended on 50 cm-length piece of conventional yarn with the hasp rotation frequency of 13000 min-1 and spinnability of 740 b/m, the yarn breakage occurred in 5.7 seconds. When a load of 260 kg was suspended on compact yarn, hasp rotation frequency and spinnability of which was not changed, the yarn torn in 6 seconds. The compact yarn, in comparison to the conventional one showed bigger resistance (260 g instead of 210 g).

When a load of 210 kg was suspended on the conventional yarn with hasp rotation frequency of 17000 min-1 and spinnability of 740 b/m, the yarn breakage happened in 4.1 seconds. When a load of 260 kg was suspended on compact yarn with the same hasp rotation frequency and spinnability, the yarn breakage occurred in 3.1 seconds. On the following steps of the testing when the weight of the load suspended on the yarn was decreased, the compact and conventional yarn samples showed greater resistance against the breakage, namely the resistance against breakage time was increased. When a load of 180 kg, instead of 210 kg, was suspended on the conventional yarn with a hasp rotation frequency of 13000 min1 and spinnability of 740 b/m, the sample yarn breakage was in 34.7 seconds. The same testing applied on the compact yarn, the load weight was 320 kg instead of 260 kg, and the sample yarn breakage was in 50.8 seconds. Alike changes were observed in conventional and compact yarn samples at hast rotation frequency of 13000 min-1 and 17000 min-1, and with spinnability of 860 b/m. The yarn breakage time according to the load weight is explained by the location and state changing of fibers within the yarn structure.
To investigate the changes occurring within the yarn structure, we studied the extensibility and tensile of yarn samples during loading and unloading period. The compact and conventional yarns spanned with the hast rotation frequency of 13000 min⁻¹, and spinnability of 740 b/m were tested. To investigate the deformation at initial time when the load influences the sample, we studied the changes observed under the influence of load with a weight of 50 g.

The process of structural changes is observed at the beginning of loading. A certain period is required to achieve the parameters of main physical and mechanical yarn features. The fibers in yarn, formatted within this period, change their orientation, the gaps between them start do disappear with the influence of external forces and twisting actions, and yarn obtains certain strenght. When the external forces are applied for a longer period of time, in accordance with their value and strength, the yarn slowly starts to lose its resistance resource, and at limited time loses its resistance. If this time is indicated as \( t_0 \), its value shall be dependent on physical and mechanical yarn parameters and the value of external forces. Moreover, the yarn deformation terms are different and it is important to find out which of these terms reflect the deformation adequately.

### 4. Results

The results calculated on the basis of the tested and advised model are turned into absolute values and can be found in Table 1. When compared, it was established that the relative difference between the results for compact yarn is 6 %, and for conventional yarn is 11 %.

Table 1. The changing values of deformation due to time at the beginning of loading

<table>
<thead>
<tr>
<th>Line type</th>
<th>Yarn type</th>
<th>Time, second, ( t )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>Testing</strong></td>
<td><strong>Compact</strong></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><strong>Conventional</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Theoretical</strong></td>
<td><strong>Compact</strong></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><strong>Conventional</strong></td>
<td>0</td>
</tr>
</tbody>
</table>

The parameters \( \alpha, \beta, \) are appeared to be equal to the following values. For compact yarn: \( \alpha=94, \ t_n=3,3 \ sec., \ 0=0,183, \ \beta=1,8, \) for conventional yarn: \( \alpha=20, \ t_n=1,8 \ sec., \ 0=0,134, \ \beta=5 \)

In figure 1 the received results are shown in graphics, where the lines 1 and 4 represent testing, the lines 2 and 3 represent theory. They show the results obtained based on model. The comparison analyzing indicated that there is a big difference in the results of the beginning process. The reason for that is high possibility of error while calculating the small values at the beginning. The results at other points are not significant. That is why, practically, it is not required to consider and take into account small values.
Conclusions
1. The study of scientific literature found that the methods and criteria for assessing the performance of mechanical characteristics of the yarn is perfect, but the relationship of the mechanical properties of the structure of the yarn and the terms of its formation is not enough consecrated. Nor is the dependence of the structure of the yarn from a number of technological and kinematic (high-speed) factors, and ways to reduce the loss of twist, and methods of controlling the density of the yarn structure management studies almost not considered.
2. A comparative analysis of scientific sources to identify the main scientific problem, which is to study the mechanical properties of the yarn within the parameters of formation conditions of its structural changes based on the theory of elasticity and the development of recommendations for the management structure in order to improve performance of mechanical characteristics of produced yarn.
3. It is found that the spindle speed and the number of twists (twisting) of yarn influence on the structure and mechanical properties of yarn. By increasing of spindle speed the before yarn breaking load increases, and deformation of yarn in tension decreases.

References
Development auxiliaries for dyeing polyester with disperse dyes at low temperatures

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Abstract

High-molecular weight organic compounds known as carriers are widely used to expedite polyester dyeing at atmospheric pressure at 100 ºC. However, carriers are usually poorly biodegradable and can partially plasticize fibres. Also, dyeing at temperatures above 100 ºC in the absence of a carrier entails using expensive equipment. In this work, we developed an alternative method for dyeing polyester at temperatures below 100 ºC that reduces energy expenses, dispenses with the need to invest in new equipment and avoids the undesirable effects of non-biodegradable carriers. The method uses disperse dyes in a micro-emulsion containing a low proportion of a non-toxic organic solvent and either of two alternative development auxiliaries (coumarin and o-vanillin) that is prepared with the aid of ultrasound.

1. Introduction

PET fibres are hydrophobic [1] and contain no chemically active groups, which hinders their dyeing in aqueous media [2] and requires using disperse dyes that are almost insoluble in water [3,4]. In fact, dyeing polyester typically entails dispersing a swelling agent (a carrier) and the dye among fibres at a high temperature and pressure [5]. Efficiently using disperse dyes with polyester fibres entails operating at temperatures above their glass transition point (80 ºC) [6–8]. Some organic solvents used as carriers to swell polyester fibres for dyeing contain phenyl-phenol, phenyl-chloride or phenyl-alkyl groups, among others [9–11]. As noted earlier, carriers are often scarcely biodegradable and tend to plasticize fibres, thereby lowering their glass transition temperature ($T_g$) [12].

Carrión-Fite [7] developed an alternative method for dyeing polyester with reduced energy costs, investments and unwanted effects [13]. The method uses temperatures as low as 40 ºC or even lower in combination with disperse dyes in a micro-emulsion containing a low proportion of an organic solvent (an alkyl halogen) and phosphoglyceride as emulsifier that is prepared under sonication [7]. Growing ecological concerns have led to strict regulation of textile dyeing and finishing processes [14], which has promoted a search for natural, safer substances for use by the wet textile processing industry [7, 14, 15]. For example, Pasquet et al [15] used o- and p-vanillin at high concentrations as alternatives for toxic carriers in the low-temperature dyeing of polyester fabrics with low-molecular weight disperse dyes in the presence of ethanol as co-solvent.

In this work, we developed an alternative method for dyeing polyester with disperse dyes at a low temperature. The method uses a micro-emulsion consisting of a non-toxic organic co-solvent n-butyl
acetate, which was previously used by Carrion-Fite [15] and either of two agro-sourced development auxiliaries: o-vanillin, which was previously employed by Pasquet et al [16], or coumarin. The microemulsion is prepared with the aid of ultrasound. The dyeing process was conducted by using various low-molecular weight disperse dyes at different temperatures below 100 °C and its kinetics at each temperature examined.

2. Experimental

2.1. Materials

Fabric. Standard polyester, Type 30 A (Code 30,000), from wfk Testgewebe GmbH (Brüggen, Germany) (ISO 105-F10).

Chemicals. The low-molecular weight disperse dyes Rubin Foron E-5R (C.I. Disperse Red 73), and Blue Foron E-BL (C.I. Disperse Blue 56), both supplied by Clariant (Muttenz, Switzerland) (see Figs 1 and 2).

Organic solvent. Pure n-butyl acetate (MW = 116.16 g·mol⁻¹) supplied by Panreac (Barcelona, Spain).

Auxiliaries. Coumarin 99% pure (MW = 146.15, CAS No. 91-64-5) supplied Acros (New Jersey, USA) and o-vanillin (2-hydroxy-3-methoxybenzaldehyde, MW = 152.15, CAS No. 148-53-8) in 99% purity supplied by Acros (New Jersey, USA).

Solvent for extraction of disperse dyes on polyester. N,N-Dimethylformamide for analysis (MW = 73.10 g·mol⁻¹) supplied in 99.8% purity by Panreac (Barcelona, Spain).

Non-ionic surfactant for pre-dyeing washing. Hostapal, obtained from Archroma GmbH (Sulzbach, Germany).

Post-dyeing reductant. QP-grade 85% pure sodium dithionite (MW = 174.11 g·mol⁻¹) and analytical-grade sodium hydroxide purissimum, both supplied by Panreac.

2.2. Equipment

Dyeing. A Linitest dyeing apparatus furnished with 300 ml sealed cans that was purchased from Atlas MTT GmbH (Germany)

Washing. A Launder-Ometer with 550 ml sealed cans also purchased from Atlas (Illinois, USA).

Sonication. A Labsonic 1510 shaker equipped with a standard probe of 19 mm Ø that was supplied by B. Braun (Hessen, Germany).

2.3. Procedures

2.3.1 Fabric pre-washing. Cleanliness in the standard polyester fabric used was ensured by washing with Hostapal detergent at a 0.5 g·L⁻¹ concentration at 40 ºC for 30 min.

2.3.2 Dyeing conditions. The dyeing bath contained 3 g of polyester fabric, a 2% concentration of disperse dye, a 1 ml/1 g o.w.f. concentration of solvent (n-butyl acetate) and a 4% o.w.f. concentration of auxiliary. The bath ratio was 1:60 and the temperature 65, 75, 83 or 95 ºC. The dyeing apparatus was used with closed containers at a constant agitation rate and temperature. The operation time was 120 min —by exception, that used at the lowest temperature (65 ºC) was 150 min.

2.3.3 Dyeing procedure. Each dyeing bath was prepared from a 4% o.w.f. concentration of auxiliary (o-vanillin or coumarin) that was dispersed in 3 ml of n-butyl acetate and made to 180 ml (B.R: 1:60) with distilled water. Emulsification was facilitated by mechanical stirring with a propeller shaker, followed by ultrasound (2 w/ml, 1 min). The auxiliary emulsion contained a 2% o.w.f. concentration of disperse dye — previously dissolved in the solvent — in the required volume for the applicable bath ratio (180 ml). Each emulsion was warmed to the present temperature for each assay, which was kept constant throughout the dyeing process. The temperatures used were 65, 75, 83 and 95 ºC. One-half of all tests used o-vanillin and the other half coumarin as auxiliary.

2.3.4 Post-dyeing washing. After dyeing, the fabric was washed in a reductive medium to remove all dye absorbed onto fibre surfaces. The reduction washing process consisted of 0.5 g/l soda and 2 g/l sodium hydrosulphite in distilled water and was followed by washing at 50 ºC for 30 min. The bath ratio was 1:50 (150 ml per sample). The equipment used to wash dyed fabric was a Launder-Ometer with 550 ml cans for each specimen. An amount of 3 g of specimen was washed in a 150 ml wash bath under the above-described conditions. After, the wash fastness of a dyed fabrics during 120 min was obtained.

2.3.5 Determination dye absorption. The amount of dye absorbed by the polyester fabric was determined by extraction with N,N-dimethylformamide (DMF) and calculated from a linear line for the calibration of each disperse dye. As per the Beer–Lambert law, the absorbance at the maximum wavelength in the visible spectrum was a linear function of the concentration of dye dispersed in DMF.

3. Result and discussion

3.1. Dyeing kinetics and rate constant

Figures 5–8 illustrate the kinetics of dyeing with the two disperse dyes in the presence of the two auxiliaries used, namely: C.I. Disperse Red 73 with coumarin (Figure. 5), C.I. Disperse Red 73 with o-vanillin (Figure 6), C.I. Disperse Blue 56 with coumarin (Figure. 7) and C.I. Disperse Blue 56 with o-vanillin (Figure. 8).

The diffusion of dyes into fibres depends on the local rate of dye transport in the substrate in relation to the concentration gradient, the geometry of the medium, and the radius of the fibre cross-section. The difficulty of measuring these variables led us to use the following Cegarra-Puente kinetic equation [8]:

\[ \text{Ln} \left(1 - \frac{C_t}{C_\infty}\right) = -Kt \] (1)
Where

\( C_t = \) dye concentration on fibres at time \( t \)

\( C_\infty = \) initial concentration in the dye bath

\( K = \) dyeing rate constant

\( t = \) time

**Figure 5** Kinetics of dyeing with C.I. Disperse Red 73 absorbed by polyester fabric at different temperatures in the presence of butyl acetate (16.666 g·l\(^{-1}\)) and coumarin (0.666 g·l\(^{-1}\)).

**Figure 6** Kinetics of dyeing with C.I. Disperse Red 73 absorbed by polyester fabric at different temperatures in the presence of butyl acetate (16.666 g·l\(^{-1}\)) and o-vanillin (0.666 g·l\(^{-1}\)).

**Figure 7** Kinetics of dyeing with C.I. Disperse Blue 56 absorbed by polyester fabric at different temperatures in the presence of butyl acetate (16.666 g·l\(^{-1}\)) and coumarin (0.666 g·l\(^{-1}\)).

**Figure 8** Kinetics of dyeing with C.I. Disperse Blue 56 absorbed by polyester fabric at different temperatures in the presence of butyl acetate (16.666 g·l\(^{-1}\)) and o-vanillin (0.666 g·l\(^{-1}\)).

Table 1 shows the dyeing absorption rate constants, and their respective correlation coefficients, as calculated from equation (1).
Table 1. Absorption rate constant (K) and correlation coefficient (r) for the kinetics of dyeing of polyester with disperse dyes in the presence of o-vanillin or coumarin as development auxiliary.

<table>
<thead>
<tr>
<th>Disperse dyes</th>
<th>Auxiliary agent: o Vanillin</th>
<th>Auxiliary agent: Coumarin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rate constant</td>
<td>Correlation coefficient</td>
</tr>
<tr>
<td>C.I. Disperse Red 73 at 95ºC</td>
<td>0.0073</td>
<td>0.9476</td>
</tr>
<tr>
<td>I. Disperse Red 73 at 83 ºC</td>
<td>0.0054</td>
<td>0.9672</td>
</tr>
<tr>
<td>C.I. Disperse Red 73 at 75 ºC</td>
<td>0.0037</td>
<td>0.9723</td>
</tr>
<tr>
<td>C.I. Disperse Red 73 at 65 ºC</td>
<td>0.0017</td>
<td>0.9568</td>
</tr>
<tr>
<td>C.I. Disperse Blue 56 at 95ºC</td>
<td>0.0221</td>
<td>0.9874</td>
</tr>
<tr>
<td>C.I. Disperse Blue 56 at 83 ºC</td>
<td>0.0155</td>
<td>0.9316</td>
</tr>
<tr>
<td>C.I. Disperse Blue 56 at 75 ºC</td>
<td>0.085</td>
<td>0.9455</td>
</tr>
<tr>
<td>C.I. Disperse Blue 56 at 65 ºC</td>
<td>0.0027</td>
<td>0.8154</td>
</tr>
</tbody>
</table>

As can be seen, the absorption rate constant for both dyes increased with increasing temperature. Also, the correlation coefficients were good (in general, higher than 0.94 with o-vanillin and somewhat lower but still exceeding, in general, 0.91 with coumarin). Exhaustion after dyeing was acceptable in all cases except below 75 ºC — this temperature is lower than glass transition temperature of polyester.

3.2 Wash fastness of polyester fabric dyed

Table 2 shows colour fastness of to domestic and commercial laundering according to the standard methodology and using the A2S test indicated in this standard [17].

Table 2 Colour fastness of the polyester dyed

<table>
<thead>
<tr>
<th>PET fabric dyed 120 minutes</th>
<th>Auxiliary : O_Vanillin</th>
<th>Auxiliary : Coumarin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray Scale</td>
<td>PET</td>
<td>Cotton</td>
</tr>
<tr>
<td>C.I. Disperse Red 73 at 65ºC</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>C.I. Disperse Red 73 at 75 ºC</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C.I. Disperse Red 73 at 83 ºC</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>C.I. Disperse Red 73 at 95 ºC</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>C.I. Disperse Blue 56 at 65 ºC</td>
<td>2-3</td>
<td>3</td>
</tr>
<tr>
<td>C.I. Disperse Blue 56 at 75 ºC</td>
<td>4-5</td>
<td>3</td>
</tr>
<tr>
<td>C.I. Disperse Blue 56 at 83 ºC</td>
<td>4-5</td>
<td>4</td>
</tr>
</tbody>
</table>
Generally, in respect to Table 2 dyed fabric the washing fastness is acceptable for all samples and their values are quite similar for both dyes and slightly better in coumarin than o-vanillin agent. Staining of the white polyester fabric is regular for all dyes and auxiliaries tested. In respect to the white cotton fabric values are almost similar and shows the regular level.

**4. Conclusions**

This paper reports a new method for dyeing polyester fabric with disperse dyes at temperatures below 100ºC. The dyes are dispersed in a small volume of n-butyl acetate to obtain a micro-emulsion to which a development auxiliary (coumarin or o-vanillin) is added. The low molecular weight disperse dyes used exhibited acceptable exhaustion after 120 minutes and gray scale values of washing fastness was slightly better than o-vanillin. The absorption rate constants values increases with increasing temperature.

