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Content

EFFECT OF MECHANICAL CRIMP OF JUTE FIBRE ON THE THERMAL PROPERTIES OF WOVEN FABRICS

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Abstract: *The aim of this paper is to find the effect of mechanical crimp of jute fibre on the thermal properties of woven jute fabrics. In this study, crimp box and gear crimping method were used to impart mechanical crimp into jute sliver. Crimps were divulged to enhance the cohesion between fibres that make it suitable for spinning. Jute yarns were produced by inserting a different number of crimps and woven fabrics were produced by using these yarns. Fabric thickness, porosity, air permeability and thermal conductivity tests were done according to standard method and found that fabric porosity, air permeability and thermal conductivity of the fabric decreased and fabric thickness increased with the increased number of crimps and fabrics from gear crimping method showed better effect than that of crimp box method. The study on jute woven fabric will provide quantitative experimental data for potential applications with advantages of lightweight, cost-effective, easy to manufacture, biodegradable and excellent mechanical properties.*

Keywords: *Mechanical crimp, crimp box method (CBM), gear crimp method (GCM), fabric porosity, air permeability and thermal conductivity.*

1 INTRODUCTION

The heat and air transferring properties of textiles, which are fundamental factors related to clothing comfort, are affected by the mechanical characteristics of the fabrics, yarns and also fibre properties. The mechanical properties can be depended on the yarn's physical properties and fabric structures [1]. Jute is a technical fibre with some special properties. Nowadays, jute woven fabrics are widely used for thermal issues and composite materials for its functional properties [2]. Functional properties are sometimes involved with yarn properties which are greatly related with fibre crimp. Jute is a natural fibre having no natural crimp. So, mechanical crimp is imparted into jute fibres in order to enhance the cohesion between fibres and to make it suitable for subsequent processes like spinning and weaving [3]. Nowadays, mechanical crimp is imparted into jute sliver during drawing in the 2nd and 3rd draw frame machine. The CBM is widely used for jute crimping. In the CBM, the sliver leaves the nip of the drafting rollers and passes down the sliver plate into the nip of a pair of fluted delivery rollers, the upper one of the pair is spring-loaded and positively driven.

A lid is used in the crimping box. Some weight is applied to the lid and it creates a pressure or load on the sliver in the crimp box. As a result, fibre is compressed under pressure and irregular crimp is produced into jute sliver. The length of time on any particular place of sliver remains in the crimp box can be controlled by means of small weights which can be added to the lid. If different weight is used, then crimp produced into sliver also gets changed. A heavy weight causes a greater mass of sliver in the box to lift it up and develops more crimp in the fibres [4]. This crimp creates inter-fibre cohesion which is very important for jute processing. In CBM, crimps produced with irregular size and shape. As a result, the number of crimps per inch or per unit length also becomes irregular [3]. On the other hand, for GCM, two crimping rollers are used to impart crimp into sliver. After passing the nip of the drafting rollers, it passes over the sliver plate into the nip of a pair of fluted delivery roller, then passes between the nips of the gear crimping rollers, then crimp is formed in the sliver which is regular in size and shape. The lower crimp roller is positively driven and the upper crimping roller is spring-loaded. The pair of crimping rollers should be changed to change the number of crimps in per unit length.

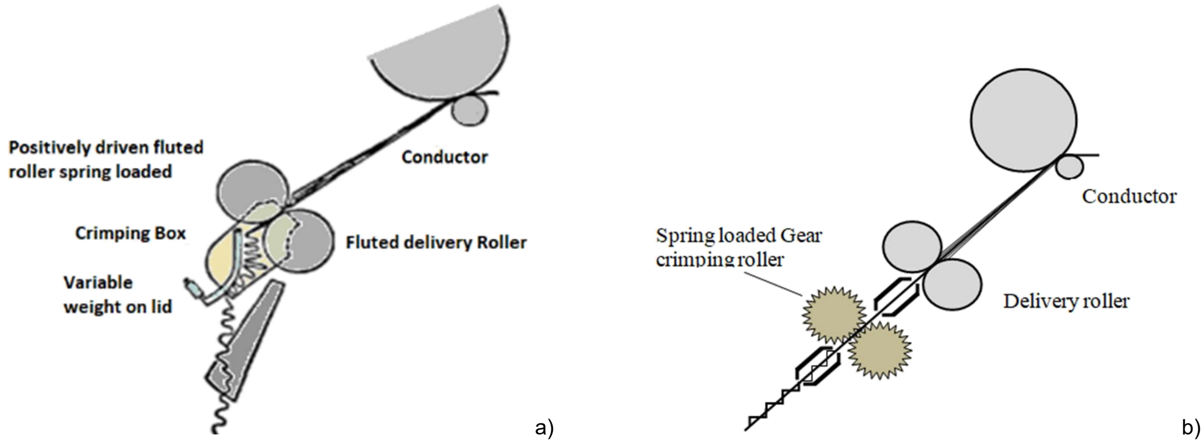

Figure 1 a) Crimp Box Method (CBM) [4] and b) Gear Crimp Method (GCM)

The crimps affect the fabric thickness, fabric porosity, air permeability and thermal conductivity of the fabric. Air permeability and thermal conductivity of the fabric are related to fabric thickness and porosity [5, 6]. Thermal protective clothing contains an inner layer, middle layer and outer layer. The inner layer provides next to skin comfort by wicking the sweat at the skin surface for better evaporative cooling and quick drying. The middle layer normally provides insulation. The outer layer aims to protect people against environmental conditions [7]. Heat transfer by conduction depends on thermal conductivity and thermal resistance of the material. Heat transfer portent can help in accepting the fabric used as thermal obstacle with lower thermal conductivity, hence understanding the concept of mode of heat transfer through textile material becomes essential [8]. Heat transfer in porous materials occurs from high to low temperature section. Hence, a temperature difference has to occur between the two sections for transfer of heat. Mostly, heat is transferred through conduction, convection, and radiation from high temperature to low temperature. The total thermal conductivity decreases when material density increases and conduction is the main source of heat loss at higher mass such as gram per square meter (GSM) and thickness of fabric. Thermal conductivity of a material increases with a given temperature gradient. The more a material absorbs thermal energy, the more it acts as a thermal conductor, and also the total thermal resistance of the material is a function of the actual thickness of the material [9, 10]. However, various studies are conducted on preparation of multilayer fabric by using fibers such as cotton, wool, normal polyester and hollow polyester of varying fineness [11-13], but jute fiber is not reconnoitred as raw material for multilayer fabric. In this research work, jute fibre was used with an increased number of crimps to evaluate the thermal conductivity of the jute woven fabrics.

2 MATERIALS AND METHODS

2.1 Materials used

100% jute fibre was used for this research work. CBM and GCM were used to impart crimp in the sliver. Different yarns were produced with various numbers of crimps in the jute sliver. In CBM, crimps are irregular in size, shape and number. But in GCM, crimps are regular in size and shape. The number of crimps is also regular in per unit length. Woven jute fabrics were produced with plain structure by using these special yarns with 16 ends and 12 picks per inch in CCI loom. Sample details are given in Table 1.