**5. References**

[17] Textiles. Test for colour fastness. 2010 Part C06: Colour fastness to domestic and commercial laundering (ISO 105-C06:2010), adapted to Spanish by UNE-EN ISO 105-C06
An investigation on the effect of elastane draw ratio on air permeability of denim bi-stretch denim fabrics

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Email: hcelik@gantep.edu.tr

Abstract. Elastane is used in all areas where a high degree of elasticity is required. The elastane core spun yarns are preferred to provide a better stretch for woven fabrics. In this study, it is intended to investigate the effects of elastane draw ratio on air permeability of denim woven fabrics. For this study, 29.5 Tex cotton combed ring spun yarn samples were produced with four different elastane draw ratios (3.07, 3.33, 3.63, 3.99). 3/1 Twill and 2/2 Twill denim fabric samples were woven by using the sample yarns in weft direction with three different weft densities (21, 25, 29 wefts/cm). In doing so, 24 denim fabric samples were obtained. Then air permeability of fabric samples were measured. Analysis of variance (ANOVA) was applied to determine the statistical significance of the effects of elastane draw ratio, weft sett and weave type on fabric air permeability.

1. Introduction
Elastane is used in all areas where a high degree of elasticity is required for example; in tights, sportswear, swimwear, corsetry and in woven and knitted fabrics. Elastane is a prerequisite for fashionable or functional apparel which is intended to cling the body, while at the same time remaining comfortable [1]. The elastane core spun yarns are preferred to provide a better stretch for woven fabrics. Especially, bi-stretch woven fabrics produced by using elastane core spun yarns in both warp and weft direction became more of an issue recently. In the literature, there are many studies which deal with the performance properties of woven stretch fabrics [2-8]. Apart from these studies, there are some studies which investigate the effect of elastane draw ratio in the yarn on woven fabric properties. Baghaei et al. determined that the decrease in draw ratio of elastane core lead to decrease in elastic recovery of woven stretch fabrics [9]. El-Ghezal et al. examined that as the elastane’s ratio in the yarn increases, the breaking elongation of stretch denim fabric decreases. Also, a consistent trend was not observed for breaking strength of the sample fabrics [10]. In another experimental study, it is observed that increasing the elastane ratio enhanced the fabric extensibility and air permeability. Beside, the elastane ratio reduced the tensile strength, shrinkage and permanent stretch of woven fabrics [11]. In another study, it was revealed that by increasing the draw ratio of elastane core, the fabric tensile strength and stretchability increase while the fabric tear strength and recovery after stretch decrease [12]. Kaynak investigated the effects of elastane draw ratio, load and relaxation type on stretch and recovery properties of woven bi-stretch fabrics. In this study, an optimization model was developed to determine the optimum elastane draw ratio, load applied to the fabric and relaxation type for the best stretch and permanent stretch [13]. Previous studies examined the effects of elastane draw ratio in the yarn on fabric performance properties. But there is still lack of information on this issue.
In this study, it is aimed to investigate the effects of elastane draw ratio, weft sett and weave type on air permeability of woven bi-stretch denim fabrics considering the air permeability as a thermal comfort property.

2. Material and Method

For this study, 29.5 Tex cotton combed ring spun yarn samples were produced with four different elastane draw ratios (3.07, 3.33, 3.63, 3.99). Linear density of elastane core is 7.8 Tex. Uster HVI test device was used to determine the cotton fiber properties used in this study. Cotton fiber properties are given in Table 1. In this study, the samples are called by elastane draw ratio. Uster Tester 5 and Uster Tensorapid 3 test devices were used to determine the yarn properties (Table 2).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micronaire, µg/inch</td>
<td>4.85</td>
</tr>
<tr>
<td>Length, mm</td>
<td>29.50</td>
</tr>
<tr>
<td>UI, %</td>
<td>84.5</td>
</tr>
<tr>
<td>SFI</td>
<td>7.9</td>
</tr>
<tr>
<td>Strength, cN/tex</td>
<td>33.6</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>8.0</td>
</tr>
<tr>
<td>SCI</td>
<td>152</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Samples (elastane draw ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.99</td>
</tr>
<tr>
<td>U, %</td>
<td>8.57</td>
</tr>
<tr>
<td>CVm, %</td>
<td>10.82</td>
</tr>
<tr>
<td>Thin places, -50%/km</td>
<td>0</td>
</tr>
<tr>
<td>Thick places, +50%/km</td>
<td>8.8</td>
</tr>
<tr>
<td>Neps, +200% / km</td>
<td>16.3</td>
</tr>
<tr>
<td>Hairiness</td>
<td>6.06</td>
</tr>
<tr>
<td>Tenacity, cN/tex</td>
<td>15.15</td>
</tr>
<tr>
<td>Breaking Elo.,%</td>
<td>8.3</td>
</tr>
</tbody>
</table>

The sample yarns were used as weft for producing the fabric samples. Three different weft sett (21, 25, 29 wefts/cm) and two different weave types (Twill 3/1 and Twill 2/2) were applied. In doing so, 24 denim fabric samples were obtained. Warp sheet was indigo dyed and composed of 37 Tex, dual core (PBT - Elastane) ring spun yarn. The fabric samples were conditioned according to TS EN ISO 139 (2008) [14] before the tests and the tests were performed in the standard atmosphere of 20±2°C and 65±4% relative humidity. The structural properties of fabric mass, fabric density and thickness were determined according to TS EN 12127 (1999), TS 250 EN 1049-2 (1996) and TS 7128 EN ISO 5048 (1998) [15-17], respectively (Table 3).

The air permeability of the samples was determined after dry relaxation. Air permeability of samples was determined according to TS 391 EN ISO 9237 (1999) with digital air permeability test device at 100 Pa pressure drop [18].
Table 3. Structural properties of fabric samples.

<table>
<thead>
<tr>
<th>Weft sett, wefts/cm</th>
<th>Elastane draw ratio</th>
<th>Twill 3/1</th>
<th></th>
<th>Twill 2/2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Thickness, mm</td>
<td>Fabric mass, g/m²</td>
<td>Thickness, mm</td>
<td>Fabric mass, g/m²</td>
</tr>
<tr>
<td>21</td>
<td>3.99</td>
<td>0.62</td>
<td>269</td>
<td>0.61</td>
<td>273</td>
</tr>
<tr>
<td></td>
<td>3.63</td>
<td>0.62</td>
<td>270</td>
<td>0.60</td>
<td>263</td>
</tr>
<tr>
<td></td>
<td>3.33</td>
<td>0.62</td>
<td>269</td>
<td>0.59</td>
<td>262</td>
</tr>
<tr>
<td></td>
<td>3.07</td>
<td>0.64</td>
<td>285</td>
<td>0.62</td>
<td>274</td>
</tr>
<tr>
<td>25</td>
<td>3.99</td>
<td>0.60</td>
<td>289</td>
<td>0.58</td>
<td>288</td>
</tr>
<tr>
<td></td>
<td>3.63</td>
<td>0.62</td>
<td>288</td>
<td>0.57</td>
<td>286</td>
</tr>
<tr>
<td></td>
<td>3.33</td>
<td>0.61</td>
<td>282</td>
<td>0.57</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>3.07</td>
<td>0.62</td>
<td>287</td>
<td>0.56</td>
<td>275</td>
</tr>
<tr>
<td>29</td>
<td>3.99</td>
<td>0.61</td>
<td>305</td>
<td>0.56</td>
<td>303</td>
</tr>
<tr>
<td></td>
<td>3.63</td>
<td>0.60</td>
<td>302</td>
<td>0.55</td>
<td>297</td>
</tr>
<tr>
<td></td>
<td>3.33</td>
<td>0.62</td>
<td>306</td>
<td>0.53</td>
<td>293</td>
</tr>
<tr>
<td></td>
<td>3.07</td>
<td>0.61</td>
<td>301</td>
<td>0.54</td>
<td>292</td>
</tr>
</tbody>
</table>

3. Result and Discussion

Air permeability results of the 3/1 Twill and 2/1 Twill fabric samples at different weft setts are given in Figure 1 and 2 respectively. From Figure 1 and 2, it can be clearly seen that the air permeability of the samples decrease as the weft sett of the samples is increased. This situation can be attributed to the fact that when the weft sett of the fabric is increased, the pores between the warp and weft yarns get smaller. Since less open area is provided for air passage through fabric structure, the air flux will be exposed more drug resistance during the passage.

For each weft sett of 3/1 twill fabric, there are changes in air permeability performance with respect to the draw ratio changes (Figure 1). The highest performance values are obtained with 3.63, 3.07 and 3.07 draw ratios for 21, 25 and 29 wefts/cm setts respectively.

Figure 1. Air permeability results of 3/1 twill fabric samples

According to the results given in Figure 2, it can be said that the draw ratio has a diminishing effect on the air permeability performance of the 2/2 twill fabric samples. It can be observed that there is a tendency of decrease in air permeability values for all weft sett values of 2/2 twill fabrics in proportion to the increase of the elastane core draw ratio (Figure 2). The highest air permeability values are
obtained with 3.07 elastane draw ratio for all weft sett values of 2/2 twill fabrics. The lowest air permeability performances are obtained with 3.99, 3.63 and 3.99 draw ratios for 21, 25 and 29 wefts/cm setts of 2/2 twill samples respectively (Figure 2).

Figure 2. Air permeability results of 2/2 twill fabric samples

The air permeability performance of the fabric samples are compared with respect to their weave patterns in Figure 3. For 21 wefts/cm thread density, higher air permeability performance is obtained with 2/2 twill pattern than 3/1 twill pattern for each elastane draw ratio. The air permeability results of the 2/2 twill and 3/1 twill weave samples with 25 and 29 wefts/cm thread densities are close to each other for each elastane draw ratio. When the draw ratios of 3.07 and 3.33 are investigated for 25 wefts/cm sett, it can be said that air permeability performance of the samples with 2/2 twill pattern are higher than that of 3/1 twill samples. For both 25 and 29 weft/cm setts, the higher air permeability performance are obtained with 3/1 twill pattern at 3.63 and 3.99 elastane draw ratios than that of 2/2 twill weave samples at these draw ratios.

Figure 3. Air permeability results of 3/1 and 2/2 twill fabric samples
Analysis of variance (ANOVA) was performed to determine the statistical significance of the effects of elastane draw ratio, weft sett and weave type on fabric air permeability. For this aim the statistical software package SPSS 21.0 was used to interpret the experimental data. All test results were assessed in 95% confidence interval.

Table 4. ANOVA for air permeability.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>20878.486a</td>
<td>23</td>
<td>907.760</td>
<td>255.783</td>
<td>0.000</td>
<td>0.965</td>
</tr>
<tr>
<td>Intercept</td>
<td>201828.400</td>
<td>1</td>
<td>201828.4</td>
<td>56869.8</td>
<td>0.000</td>
<td>0.996</td>
</tr>
<tr>
<td>Weftsett</td>
<td>20118.941</td>
<td>2</td>
<td>10059.47</td>
<td>2834.48</td>
<td>0.000</td>
<td>0.963</td>
</tr>
<tr>
<td>Drawratio</td>
<td>138.559</td>
<td>3</td>
<td>46.186</td>
<td>13.014</td>
<td>0.000</td>
<td>0.153</td>
</tr>
<tr>
<td>Weavetype</td>
<td>162.362</td>
<td>1</td>
<td>162.362</td>
<td>45.749</td>
<td>0.000</td>
<td>0.175</td>
</tr>
<tr>
<td>Weftsett * Drawratio</td>
<td>49.502</td>
<td>6</td>
<td>8.250</td>
<td>2.325</td>
<td>0.034</td>
<td>0.061</td>
</tr>
<tr>
<td>Weftsett * Drawratio * Weavetype</td>
<td>312.681</td>
<td>2</td>
<td>156.341</td>
<td>44.053</td>
<td>0.000</td>
<td>0.290</td>
</tr>
<tr>
<td>Weavetype</td>
<td>74.150</td>
<td>3</td>
<td>24.717</td>
<td>6.964</td>
<td>0.000</td>
<td>0.088</td>
</tr>
<tr>
<td>Weavetype</td>
<td>22.291</td>
<td>6</td>
<td>3.715</td>
<td>1.047</td>
<td>0.396</td>
<td>0.028</td>
</tr>
<tr>
<td>Error</td>
<td>766.574</td>
<td>21</td>
<td>3.549</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>223473.460</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>21645.060</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* R Squared = 0.965 (Adjusted R Squared = 0.961)

According to ANOVA results, weft sett, weave type and elastane draw ratio has statistically significant effects on air permeability (p=0.000<0.05). In addition, according to multiple comparison test results for weft sett, each weft sett value (21, 25, 29 wefts/cm) has statistically different effects on air permeability, in 95% confidence interval. On the other hand, elastane draw ratios of 3.33, 3.63 and 3.93 have statistically similar effect on air permeability, whereas 3.07 elastane draw ratio has statistically different effect on air permeability than other values (3.33, 3.63, 3.93). The 3.07 elastane draw ratio has an increasing effect on air permeability.

4. Conclusion
In this study, the effects of elastane draw ratio, weft sett and weave type on air permeability of bi-stretch denim fabrics are investigated.

In accordance with the statistical analysis results, the draw ratio, weft sett and weave pattern parameters have got significant effect on air permeability performance of the denim fabric samples. Since the higher thread density lead to less open spaces for air flux, the increase in weft sett has a decreasing effect on all samples.
For 25 wefts/sett of 3/1 twill fabric, closer air permeability results were obtained for all draw ratios. The air permeability performance of 3/1 twill fabric samples changes with respect to the draw ratio changes. The increase of the elastane draw ratio has a decreasing effect on the air permeability performance of the 2/2 twill fabric samples.

In order to investigate the effect of weave pattern on the air permeability performance of fabric samples with different elastane draw ratios, the test results are compared with regard to the pattern type. It is concluded that for all elastane draw ratios, there are significant differences between air permeability performance of 2/1 twill and 3/1 twill fabrics. For all draw ratios, the highest differences between the performances of two patterns were obtained for 21 wefts/cm sett.

Acknowledgement
The authors are grateful to Kara Holding Textile Mills for production of yarn samples and Çalık Denim for production of fabric samples.

References
[15] TS EN 12127:1999 Textiles- Fabrics- Determination of mass per unit area using small samples
[16] TS 250 EN 1049-2:1996 Textiles-Woven Fabrics-Construction-Methods of Analysis-Part 2 Determination of Number of Threads Per Unit Length
[18] TS 391 EN ISO 9237:1999 Textiles-Determination of permeability of fabrics to air
Application of wool reactive dyes for hair coloration

D Chae and J Koh

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Abstract In this study, the low temperature dyeing properties of wool reactive dyes were investigated for the feasibility study of hair coloration using wool-reactive dyes. The low temperature (30°C, 40°C) wool reactive dyeing properties were compared to the conventional temperature (80°C) wool reactive dyeing and their dyeing properties were compared with those at high temperature. The experiment results showed that the application of low temperature wool reactive dyeing to hair coloration is sufficiently feasible in terms of dyeability and shampooing fastness.

1. Introduction
The reactive dyes are unique among other dyes in that they are covalently bonded to the substrate (Figure 1), that is, the dye and fiber substrate form a bond of shared electrons. The energy required to split this bond is of the same order as that required to split carbon-carbon bonds in the substrate itself—hence the high degree of wet fastness observed with these dyes.
In this study, the low temperature dyeing properties of wool reactive dyes were investigated for the feasibility study of hair coloration using wool-reactive dyes.

Figure 1. Chemical structure of reactive dyed wool

2. Experimental

2.1. Material

Figure 2. Wool reactive dyes used in present study (a) CI Reactive Yellow 39 (b) CI Reactive Red 84 (c) CI Reactive Blue 69
Scoured twill woven wool fabrics were used for the low temperature reactive dyeings. The wool reactive dyes (Figure 2, CI Reactive Yellow 39, CI Reactive Red 84 and CI Reactive Blue 69) and leveling agent (Albegal B) were supplied by Huntsman. Sodium sulfate, ethyl lactate and the other chemicals were all reagent grade.

2.2. Dyeing
A 40 ml dyebath, suitable for a 2.0 g sample of wool fabric, containing dyes (2.0% owf), levelling agent (1.0% owf), sodium sulfate (10% owf) and acid donors (ethyl lactate 0.2% v/v) for pH control was prepared. Dyeing was performed for 5 min at 30, 40 and 80 °C in an laboratory dyeing machine (DLS-6000, Daelim Starlet Co. Ltd). The color strength ($f_k$) and CIELAB values of the dyed fabrics were measured using a spectrophotometer interfaced with a personal computer. To evaluate the color fastness of the wool reactive dyeings, shampoo fastness test was carried out for 5 min at 40°C.

2.3. Evaluation of leveling properties
24 spots of the dyed wool were measured with a spectrophotometer, and the levelness parameter ($L$) was determined using the given equation as follows;

$$L = 1.2 \times (2.0 - \ln U), \quad (U \geq 0.3114)$$
$$L = 5.0 - 1.2 \times \exp(7/6) \times U, \quad (U < 0.3114)$$

where

$$U = \sum S_r(\lambda) \times V(\lambda)$$

$s_r(\lambda)$ = Relative sample standard deviation of $(K/S)_\lambda$
$V(\lambda)$ = Spectral luminous function

2.4. Shampoo fastness test
In order to evaluate the color fastness of the wool reactive dyeings, shampoo fastness test was carried out for 5 min at 40°C. After 5 times shampooing, color loss (reduction in color strength, $f_k$) during shampooing was determined as follows;

$$\text{Color loss(\%)} = 100 \times \frac{f_{k,0} - f_{k,5}}{f_{k,0}}$$

where $f_{k,0} = f_k$ before shampooing
$f_{k,5} = f_k$ after 5th shampooing

3. Results and discussion

![Figure 3. Color strength ($f_k$) of wool reactive dyeing at various temperatures](image-url)
Figure 3 shows the dyeability of wool reactive dyeings at various dyeing temperatures. The color strength ($f_k$) of the low temperature (40°C) dyeing exhibited around 15~20 while that of the conventional high temperature (80°C) dyeing was 70-155. The addition of leveling agent improved the dyeability of the wool-reactive dyeing at each dyeing temperature, which is ascribed to the amphoteric characteristics of the leveling agent (Figure 4). The amphoteric group overcome the tippy dyeing properties of wool by forming dye-surfactant complexes which at lower temperatures probably exhaust more evenly and extensively onto the surface of the wool fiber than does the dye alone. As the dyebath temperature is raised the dye-surfactant complex breaks down, allowing the dye to penetrate and react with the fiber.

![Figure 4. Leveling agent (Albegal B) effect on the dyeability of wool reactive dyeing, from left to right, yellow, red and blue](image)

However, as shown in Table 1, no significant differences in the levelness of the dyed samples in our laboratory scale dyeing were detected. The levelness achieved was in the range of 4.2-4.9.

<table>
<thead>
<tr>
<th>Dye</th>
<th>Temperature</th>
<th>With Albegal B</th>
<th>Without Albegal B</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI Reactive Yellow 39</td>
<td>80°C</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>40°C</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>30°C</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>CI Reactive Red 84</td>
<td>80°C</td>
<td>4.6</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>40°C</td>
<td>4.7</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>30°C</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>CI Reactive Blue 69</td>
<td>80°C</td>
<td>4.3</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>40°C</td>
<td>4.5</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>30°C</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Figure 5 shows gradual decrease in color strength with increase in number of shampooing. In yellow, 15.38% of color loss showed after 5th shampooing, at 30°C wool dyeing. At 40°C wool dyeing, yellow color strength decreased 9.56% after 5th shampooing. About red, 22.17% of color loss at 30°C wool dyeing, and 19.61% loss at 40°C wool dyeing. Blue showed 18.85% loss at 30°C wool dyeing, and 17.03% loss at 40°C wool dyeing.
Figure 5. Color loss during repeated shampooings of reactive dyed wool (a) Yellow (b) Red (c) Blue

**Conclusion**

In this study, the low temperature dyeing properties of wool reactive dyes were investigated for their application to hair coloration. 14.2–20.5% color strength of high temperature (80°C) dyeing was achieved by low temperature reactive dyeings at 40°C. Color loss (%) during repeated shampooings up to 5 was in the range of 9.56–22.14%. The overall experiment results showed that the application of low temperature wool reactive dyeing to hair coloration sufficiently feasible, even though further studies on the application of wool reactive dyes on human hair dyeing are necessary before any definite conclusions can be drawn.

**References**

Ozone Bleaching of Cellulose

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Abstract
In this study, ozone treatment has been investigated in seeking of a more environmentally friendly alternative process for bleaching of cellulosic fibers. The primary advantage of ozone treatment is reduced environmental impact especially in case of chemical oxygen demand (COD) values of the process effluent. The highly oxidative ozone gas substitutes conventional harsh chemicals and decomposes back to oxygen owing to its limited half-life. Hence, ozone treatment seems as a good alternative for oxidative bleaching purposes of cellulose.

1. Introduction
Untreated cotton has a natural yellow-brown color. This natural yellow-brown color of cotton is related to the pigments of the cotton flower. This natural yellow-brown color of cotton is preferably removed before dyeing especially at light shades, because it changes the final color of the dyed textile material if not removed [1-3].

The removal process for the natural yellow-brown color of cotton is the bleaching process. Bleaching is a very common process for textile finishing, especially for cellulose, and hydrogen peroxide is the most widely used bleaching agent. Hydrogen peroxide bleaching of cellulose is carried out at elevated temperatures, usually at the boil. Conventional cellulose bleaching process by hydrogen peroxide includes the use of hydrogen peroxide along with an activator which is usually caustic soda (NaOH), a stabilizer which is usually silicates or organic ones and a wetting agent [1-5].

The use of various chemicals in a process pollutes water with chemical components left in the effluent. Therefore, research has been made to achieve more environmentally friendly preparation processes using enzymes or other bleaching agents such as ozone [1, 6-9].

Research on the bleaching effect of ozone on cotton has been performed considering the high redox potential of ozone. The redox potential of ozone is 2.07eV and the redox potential of conventional bleaching agent hydrogen peroxide is 1.77 V. Ozone gas was produced in ozone generators and cotton was treated by this ozone. Promising results were reported by ozone treatment [1, 9-11].

2. Bleaching of Cotton by Ozone
Prabaharan and Rao [10] studied the ozone bleaching of cotton fabrics on a commercial quality grey cotton fabric with starch size on it. They adjusted several wet pickup rates and placed the samples in a reactor in which ozone gas was fed. They reported that treatments were conducted at room temperature with 100g/m3 ozone concentration for 5, 10 and 15 min. They reported that wet pickup rates effected the final whiteness values after ozone treatments and a peak was observed at 24% wet pickup rate. The whiteness index values increased up to 90 at 24% wet pickup rate for 15 min
treatment. The authors explained this phenomenon as: whiteness increased by the hydration of hydroxyl group but then decreased by excess water above 24% which probably fills intermisellar spaces to retard ozone.

Eren and Ozturk [9] studied bleaching of cotton by ozone treatment in water. They used 5.7 mg/min ozone to treat the greige cotton fabrics in water at a liquor to goods ratio of 20:1 at room temperature. They reported that the whiteness degrees achieved after 60 and 90 min ozone treatments were comparable to the whiteness degrees of the conventional peroxide bleached samples for the pre-scoured samples (Figure 1).

Figure 1. Whiteness of the scoured samples after peroxide and ozone bleaching treatments [9].

3. Bleaching of Cotton by Ozone and Ultrasound

Eren et al. [1] also tested the bleaching effect of ozone on cotton by ultrasonic support. The whiteness (Stensby) results achieved by ultrasonic support are presented on Figure 2. Ozone bleaching yielded very successful results in 30 min time under ultrasonic support. These whiteness values were accompanied by substantial reductions in the COD load of the process effluent in case of ozone treatment [1].

Figure 2. Effect of the ozonation and ultrasonic homogenizer (Ozonation+UH) combination on the whiteness of cotton fabrics (The temperature of the Ozonation + UH bleaching bath solution increase to 45,60 and 70 °C after 10, 20 and 30 min. of application respectively and 30 min. Ozonation+ UH*
processing was stabilized at 30 °C through the process by cooling for comparison. Peroxide bleaching was carried out at 90°C for 60 min.) [1]

4. Result
The results of few studies on ozone bleaching of cotton has been summarised. Researchers reported that considerable whiteness degrees could be achieved by ozone treatment without severe damage to fabric. Consequently, ozone treatment can be considered as a more environmentally friendly alternative for bleaching of cotton.

References
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Decolorisation of Disperse Dark Blue 148 with Ozone

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Abstract
The aim of this study is decolorisation of CI Disperse Dark Blue 148 dye by ozone treatment which is one of the most attractive alternatives for solving the problem of color in textile dyeing effluents. A venturi injection system added dyeing chamber for getting ozone from the ozone generator. And additive (acetic acid and dispersing agent) put in the dyeing. After the coloration, the experimental color, chemical oxygen demand (COD), pH, temperature (°C) and conductivity (µS/cm) were measured. The results encourage the use of the system for decolorisation trials as well as dyebath effluent recycling.

1. Introduction
Dyes and pigments have been used for coloring in the textile industry for many years [1,2]. Disperse dyes are the most important dyes also used in dyeing PET fibers.[3] The wastewater from textile dyeing typically contains high concentrations of colorants, effective decolorization methods are urgently required [2]. Wastewater discharge is extremely variable in composition, exhibiting strong colour, fluctuating pH, and significant COD loads [4]. Many techniques able to remove colour are listed in the literature, such as coagulation-flocculation, adsorption and membrane filtration, have been used to decolorize textile effluents, these techniques suffer disadvantages of sludge generation, adsorbent regeneration and membrane fouling. Oxidation is one of the potential alternatives to decolorize and to reduce recalcitrant wastewater loads from textile dyeing and finishing effluents[3-5] Because of O₃ is an unstable molecule and rapidly decomposes to O₂ that is capable of participating in many chemical reaction with inorganic and organic substances [3-7]

2. Materials and Method
In this study, CI Disperse Dark Blue 148 disperse dye was used at 0.1 g/l. The molecular structure of dye as shown Figure 1. The dye solutions were prepared either by using dye alone or by using dye and additives together. The dyeing additives were 1 ml/l acetic acid and 1 ml/l dispersing agent.
A Prodozon PRO DO25 model ozone generator (Ankara, Turkey) with a maximum ozone generation capacity of 25 g/h was used during the experiments. Ozone gas flow rate was adjusted to 5 g/h ozone was fed through a venture injector placed on the liquor circulation pipe of a Atac BB01F sample dyeing machine (Atac Co., Istanbul, Turkey). All connections were made by teflon tubing lines. The total amount of the treated liquor was 10 liters. The treatment time was extended to 20 min by 2.5 min steps. The ozone integrated system is given on Figure 2.

Table 1. pH and Temperature (°C) and conductivity (μS/cm) Color (Absorbance at 622 nm) and COD (mg/l) values of ozone applied samples for 0.1 g/l dyestuff solution.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>pH</th>
<th>Conductivity (μS/cm)</th>
<th>Absorbance (622 nm)</th>
<th>COD (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated dyestuff solution</td>
<td>11.2</td>
<td>7.4</td>
<td>106.1</td>
<td>0.770</td>
</tr>
<tr>
<td>2.5 min. ozone</td>
<td>13.1</td>
<td>6.6</td>
<td>149.6</td>
<td>0.575</td>
</tr>
<tr>
<td>5 min. ozone</td>
<td>13.7</td>
<td>6.1</td>
<td>150.7</td>
<td>0.461</td>
</tr>
<tr>
<td>7.5 min. ozone</td>
<td>14.5</td>
<td>5.6</td>
<td>153.2</td>
<td>0.280</td>
</tr>
<tr>
<td>10 min. ozone</td>
<td>15.2</td>
<td>5.3</td>
<td>156.9</td>
<td>0.079</td>
</tr>
<tr>
<td>12.5 min. ozone</td>
<td>16.1</td>
<td>4.8</td>
<td>159</td>
<td>0.027</td>
</tr>
<tr>
<td>Time (min.)</td>
<td>Temperature (°C)</td>
<td>pH</td>
<td>Conductivity (µS/cm)</td>
<td>Absorbance (622 nm)</td>
</tr>
<tr>
<td>------------</td>
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<td>----------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Untreated dyestuff solution</td>
<td>12.7</td>
<td>3.8</td>
<td>207</td>
<td>0.633</td>
</tr>
<tr>
<td>2.5 min. ozone</td>
<td>13.6</td>
<td>3.7</td>
<td>214</td>
<td>0.465</td>
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<tr>
<td>5 min. ozone</td>
<td>14.1</td>
<td>3.7</td>
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<td>7.5 min. ozone</td>
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<td>3.6</td>
<td>220</td>
<td>0.216</td>
</tr>
<tr>
<td>10 min. ozone</td>
<td>15.4</td>
<td>3.6</td>
<td>222</td>
<td>0.123</td>
</tr>
<tr>
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<td>15.8</td>
<td>3.6</td>
<td>230</td>
<td>0.054</td>
</tr>
<tr>
<td>15 min. ozone</td>
<td>16.3</td>
<td>3.6</td>
<td>230</td>
<td>0.034</td>
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<td>16.8</td>
<td>3.6</td>
<td>230</td>
<td>0.021</td>
</tr>
<tr>
<td>20 min. ozone</td>
<td>17.1</td>
<td>3.6</td>
<td>230</td>
<td>0.010</td>
</tr>
</tbody>
</table>

**Table 2.** pH and Temperature (°C) and conductivity (µS/cm) Color (Absorbance at 622 nm) and COD (mg/l) values of ozone applied samples for dyestuff solution with additives.

Figure 3. Color change during ozone treatment for a. 0.1 g/l dye solution b. dye and additives together (1- Control (Untreated dyestuff solution). 2- 2.5 min. ozone. 3- 5 min. ozone. 4- 7.5 min. ozone. 5-10 min. ozone. 6- 12.5 min. ozone. 7- 15 min. ozone. 8- 17.5 min. ozone 20s ozone 9- 20 min. ozone)

Figure 4 shows the absorbance values. Both solutions of 0.1 g/l disperse dye with and without additives (acetic acid and dispersing agent) yielded similar decolorisation rates after 15 min treatment. However, decolorisation rate was a little higher for the dye solution without additives.
Figure 4. Color change during ozone treatment for 0.1 g/l dye solution with and without additives (1- Control (Untreated dyestuff solution). 2- 2.5 min. ozone . 3- 5 min. ozone . 4- 7.5 min. ozone. 5-10 min. ozone . 6- 12.5 min. ozone. 7- 15 min. ozone. 8- 17.5 min. ozone 20s ozone 9- 20 min. ozone)

Figure 5 shows the COD values. The solutions of 0.1 g/l disperse dye with and without additives (acetic acid and dispersing agent) made a quite difference COD value all the ozone treatment time. It is originated from the using additives (acetic acid and dispersing agent) with dyeing. As it is known using chemical makes the solution worse about the COD values.

Figure 5. COD (mg/l) during ozone treatment for 0.1 g/l dye solution with and without additives (1- Control (Untreated dyestuff solution). 2- 2.5 min. ozone . 3- 5 min. ozone . 4- 7.5 min. ozone. 5-10 min. ozone . 6- 12.5 min. ozone. 7- 15 min. ozone. 8- 17.5 min. ozone 20s ozone 9- 20 min. ozone)

4. Conclusion
This pilot-scale study investigated a venturi injection system added the dyeing chamber for getting ozone from the ozone generator. This system to the decolorisation of disperse dark blue 148 was achieved successfully either in presence of dyeing additives or not. The rapid decolorisation effect of
ozone is reported before in the literature mostly by using a diffuser to feed ozone into the reaction chamber [8-10]. However, in this study, trials were performed on ozone feeding integrated sample dyeing machine. Hence a venturi injection system was equipped rather than diffusers. The results encourage the use of the system for decolorisation trials as well as dyebath effluent recycling.

References
Supercritical Carbon Dioxide for Textile Applications and Recent Developments

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Abstract

In textile industry, supercritical carbon dioxide (scCO₂), possessing liquid-like densities, mostly find an application on textile dyeing processes such as providing hydrophobic dyes an advantage on dissolving. Their gas-like low viscosities and diffusion properties can result in shorter dyeing periods in comparison with the conventional water dyeing process. Supercritical carbon dioxide dyeing is an anhydrous dyeing and this process comprises the usage of less energy and chemicals when compared to conventional water dyeing processes leading to a potential of up to 50% lower operation costs. The advantages of supercritical carbon dioxide dyeing method especially on synthetic fiber fabrics hearten leading textile companies to alter their dyeing method to this privileged waterless dyeing technology. Supercritical carbon dioxide (scCO₂) waterless dyeing is widely known and applied green method for sustainable and eco-friendly textile industry. However, not only the dyeing but also scouring, desizing and different finishing applications take the advantage of supercritical carbon dioxide (scCO₂). In this review, not only the principle, advantages and disadvantages of dyeing in supercritical carbon dioxide but also recent developments of scCO₂ usage in different textile processing steps such as scouring, desizing and finishing are explained and commercial developments are stated and summed up.

1. Introduction

Approximately 60% of the humankind cannot reach clean water resources and moreover changing climate and environmental conditions may result in harsh droughts in the future leading to more water scarcity for more people; therefore, water sustainability is very critical for world sustainability. Roughly 100-150 litres clean water is required to process 1 kg of textile materials and scCO₂ treatment possess great opportunities for water savings in textile finishing processes [1, 2].

2. Apparatus for Supercritical Carbon Dioxide Treatment of Textiles

A commercially available supercritical carbon dioxide beam dyeing machine with a capacity of 100 to 200 kg of fabric, as fabric roll, per batch in an open width of 60 or 80 inches was produced by DyeCoo Textile Systems BV and FeyeCon Co., Ltd. for Yeh Group of Thailand in 2010 [3].
Recently, for the first time, novel water-free fabric rope fabric dyeing machine in supercritical carbon dioxide fluid media was effectively designed, produced and built in a pilot scale plant (Figure 1) [3]. The results of the novel rope dyeing in supercritical carbon dioxide media were satisfactory and commercially acceptable with good wet-wash and rub color fastness levels (4 to 5 gray scale ratings) and color uniformity [2].