Table 1 Sample details for different crimping method

Crimping method	No. of crimps per unit (2.54 cm)	Structure of fabric	Construction of fabric
Crimp Box	2.5	$\frac{1}{1}$ Plain weave	$\frac{6.3\ x\ 4.7}{210x210}$ X 45.72 cm
	3.5		$\frac{6.3\ x\ 4.7}{214x214}$ X 45.72 cm
	5.0		$\frac{6.3\ x\ 4.7}{298x298}$ X 45.72 cm
Gear Crimp	3.0		$\frac{6.3\ x\ 4.7}{218x218}$ X 45.72 cm
	4.0		$\frac{6.3\ x\ 4.7}{258x258}$ X 45.72 cm
	5.0		$\frac{6.3\ x\ 4.7}{311x311}$ X 45.72 cm

2.2 Methods used

Fabric porosity test was done by using PMI. Air permeability testing was carried out with Air Permeability Tester following ASTM D 737-96 standard. Fabric thickness and thermal conductivity testing was carried out with Fabric Touch Tester following ASTM D1776 standard. For every test, five observations or measurements were taken.

Fabric porosity test: Capillary Flow Porometer, Porous Materials Inc. PMI was used to test the fabric porosity. Machine parameters for the test were as: Tortuosity factor 0.715, fluid used Galwick, surface tension 15.9 dynes/cm, bubble point pressure 0.015 PSI. The density of the fabric was less, so bubble point pore diameter was considered for measuring the fabric porosity.

Factors affecting the test results: Flat textile materials like woven fabrics, are porous materials which permit the transmission of energy and substances and are hence interesting materials for different applications. Porosity of the woven fabrics depends on some factors such as type of material, warp and weft yarn count, warp and weft density, twist of yarn, type of weave, fabric weight and fabric thickness.

Air permeability test: Air permeability tester was used to test the air permeability of jute fabrics. Test specimen dimensions vary considerably depending on the requirements and are described in related section in the ASTM book of standards. Samples were conditioned using standard procedures. The recommended test conditions were 23±2°C as a standard laboratory atmosphere and 65±5% relative humidity. Supplied air pressure was 100 Pa and test pressure was 20 Pa. The test area for the test was 38 cm^2 and the test pressure was 100 Pa. A circle of fabric of the above area was clamped into the tester and through the use of vacuum; the air pressure is made different on one side of the fabric. Airflow will occur from the side with higher air pressure, through the fabric, to the side with the lower air pressure. From this rate of air flow, the air permeability of the fabric is determined.

Factors affecting the test results: Air permeability is a function of the thickness, tightness factor and porosity of the woven and knitted fabrics. The type of fabric structure, the design of weave, the number of warp and weft yarns per cm or inch, the amount of twist on yarn and the size of yarn and the type of yarn structures affected the air permeability of the woven fabric.

Thermal conductivity test: Fabric Touch Tester (FTT) [14] was used to measure the thermal conductivity of the fabric. It is used to measure simultaneously physical properties related to touch feels of textiles such as knitted and woven fabrics in four modules as follows. FTT can measure all these four modules including warp and weft directions as well as face and back sides with in five minutes. Thermal conductivity was tested using the ASTM D1776. The samples should be conditioned in the standard atmosphere for testing which are 21±1°C (70±20°F) and RH 65±2% for at least 24 hours prior to testing. The test samples should be cut in the shape of a letter 'L' with 200 mm arms in two sides. Face-side up specimens (A) should be tested first and then back-side up specimens (B) should be tested. Fabric thickness was also tested with this machine.

Factors affecting the test results: Thermal conductivity is not always constant. The rate of heat flow between the fabric and the skin is strongly determined by the fabric property, which is called thermal inertia. Thermal inertia is defined as the product of thermal conductivity and a combination of thermal conductivity of the fibre substance and that on the air contained within the fabric. The fibre properties also affected the thermal conductivity. The tightness factor of the fabric significantly affects thermal conductivity [15]. For tighter structures, the density of fibre and fabric increased, so that heat loss decreased. Finally, the main factors which affect the thermal conductivity of fabrics were fibre types, density of the material, moisture of the material and ambient temperature.

3 RESULTS AND DISCUSSION

Woven jute fabrics are widely used as technical and non-technical textiles like geo-textiles, composite materials and many diversified products for thermal issues. In this research work, some properties of jute woven fabrics were analysed to introduce jute fibre as thermal insulation material. Confidence intervals and standard deviation for all test results were also calculated to understand the better comparison of two crimp methods. Different test results of fabrics for various crimp methods and standard deviation are shown in Tables 2 and 3.

Table 2 Yarn count and different fabric properties for different number of crimps for various crimp methods

Crimping method	No. of crimps (2.54 cm)	Yarn count [tex]	Fabric thickness [mm]	Fabric porosity [µm]	Air permeability [cc/cm²/s]	Thermal conductivity [W/m/K]
Crimp box	2.5	210.9	1.454	565.2002	321.4	0.062
	3.5	214.1	1.606	439.2359	224.4	0.053
	5.0	298.9	1.616	177.1085	193.0	0.037
Gear crimp	3.0	218.6	1.622	539.3081	238.2	0.055
	4.0	258.9	1.634	219.3566	213.2	0.045
	5.0	311.6	1.688	95.6007	171.8	0.033

Table 3 Standard deviation for different test of fabrics for various crimp methods

Series	Type of test	Standard deviation CBM			Standard deviation GCM		
1	No of Crimp (2.5 cm)	2.5	3.5	5.0	3.0	4.0	5.0
2	Fabric thickness [mm]	0.0594	0.0611	0.0853	0.0712	0.0568	0.0277
3	Fabric porosity [µm]	0.4083	0.7475	0.5228	0.7871	0.6358	0.5807
4	Air permeability [cc/cm^2/s]	11.2606	8.1731	7.7136	5.2631	6.2209	5.7184
5	Thermal conductivity [W/m/K]	0.00130	0.00114	0.00158	0.00158	0.00187	0.00130

Fabric thickness

Fabric thickness is one of the important parameter or properties to determine some other properties of fabric like air permeability and thermal conductivity. When fabric thickness is greater, the thermal insulation property is also changed. In this research, it is found that fabric thickness is affected and improved by the increased number of crimps. Though all the technical parameters of the production process were remained same, the count of the yarn changed due to the increased number of crimps per unit length. Yarn count and the thickness of fabrics are changed due to the increased number of crimps per unit length (2.54 cm) and it is shown in the Table 2. It was found that thickness of fabric produced from GCM method is slightly higher than that of CBM, as more fibre is compressed in the yarn and yarn diameter is also higher for GCM [3].

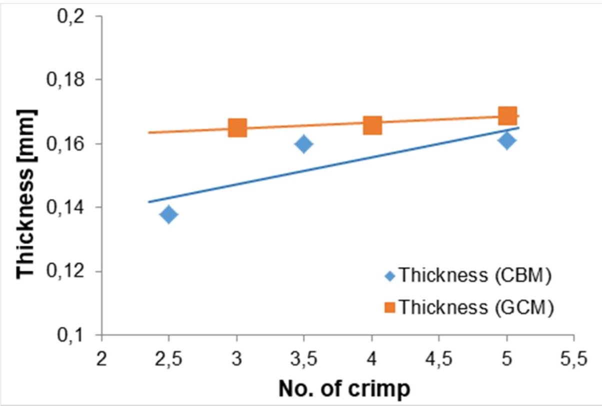

Figure 2 Thickness vs number of crimps for different crimp methods

It is seen from the Figure 2 that fabric thickness increased in every step of increased crimp and it is also exposed that thickness of fabric is slightly more for GCM than that of CBM. Confidence intervals are seen from Figure 3 and 4 for fabric thickness for various crimp methods and it is found that confidence intervals overlap which indicate the differences in values for thickness are hence statistically insignificant.

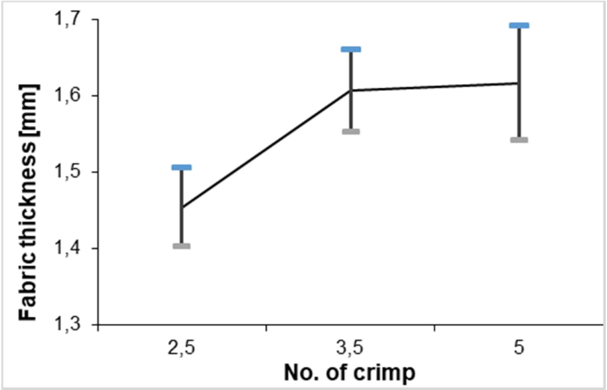

Figure 3 Confidence interval of fabric thickness of CBM with upper and lower limit

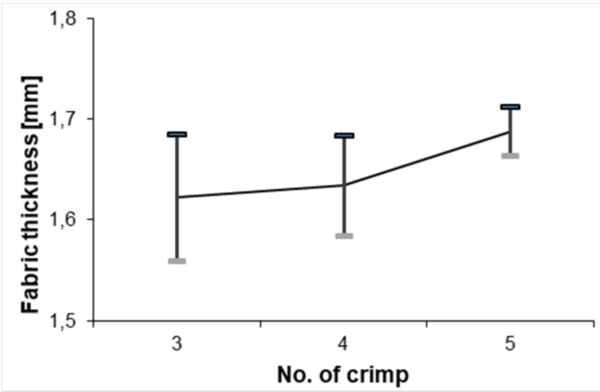

Figure 4 Confidence interval of fabric thickness of GCM with upper and lower limit

Fabric porosity

The porosity of the fabrics is the voids between weft and warp yarns in the fabrics. The pore diameter of the fabric defines the void space available in the fabric. The air and other fluids pass through the pores from the surface of the fabric. It is seen from the Figures 5, 6 and 7 that, porosity of the fabrics produced from GCM showed fabrics with lower pore size than that of CBM. As, yarn counts and fabric thickness were increased for more number of crimps, so pore size of the fabrics gradually becomes small, which affects the permeability of the fabrics.

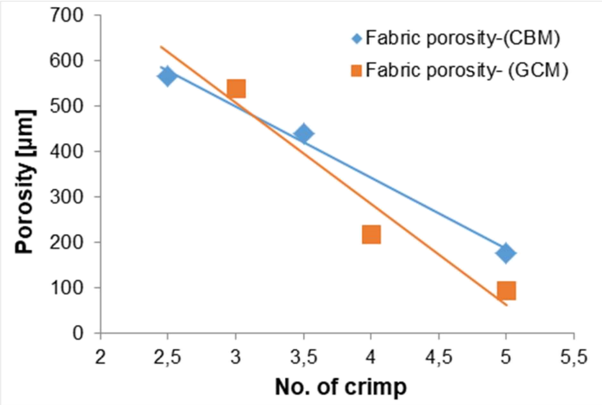

Figure 5 Porosity vs number of crimps for different crimp methods

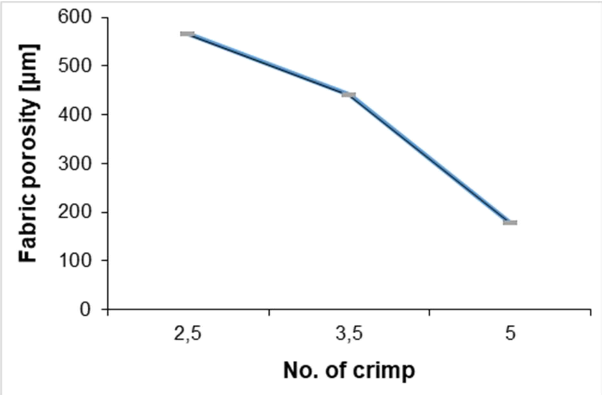

Figure 6 Confidence interval of fabric porosity of CBM with upper and lower limit

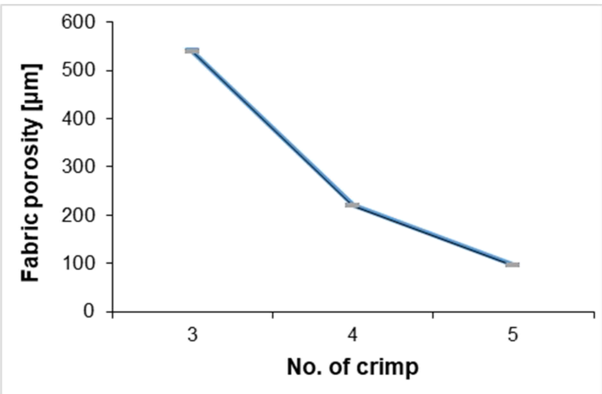

Figure 7 Confidence interval of fabric porosity of GCM with upper and lower limit

Air permeability

Air permeability property of fabrics is almost dependent on the fibre and yarn properties. It also depends on the fabric structure. The air is subjected to a higher resistance in fabrics with yarns produced with more number of crimps due to the smaller inter-yarn pores, more cohesion and more thickness of fibres. Figures 8, 9 and 10 show air permeability of fabrics produced from GCM and CBM. It is seen from the figures that air permeability of the fabric was decreased for higher number of crimps due to more diameter of yarn and more thickness of fabric. The porosity of the fabric also affects the air permeability and due to the smaller pore size of fabric having more crimp, hence the air permeability decreases gradually.

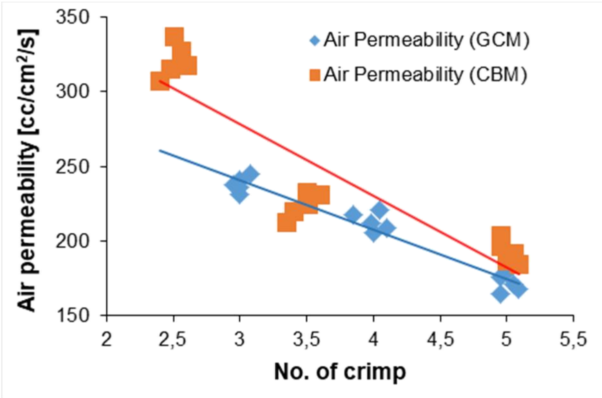

Figure 8 Air permeability vs number of crimps for different crimp methods

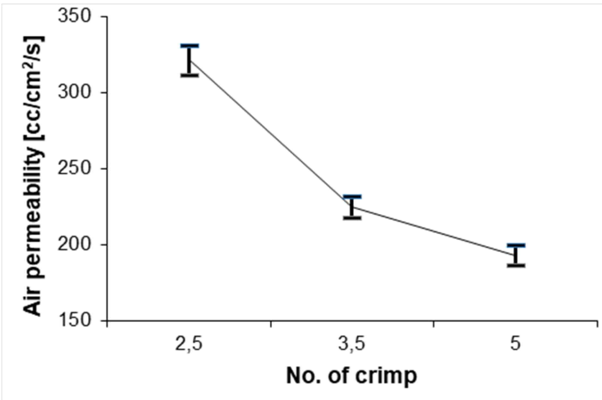

Figure 9 Confident interval of air permeability of CBM with upper and lower limit

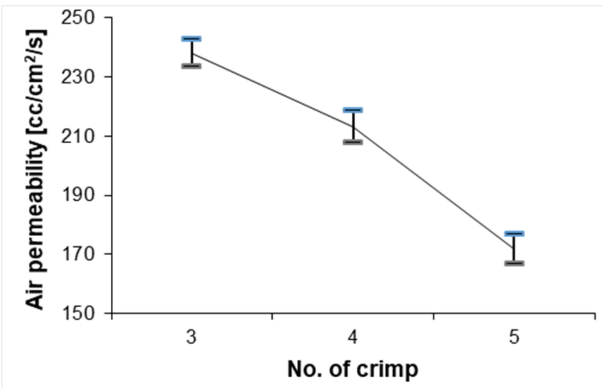

Figure 10 Confident interval of air permeability of GCM with upper and lower limit

Thermal conductivity

The mechanical properties of fabrics are depended on the physical properties of yarns and fabric structures. It is seen from the Figures 11, 12 and 13, where thermal conductivity decreases with the increase of number of crimps and for both cases, it decreased.