(43) fluid inlet; (44) drive reel; (45) fabric rope along with a special guide tape; (46) tooth-locked quick open-closure hatch; (47) grid baffle; (48) fabric container; (49) grid tray; (50) fluid outlet; (51) electrically aided heating jacket. [2]
3. Apparatus for Supercritical Carbon Dioxide Treatment of Textiles

Supercritical carbon dioxide (scCO2) waterless dyeing is widely known and applied green method for sustainable and eco-friendly textile industry. However, recently, not only dyeing but also pretreatment processes such as scouring, desizing and different finishing applications take the advantage of Supercritical carbon dioxide (scCO2) leading to enormous fresh water saving, cleaner and greener way of production and massive amount of contribution for world sustainability.

One of these usage applications of supercritical carbon dioxide (scCO2) is in surface modification of polyester fabrics as a pretreatment. In their study, glycerol polyglycidyl ether was impregnated as a cross-linking agent into polyester fabric through supercritical carbon dioxide, afterwards, immobilization operations were performed, containing pad-dry cure application and the solution process to finish the glycerol polyglycidyl ether-polyester fabric via natural functional agents such as sericin, collagen, or chitosan. It is reported that glycerol polyglycidyl ether can penetrate to the surface of polyester fabric in supercritical carbon dioxide pretreatment process. Moreover, used natural functional agents (sericin, collagen, or chitosan) can similarly be immobilized on the surface of this fabric (glycerol polyglycidyl ether-polyester fabric) particularly for the process of pad-dry-cure. The modified polyester fabric exhibited progression in surface hydrophilicity and wettability, moisturisation efficiency, and antibacterial activities [5].

C. Wang et Al. [6] studied the scouring possibility of polyester fibers by utilizing scCO2 as a medium, the oil removal efficiency from polyester fibers reached to +99%. It is stated that successful scouring was carried out for polyester fibers in supercritical carbon dioxide media.

Supercritical carbon dioxide has recently found different application types also in textile finishing. For instance, A.L.Mohamed et. Al. [5] studied supercritical carbon dioxide assisted silicon based finishing on cotton fabric. In here, researchers used supercritical carbon dioxide as a medium for finishing cotton fabrics with modified dimethylsiloxane polymers terminated with silanol groups. 3-isocyanatepropyltriethoxysilane and tetraethylorthosilicate were utilized as cross-linkers for covalent bonding formation between silicon and cellulose polymers of cotton fiber. It is reported that all cotton fibers applied with silicon (PDMS) and 3-isocyanatepropyltriethoxysilane possess larger silicon amounts than those applied with tetraethylorthosilicate. Supercritical carbon dioxide medium procures nice cotton surface coating via a 3D network of DMS compound and cross linker leading to the highest DMS concentration formation in a layer between 1 and 2 micron under the cotton fiber surface [5].

In the case of antimicrobial finishing attainment, T. Baba et. al. [7] impregnated chitin and chitosan to polyester (PET) fabric using supercritical carbon dioxide in order to achieve high anti-bacteria property durable to washing. Chitosan-lactic acid salt was effectively applied to polyester fabric using supercritical carbon dioxide media. On the other hand, chitin could not be impregnated successfully. Even after 50 home washing cycles, 70% of the chitosan still stayed on polyester fabrics and therefore polyester fabric still continues to exhibit anti-microbial properties. It is known that it is very difficult to impregnate chitosan to polyester fabric permanently in an aqueous system. However in here, it is important to state that chitosan could be fixed by impregnation onto polyester fabric strongly through the medium of supercritical carbon dioxide [7].

4. Result

Waterless dyeing exhibits environmental benefits for sustainable world. Similarly waterless scouring, desizing and finishing bring about the same advantages for sustainable textile pre-treatment and finishing leading to more sustainable future.
Acknowledgement

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References


Fatigue behaviour of core-spun yarns containing filament by means of cyclic dynamic loading

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Abstract. The behaviour of yarns under dynamic loading is important that leads to understand the growth characteristics which is exposed to repetitive loadings during usage of fabric made from these yarns. Fabric growth is undesirable property that originated from low resilience characteristics of fabric. In this study, the effects of the filament fineness and yarn linear density on fatigue behaviour of rigid-core spun yarns were determined. Cotton covered yarns containing different filament fineness of polyester (PET) draw textured yarns (DTY) (100d/36f, 100d/96f, 100d/144f, 100d/192f and 100d/333f) and yarn linear densities (37 tex, 30 tex, 25 tex and 21 tex) were manufactured by using a modified ring spinning system at the same spinning parameters. Repetitive loads were applied for 25 cycles at levels between 0.1 and 3 N. Dynamic modulus and dynamic strain of yarn samples were analyzed statistically. Results showed that filament fineness and yarn linear density have significance effect on dynamic modulus and dynamic strain after cyclic loading.

1. Introduction

The fabrics are always under the influence of repetitive loads, especially from the motions of the knee and elbows. As a result of these repetitive forces, deformation such as bagging occurs. In this respect, fatigue behaviour of yarns that makes up the fabric is most important according to their usage areas. There are various studies on determine fatigue behaviour of yarn [1-4]. Shahbeh et al. investigate the effect of spinning parameters (core and sheath part, twist factor, pre-tension of core part) of core spun yarns and number of cyclic loads such as 100, 500 and 1000 on yarn tensile properties after cyclic loadings. They produced core spun yarns with nylon and polyester core, separately, covered with polyester/cotton, polyester and viscose sheath fibers. They stated that Taguchi method of variance analysis showed that twist factor, pre-tension on core part, number of cyclic loads and sheath materials had found to be significant except core material on the breaking strength of core-spun yarns after tensile fatigue cyclic loading [3]. Eldessouki et al. compared on physical properties of the 20 tex 100% viscose vortex yarns under dynamic loading produced on different spinning systems developed by Rierer and Murata companies. Besides, they produced 20 tex 100% viscose different yarn samples by rotor spinning system. Yarn samples were loaded for 40 cycles at levels between 0.2 and 1 N, followed by a continuous extension until the yarn breakage. And also sonic modulus of yarns were measured the velocity of the sonic pulses in the yarns at 5 kHz. Young’s modulus, maximum force, maximum
elongation, work of rupture and sonic modulus of different yarns were evaluated. It was resulted that spinning technology had no significant difference in terms of initial modulus and maximum elongation of yarns. On the other hand, a significant difference between the technologies was observed in the maximum loading and the work of rupture [2]. Dubinskaite and Milasius studied on the dynamic properties of the PA 6 and PA 6.6 carpet yarns after 10 cyclic loads. Dynamic strain, quasistatic elongation and dynamic modulus of yarns were calculated from the response of the test results at each cyclic load. It was stated that dynamic strain and quasistatic elongation of PA 6.6 is higher than PA 6. In addition dynamic modulus of PA6 yarns were found to be higher that is PA6 yarns as stronger and stiffer can be used for carpets exposed to highly traffic wear.

This study represents the fatigue behaviour of rigid core-spun yarn structure containing PET draw textured filament yarn (PET DTY) with respect to different filament fineness and yarn linear densities. For this purpose, rigid core-spun yarns were manufactured on a modified ring spinning machine at the same spinning conditions and tenacity of these yarns were conducted after determined number of cyclic loading on CRE (constant rate of extension) tensile tester. Statistical analysis was carried out to determine the significance of independent variables on response variable as well as fatigue behaviour of yarn under repeated cyclic loading.

2. Material and Method

In this study, PET DTY filaments with five different types of fineness (100d/36f, 100d/96f, 100d/144f, 100d/192f and 100d/333f) were selected among the most used commercial form of conventional microfilaments. These filaments were used as core part of combed cotton covered rigid core-spun yarns with four different yarns linear densities (37 tex, 30 tex, 25 tex and 21 tex). Cotton fibre with 30 mm length, 4.5 micronaire and 34 g/tex strength was used as sheath fiber. In this respect, yarn samples were manufactured on a modified ring spinning system which is illustrated in figure 1 and all spinning parameters were kept constant like as; 8000 rev/min spindle speed, 3.9 twist factor ($\alpha_c$) and 984 tex combed cotton roving linear density.

![Figure 1. Modified ring spinning system and core-spun yarn view (It may not be reproduced without permission) [5].](image-url)
When the analyses of dynamic properties of yarns are taken into consideration, moduli of yarns have critical importance to determine fatigue behaviour by applying repeated loads on yarns. Modulus is generally expressed as the relationship between the force applied and the resultant elongation. Dynamic modulus can be calculated with the equation (1) which is given below and shows information about fiber stiffness and resilience. We can say that the higher the dynamic modulus the stiffer the fiber, on the other hand the lower the dynamic modulus the more flexible the fiber [6].

\[ E_d = \frac{F_{u} - F_{l}}{(\varepsilon_{u} - \varepsilon_{l})T_f} \]  

(1)

where:
- \( F_{u} \): upper level of force in cN of cyclic loading,
- \( F_{l} \): lower level of force in cN of cyclic loading,
- \( \varepsilon_{u} \): elongation at upper level of force of cyclic loading,
- \( \varepsilon_{l} \): elongation at lower level of force of cyclic loading,
- \( T_f \): linear density of yarn in tex [6].

Dynamic strain which is fatigue behaviour of yarn that is defined as the percentage elongation under the loads in each cycle and equation can be expressed as equation (2).

\[ \varepsilon_d = \frac{\varepsilon_{u} + \varepsilon_{l}}{2} \]  

(2)

where:
- \( \varepsilon_{u} \): elongation at upper level of force of cyclic loading,
- \( \varepsilon_{l} \): elongation at lower level of force of cyclic loading [6].

To determine the dynamic modulus and strain of yarn samples, fatigue test was performed on Instron 5944 tensile test device applying cyclic loading and unloading on the yarn. Gauge length and speed of testing were set to 250 mm, 250 mm/min, respectively, like in accordance with BS EN ISO 2062:2009-Textiles-Yarns from packages-Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester. In order to achieve fatigue test, yarn samples were loaded for 25 cycles at levels between 0.1 and 3 N. Maximum force level was identified as 50% percent of yarn tenacity by applying force within the region of yarn's yield point. After cyclic loading completed, test continued with continuous extension until the yarn break. Dynamic modulus of yarn samples was determined for 25th cycles in order to analyze the final situation, so that upper and lower levels of force and corresponding elongations of 25th cycles were used. In addition, dynamic strain was also calculated for 25th cycles i.e. after the final cyclic loading.

Before carrying out fatigue test, the specimens were conditioned in a standard atmosphere at 20±2°C temperature and 65±4% relative humidity for 24 hours according to the standard of BS EN ISO 139:2005+A1:2011-Textiles-Standard atmospheres for conditioning and testing. To compare the significance difference between dynamic modulus and dynamic strain of yarn samples statistically, analysis of variance was performed by using SPSS package program.

3. Result and Discussion

Figure 2 illustrates dynamic modulus of rigid core-spun yarn samples with different filament fineness and yarn linear density by using equation (1) to determine after 25th cycles of loading.
As seen in figure 2, dynamic moduli of rigid core-spun yarns with PET DTY filaments with different filament fineness as core part change from higher to lower values of yarn linear densities. The dynamic modulus values are higher at coarser yarn and it can be said that the coarser yarns are stiffer than finer ones. In general, dynamic modulus of yarn decreases from coarser to finer yarn. As the yarn is finer makes probably yarn more resilient in terms of increasing PET PDY filament percentage in the cross section. Dynamic strain of rigid core-spun yarn samples are also shown in figure 3.

![Figure 2. Dynamic modulus of rigid core-spun yarns.](image)

![Figure 3. Dynamic strain of rigid core-spun yarns.](image)

It is seen in figure 3 that the dynamic range increases with the increase of the PET DTY filament ratio from 37 tex to 21 tex yarn linear density. In addition, the increase in dynamic strain with respect to yarn linear density probably indicates that the deformed fibers have a high ability to return to their original state with lower residual elongation [6]. When the effect of filament fineness on dynamic strain is taken into consideration it was found to be significant. Rigid core-spun yarns with microfilament core part are found to have lower dynamic strain than conventional ones. This situation demonstrates the ability of resilience of microfilament rigid core-spun yarns are higher.
To determine the significant effect of filament fineness and yarn linear densities on both dynamic modulus and dynamic strain analysis of variance was performed and tests between subject effects is shown in table 1. Both filament fineness and yarn linear density have significant effect on dynamic modulus and dynamic strain. In addition, the individual effect size of filament fineness and yarn linear densities are illustrated as partial eta squared value. The effect size of yarn linear density on dynamic modulus was found to be highly significant with the value of 91.3%. On the other hand, filament fineness has much more lower effect on dynamic modulus with 17.2%. Nevertheless, filament fineness and yarn linear densities have higher effect on dynamic strain as 87.2% and 97.3%, respectively. 91.9% value of $R^2$ of dynamic modulus has the strong relationship with filament fineness and yarn linear density that means the better the model fits. The similar result has been observed for dynamic strain with the 97.9% value of $R^2$.

### 4. Conclusion

The influence of filament fineness and yarn linear densities on dynamic modulus and dynamic strain after 25th cycles of loading was investigated. It was observed that the yarn samples have significant difference in terms of dynamic modulus and dynamic strain. In general, coarser yarns have higher dynamic modulus; it can be directly affect the resilience properties of yarn negatively. Microfilament rigid core-spun yarns have lower dynamic strain which contribute the ability of resilience of yarns after repeated loading cycle. It can be concluded that both filament fineness and yarn linear density have statistically significant on dynamic modulus and dynamic strain with high relationship.
Acknowledgement

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References


Improving quality of OE spun yarn

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Abstract. During the formation of OE yarns on high frequency spinning rotors, dynamic shocks occur which lead to variations in the yarn tension. It is well known that by increasing the spinning speed the irregularity of yarn also increases. The variation of the yarn tension reduces the quality of the product (yarn). The aim of this research work is to find method to decrease the yarn irregularity without decreasing the spinning speed. In this paper also the way of improving of the quality of OE spun yarn is discussed. The OE yarn irregularity has been decreased by changing the construction of existed OE rotor’s separator (OERS). The yarn passes through the yarn lead-funnel to the yarn lead-out tube. The variation of the yarn tension results in the change of the yarn friction on the yarn lead-out wall of the funnel. Then concentric protrusion formed at the centre on the surface of the base lead-out funnel lets the yarn contact the separator and it presses a spring disposed in a recess formed in the separator. As a result, the spring is deformed (axially) and allows the reciprocation the yarn lead-out funnel and yarn lead-out tube, whereby the vibration leading to changes in the yarn tension are absorbed.

1. Introduction
The expansion of the range of yarns - one of the products of the textile industry and the intensive increase in demand for it - has led to the improvement of equipment that carries out technological processes. There was a need to identify all the factors that affect the manufacturing processes of yarn, to analyze and find appropriate solutions. Recently, as a result of a sharp increase in the speed of the spinning machines increased productivity and quality indicators produced yarn deteriorated, i.e. irregularity of its structure and common properties level increased. An analysis of the literature shows that a wide range of research carried out to assess the performance of the mechanical properties of yarn. Also the prediction and assessment of the mechanical properties of yarn derived from various textile fibers has been studied. The relationship between fiber characteristics and yarn strength and parameters of spinning machines has been examined by the following scholars as J.W.S.Hearle, W. Oxenham, L.V.Langenhove, Demet Yilmaz, Fatma Göktepe, X.Shao, Y.Guo в Y.Wang, Y.Zeng, А.Basu, D.Rajesh, V.P.Sherbakov, G.I.Chistoborodov, . .Stolyarov. Many researchers are concerned with predicting and assessing the structure and mechanical properties of the ring and OE yarns and try to explain their mechanical properties based on the structural statement [1-5]. These studies mainly concern the relationship between the tenacity of the yarn and the fiber properties. Despite the fact that OE yarn has a lower strength than the ring yarn, this system is well known for its
performance characteristics and formation. In all of the above works, devoted to predict and assess of the mechanical properties of yarn indicators, studies, connected with the influence of the features of spinning process, has not been conducted. The purpose of this study is to develop the methods for improving mechanical properties of OE yarn, taking into account ways and features of technological processes of spinning.

2. Theoretical part
Conditionally accepting cross-section of yarn for the circle, one can determine its surface area $S_y$.

$$S_y = \frac{\pi d_y^2}{4} \quad (1)$$

It is also possible to define values of the initial stiffness to yield point of the yarn. Absolute values of extension force under deformations $\varepsilon_y = 0.5\%$ and $1.0\%$ are used for it, and also value of stiffness to yield point $E$ in pascals is determined according to the formula:

$$E = \frac{F}{\varepsilon_y \cdot S_y} \quad (2)$$

Absolute value of deformation is equal to $\varepsilon_y = 0.005$ and $\varepsilon_y = 0.01$. In this formula the stretching stress $F$ is measured in cN, which is defined according to the data of the tensile tester Statimat-

Thus, it is revealed that as a result of changes in the frequency of the spinning camera rotation, also initial stiffness to yield point of the yarn change (when $\varepsilon_y = 0.5\%$; $\varepsilon_y = 1.0\%$), that shall be taken into account when evaluating mechanical characteristics of the yarn. It is found that if under deformation $\varepsilon_y = 0.5\%$, Young's modulus of 16.107 Pa is received under frequency of the spinning camera rotation 45000 min$^{-1}$, then under frequency of the spinning camera rotation 90000 min$^{-1}$ it increases up to 463,6 $10^7$ Pa, i.e. it increases 29 times. Under deformation $\varepsilon_y = 1.0\%$ stiffness to yield point is equal to 120,3 $10^7$ Pa. It is also found that under frequency of the spinning camera rotation 90000 min$^{-1}$ stiffness to yield point makes up 400,2 $10^7$ Pa, that means an increase by 3.3 times. Since diameter of the yarn is changed under the influence of rotational frequency of the spinning camera, then one of the indicators of mechanical properties of yarn changes-initial stiffness to yield point. Of course, this fact shall be considered when forecasting and measuring mechanical characteristics, associated with the structure of OE spun yarn. It is this state, taken into account in the theory of elasticity of the yarn, i.e., the yarn is treated as anisotropic body. Using the curve of stretching and based on the theory of elasticity of the yarn, it is possible to predict the mechanical properties of yarn.

3. Experimental
The influence of the rotational speed on the yarn structure is studied through experiment, the essence of which is to determine the deformation characteristics of the yarn, received at different speeds of the spinning rotor. The experiments were conducted on OE spinning machine BD-330, from Saurer (Schlafhorst). Yarn with linear density of 50 tex was produced from cotton under different frequencies of the rotor of 60000 min$^{-1}$, 75000 min$^{-1}$ and 90000 min$^{-1}$ (figure 1). It should be noted that the change of the rotational speed of the rotor causes yarn breaking load changes undue. With the aim to study the effects of rotor speed on yarn structure, tensile deformation curves are built.
In order to identify features of the structural changes occurring by the change of the frequency of the rotor, the tensile behavior over the time is presented (figure 2).

The increase of the frequency of the rotor’s rotation leads to increased variation of the yarn properties, which certainly reduces the quality of the yarn. This is due to the fact that by increasing frequency of the rotor, variation on yarn tension in the cylinder increases and, therefore, tension of fibers in the torsion triangle varies. Under the influence of the variable yarn tension, the arrangement of fibers at its open end changes, and it becomes the source of the structural irregularity. To reduce its value, it is necessary to reduce the thread tension variation in the cylinder by different methods. To eliminate these deficiencies and improve the quality of manufactured textile products, when predicting and measuring the mechanical properties of OE yarn, it is necessary to take into account the factors, in particular, features of the technological processes of spinning, which affect structural changes of the yarn. The improvement of the mechanical properties of OE yarn can be achieved through the development of new structural devices and variation of operating parameters of spinning machines. One of such methods is the use of elastic elements in the yarn formation zone. Elastic yarn-lead out funnel is proposed (figure 3), fitted with a spring element, due to which yarn guide has the ability to move along its axis.
Experimental funnel was patented and installed on the OE spinning machine BD-330. When changing the frequency of the rotor from 60000 min⁻¹ to 90000 min⁻¹, samples of yarn with linear density of 20, 30 and 40 tex with twist factor 50 have been produced. The test results on the mechanical properties of the new yarn are given in table 1.

Table 1. Mechanical characteristics of OE yarns, produced using elastic yarn guide

<table>
<thead>
<tr>
<th>No</th>
<th>Yarn indicators</th>
<th>Options for yarn</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>normal</td>
<td>new</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Linear density, tex</td>
<td>20</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Breaking load, cН</td>
<td>237</td>
<td>492</td>
<td>237</td>
</tr>
<tr>
<td>3</td>
<td>Irregularity on breaking load,%</td>
<td>6,7</td>
<td>5,7</td>
<td>2,5</td>
</tr>
<tr>
<td>4</td>
<td>Breaking elongation,%</td>
<td>5,13</td>
<td>5,92</td>
<td>6,0</td>
</tr>
<tr>
<td>5</td>
<td>Variation on breaking elongation,%</td>
<td>6,5</td>
<td>6,3</td>
<td>1,8</td>
</tr>
<tr>
<td>6</td>
<td>Breaking tenacity, cН/tex</td>
<td>12,07</td>
<td>12,56</td>
<td>12,08</td>
</tr>
<tr>
<td>7</td>
<td>Variation on breaking tenacity, %</td>
<td>6,7</td>
<td>5,7</td>
<td>2,5</td>
</tr>
<tr>
<td>8</td>
<td>Work of rupture, cН/cm</td>
<td>348</td>
<td>782</td>
<td>384</td>
</tr>
<tr>
<td>9</td>
<td>Variation on work of rupture,%</td>
<td>12,2</td>
<td>10,1</td>
<td>4,1</td>
</tr>
<tr>
<td>10</td>
<td>Break time, sec</td>
<td>0,31</td>
<td>0,36</td>
<td>0,36</td>
</tr>
<tr>
<td>11</td>
<td>Mass variation on Uster, %</td>
<td>14,73</td>
<td>12,58</td>
<td>15,03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>Thin places-50%, pcs/1000m</td>
<td>35</td>
<td>1,0</td>
<td>40,0</td>
</tr>
<tr>
<td>13</td>
<td>Thick places +50%, pcs/1000m</td>
<td>66,3</td>
<td>17,5</td>
<td>85,0</td>
</tr>
<tr>
<td>14</td>
<td>Number of nepes, pcs/1000m</td>
<td>421,3</td>
<td>47,5</td>
<td>586,3</td>
</tr>
</tbody>
</table>

As it can be seen from the table above, the elastic yarn guide (funnel) smoothes the fluctuations of the yarn tension in the cylinder and decreases the variation of both linear density and breaking load. Samples of yarn with linear density 20 tex have equal breaking load (237 cN) under both options, but the variation of the breaking load is different.

Variation of the breaking load of the new yarn produced with proposed mechanism is 2.7 times lower (2.5%) than the variation of normal yarn (6.7%). Variation of the breaking extension of the new yarn (1.8%) accordingly is 3.6 times lower than the variation of the normal yarn (6.5%). Along with this, variation on Uster of the new yarn with linear density of 20 tex (15.03%) exceeds the variation of the normal yarn (14.73%) by 2%, which is likely related to the amount of nepes. If new yarn has 586.3 nepes in one kilometer length, the normal yarn contains 421.3 nepes, which is lower by 39.2%. It should be noted that this does not constitute structural variation and nepes can be removed during the winding process. To analyze the performance of the yarn with linear density of 40 tex, it is possible to notice that the new yarn has similar variation of breaking load (5.7%) and it exceeds the breaking load of the normal yarn (492 cN) against (516 cN) by 5%. Mass variation on Uster, number of thick places and
neps is less in comparison with normal yarn. With a view to assess stress strain state of yarn samples, it is necessary to compare stress-strain curves, obtained through tensile tests (figure 4).

In order to achieve greater efficiency, it is necessary to choose suitable spring element, depending on the range of the linear density of the yarns, and to continue the current research work.

4. Results

It can be seen that the normal yarn with linear density 40 tex has pre-breaking curves, very much scattered (see figure 4, a, 1), and the new yarn has non-scattered pre-breaking curves. It shows that the new yarn has very uniform stiffness to yield point (see figure 4, and 2). So apparently in the countries of the European Union, as usual, stiffness on the yield point is estimated at 0.5% and 1.0% of yarn extension. Taking into account the results of these experiments for the evaluation of the mechanical characteristics of the yarn, it is necessary to introduce an additional test for the determination of the variation of its stiffness on the yield point.

The curves of the yarn tensile tests with linear density 20 tex, which are quite compact, but the breaking points of the normal yarn are dispelled noticeably that shows variation on its breaking load (see figure 4, b, 1). Breaking points of the new yarn are concentrated (see figure 4, b, 2), which is the criterion for uniformity on rupture. In both cases, evident advantage of the spring element is the production of yarns with better quality characteristics.

Figure 4. Stress-strain curves, 1) Normal yarn with linear density 40 tex; 2) New yarn with linear density 20 Tex
5. Discussion
As the figures show, the increase of the frequency of the rotor, leads to decrease of the yarn deformation. Yarn, produced under frequency of the rotor of 60000 min\(^{-1}\), has the highest value of deformation, and yarn, produced at the frequency of the rotor of 90000 min\(^{-1}\), has the lowest deformation. This is due to the structural change, i.e. changing of the fibers location in the yarn, which occurs under different linear speeds of the rotor. By increased frequency of the rotor the centrifugal force increases and, consequently, the value of the force increases, dipping fiber in the singeing plate. This contributes to more dense arrangement of fibers in fiber ribbon, and hence, yarn density increases. As a result, the friction between the fibers increases, which leads to increase a number of fibers, and resistance to stretching. Thus, with the change of the frequency of the rotor, structural transformation of the yarn occurs, i.e. the fibres are denser. Besides changes of fibers location density, their tension (straightening) increases in the torsion triangle and they enter in the yarn body more elongated, and therefore yarn has less breaking elongation. Thus, the dependence of the mechanical deformation characteristics and in particular, the yarn deformation characteristics, than the frequency of the rotor has been determined, and it is found that with increased frequency of the rotor, the the resistance to stretching increases and the deformation decreases, i.e. the tensile deformed state of the yarn changes.

References
The effect of warp tension on the colour of jacquard fabric made with different weaves structures

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Abstract. The aims of this paper is to demonstrate the effect of warp tension on fabric colour for several types of weaves structures, and found a relationship between them. The image analyse technique used to determine the proportion of yarns colour appearance, the advantage of this techniques is the rapidity and reliability. The woven fabric samples are consisting of a polyester warp yarn with continuous filaments and density of 33 end/cm, a polypropylene weft yarn with a density of 24 pick/cm, and the warp tension ranged between 12-22 cN/tex. The experimental results demonstrated the effect of the warp tension on the colour of fabric, and this effect is related to several factors, where the large proportion of warp appearance leads to larger effect on fabric colour. The difference in the value of colour differences ΔEcmc is larger is in the range 16 to 20 cN/tex of warp tension. Using statistical methods, a mathematical model to calculate the amount of the colour difference ΔEcmc caused by the change in warp tension had been proposed.

1. Introduction
Designing of fabrics require using a set of coloured yarns, which in combination give a wanted visual appearance. This is done by combining the yarns in the weave, either by showing the colour or hiding a warp above the weft or vice versa [1][2].

The use of weft and warp coloured yarns with weave structure allow to development fabric designs, by appear the desired colour in one area of the design, and we can obtain more large of colours effects by changing the fabric constructional parameters [3] [4] [5], this constructional parameters of fabric can influence even more the fabric reflect [6].

The relation between colour and weave structures have been analysed in several paper, The effect of small waves repeat in the derivation of colours is analysed by Dawson [7], where the sizes of the smallest sets of yam colour sequences that cover all possibilities are determined, and all effects with plain weave identified. Dimitrovski and Gabrijelcic [8] gave a mathematical relationship to determine the proportion of yarn colour appearance in any weave structure.

The warp tension in the weaving loom have been the subject of many investigation [9] [10][11][12][13] to increase loom producing by decrease cutting of warp yarn, by suitable warp tension value, and to improve the fabric quality.
Musa Kılıç and Ayşe Okur [15] were investigate the relationships between yarn diameter measured and yarn strength, and they gave a statistically relationships between yarn diameter variation and strength variation.

The image analysis techniques used for the identification of textile products [15][16], where the relation between weave diagram and its diffraction pattern established using digital image processing technology.

A different process techniques had used to analyses the pictures or images that have been converted to numerical form. The advantage of image analysis techniques is rapid and reliable instrumental method for measurement, analysis, and real time dynamic controls [17].

This research aims to demonstrate the effect of warp tension on fabric colour for several types of weaves structures, and found a relationship between them. And determine the proportion of yarns colour appearance using the digital image analysis.

2. Materials and methods

2.1. Specimens preparing
The studies woven fabric samples are consisting of a polyester warp yarn with continuous filaments and density of 33 end/cm, a polypropylene weft yarn with a density of 24 pick/cm. The warp tension ranged between 12-22 cN/tex.

The specimen fabrication had done on the loom model (Alpha) from the production company (Somet) Italy, Figure 1. The tests of specimen have been done after the production without any finishing process.

![Figure 1. Used loom.](image)

2.2. Digital image analysis to determine the proportion of yarns colour appearance
To determine the proportion of yarn appearance from the weft and from warp, we use the image analysis program. Were in the first stapes a fabric images taken using optical microscope, this image was first compressed from 256 to 16 and filtering in the pre-processing.

The used yarns diameters are determine by a microscope, Figure2. These values will be introduced in the program with the weave structure to detect the yarn area; the component analysis determines the proportion of warp yarns colour.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Weave structure</th>
<th>Yarn colours</th>
<th>Structure weave</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1/4</td>
<td>Satin 1/4</td>
<td>Warp colour is black, weft colour is white</td>
<td></td>
</tr>
<tr>
<td>S1/4e1, S1/4e2</td>
<td>Satin 1/4 1st weft, Satin 1/4 2nd weft</td>
<td>Warp colour is black, 1st weft colour is white, 2nd weft colour is golden</td>
<td></td>
</tr>
<tr>
<td>S4/1a1, S4/1a2</td>
<td>Satin 4/1 1st warp, Satin 4/1 2nd warp</td>
<td>1st warp colour is white, 2nd warp colour is black, weft colour is black</td>
<td></td>
</tr>
<tr>
<td>S1/9e1, S9/1a2</td>
<td>Satin 1/9 1st weft, Satin 9/1 2nd warp</td>
<td>Warp colour is black, 1st weft colour is white, 2nd weft colour is black</td>
<td></td>
</tr>
<tr>
<td>S7/1</td>
<td>Satin 7/1</td>
<td>Warp colour is black, weft colour is white</td>
<td></td>
</tr>
<tr>
<td>S6/2</td>
<td>Satin 6/2</td>
<td>Warp colour is black, weft colour is white</td>
<td></td>
</tr>
<tr>
<td>T7/1</td>
<td>Twill 7/1</td>
<td>Warp colour is black, weft colour is white</td>
<td></td>
</tr>
</tbody>
</table>
2.3. Measure the colour of the samples
A spectrophotometer device was used to measure the colour of the samples, by measuring the difference between the previous values of the reference sample and the location of the sample conducted by the measurement process we get the colour differences $ΔE_{cmc}$.

When the colour differences $ΔE_{cmc}<1$ the difference of colour cannot be detected visually by the eye.

Figure 2. Diameters of used yarns.

Figure 3. Flowchart of yarns colour proportion determined method.
3. Results and discussion

From Figure 4 it can be observed that there is a relationship between the warp tension and the colour differences $\Delta E_{\text{cmc}}$ value for different types of weave structures, the difference in the value of colour differences $\Delta E_{\text{cmc}}$ is larger in the range 16 to 20 cN/tex of warp tension.

![Figure 4](image_url)

**Figure 4.** Relationship between warp tension and $\Delta E_{\text{cmc}}$ value for different structure.

In the zone of 16 to 20 cN/tex of warp tension the relations between warp tension and the colour differences $\Delta E_{\text{cmc}}$ are approximately linear, Figure 5.

![Figure 5](image_url)

**Figure 5.** Relationship between warp tension and $\Delta E_{\text{cmc}}$ value for different structure in the range 16 to 20 cN/tex of warp tension.
The first parameter of fabric structure is the warp appearance, and from the digital image analysis we demonstrated the relationship between warp appearance proportions and different weaves structure, Figure 5.

![Figure 5. Relationship between warp appearance proportion and different weaves structure.](image)

The linear relations between warp tension and the colour differences $\Delta E_{cmc}$ and the value of represented in the table 2 for each weave structure used in the range 16 to 20 cN/tex of warp tension with value of warp appearance proportion, from this table we observe a relation between the constants in the linear equations and the warp appearance.

<table>
<thead>
<tr>
<th>Weave structure</th>
<th>warp appearance %</th>
<th>Relationship between warp tension $T_a$ and $\Delta E_{cmc}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1/4</td>
<td>17.9</td>
<td>$\Delta E_{cmc} = 0.0350 T_a + 0.0533$</td>
</tr>
<tr>
<td>S1/4e1, S1/4e2</td>
<td>20.8</td>
<td>$\Delta E_{cmc} = 0.0763 T_a - 0.4658$</td>
</tr>
<tr>
<td>S4/1a1, S4/1a2</td>
<td>79.8</td>
<td>$\Delta E_{cmc} = 0.6225 T_a - 9.1217$</td>
</tr>
<tr>
<td>S1/9e1, S9/1a2</td>
<td>35.2</td>
<td>$\Delta E_{cmc} = 0.0888 T_a - 0.2075$</td>
</tr>
<tr>
<td>S7/1</td>
<td>87.5</td>
<td>$\Delta E_{cmc} = 0.7200 T_a - 10.66$</td>
</tr>
<tr>
<td>S6/2</td>
<td>75</td>
<td>$\Delta E_{cmc} = 0.5325 T_a - 7.6983$</td>
</tr>
<tr>
<td>T7/1</td>
<td>87.5</td>
<td>$\Delta E_{cmc} = 0.7150 T_a - 10.457$</td>
</tr>
</tbody>
</table>

From table 2, and using statistical methods, the mathematical model to calculate the amount of the colour difference $\Delta E_{cmc}$ caused by the change warp tension in the in the range 16 to 20 cN/tex, is the following:
\[ \Delta E_{\text{cmc}} = (\beta \cdot W_a - \mu) \cdot T_a - \lambda \cdot W_a + \eta \]

Where:
\( \Delta E_{\text{cmc}} \): Colour differences,
\( W_a \): Warp appearance,
\( T_a \): Warp tension [cN/tex].

<table>
<thead>
<tr>
<th>( \beta )</th>
<th>( \mu )</th>
<th>( \lambda )</th>
<th>( \eta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.172</td>
<td>0.15</td>
<td>3.56</td>
</tr>
</tbody>
</table>

### Table 2. value of mathematical model constants

#### 4. Conclusions

Warp tension has an effect on the colour of fabric, and this effect is related to several factors. The large proportion of warp appearance leads to larger effect on fabric colour.