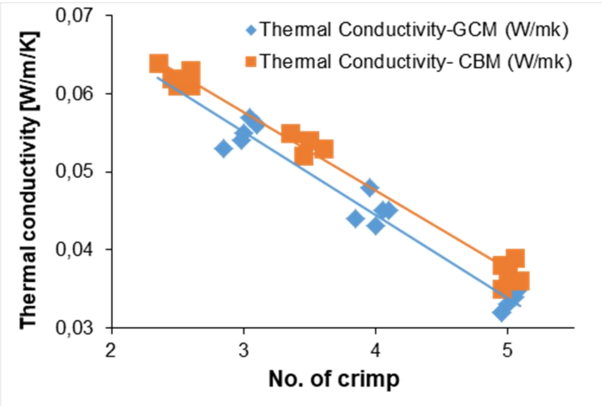

Figure 11 Thermal conductivity vs number of crimps for different crimp methods

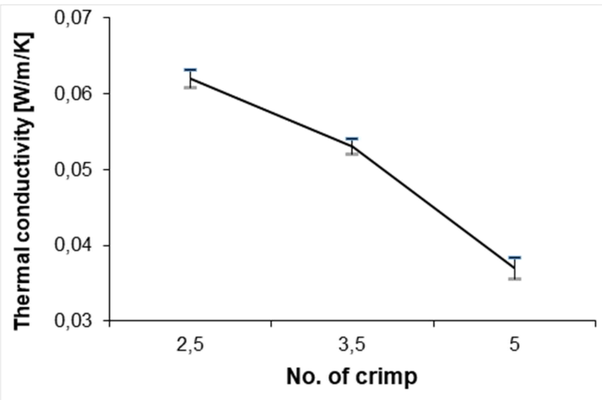

Figure 12 Confident interval of thermal conductivity of CBM with upper and lower limit

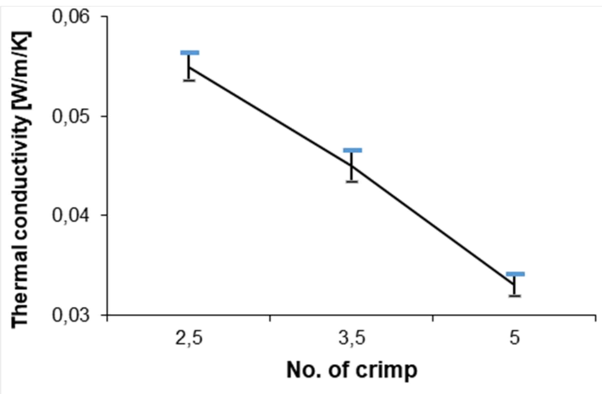

Figure 13 Confident interval of thermal conductivity of GCM with upper and lower limit

Because, crimp effect results in the increase in thickness and inter-fibre cohesion, which has lower thermal conductivity. Thus the thermal resistance of fabrics produced with higher number of crimps [16]. Thermal conductivity of fabrics with GCM is less than the fabrics produced with CBM. Comparatively, fabrics of GCM shows better insulation property than that of CBM, as GCM imparts more regular size and shape of crimps which accumulate more fibres in the unit length.

4 CONCLUSION

The jute is a very technical fibre and the demand of this fibre for diversified end uses is increasing day by day. Jute fibres can be used as winter cloth or as insulation layers for multilayer fabric. In this research, it is found that yarns produced from GCM is more bulky and thick compared to yarns produced from CBM because of symmetries and higher number of crimp. The porosity of the fabric becomes also lower for amplified cross-section of yarn. Moreover, the fabrics show better insulation, such as air permeability is decreased with the increased number of crimps per unit length. Again thermal conductivity of fabric is also decreased for higher number of crimps. Therefore it can be concluded that GCM exhibits better results for the fabric and this is a new era to use jute fibre as winter cloth for their better thermal insulation property.

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INFLUENCE OF ANTISTATIC POLYESTER FIBERS ON THE PROPERTIES OF COTTON AND POLYESTER SINGLE JERSEY KNITTED FABRICS

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***Abstract**: In this research, the influence of the antistatic polyester fibers containing carbon black on the comfort properties of 100% and blended cotton as well as on 100% and blended polyester single jersey knitted fabrics was evaluated. The research results revealed that the behavior of the investigated knitted fabrics was dependent on their structure and mechanical characteristics. The electrical resistance of knitted fabrics decreased significantly due to the use of 4% antistatic polyester fibers. The electrical resistance of the pure and blended cotton knitted fabric was lower than that of the pure and blended polyester knitted fabrics. Antistatic polyester fibers positively influenced the air permeability of the polyester knitted fabric. The air permeability of 100% and blended cotton fabrics was approximately 3.5 times compared to both 100% and blended polyester fabrics, respectively. The carbon black polyester fibers influenced the decrease in thermal resistance, the increase in vapor permeability, and the minor increase in vapor resistance of both cotton and polyester knitted fabrics. Thermal resistance was lower, water vapor resistance was significantly higher, and relative water vapor permeability was slightly lower for the cotton and cotton/antistatic polyester knitted fabrics than for the polyester and polyester / antistatic polyester knitted fabrics, respectively. Therefore, the research results revealed that the presence of 4% antistatic polyester fibers in cotton and polyester knitted fabrics positively influenced their antistatic behavior and improved or almost did not alter their comfort properties.*

***Keywords:** knitted fabric, polyester, cotton, black carbon, antistatic properties, comfort properties.*

1 INTRODUCTION

Textiles are most commonly used to cover the human body. However, the responsible and motivated choice of textile fabric for a particular garment aiming to fulfil its required functions taking into account also both environment conditions and wearing intensity is a very complicated process. Therefore, textiles suitable for fulfilling specific functions of active leisure or sportswear are only those manufactured from innovative microfibers with complicated knitted structures such as double or three layers [1] and with finishes such as those that provide antistatic properties, etc. Donciu [2] investigated polyester and cotton fabrics knitted from yarns with copper and stainless steel core conductive fibers to approve their suitability for protective garments. Hebeish et al. [3] developed the new antistatic non-woven and weft knitted materials with conductive fibers. They concluded that the achieved specific properties of the weft knitted fabrics confirm their suitability for the manufacture of protective garments, i.e., for clean-room clothing, which should create a barrier for the generation of static charges.

Donciu [4, 5] investigated integral bilayer knit fabrics with carbon-based fibers and determined that the outer layer that was open to the working environment was mainly dissipative and capable of ensuring protection against electrostatic energy transfer to the working environment. However, the inner layer that contacted the human body became mainly conductive and ensured the controlled conductivity of the accumulated electrostatic charge. The antistatic properties of knit fabrics made from two types of modacrylic knitted fabrics containing antistatic PET fibers were investigated by Kim and Kim [6]. The results obtained were compared with those of the antistatic properties of cotton fabric by rubbing with wool and cotton fabrics attached to the measuring apparatus. Excel® knit fabric with modacrylic was observed to show better antistatic properties [6]. Kwon, et al. [7] showed that poly (ethylene terephthalate) (PET)/lyocell blended textiles had better antistatic property than the 100% polyester and lyocell fabrics. Seshadri and Bhat [8] determined that polypyrrole incorporated into cotton fabrics improved their antistatic and antimicrobial properties.

Abdel Halim et al. [9] proposed permanent fixation of chitosan or monochlorotriazinyl-β-cyclodextrin for the finishing of cotton/polyester and polyester fabrics. In this way, they determined that the suggested finish improved the fabric's ability to better absorb moisture from air and water. Furthermore, it was determined that increased humidity of the fabric improved its electrical conductivity and antistatic properties. Pasta, et al. [10] determined that dislocated carbon nanotubes on the surface of cotton fibers created an electrically conductive network. Previous researches [11] also determined that electrical resistivity decreased and thermal conductivity increased due to the coating of cotton fabrics with carbon black particles. Hu, et al. [12] determined that the mixture of carbon black, dispersing agent, and PBT leads to the desirable conductivity of the fibers. Moreover, they also stated that fabrics manufactured from fibers with the core/sheath configuration could be successfully used for different applications within the textile industry. Thus, an overview of the published research showed that the antistatic properties of textiles can be improved most commonly by applying different finishes for their treatment. However, the antistatic properties created in this way showed a tendency to deteriorate due to textile laundering.

Today, sportswear development is directed towards enhancing their functional properties and suggesting optimal decisions about how to integrate electronic devices within a garment structure to monitor or increase its comfort properties. However, due to the static electricity of synthetic knitted fabrics, a negative impact on the functionality and stability of smart clothing during its wear process may occur. Thus, it is necessary to improve their antistatic properties. Furthermore, the literature review showed that the analyzed antistatic fibers were more suitable for protective clothing, etc., but not for leisure or sportswear. Thus, the objective of the current research was to investigate the influence of carbon black-containing antistatic polyester fibers on the structure, antistatic and comfort properties of cotton and polyester single jersey knitted fabrics. In this investigation, the differences between the properties of newly developed cotton and polyester knitted fabrics were also highlighted.

2 EXPERIMENTAL WORK

Antistatic polyester fibers were produced from the mixture of 0.5% carbon black and melted polyethylene terephthalate applying the fiber extrusion technique (Table 1). Polyester fiber, specifically poly(ethylene terephthalate) (PET) fiber, is the largest volume of synthetic fiber produced worldwide. Later, from the filaments produced, the staple fibers were cut. Commercially available cotton and polyester fibers produced by Masood Textile Mills Ltd. (Pakistan) were chosen to also manufacture knitted fabrics. The characteristics of the fibers involved in this research are summarized in Table 1.

Table 1 Characteristics of the fibers

Code	Fiber	Density [g/cm^3]	Linear density [dtex]	Length [mm]
CO	cotton	1.54	1.77-1.84	28
PES	polyester	1.39	1.3	38
PET^C	antistatic polyester	1.40	1.3	38

From the prepared fibers, CO, CO/PET^c, PES and PES/PET^c yarns of the same count 24.6 tex (24 Ne) were twisted. Their characteristics are presented in Table 2.

Before testing, the fibers′ samples were conditioned and all tests were performed under standard atmospheric conditions: 20±2°C temperature and 65±2% relative humidity for 24 hours as required according to the standard ISO 139 [13].

Tensile strength and elongation of the manufactured yarns were determined using the Uster® Tensorapid measurement system according to the standard ASTM D 2256 [14]. The relative measurement errors of the mean tensile strength values, calculated from the five tested samples, in each sample group varied from 1.87% up to 5.09%, and for the yarn elongation from 2.46% up to 7.69%. The twist per inch of the yarns was determined according to the ISO 17202 standard [15].

A simple and widely used single jersey pattern was chosen to manufacture the knitted fabrics. In this research, the circular weft knitting machine of diameter 30 and the machine gauge 20 (Fukuhara, Japan), with the needles 1860 and the feeders 90, was used. The stitch length of 3.2 mm was chosen to knit all investigated fabrics.

Table 2 Yarns characteristics

Yarn code	Composition	Diameter [mm]	Twist [inch^{-1}]	Tensile strength [N]	Elongation [%]
CO	100% cotton	0.255	20.8	3.39	4.29
CO/PET^C	96% cotton 4% antistatic polyester	0.254	21.6	3.73	5.92
PES	100% polyester	0.313	13.8	7.16	10.97
PES/PET^C	96% polyester 4% antistatic polyester	0.268	13.2	7.50	11.11

Table 3 Characteristics of the knitted fabrics

Fabric code	Yarn code	Thickness [mm]	Area density [g/m^2]	Density [cm^{-1}]		Loop length [mm]	Tightness factor	Porosity
				Wale count	Course count			
M1	CO	0.80	186	13	18	4.2483	1.17	0.90
M2	CO/PET^C	0.84	193	13	19	4.2316	1.17	0.89
M3	PES	0.60	152	10	16	5.2146	0.95	0.93
M4	PES/PET^C	0.59	153	10	16	4.4649	1.11	0.94

The samples of the knitted fabrics′ were washed according to the standard test method AATCC 135 [16] in aqueous detergent at 40°C temperature. After the washing, the knitted fabrics′ samples were tumbler dried and placed on the racks for 48 h of relaxation. The characteristics of the knitted fabrics manufactured are given in Table 3.

Fabric thickness was measured with the UNI-THICKNESS LAB 1880 meter (MESDAN, Italy) according to the ASTM D 1777 standard [17] applying a pressure of 1 kPa in a 20 cm^2 area. The thickness of each sample was measured at five different places and the mean value of the thickness for each knitted fabric was calculated. The relative errors of the measured thicknesses varied from 1.19% up to 1.69%.

The area density of the investigated knitted fabrics was determined according to the standard ASTM D 3776 [18], and the course and wale counts per cm according to the standard ASTM D 8007 [19]. The coefficient of variation did not exceed 5%.

Peirce [20] stated that for a normal structure, the length of the loop L depends only on the thickness of the yarn d. Thus, the loop length of the investigated knitted fabric was calculated according to equation (1):

$$L = 16.66\mathrm{d} \tag{1}$$

The tightness factor (TF) of the knit fabrics was calculated according to equation (2):

$$TF = \frac{\sqrt{T}}{L} \tag{2}$$

where: T is the count of yarns [tex]; L is the loop length of the knit fabric [mm].

The porosity P of the knitted fabrics was calculated according to equation (3):

$$P = 1 - \frac{(\rho_b)}{(\rho_s)} \tag{3}$$

where: ρ_b is the density [g/cm^3] of the knitted fabric (fabric weight in g/cm^2 and fabric thickness in cm); ρ_s is the fiber density [g/cm^3].