The difference in the value of the colour differences \( \Delta E_{\text{cmc}} \) is larger in the range 16 to 20 cN/tex of warp tension.

Using the digital image analysis we demonstrated the relationship between warp appearance proportions and different weaves structure.

Using statistical methods, a mathematical model to calculate the amount of the colour difference \( \Delta E_{\text{cmc}} \) caused by the change in warp tension had been proposed.

#### References


[16] Zhang1 J, Xin and Wu X 2013 A Review of Fabric Identification Based on Image Analysis Technology Textiles and Light Industrial Science and Technology vol 2 (Science and Engineering Publishing Company) pp 120-130

Individual customizable in-Store textile production

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Abstract. The target of every company is to satisfy customer demands. Especially the clothing industry has to serve individual customer requirements. Textile products always have been and still are the defining attributes of people’s appearance. Consumer’s demands towards commercial clothing companies have been changing rapidly during the recent years. Two global megatrends have supported this change: Individualization and digitalization. Individualization created demand for frequent collection changes, while still keeping availability high. Digitalization supported the quick distribution of new trends and forced a higher amount of request during peak periods. This paper outlines how a highly individual and customizable fashion product can be produced in a store environment. It focuses on the conceptual design, taking into account the interdisciplinary approach combining production technology with IT-systems, but also addresses the economical challenge with help of a value stream analysis.

1. Introduction
In the textile and clothing industry, global value-added networks are widespread for textile and clothing production. As a result of global networking, the value chain is fragmented and a great deal of effort is required to coordinate the production processes [1]. In addition, the planning effort on the quantity and design of the goods is high and risky.

Today the fashion industry is facing an increasing customer demand for individual and customizable products in addition to short delivery times [2]. These challenges are passed down to the textile and clothing industry decreasing batch sizes and production times. Conventional clothing production cannot fulfill those demands especially when combined with more and more individual or customizable designs. Hence new production concepts have to be developed.

2. Concept Development for In-Store Fashion Production
Value Stream Aim of the STOREFACTORY project is the development of an in-store fashion production. Flat knitting is chosen as the main production process, as it offers the possibility to produce clothing without using joining technics, which is often referred as knit2wear production. As the fashion product a knitted sweater is selected [3].

The in-store user-experience consists of a bodyscanner and design stations, where the customer creates their individual fashion products. These processes are supported by a software-system, which transfers the individual body-measurements and the design into the necessary machine data. The production itself takes place on three flat-knitting-machines followed by thermosetting as well as finishing equipment for the statutory labeling. Figure 1 outlines the customer experience in the developed concept.
Using the bodyscanner, the metric data of the customer is measured. The measurements guarantee a highly individual perfect fit. The metric data then is used in the design station, where the customer can design the patterning and coloring of his product. The colors are limited to the equipped colors on the knitting machines available. One machine can be equipped with up to three different colors, which can be combined in different proportions. When the customer is satisfied with his customization, the design is transferred to the knitting machine with help of the converter unit. The converter unit not only takes into account the shrinkage, but also converts the metric data into machine-data.

Figure 1. Storefactory customer journey

3. Value Stream analysis of In-Store Production
A proper evaluation method and visualizing production processes is based on the principle of the value stream. This model has been designed to identify different types of waste within defined production segments: transportation, inventory, motion, waiting, over-processing, over-production and defects. This method captures the comprehensive process of the production and visualizes and rates processes as well as the physical flow. [4, 5]

The analysis is started by detecting the value stream along the production chain. The process steps are separated into value adding, non-value adding and information process-esses. Value adding means in this context that the condition of the processed good is changed into a more valuable state. Value is defined by the customer. The outcome of the process step will be valuable if the outcome provides a benefit to the customer. The visual implementation of the value stream analysis is achieved with a graphic tool, called the value stream map. Value stream mapping consists of a visual qualitative and quantitative analysis. [6, 7]

The value stream analysis shows the differences in production lead time of two knitted products. Both processes have the same starting and ending activity, beginning with the customer order and the customer delivery. For the conventional production, the whole process takes about 289 days. However the in-store production all in all takes about 175 minutes (see Figure 2).
The comparison on the fractions of time used to create value with the product differs a lot, when the conventional and the in-store production are set against each other. While the in-store production is generating more value adding process time, the production is more expensive. The comparison of costs is therefore also a part of the value stream analysis.

4. Thermosetting
Thermosetting is an expensive and energy intensive textile process. Thermosetting is necessary to guarantee size accuracy and dimensional stability for textile materials. Depending on the material different heat setting methods such as saturated steam or hot air are used for the fixation. The project aims to define the influence of thermosetting on mechanical properties and to analyse the correlation of heat setting parameters for wool and polyester.

With the help of a “one factor at a time” experimental design heat setting parameters are varied. Mechanical characteristics and the material quality of heat set and not heat set material are evaluated to analyse the heat setting influence. The results show that shrinkage in wales direction is higher than in course direction. The tensile strength in course direction stays constant whereas the tensile strength in wales direction can be increased by heat setting [8].

For the in-store production a thermosetting process chain of steaming, washing, drying and again steaming as shown in Figure 3 shows the best results for the woollen material used.

5. Converter Unit
To guarantee a perfect fit for the customer, the acquired thermosetting results have to be taken into account before the knitting process starts. Hence the shrinkage data is fed into a database. The so called Converter Unit describes a software solution to apply the shrinkage on the individual body measurements (see Figure 4). In addition the Converter Unit solves the task of transferring the body measurements into knitting machine data.
Different approaches have been analyzed of which two have been methodically developed, implemented and tested. The results do not differ in terms of accuracy. However, the approaches show different results regarding look and surface feel. Based on those criteria, the best results have been achieved adjusting yarn tensions directly on the machine.

The second task of the Converter Unit is to convert the metric data into machine data (see Figure 5). To fulfill this demand proprietary software is used. E.G. for flat-knitting machines by company Stoll AG & Co. KG, Reutlingen, Germany a combination of the Stoll ShapeSizer, which converts the body-metrics the product contour, and the Stoll M1+, which generates the machine readable code knowing all knitting restrictions, are used.
6. Conclusion and Outlook
Within the STOREFACTORY project, an in-store fashion production line for individually designed and shaped woollen sweater has been successfully set up. With an approximately production time of four hours from scan to fully finished products, the concept shows great potential facing the increasing customer demand for individual and customizable products. While the thermosetting analysis shows just a small impact compared to the impact of the correct finishing treatment, the desired fit can be achieved.

The Converter Unit exemplifies the necessary software solutions for the flat-knitting process and shows some generic concept to integrate different production processes such as circular knitting. The value stream analysis shows, that the in-store production concept is economically suitable. Further research has to be conducted for different products and production processes as well as a market analysis needs to assess the customer experience.

7. Acknowledgement
The authors acknowledge the financial support by the Federal Ministry for Economic Affairs and Energy of Germany (BMWi) in the project STOREFACTORY as part of the “Autonomies for Industry 4.0“ framework”.

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Wet spinning PAN-fibres from aqueous solutions of ZnCl₂ and NaSCN

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Abstract. In 2007 a chemical regulation order was adopted in Europe and China, to protect the environment and human beings from hazardous substances in consumer goods and their working environment. It is a topic of interest for the rest of the world, as well. Some substances are banned by law from industrial application. The organic solvents Dimethylformamide (DMF) and Dimethylacetamide (DMAc) are candidates for prohibition. To be prepared, the producers of carbon fibres, hollow fibres and wet spun textile products are looking for alternative solvents for their production processes and try to gain according process Know-How. Aqueous solutions of inorganic salts are the most promising alternative. Within this work, the major differences between the organic and inorganic solvents are shown and the effects on the production costs are shown. This should show the chances which are linked with the use of the alternative solvents.

1. Introduction
Wet spun Polyacrylonitrile (PAN) fibres account for about 10.2 % of the world wide produced chemical fibres [1, 2]. Typical applications are textile products like jackets or shirts and home textiles. Moreover wet spun PAN fibres are the pre material for the production of high performance carbon fibres, which are used in technical applications like sports cars and wind turbines. For economic reasons, a large number of producers use toxic solvents for the production of PAN fibres, namely DMF and DMAc. These solvents are carcinogenic and reproduction toxic and thus they have to be handled carefully. Moreover, the use of these solvents could be prohibited in the future. Less harmful alternatives are aqueous solutions of salts, like Sodium thiocyanate (NaSCN) and Zinc chloride (ZnCl₂) or the organic solvent Dimethylsulfoxide (DMSO). In this article the major characteristics of the wet spinning process with the inorganic salts are focused.

1.1. Wet spinning
For wet spinning of PAN, the polymer is dissolved in an organic or inorganic solvent and is then extruded into a bath of solvent and water. The polymer coagulates to solid fibres, which can be conducted to the washing and stretching step, before they are dried and winded up (Figure 1). During the process the fibres are stretched at high temperatures to paralyse the polymer chains and eliminate pores between the chains. As a result, the fibre properties are better and the strength of the fibres is higher. The type of solvent used for the dissolution and spinning of the polymer has a large influence on the fibre properties and affects the choice of parameters for the following process steps.
The type of solvent directly influences the process conditions and the production costs and has a major influence on the achievable fibre quality. In the following, the influence of the type of solvent on

- the fibre properties,
- the work safety,
- the production costs and
- the design of the production process

are further discussed.

2. Characteristics of wet spinning with aqueous NaSCN-solution

2.1. Fibre properties

NaSCN is an inorganic salt, which can be dissolved in pure water to receive an aqueous solution. This solution is capable to dissolve certain polymers like Polyacrylonitrile to bring them into fibre form in the wet spinning process. In comparison to organic solvents, like DMSO or DMF, the dissolution mechanism slightly differs from the mechanism of the inorganic aqueous solutions, which results in differences in the fibre formation process. In case of aqueous solutions of NaSCN and ZnCl₂, the salt changes the molecular structure of the water, which enables the water to dissolve the Polymer. As pure water is not able to dissolve PAN, the salt acts like an indirect solver for the polymer. [3,4,5,6] In the case of DMSO or DMF, we have an organic fluid, which is able to dissolve the polymer by itself [7]. This different dissolution mechanism has a big influence on the spinning process.

During the spinning process the dissolved polymer is spun into a coagulation bath and gets in contact with the coagulant (water). In case of the organic solvents the coagulant separates the solvent from the polymer because of the high bonding tendency of water and the solvent and thus the polymer goes into the solid state immediately. [7,8] To get a good fibre quality, the speed of the coagulation has to be controlled by the amount of water inside the coagulation bath. That means, you have to mix the water inside the coagulation bath with a certain amount of the organic solvent to decrease the speed of the coagulation. The slower coagulation speed usually result in better fibre properties and the formation of a dense microstructure. The amount of solvent inside the coagulation bath is usually far above 40 wt.%. [9] In case of the inorganic salts, the water itself works as the solving agent as far as it is in contact with the salt atoms. After extrusion of the polymer solution into the coagulation bath, the dissolved polymer gets in contact with the extra amount of water inside the bath. The coagulation takes place as the aqueous solution of the salt is diluted and the water loses its ability to dissolve the polymer gradually. The speed of this mechanism is much lower than the coagulation mechanism of the organic solvents. As consequence you can use pure water inside the coagulation bath or add only a small amount of salt < 14 wt.% to the coagulation bath to receive good fibre qualities. The process is thus much more resistant against the coagulation conditions than in case of the organic solvents.
2.2. Work safety and political regulations for the organic solvents
To enhance a better protection for human beings and nature towards hazardous chemicals, the European Union has adopted a substantial reform for the use and distribution of chemical substances in Europe. This Reform is named REACH (Registration, Evaluation, Authorization and Restriction of Chemicals). Currently, 163 substances are placed on the SVHC (Substances of Very High Concern) list because of their carcinogenic, mutagenic and reproduction toxic properties. DMAc and DMF, which are commonly used for the production of wet spun fibres are placed on the list in 2011 and 2012, respectively. Both solvents will be proved in a second step, where it will be decided to ban them from industrial application. Then it will be forbidden to use and sell these chemicals in larger amounts. [10]

In China a similar regulation program, the so called “China REACH”, has been adopted in 2010. Both chemicals are not restricted yet but registered and classified as hazardous substances [11]. The evaluation of the chemicals is based on the REACH reform of the European Union and performed by the CIRS (Chemical Inspection and Regulation service), which collaborates with European research groups. Thus, it is probable that the evaluation and restriction of chemicals follows the decisions of the European Union.

2.3. Production costs and design of the production line
The described coagulation mechanism of the aqueous solutions of inorganic salts NaSCN or ZnCl₂ has an effect on the design of the spinning line. In case of the organic solvents you have to slightly increase the amount of water in the first baths from < 60 % to 100% to control the coagulation speed. For this reason you usually have at least 2 coagulation baths in the line. In case of the inorganic salts, you do not need a second or third coagulation bath, which influences the investment costs for the spinning line. Moreover you can use solution polymerization for the production of the spinning solution and reverse osmosis in combination with industrial distillation for the recovery of the solvent. Other saving potentials can be realized in the ventilation system and the explosion protection equipment, because of the hazardous and inflammable nature of the organic solvents in contrast to the inorganic aqueous solutions. On the other hand, the polymer throughput is higher with the organic solvents, because of a better solvability for the PAN Polymer. All in all the production costs with NaSCN are comparable or even lower than the production costs with DMSO.

3. Conclusion
PAN fibres for textile and technical applications represent a big market with good future prospects. In Europe and China the producers will have to meet strict regulations regarding the use of harmful chemical substances in their production processes. In other countries similar approaches are considered. These political interferences mean extra costs and investments for the producers concerned in the first place, but the regulations do not have to be of disadvantage for the producers in the longer term. Better fibre properties at similar or even lower production costs are attainable. In carbon fiber production sector, some of the leading producers are already working with NaSCN and DMSO. Besides, the use of alternative solvents, especially in case of inorganic salts, is advantageous in regard to health protection of the workers and environmental effects.

References


On the technological development of cotton primary processing, using a new drying-purifying unit

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Abstract: The article reflects feasibility study of conducting research on technological development of cotton primary processing with the modified parameters of drying and cleaning process for small litter. As a result of theoretical and experimental research, drying and purifying unit is designed, in which in the existing processes a heat source, exhaust fans, a dryer drum, a peg-drum cleaner of cotton and the vehicle transmitting raw cotton from the dryer to the purifier will be excluded. The experience has shown that when a drying-purifying unit is installed (with eight wheels) purifying effect on the small litter of 34%, ie cleaning effect is higher than of that currently in operation 1XK drum cleaner. According to the research patent of RU UZ FAP 00674 "Apparatus for drying and cleaning fibrous material" is received.

1. Introduction

It is known that, for a long time cotton has been considered as the main wealth of Uzbekistan. That is the reason Uzbek people call it "white gold". In the years of independence from 1991 to the present day harvest in the Republic has decreased from 4,440 mln. tonnes to 3,350 mln. tonnes, due to decreasing quenching areas of cotton sowing and increasing the areas for crops [1]. It should be noted, that this reduction did not affect adversely country's economy, on the contrary it increased. This can be explained by the fact that there was a shift from quantity to quality of the product. Thus, nowadays Uzbekistan, according to the status of developing, moved from agro-industrial to industrial-agricultural country. It is thanks to independence that our first President of the Republic of Uzbekistan - Islam Karimov provided.

In the country breeding varieties are mainly grown such as cotton An Bayaut -2, Andijan 35, Bukhara 6, Namangan 77, C-4727 and C-6524. Processing of raw cotton is realized in cotton processing plants. In the country, there are 98 cotton processing plants. If to enumerate them by the regions of the Republic, then there are 8 plants in Tashkent region, in Syrdarya region–8, in Jizak Region–10, in Andijan region–10, in Namangan region–8, in Fergana region–7, in Kashkadarya region–10, in Surkhandarya region–10, in Samarkand region–10, in Navoi region–3, in Khorezm region–6, in the republic of Karakalpakstan–8 cotton processing plants.

The technological process of primary processing of cotton in Uzbekistan consists of several stages, and a number of transport vehicles and technological machines is used in it (figure 1).
At the beginning of the process, raw cotton is dried in a drying drum, then, using the separator, it is fed in the ginning machines, in which it is purified from small and large impurities. Raw cotton, purified from small and large impurities, using air transportation facilities, is fed to delivery auger that dispenses cotton-raw to gins. Fibres are separated from the seeds in it. Using the condenser, fiber is fed in the press, in which it is pressed into bales, and cotton seeds through the auger are transferred to the linter machine. Linter machine separates the remaining short fibers (lint) from cotton seeds.

At present, drying of raw cotton has a long drying time, which leads not only to overdrying of fiber and cotton seeds, and in addition to excessive expenditure of power and fuel. Overdrying of fibers can have a positive impact in the process of purification of raw cotton from foreign impurities, in such a way dried fiber is cleaned better from foreign impurities, but overdrying of seeds is affected adversely during ginning process.

2. Analytical part

As it is shown by numerous studies, conducted by various leading scientists in the direction of seed cotton drying [2-4] (Parpiev A P, Akhmatov M A, Gapparova M A, Usmonkulov A K and others), currently at the enterprises of cotton industry in Uzbekistan, drying process is still inefficient and overspends energy.