The influence of the antistatic polyester fibers produced (PET^C) on the antistatic properties of the cotton and polyester knitted fabrics involved in this research was evaluated on their electrical resistance R_m. This parameter was measured using the 4339B high resistance meter (Ohmmeter) manufactured by Hewlett Packard. Electrical resistance measurements were carried out at the test voltage setting V_s of 100 V and the electrical current I_M of 10 mA. Readings were recorded after 60 s of electrodes′ placement on a knitted fabric sample. The mean values of the measured resistance R_m were calculated from five samples in each sample group. The coefficient of variation ranged from 0.25% up to 0.53%.

To evaluate the comfort properties of the knitted fabrics produced, we analyzed the thermal resistance R_t, the relative water vapor permeability p_{wv}, *the* water vapor resistance *Ret,* and the air permeability R were analyzed.

The relative permeability of the water vapor p_{wv} in percent and the water vapor resistance R_{et} in m^2·Pa/W were determined applying the non-destructive method realized with PERMETEST (Sensora Instrument, Czech Republic) [21] according to the ISO 11092 standard [22]. Five samples were tested in each fabric sample group. The coefficient of variation ranged from 1.0% up to 2.0%.

The relative water vapor permeability p_{wv} [%] of the knitted fabrics tested was calculated according to equation (4) [21]:

$$p_{wv} = (u_s/u_o).100 \tag{4}$$

where: u_s is the heat loss of the free wet surface without a fabric sample; u_o is the heat loss of the wet measuring head (skin model) with a tested fabric sample.

The water vapor resistance R_{et} [m^{2}Pa/W] was calculated according to equation (5) [21]:

$$\begin{aligned} R_{et} &= (p_{wsat} - p_{wo}).\left(\frac{1}{u_s} - \frac{1}{u_o}\right) = \\ &-C.(100 - \varphi).\left(\frac{1}{u_s} - \frac{1}{u_o}\right) \end{aligned} \tag{5}$$

where: p_{wsat} is the partial saturation pressure of vapor valid for the temperature of the air in the measuring laboratory (T_o=20°C) [Pa]; p_{wo} is the partial water vapor in the laboratory air [Pa]; φ is the relative humidity [%] (φ=6%). The constant C was determined by applying the calibration procedure. A special hydrophobic polypropylene (PP) reference fabric was used for this purpose.

Five samples were tested in each fabric sample group to determine thermal resistance. The coefficient of variation ranged from 1.05% up to 3.19%.

The thermal resistance R_t [m^2K/W] was calculated from the equation (6) [21]:

$$R_t = K.(t_H - t_o).\left(\frac{1}{U_1} - \frac{1}{U_o}\right) \quad (6)$$

where: t_H is the measurement head temperature of the measuring head equal to 32-35°C; U_s and U_o represent the steady state electrical voltages shown on the digital display, for the case of measurement with and without the sample [21]. The sensitivity constant K was determined by applying the calibration procedure [21].

The air permeability test was carried out using the M021A air permeability tester with a test head of 100201 of 20 cm^2 manufactured by SDL ATLAS according to the ISO 9237 standard [23]. The test was repeated in ten places for each fabric sample. The coefficient of variation ranged from 0.19% up to 0.45%. Later, the mean air rate q_v in l/min was calculated for each fabric sample. The air permeability R was calculated according to equation (7):

$$R = \frac{q_v}{A}.167 \quad (7)$$

where: q_v is the air rate [l/min]; and A is the work area of the fabric specimen [cm^2].

3 RESULTS AND DISCUSSION

The determined characteristics of the yarns used for the manufacture of cotton, cotton/antistatic polyester, polyester, and polyester/antistatic polyester plain jersey knitted fabrics are presented in Table 2. By analyzing them, it can be seen that the tensile strength of cotton and polyester yarns increased after insertion of antistatic polyester fibers into their structure. Yang et al. [24] also stated that the use of carbon nanotubes increased the breaking strength of cotton yarns. The use of antistatic polyester fibers also increased the elongation of both cotton/antistatic polyester and polyester/antistatic polyester yarns compared to 100% cotton and 100% polyester yarns, respectively. It is worth mentioning that these mechanical parameters of the polyester and polyester/antistatic polyester yarns were almost two times higher than those of the cotton and cotton/antistatic polyester fibers, respectively. 100% and blended cotton yarns had the highest twist factor and smaller diameters compared with ones of 100% and blended polyester yarns, respectively (Table 2).

Analysis of the characteristics of the manufactured knitted fabrics (Table 3) has shown that the higher fiber density values (Table 1), as well as the width and course counts of 100% and blended cotton knitted fabrics, influenced their higher area densities compared to those of 100% and blended polyester knitted fabrics, respectively. The higher densities of the wale and the course of cotton and cotton/antistatic polyester knit fabrics could be influenced by the ability of cotton fibers to readily absorb moisture and susceptibility to shrinkage. The area density of the knitted fabrics involved in this research was linearly related to their thicknesses. That is, the thinner fabrics demonstrated their lower area densities. This observation is relevant as the thickness of the fabric has a significant influence on its insulation properties, air permeability, etc. The small decrease in area density and the increase in porosity P of cotton/antistatic polyester knitted fabric were determined compared to those of 100% cotton fabric (Table 3).

In this research, the impact of antistatic polyester yarns containing carbon black on the electrical resistance R_m and comfort properties of single-jersey cotton and polyester knitted fabrics was studied. Furthermore, the comfort properties were evaluated by analyzing their four relevant characteristics: thermal resistance R_t, relative water vapor permeability p_{wv}, water vapor resistance R_{et} and air permeability R. The summary of these properties of the single jersey knitted fabrics investigated is given in Table 4.

Air permeability R is considered as the ability of textiles to pass air through their structure at a pressure difference depending on the type of knit fabric. It is also known from the literature that porosity is the dominant factor influencing the air permeability of knitted fabrics. Therefore, as expected, the linear relationship between air permeability and porosity P of the investigated knitted fabrics was determined (Figure 1). Thus, the increase in porosity P of the knitted fabrics also influenced the increase in air permeability R. Carbon black used to enhance the antistatic properties of the knitted fabrics tested in this investigation positively influenced the air permeability R of the polyester/antistatic polyester knitted fabric, despite the fact that its tightness factor TF was higher compared to that of 100% polyester fabric (Table 3).

Table 4 Properties of the fabrics: R_m – electrical resistance; R – air permeability; R_t – thermal resistance; p_{wv} – relative water vapour permeability; R_{et} – water vapour resistance

Fabric code	R_m [Ω]	R [mm/s]	R_t [m^2K/W]	p_{wv} [%]	R_{et} [m^2Pa/W]
M1(CO)	3.44×10^{12}	450	0.019	60	2.65
M2(CO/PET^C)	2.76×10^{12}	495	0.017	62	2.70
M3(PES)	3.72×10^{13}	1655	0.028	66	1.70
M4(PES/PET^C)	3.41×10^{12}	1660	0.027	68	1.88

Analysis of the air permeability of the tested knitted fabrics (Table 4) has shown that the air permeability of 100% cotton and blended cotton fabrics was found different. Cotton blended with antistatic polyester fabric showed high air permeability than 100% cotton. It was supposed to be due to presence of antistatic polyester fiber in the blend that caused high porosity. Similar trend of an increase in air permeability observed in 100% polyester and blended polyester fabric.