Available information on the previous studies of the drying process showed that all of the studies were carried out mainly in the narrow direction, studied only drying process or design of dryers. Applied in practice, technological regulation of cotton primary processing is made without taking into account the above facts, since research has not previously been carried out on the impact of cotton drying time for the next transition process and the main process of ginning and pressing. There is no research information in this direction abroad.

Earlier at AS «Paxta sanoat ilmiy markazi» techniques have been developed for experimental determination of strength and destruction force on cotton seed hull under laboratory conditions. These procedures may serve as a basis for the development of new methods to determine the effect of seed cotton drying time on the seeds hulls strength, strength of fiber attachment to the seed and plant development bench for experimental determination of the effect of drying time on the performance of ginning process. Thus, it may be noted that this problem has not previously been studied and has no analogues in the world.

It is found that a propulsive drum dryer type 2СБ-10 (figure 2) has the following disadvantages: According to the length and cross section, dried raw cotton is distributed unevenly. Cotton free zones form, in which the coolant flows out from the drier in transit and this leads to considerable loss of heat.
The coolant in length and cross-section of the drum is unevenly distributed. If the average speed when entering the drum is 7-8 m/s, then on the last meters of the drum it drops to 0.1-0.2 m/s. Constructive design of the dryer drum limits the speed of the coolant, entering the chamber. In order to prevent entrainment of incoming moist cotton along the drum, coolant velocity is maintained within 0.6-1.5 m/s.

The boundary layer is formed on the surface of the wet material, it creates a barrier to heat transfer. The speed of the incoming coolant (0.6-0.9 m/s) for boundary layer turbulence is inadequate [5]. In this regard, the heat in the material is passed only the thermal conductivity of the layer that affects in slowing down the process of heat and moisture exchange. Minimal residence time of raw cotton in the drum is still 5-6 minutes; the time of raw cotton fall from blades is only 1.0-1.5 min. The rest of the time cotton is in the passive drying zone that is in the zone of the blades.

As it is known, currently in the process of primary processing of cotton, drying time is not regulated although this has a significant impact on the quality parameters of the final product - cotton fiber and cotton seed. The drum dryer is used as a cotton dryer. Inside the dryer, raw cotton is subjected to prolonged drying up 6-10 minutes.

By overdrying of fibers and seeds their fragility is increased, especially the peel of seeds. As a result, during the ginning process shortening of fiber increases, which reduces spinning-technological properties and kindly leads to decrease of fiber value. Seeds pubescence grows after gin because fiber is not detached from the seed peel but it is broken on bending at the saw tooth. In separation of fibers from the seeds, as a result of the fragility of the rind seeds, peel of seed is destroyed and as a result formation of defects fiber increases- fiber cuticle and broken seeds, which leads to reduction in the quality of fiber into several classes. Destruction of the seeds hulls leads to deterioration in the quality of seeds. Prolonged heat also leads to drying of the seed kernel, which affects adversely the germination of seeds sown and can affect oil output from technical seeds. Overdrying also affects to fiber during pressing. Due to high elasticity of the fiber, lightweight fiber bales are obtained, that leads to over expenditure of packing materials and underloading of cars and to frequent destruction of strapping belts.

On the basis of all the above it can be argued that the current to date production schedules require major upgrade by using the results of research on the effect of drying time cotton on the process of ginning, which allows: reducing the cost of electricity, fuel and fiber loss, improve the quality of produced products.
3. Problems solving

The aim of research is to develop modernized technology of primary processing of raw cotton which allows to reduce the cost of electricity, fuel, as well as loss of production, improve the quality of produced products.

To run this program, conduct of theoretical and experimental studies is provided in both laboratory and industrial conditions, development of new methods for setting unique laboratory researches on identifying changes of detachment force of fiber from seed peel, depending on drying time, designing and manufacturing of special laboratory bench units.

As part of this work drying-purifying unit is designed (figure 3), under use of which in the current process, exhaust fans, dryer drum, a peg-drum cleaner of raw cotton and the vehicle transmitting raw cotton from the dryer to the purifier will be excluded [6].

Drying-purifying unit works as follows: fibrous material in feeder 8 from cell through feed rollers through inlet (not shown) is fed uniformly to disk 2 on shaft 1, constantly rotating through the motor; Under influence of centrifugal force the fibrous material 2 is ejected from the disk at a certain speed (depending on the number of revolutions of the shaft 1) on the perforated shell surface 4. The weight and windage of the fibrous material and foreign materials differ from each other, so they get different speed by throwing, as a result their intensive loosening is going on. When the disc is driving from 2 to 4, the treated material is cleaned by thermal agent, supplied into the perforated shell 4, from the heating elements (6) through the shell, in the final phase of flight a fiber material hits to perforated surface of shell 4.

As a result of loosened fibrous material impact with perforated surface of shell 4 intensive weed impurity liberation takes place in the annular space, formed between the shell and the fixed 4 cylindrical casing 5, pinned to the frame, and from there they are sent to the sunk waste. Purified fibrous material with a perforated surface roll down on the tray 3 on which it is supplied to the next disc, which repeats the process, described above. Trays are installed at an angle of at least 55° to the

![Figure 3. A new drying-purifying unit](image)

1-rod; 2-disc; 3-guide; 4—grid wire surface; 5-shell; 6-heating element.
plane of the disk 2. Cleaned and peeled material is got off a drum from below through the branch pipe. Treated (filled with water steam) heat agent from the top of the annular space formed between the shell 4 and the stationary cylindrical casing 5 is given to utilization.

4. Block diagram
A system block diagram of automatic control of temperature in the drying and purifying unit is developed (figure 4).

Algorithm of temperature controlling process inside the drying and cleaning unit is as follows:

On the scale of the "center" of the signal processing coming from the temperature sensors and giving a signal to the actuator to turn on or turn off heaters, required level of minimum and maximum temperatures, depending on starting source humidity of raw cotton is set. The heaters power is turned on. Upon reaching the maximum temperature inside, the unit receives a signal from the temperature sensors in the "Center" signal processing, which instructs the actuator to shut off heaters. After that, the temperature drops inside the unit. Upon reaching the minimum temperature, according to the signal of temperature sensors, signal processing "Center" instructs the actuator to switch heaters. The process is constantly repeated.

The temperature of sensors installed inside of drying-purifying unit.

«Center» of signal processing coming from the temperature sensors and giving a signal to the actuator to turn on or turn off the heaters.

The actuator, switching on and off thermoelectric heaters (TEH) of air type.

5. Experienced data
Investigations have been done on determination the cleaning performance from small litter. Table 1 shows the results of studies to determine the cleaning effect on small litter of drying-purifying unit.

Table 1. Quality indicators of cotton raw on transitions cleaning.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Cotton contamination, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>1. Raw cotton before cleaning</td>
<td>9.1</td>
</tr>
<tr>
<td>2. Raw cotton after cleaning</td>
<td></td>
</tr>
<tr>
<td>600 turns/min</td>
<td>8.14</td>
</tr>
<tr>
<td>800 turns/min</td>
<td>7.81</td>
</tr>
<tr>
<td>1000 turns/min</td>
<td>7.46</td>
</tr>
<tr>
<td>3. Raw cotton after two cleaning</td>
<td></td>
</tr>
<tr>
<td>600 turns/min</td>
<td>7.4</td>
</tr>
<tr>
<td>800 turns/min</td>
<td>7.12</td>
</tr>
<tr>
<td>1000 turns/min</td>
<td>7.2</td>
</tr>
<tr>
<td>4. Raw cotton after cleaning three times</td>
<td></td>
</tr>
<tr>
<td>600 turns/min</td>
<td>7.14</td>
</tr>
<tr>
<td></td>
<td>7.0</td>
</tr>
</tbody>
</table>
800 turns/min | 7.13 | 4.36
1000 turns/min

5. Raw cotton after cleaning four times
600 turns/min | 6.93 | 4.3
800 turns/min | 6.95 | 4.16
1000 turns/min | 6.86 | 4.25

6. Analysis of experiments.
Analysis of the data shown in figure 5 of the graph shows that when drying-purifying unit is installed (with eight wheels) purifying effect on the small litter may reach 34%, i.e. cleaning effect higher than of that currently operated drum cleaner 1XK.

![Figure 5](image)

Figure 5. Graph of impact of speed and the number of disks of cotton cleaner unit on cleaning effect on the small litter

This cleaning effect is achieved due to the impact of raw cotton, issued from the rotating disk by centrifugal force and the subsequent impact on the mesh surface, through the hole of which small litter is screened.

According to the research, patent of RU UZ FAP 00674 "Apparatus for drying and cleaning fibrous material" is received.

7. Conclusions
1. As a result of theoretical and experimental studies, drying and purifying unit is designed, during use of which in existing processes, heat source, exhaust fans, dryer drum, a peg-drum cleaner of raw cotton and the vehicle transmitting raw cotton from the dryer to the purifier will be excluded.
2. Studies have shown that when drying-purifying unit is installed (with eight wheels) purifying effect on the small litter of 34%, i.e. cleaning effect is higher than of that currently in operation 1XK drum cleaner.
3. Preliminary calculations of economic efficiency suggests that it will be more than 100 mln. UZS per cotton plant per year, it will help improve environmental situation and working conditions.
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Compressibility and resiliency properties of wilton type woven carpets produced with different fiber blend ratio

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Abstract
Carpet is a textile structure that composed of three components: warp (stuffer and chain warp), weft and pile yarns. These textile products are used for areas which will stand up to the use of home, hotel, work place etc. Furthermore, the capable of carpets are related to its especially pile performance during use in various areas. During usage, carpets made from various type of raw materials of pile yarn also acts differently that these differentiate determines carpet performance, as well. This study was focused on the compression and resilience behaviour of carpet composed of 100% viscose and 100% acrylic pile yarns and blended pile yarns of blend ratios, 80%/20%, 50%/50% and 20%/80% viscose/acrylic. During the yarn production process, all spinning conditions were kept constant in order to eliminate the yarn production parameters. Five different types of wilton face to face carpet samples were produced from these yarns at the same pile height and pile density. Compressibility properties of carpets were examined whether blend ratio was statistically significant on carpet resilience or not. The behaviour of pile yarns under pressure is important that leads to understand the growth characteristic which is exposed to decrease and increase loadings during usage of carpet made from these yarns. Results indicated that blend ratio of pile yarns have significance effect on compression behaviour of carpet samples.

1. Introduction
Compressibility and resilience properties of carpets are under influence of pile yarn materials, carpet construction, pile height etc. Pile yarn characteristic is the main parameter that affects resiliency directly. Several studies were related to determine the compressibility behaviour as well as change in thickness of carpets under loading and unloading [1-8]. Studies show that compressibility behaviour of carpets are affected by especially raw materials, fiber thickness and pile height.

This study was focused on determination of compression and resilience behaviour of carpet composed of acrylic/viscose fibers with different blend ratios. In the production of pile yarns all spinning production parameters was kept constant. Wilton face to face carpet samples were produced on the same weaving condition such as pile height, pile density and carpet construction.
Compressibility properties of carpets were examined whether blend ratio was statistically significant on carpet resilience.

2. Material and Method
Viscose and acrylic fibers that have 38 mm length and 1.3 dtex linear density were used as raw materials. 100% viscose and 100% acrylic pile yarns and blended pile yarns of blend proportions 80%/20%, 50%/50% and 20%/80% viscose/acrylic were selected to manufacture 32.8 tex yarn samples at constant spinning production parameters (16500 rev/min spindle speed, 550 turns/m twist value). Then, these yarns were folded 4 times with 300 turns/m twist value in order to make them suitable yarn linear density for weaving carpet samples.

Wilton face to face carpet samples were produced on Van de Wiele Carpet weaving machine at the same condition in order to eliminate the weaving parameters. Weaving machine speed was 110 picks/min and carpet construction was 1/1 V. In addition, properties of yarns used for carpet production is illustrated in Table 1.

<table>
<thead>
<tr>
<th>Yarn Type</th>
<th>Raw Material</th>
<th>Yarn linear density (tex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pile yarn</td>
<td>100% Viscose</td>
<td>151</td>
</tr>
<tr>
<td></td>
<td>80%/20% Viscose/Acrylic</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>50%/50% Viscose/Acrylic</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>20%/80% Viscose/Acrylic</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>100% Acrylic</td>
<td>100</td>
</tr>
<tr>
<td>Warp yarn</td>
<td>Stuffer yarn</td>
<td>210</td>
</tr>
<tr>
<td></td>
<td>80%/20% Polyester/Cotton</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>Chain yarn</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>80%/20% Polyester/Cotton</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>100 % Cotton</td>
<td>295</td>
</tr>
</tbody>
</table>

After weaving carpet samples; back coating, dusting, cutting processes were achieved. Before carrying out compressibility test, the specimens were conditioned in a standard atmosphere at 20±2°C temperature and 65±4% relative humidity for 24 hours according to the related standard [9]. Compressibility test was performed on SDL Atlas digital thickness gauge device which is illustrated in figure 1 under different loads in accordance with BS 4098 and BS 4051 standards [10-11].

![Figure 1](image_url) SDL digital thickness gauge

Firstly, 100*100 mm carpet sample was placed under the press foot of the device (2 kPa) for 30 seconds, thickness was noted. Then, 5 kPa, 10 kPa, 20 kPa, 50 kPa, 100 kPa, 150 kPa and 200 kPa loads were applied for 30 seconds, respectively, thickness was again noted for each loads. After that, each load was removed individually and thickness was measured for each removing of loads.
thickness values of carpet samples versus to pressure were drawn so as to display the variation of each pressure. Thickness-pressure curve for 100% acrylic cut-pile carpet is given as an example in figure 2. In figure 2, loading part represents compression under loads and unloading part represents recovery of loads.

**Figure 2.** Thickness-pressure curve for 100% acrylic cut-pile carpet

In order to examine the blend ratio effect on compressibility of carpet samples, compression recovery can be obtained from equation (1).

\[
C_i \quad r \quad (%) = \frac{t_r - t_2}{t_2 - t_{200}} \times 100
\]  

(1)

where;

- \( t_i \) is the initial thickness at 2 kPa pressure (A)
- \( t_{200} \) is compressed thickness at 200 kPa pressure (B)
- \( t_r \) is recovered thickness at 2 kPa pressure after loading to 200 kPa pressure (C)

The work of compression (\( W_{cc} \)), in joules per square meter, can be expressed as equation (2) as the area under the loading area “ABD” in figure 2.

\[
W_{cc} = \frac{j}{m^2} = 1.5t_2 + 4t_5 + 7.5t_i + 20t_2 + 40t_5 + 50t_i + 150t_1 - 173t_2
\]  

(2)

The work of recovery (\( W_{cr} \)), in joules per square meter, can be expressed as equation (3) as the area under the unloading area “BCE” in figure 2.

\[
W_{cr} = \frac{j}{m^2} = 1.5t_2 + 4t_5 + 7.5t_i + 20t_2 + 40t_5 + 50t_i + 150t_1 - 173t_2
\]  

(3)

The percentage work recovery, as estimated by the ratio of the work of recovery to the work of compression, can be calculated with equation (4).

\[
W_{rf} \quad r \quad % = \left( \frac{W_{cr}}{W_{cc}} \right) \times 100
\]  

(4)

In order to compare the significance effect of blend ratio statistically, analysis of variance (ANOVA) was performed by using SPSS package program. The experimental results of compression recovery, work compression, work recovery and percentage work recovery as response variables were statistically analysed using ANOVA at 95% confidence interval.
3. Result and Discussion
The average values of compressibility performance of carpet samples calculated from related equations are given in table 2. Figure 3 illustrates thickness changes of carpet samples under loading and unloading pressure. It can be said that 100% acrylic, 20%/80% viscose/acrylic and 50%/50% viscose/acrylic cut-pile carpets behaviour under compression are similar and lower than 100% viscose and 80%/20% viscose/acrylic carpets compressibility performance. That means if a carpet has a higher resilience and compression energy against pressure applied, the pile yarn demonstrates better recovery. As a result, more resistance against the compression energy of cut-pile carpets with acrylic fiber blend ratio ≥50% and thus a higher carpet thickness will be obtained.

<table>
<thead>
<tr>
<th>Carpet Sample</th>
<th>Compression recovery (%)</th>
<th>Work compression (J/m²)</th>
<th>Work recovery (J/m²)</th>
<th>Work recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 % Viscose</td>
<td>37.30</td>
<td>215.36</td>
<td>67.91</td>
<td>31.55</td>
</tr>
<tr>
<td>80%/20% Viscose/Acrylic</td>
<td>42.60</td>
<td>240.32</td>
<td>75.43</td>
<td>31.47</td>
</tr>
<tr>
<td>50%/50% Viscose/Acrylic</td>
<td>45.87</td>
<td>280.75</td>
<td>92.11</td>
<td>32.82</td>
</tr>
<tr>
<td>20%/80% Viscose/Acrylic</td>
<td>48.28</td>
<td>277.56</td>
<td>87.87</td>
<td>31.57</td>
</tr>
<tr>
<td>100% Acrylic</td>
<td>48.03</td>
<td>295.81</td>
<td>80.29</td>
<td>27.18</td>
</tr>
</tbody>
</table>

Figure 3. Carpet thickness versus to pressure curves at different fiber blend ratio

The compression recovery of cut-pile carpet samples with different blend ratio is shown in figure 4. It is clearly seen that the percentage of compression recovery increases with increasing the acrylic blend ratio. It can be probably said increase in the resilience of cut-pile carpets from low to high ratio of acrylic fiber in cut-pile carpets.