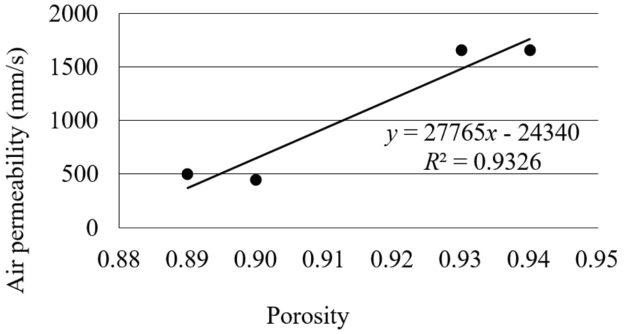

Figure 1 Dependence between air permeability *R* and porosity *P* of knitted fabrics

According to the resistance to standard [22], the resistance to water vapor R_{et} is defined as the difference in water vapor pressure between the two faces of a knit fabric divided by the resulting evaporative heat flux per unit area in the direction of the gradient. From the results presented in Table 4, it can be seen that the water vapor resistance R_{et} of cotton and cotton/antistatic polyester knitted fabrics was significantly higher than one of the polyester and polyester/antistatic polyester fabrics. This may be explained by the higher absorption and thickness of the 100% and blended cotton fabrics compared to ones of the 100% and blended polyester fabrics. A minor increase in the vapor resistance of cotton and polyester knitted fabrics was observed as a result of the use of antistatic polyester fibers in their structure. Similar tendencies were also confirmed in previously published research, which stated that air permeability and thermal and water vapor resistance depended on the structural parameters of the fabrics.

In the current investigation, it was determined that the resistance to water vapor R_{et} decreased when the porosity of the fabric *P* increased (Figure 2a) and showed a tendency to increase due to the increase in the *TF* tightness of the fabric (Figure 2b).

Relative water vapour permeability p_{wv} was found slightly higher for cotton blended fabrics than 100% cotton and similarly for polyester (blended polyester > 100% polyester) knitted fabrics (Table 4). Thus, the embedded carbon black polyester fibers influenced the increase in the vapour permeability p_{wv} of 100% cotton and 100% polyester knitted fabrics. Supposedly, it occurred because of the small diameter of antistatic polyester fibers compared to cotton fibers, which caused high porosity leading to high vapor permeability.

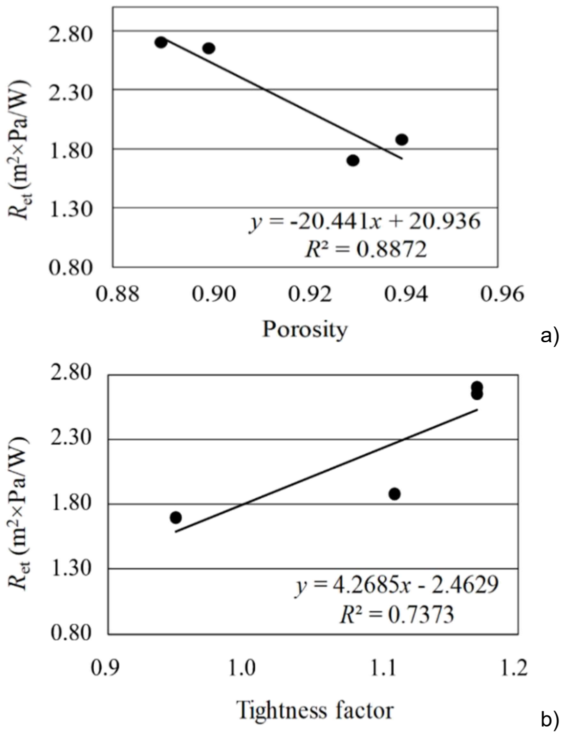

Figure 2 Dependence of the water vapor resistance R_{et} on the porosity *P* (a) and the tightness factor *TF* (b) of the knitted fabrics

Thermal resistance R_t is defined as the temperature difference between the two faces of a knit fabric divided by the resulting evaporative heat flux per unit area in the direction of the gradient [21]. The thermal resistance R_t is generally related to the thickness of the fabric, but the composition also influences the thermal resistance of the fabrics. The thermal resistance R_t of the cotton and cotton/antistatic polyester knitted fabrics was lower than that of the polyester and polyester/antistatic polyester knitted fabrics. Carbon black influenced the decrease in thermal resistance R_t of both cotton and polyester knitted fabrics (Table 4). It was supposed that due to the inherent nature of carbon being conductive that there was more heat conductance in the material. It was also previously determined that the thermal conductivity of carbon was high and the thermal resistance low, and the covering of the cotton fabric by carbon also influenced the increase in its thermal conductivity.

In this investigation, the electrical resistance R_m of the investigated knitted fabrics was measured to predict their antistatic properties. From the results presented in Table 4 it can be seen that the electrical resistance R_m of 100% polyester knitted fabrics was highest due to the non-conductive nature of the polyester fibers. Therefore, they tend to accumulate electrical charge for a long time. The electrical resistance of 100% cotton knitted fabric and blended polyester knitted fabrics was lower than that of 100% polyester knitted fabrics. Furthermore, 4% of antistatic polyester fibers embedded in the structures of polyester and cotton fabrics significantly decreased their electrical resistance R_m, as previously determined similarly. Thus, the research results showed that the presence of 4% antistatic polyester fibers in cotton and polyester knitted fabrics positively influenced their antistatic behavior. Telipan et al. [25] and Varnaitė Žuravliova et al. [26, 27] stated that textiles having 10^{10}-10^{12} Ω vertical resistance could be defined as antistatic textiles.

Thus, in the current research, it was shown that the use of antistatic polyester fibers for the purpose of reducing the static electricity of knitted fabrics improved or almost did not alter the comfort properties of the knitted fabric.

4 CONCLUSION

In the current research, the influence of antistatic polyester fibers containing 4% carbon black on the antistatic and comfort properties of 100% and blended cotton as well as on 100% and blended polyester single jersey knitted fabrics was evaluated. The research results revealed that the behaviour of 100% and blended cotton fabrics was different from one of 100% and blended polyester knitted fabrics. The tensile strength and elongation of the cotton and polyester yarns used to manufacture knitted fabrics were determined to increase due to the presence of antistatic polyester fibers in their structure. These mechanical characteristics of 100% and blended polyester yarns were almost two times higher than ones of 100% cotton and cotton/antistatic polyester yarns, respectively. The research results also revealed that the higher fiber density and the wale and course counts of 100% and blended cotton knitted fabrics influenced their higher area densities compared to those of 100% and blended polyester knitted fabrics, respectively. A small decrease in area density and an increase in porosity of cotton/antistatic polyester knitted fabric were determined compared to those of 100% cotton fabric.

The antistatic properties of the knit fabrics involved in this investigation were evaluated on the basis of their electrical resistance. The electrical resistance of 100% cotton knit fabric and blended polyester knit was lower than that of 100% cotton knit fabrics and blended polyester knit, and the use of 4% antistatic polyester fibers in polyester and cotton fabrics significantly decreased their electrical resistance. The carbon black used to enhance the antistatic properties of the fabrics positively influenced the air permeability of the polyester/ /antistatic polyester knitted fabric. The air permeability of 100% and blended cotton fabrics was approximately 3.5 times compared to both 100% and blended polyester fabrics, respectively.