ANOVA results for recovery, compression recovery, work of compression, work of recovery and percentage work of recovery after compressibility test are given in table 3. ANOVA results indicate that fiber blend ratio has a statistically significant effect on compression recovery, work compression and work recovery variables with $p<0.005$ at the level of 95% confidence interval. On the other hand, it is seen that fiber blend ratio has no significant effect on work recovery in percent ($p=0.149$).
Figure 4. Compression recovery versus fiber blend ratio

Table 3. ANOVA results of carpet samples compression behaviour

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compression recovery (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>419.703</td>
<td>4</td>
<td>104.926</td>
<td>7.828</td>
<td>.001</td>
</tr>
<tr>
<td>Within Groups</td>
<td>268.072</td>
<td>20</td>
<td>13.404</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td>687.775</td>
<td>24</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Work compression (J/m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>21907.701</td>
<td>4</td>
<td>5476.925</td>
<td>16.985</td>
<td>.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>6449.184</td>
<td>20</td>
<td>322.459</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td>28356.886</td>
<td>24</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Work recovery (J/m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>1866.501</td>
<td>4</td>
<td>466.625</td>
<td>4.061</td>
<td>.014</td>
</tr>
<tr>
<td>Within Groups</td>
<td>2297.977</td>
<td>20</td>
<td>114.899</td>
<td>--</td>
<td>--</td>
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<tr>
<td>Total</td>
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<td>24</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Work recovery (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>93.685</td>
<td>4</td>
<td>23.421</td>
<td>1.902</td>
<td>.149</td>
</tr>
<tr>
<td>Within Groups</td>
<td>246.220</td>
<td>20</td>
<td>12.311</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td>339.905</td>
<td>24</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

4. Conclusion

In this research, the compression and resilience properties of acrylic and viscose cut-pile carpets consisting of different fibre blend ratios were investigated. It can be stated that results demonstrate the compression performance indications of the cut-pile carpet samples with ≥50% of acrylic fiber ratio can be less deformed under pressure. The most important predictor of resilience characteristics of carpet is compression recovery in percent, and result shows that high ratio of acrylic fiber contributes this response variable directly.

Acknowledgement

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Preliminary Study on the Correlation between Color Measurement of Dyed Polyester and Its Image Files

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Abstract. As the internet becomes more popular, buyers send image files to manufacturers instead of sending swatches. However, this method may cause problems because different from the monitor between the buyer and the manufacturer, and also there is a problem depending on the light source. In order to overcome these problems, we investigated the relationship between color measurement values of dyed fabrics and RGB values of image files. The RGB values of image files tended to decrease with increasing dye concentration in all three colors. Correlation between RGB values and a*, b* values was observed at low concentration, but there was little correlation at high concentration. In the case of yellow color, there is no correlation between the L*a*b* values obtained from the dyed fabric and RGB values obtained from the image file.

1. Introduction

In traditional dyeing process, the buyer sent the swatch directly to the manufacturer by parcel service, and the manufacturer did the coloring of the fabric to match the color. It took about two weeks to get the correct color from the time it was mailed, get confirmation from the buyer, and start mass production over 10,000 yards. But since the Internet has become popular, buyers are sending image files instead of sending swatch directly to manufacturer. The total production time is shortened because there is no need to send swatch. However, this method has the following problems. Firstly, the colors appear differently on the monitor because the monitor is different between the buyer and the manufacturer. Secondly, when make image file is created by shooting with a digital camera, the color of image changes depending on the shooting environment such as light source, illumination and moisture content of the sample. Finally, when the color is matched by the naked eye, there is a problem that the color differs depending on the light source. In order to overcome these problems, we investigated the relationship between color measurement values and RGB values. We obtained CIE L*a*b* values by measuring L, a, b values of dyed PET (Polyethylene terephthalate) fabric with a spectrophotometer, and scanned the dyed fabric to create image file. The obtained CIE L*a*b* values were converted into RGB values by various formulas in order to compare with the RGB values of the image file.

2. Experimental

All chemicals such as sodium hydrosulfite, sodium hydroxide, acetic acid were laboratory grade reagents. The PET fabrics were dyed using disperse dyes (Red – C.I. Disperse Red 152, Blue - Unknown, Yellow – C.I. Disperse Yellow 114) in an IR dyeing machine at a liquor-to-goods ratio of 1:20. The dyebaths were prepared with various concentration of dyes (0.1 – 7 % o.w.f). Dyeing temperature was 90 °C. The dyebath temperature was raised at a rate of 1 °C/min to 130 °C, maintained at this temperature for 60 min and rapidly cooled to room temperature. The dye fabrics were reduction-cleared (1 g/l sodium hydroxide, 1 g/l sodium hydrosulfite at 80 °C for 20 min).

The conversion from XYZ to L*a*b* was calculated using the following equation.

\[
L^* = 116f \left( \frac{Y}{Y_n} \right) - 16, \quad a^* = 500 \left[ f \left( \frac{X}{X_n} \right) - f \left( \frac{Y}{Y_n} \right) \right], \quad b^* = 200 \left[ f \left( \frac{Y}{Y_n} \right) - f \left( \frac{Z}{Z_n} \right) \right]
\]

Where \( f(s) = s^{1/3} \) for \( s > 0.008856 \)
and \( f(s) = 7.787s + \frac{16}{116} \) for \( s \leq 0.008856 \)

\[
L^* = 100 \sqrt[3]{\frac{Y}{Y_n}}, \quad a^* = K_a \left( \frac{X/X_n - Y/Y_n}{\sqrt{Y/Y_n}} \right), \quad b^* = K_b \left( \frac{Y/Y_n - Z/Z_n}{\sqrt{Y/Y_n}} \right)
\]

Where \( X, Y, \) and \( Z \) are the CIE tristimulus values.

\( X_n, Y_n, \) and \( Z_n \) are the tristimulus values for the illuminant.

\( K_a, K_b \) are chromaticity coefficients for the illuminant.

The image files of dyed fabrics were scanned by Epson scanner and the RGB values were obtained from the image file using Adobe Photoshop. The color parameter of dyed polyester fabrics were determined on a Macbeth Coloreye 3300 spectrophotometer, under standard illuminant D65 using the 10’ standard observer.

3. Results and Discussion

![Figure 1](image1.png)

**Figure 1.** Effect of dye concentration on the color yields of dyes.

Figure 1 shows the build-up of the dyes on PET fabrics. The color yield of red and blue dyes continuously increased as concentration of dyes increased suggesting that red and blue dyes have a good build-up property. However, yellow dye shows limited build-up and reached saturation at 3-4 %owf. Therefore, it is necessary to replace the yellow dye into a dye with good build-up property.
The RGB and L*a*b* values of red dye on PET fabric is shown in Figure 2. In the red color, the RGB values decrease as the dye concentration increases. As the dye concentration increases, the value of a* increases until 2 % owf and then decreases. In Figure 2 (c), the b* value increases as the dye concentration increases. When the dye concentration is low, the slope of the curve obtained from the dyed fabric and the image file is similar. However, when the concentration of the dye is high, the values of a* and b* don’t fit well with the trendline because the RGB value can’t represent a negative value and is replaced with zero.

The RGB and L*a*b* values of blue dye on PET fabric is shown in Figure 3. In the blue color, the RGB values also decrease as the dye concentration increases. The a* value increases as the dye concentration increases.
concentration increases. As the dye concentration increases, the value of b* increases until 3 %owf and then decreases. When the dye concentration is low, the slope of the curve obtained from the dyed fabric and the image file is similar. However, when the concentration of the dye is high, the values of a* don’t fit well with the trendline. This can also be explained using the limits of the RGB value range. Unlike red color, b* values are well suited to trendlines even at high concentration of dye, which is probably due to the good build-up property of blue dye.

Figure 4. The relationship between RGB from image file and L*a*b* values of yellow dye on PET fabric according to dye concentration. (a) R-a (b) G-a (c) B-b

The RGB and L*a*b* values of yellow dye on PET fabric is shown in Figure 4. In the yellow color, the RGB values also decrease as the dye concentration increases. However, yellow color is less similar at low concentrations than other colors. Especially at high concentration, there is no tendency because yellow dye reaches saturation at 3-4 %owf and have limited build-up property.

4. Conclusions
All the dyes showed good build-up property except yellow dye. The RGB values tended to decrease with increasing dye concentration in all three colors. The CIE values are better than the Hunter values for this preliminary study. At low concentrations, a* and b* values fit well with trendlines, but not at high concentrations. In the case of yellow color, there is no tendency between the L*a*b* values obtained from the dyed fabric and RGB values obtained from the image file. From these results, we looked some possibility of using image files instead of swatches in the dyeing process. We need to examine some dyes further more.
Disperse dyeing properties of (easy dyeable polyester)/spandex blend

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Abstract. Using a low and a high energy disperse dye, several dyeing properties, like colour depth, partition ratio, degree of dye exhaustion, build-up and fastness properties of (easy dyeable polyester)/spandex blend were thoroughly investigated. Various dyeing temperatures ranging from 90°C to 130°C were applied. To check its performance, the conventional (regular polyester/spandex) blend was also dyed. (easy dyeable polyester)/spandex blend showed higher dyeability on PET and lower staining on spandex at low temperature compared to (regular polyester)/spandex blend.

1. Introduction

Spandex (generic name of polyurethane fiber) has the unusual characteristics of high elasticity. In textile industry, it is usually blended with other fibers. Although the blend ratio is very low, it imparts the blend excellent comfortability and wear ability [1].

The textile technologists usually encounter two major problems during disperse dyeing of (regular polyester)/spandex blend, namely (i) dye ability at low temperature in order to protect the spandex from damage and (ii) lower degree of wet fastness properties of the blend due to staining of spandex, [2]. To solve those difficulties, the researches were focused on identifying dyes that would exhaust less on the spandex and would have excellent dyeing behavior on the (regular polyester)/spandex blend at lower temperature [2-4]. As the spandex being more accessible to the alkaline reduction chemicals than the polyester, some researchers also examined the efficiency of reduction cleaning process on the removal of the disperse dye stain from the spandex [5].

In this present study, to overcome those two technical problems, a chemical modification of regular polyester named as easy dyeable polyester (abbreviated as EDP, Figure 1) through copolymerization had been adopted without changing the bulk properties of the regular polyester. Disperse dyeing properties of spandex and easy dye able polyester, and regular polyester fibers were studied.

![Figure 1. Chemical Structure of EDP](image-url)
2. Experimental

2.1. Material
Spandex knitted fabric (70 denier, $T_g=-20 \, ^\circ C$), polyethylene terephthalate (PET) knitted fabric (75 denier/72 filament), EDP knitted fabric (75 denier/72 filament) and two disperse dyes as listed in figure 2 and figure 3, namely CI Disperse Red 60 (low energy) and CI Disperse Red 167 (high energy) were applied in this study. Before dyeing, the spandex fabric was scoured, using 0.2g/l NaOH and 1g/l scouring agent (AZ-100) at 80 °C for 20 min.

![Figure 2. CI Disperse Red 60.](image1)

![Figure 3. CI Disperse Red 167.](image2)

2.2. Dyeing
The EDP/spandex (80:20) and PET/spandex (80:20) blend were dyed at 90 , 100 , 110 , 120 and 130 °C for 60 minutes in a dye bath of liquor ratio 20:1 using 1g/l dispersing agent and keeping pH 4.0-4.5(acetic acid) . The dye concentration was 1% (o.w.f). The dyeing was carried out using Daelim Starlet II Infrared Dyeing Machine (Korea).

2.3. Reduction clearing
The dyed samples were reduction cleared at 80 °C for 20 min in a bath of sodium hydroxide (2g/l) and sodium hydrosulphide (2g/l).

2.4. Measurement
2.4.1. Partition ratio. After dyeing at different temperature, colorimetric properties using spectrophotometer (D65 illumination, 10° observer) and absorbance of extracted dye solution (40ml dimethylformamide per 0.1g of fabric) from dyed sample using UV-vis spectroscopy (Algine 8453, made in USA) were measured to calculate the partition ratio.

\[
\text{Partition ratio} = \frac{C_s}{C_f}
\]

Where, $C_s$ and $C_f$ are the colour depth of spandex and PET or EDP respectively. Again,

\[
\text{Partition ratio} = \frac{A_s \times 4}{A_f}
\]

Where, $A_s$ and $A_f$ are the absorbance of the extracted dye solution from spandex, PET or EDP. This case, equal weight of spandex and PET, and EDP were dyed.

2.4.2. Degree of dye exhaustion. The dye exhaustion on each blend was calculated by residual dye bath method as indicated in equation 3. Besides that, the exhaustion on each fabric as the dyeing time increased was determined by equation 4. This case, the absorbance of the extracted dyes was used to find out the amount of dye on each fabric using the Beer-Lambert law.

\[
\% \text{Exhaustion} = \left(1 - \frac{A_f}{A_i}\right) \times 100
\]

Where, $A_i$ and $A_f$ are the initial and residual dye bath absorbance.

\[
\% \text{Exhaustion} = \left(\frac{D_i}{D_f}\right) \times 100
\]

Where, $D_f$ is the amount of dye extracted from PET or EDP or spandex (in mg), $D_i$ is the initial amount of dye in the dye bath (in mg).
3. Result and discussion

The partition ratios calculated by using equation (1) and (2) are shown in Figures 4 and 5. On the one hand, partition ratio on spandex and PET increases at low temperature but decreases when temperature is increased above 100 °C. On the other hand, the EDP has exceptionally lowered the partition ratio of disperse dye on spandex and EDP blend at temperature below 100 °C. Between the dyes, high energy dye has high partition ratio on spandex than low energy dye. After reduction clearing, the lowered partition ratio for both blends indicates that more disperse dye has been removed from spandex.

![Figure 4](image1.png)  
**Figure 4.** Partition ratio (a) CI Disperse Red 60 and (b) CI Disperse Red 167.

![Figure 5](image2.png)  
**Figure 5.** Partition ratio (a) CI Disperse Red 60 and (b) CI Disperse Red 167.

Color efficiency on the surface of PET/spandex and EDP/spandex blend is mainly determined by the PET and EDP respectively. Because the blend ratio of spandex is mainly very low and it is usually hidden inside the blend due to its elastic nature. To investigate the shade depth in details, the samples were collected separately as the dyeing time increased at different dyeing temperature and the color depth of each of the fabric for both dyes was measured. It is revealed from figure 6 and 7 that EDP exhibits better color depth at all dyeing temperature. It can also be seen that the color depth of EDP at 90 °C is almost similar to the color depth of PET at 130 °C, even though the spandex was blended with them. This result represents the excellent dye ability of the EDP/spandex blend at lower temperature. This unique behavior of the EDP/spandex blend can be explained by the co-polymer of polyethylene glycol group in EDP that created more flexibility and large surface area allowing faster dye uptake on the EDP at low temperature. It is also to be mentioned that the high energy dye confers two times higher color depth in EDP than low energy dye. It should be noted that as the dyeing time increases,
there is some variation in color depth in spandex at high temperature. This is mainly the uneven color distribution on the surface of spandex.

**Figure 6.** Color depths by applying CI Disperse Red 60 at different dyeing temperature.

**Figure 7.** Color depths by applying CI Disperse Red 167 at different dyeing temperature.

Dye exhaustion was calculated in two different methods. Firstly, dye exhaustion on each blend by residual dye bath method. It shows that the PET/spandex has high exhaustion than EDP/spandex blend as illustrated in figure 8, the reason is not understood. Secondly, dye exhaustion was also calculated
for individual fabric as the dyeing time increased by using equation 4 that is depicted in figure 9 and 10 for two dyes respectively. At low temperature, the disperse dye is exhausted more on spandex than PET owing to the lower glass transition temperature of spandex. However, as the dyeing temperature is increased to 110°C, the dyes transfer from spandex to PET. But completely opposite behavior is observed in case of EDP/spandex blend. At the low temperature the disperse dye exhausts more on EDP than spandex and at high temperature the exhaustion on spandex is slightly increased but is still below than EDP. This observation may be related to the greater amount of amorphousness of EDP than PET. Indeed, the dye study shows that the high energy dye has more adsorption on spandex owing to its low adsorption on PET or EDP. That is more acute in case of PET/spandex blend. Low energy dye demonstrates opposite property. Exceptionally, the both dyes have low distribution on spandex when blended with EDP. This low exhaustion of disperse dye on spandex might be an effective indication of reduction of excessive stain of spandex. It is also to be mentioned that as the dyeing time increased the samples were collected and directly extracted without doing any washing. As a result each sample shows some variation in exhaustion at temperature below 80°C.

Figure 8. Residual dye bath Exhaustion (a) CI Disperse Red 60 and (b) CI Disperse Red 167.

Figure 9. Dye Exhaustion on each fabric by applying CI Disperse Red 60.
Figure 10. Dye Exhaustion on each fabric by applying CI Disperse Red 167.

4. Conclusion
The result of this study indicates that EDP/spandex blend exhibits excellent dyeing properties at temperature below 120℃, a temperature designed to keep the spandex flexible. The study again demonstrates that both dyes used in this study, exhausts less on spandex when blended with EDP but exhausts high when blended with PET. The EDP/spandex blend also needs low dye concentration to build up well at low temperature than PET/spandex blend. It is expected that the low dye concentration to build up and low exhaustion of disperse dye on spandex will reduced the excessive staining of the spandex and confers fastness rating that somewhat higher than the conventional PET/spandex blend.

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