The thermal resistance of the cotton and cotton/antistatic polyester knitted fabrics was shown to be lower than that of the polyester and polyester/antistatic polyester knitted fabrics. Carbon black influenced the decrease in thermal resistance of both cotton and polyester knitted fabrics. The relative permeability of the water vapour was slightly higher for 100% and blended polyester knitted fabrics mixed compared with those of 100% and blended cotton fabrics, respectively. Also, the embedded carbon black influences the increase in the vapour permeability of the 100% cotton and 100% polyester knitted fabrics. The water vapor resistance of cotton and cotton/antistatic polyester knitted fabrics was significantly higher than that of polyester and polyester/antistatic polyester fabrics. A minor increase in the vapor resistance of cotton and polyester knitted fabrics was observed as a result of the use of antistatic polyester fibers in their structure. The resistance to water vapor decreased as the porosity of the fabric increased and showed a tendency to increase as a result of an increase in the tightness of the fabric.

Therefore, the research results showed that the presence of 4% antistatic polyester fiber in cotton and polyester knitted fabrics positively influenced their antistatic behavior. Furthermore, it was shown that the use of antistatic polyester fibers for the purpose of reducing static electricity of knitted fabrics improved or almost did not alter the comfort properties of the knitted fabric investigated.

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PECULIARITIES OF FUNCTIONING AND DIAGNOSTICS OF CROSS-SECTORAL ECONOMIC LINKS OF THE TEXTILE INDUSTRY OF UKRAINE

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Abstract: *The analysis of cross-sectoral links and their comparative assessments identified the main problems of development of the textile industry of Ukraine. These include: high dependence on imported raw materials and components, low price competitiveness of Ukrainian textile industry products in the domestic market, the concentration of a significant part of production on the production of toll raw materials, imports of used clothing and footwear, cross-sectoral imbalance of Ukrainian textile industry. In particular, it is determined that the products of the textile industry in general, consumed by the Ukrainian economy are almost 60% covered by imports. Products used by the textile industry in their activities (costs) are covered by imports by a total of 49%. Ways to solve the identified problems and, thus, to optimize cross-sectoral linksships are proposed.*

Keywords: *textile industry, export, import, cross-sectoral links.*

1 INTRODUCTION

Today, the textile industry is one of the basic strategic segments of the Ukrainian economy, which provides 5% of budget revenues and 2.6% of merchandise exports, and therefore has significant potential for further development. In Ukraine, there are more than 2.3 thousand enterprises (small and medium) of the textile industry, which employ about 85 thousand workers, and the volume of their products reaches 0.81 billion USD. A production is mainly concentrated in medium-sized enterprises (accounting for 14% of the total number of textile enterprises) – they sell ≈80% of products, while in 2014 small enterprises (or 86%) account for only ≈20% of products.

In Ukraine, textile, clothing, knitwear, leather goods, fur and other light industry industries are gradually increasing their capacity and are actively developing. Thanks to high-quality tailoring and democratic prices, fabrics and clothes of domestic producers are actively gaining popularity not only in the domestic but also in the international market. However, despite the rather dynamic development of this type of processing industry, its operation is accompanied by a number of problems. First of all, it is unequal conditions of competition in the domestic market, instability of tax legislation, outdated mechanism of product safety control. In addition, there is low productivity, shortage of qualified personnel, limited choice of raw materials and others. Most Ukrainian companies still do not export finished national products, but only provide services.

Cooperation with European partners is based on the implementation of certain labour-intensive operations, while procurement, sales, design and logistics are performed by the customer. Under such conditions, the delineation of promising directions of development of light industry in Ukraine and substantiation of effective ways to stimulate such development should be based on detailed analytical macro-level studies of trends in the dynamics of this segment of the national economy, in particular, compared to EU member states.

The aim of the article is to identify the problems of development of the textile industry of Ukraine on the basis of the analysis of its intersectional relations and comparisons with individual EU countries.

A relatively small number of studies have been devoted to solving the problems of light industry production in Ukraine over the last 10 years. Thus, in [1-3], the existence of significant, however, unrealized potential for the development of domestic light industry is analytically substantiated. In [4, 5], the analysis of the domestic market of light industry products in Ukraine was carried out, as well as the main problems of its development were identified, in particular, the high degree of “shadowing”, the growth of imports of used clothes and shoes, etc. These studies focus on the lack of necessary economic and regulatory conditions in Ukraine for the competitive development of light industry. Despite the significant market prospects, as well as the socio-economic significance of this segment of industry, Ukraine has not yet undergone reforms that would help address the issues identified. In addition, in recent years in the domestic scientific space there has been no thorough, comprehensive scientific and analytical research that would reflect current trends and prospects for the development of Ukrainian light industry in the context of global economic trends.

The textile industry of other countries is also going through a difficult period, in particular those in which this industry was once successful. Thus, in [6] it is noted that as one of the oldest industries in the world, textile industry in Serbia (and Yugoslavia) was very developed and carried a lot of importance in GDP creation, absorption of the unemployed workers (especially women), and exports income. Recently, however, the country's large textile enterprises have been liquidated, and the activities of those that remain depend heavily on imports. Similar processes are taking place in Romania, which was among the leaders in the EU in the production of textile products. However, with the rising cost of labour in the country began to lose its position in the textile market. This, as well as the dependence of the development of the Romanian textile industry on lohn production, is discussed in [7, 8].

The Polish textile industry is also experiencing a number of similar problems. This is a problem of outsourcing, dependence on imports, and low wages in the industry [9]. In addition, important issues for the Polish textile industry are the issues of environmental safety and efficiency of this sector of industry [10].

Almost similar problems in the functioning of industry are typical for Armenia. These are, first of all, low labour productivity, dependence on imports and foreign investment, low level of manufacturability and innovation of production [11].

Kazakhstan's textile industry also faces similar challenges. This includes dependence on imported raw materials, high export orientation, but at the same time a low level of coverage of the domestic market [12].

The textile industry of these and other countries faces similar domestic problems. First of all, these are unsatisfactory economic and regulatory conditions for the development of national textile industries focused on the production of higher value-added products and the domestic market. The potential of these countries in the production of raw materials for textile production is also not stimulated.

It is important to note that the mentioned problems of development of the textile industry are not narrow branch features, and difficult challenges for all economy of the countries. And this is explained by the fact that the textile industry ideally cooperates with many sectors of the economy. This includes agriculture, chemical, engineering, transport, trade, science and education, culture, consumer market. Failure to solve problems in the textile industry causes a number of problems in related sectors and the economy as a whole.

Liberal approaches in the situation of unequal and non-competitive conditions that have developed in the textile industry of many countries threaten the economic interests of countries. Therefore, the unsatisfactory development of the textile industry should be considered as a set of problems of many sectors of the economy.

2 RESEARCH METHOD

The results of this study are a continuation of a number of author's studies focused on the study and solution of problems of industrial sectors of the economy through the analysis, evaluation and optimization of their cross-sectoral links [13-16]. The key feature and advantage of this and the mentioned author's researches is that the analysis and estimation of activity of industrial sectors is carried out in the context of studying of structures of their intermediate, final and general consumption. This makes it possible to analyse and evaluate the two main activities of any sector of the economy: consumption and use (input). The study of the first direction (consumption) shows for which types of economic activity the studied sector of industry (in this case textile) produces products. In other words, the sectors of the economy that use the products of the textile industry in their activities are identified. This takes into account their shares in the products of the textile industry of intermediate, final and total consumption of the country's economy in terms of domestic and imported components. The study of the second direction shows the structure of intermediate consumption in terms of economic activities used in the textile industry. It is necessary to calculate the share of costs (intermediate consumption products) of the textile industry covered by imports. The calculated and analysed structures of consumption and use (input) of the textile industry of the studied country (in the case of Ukraine) are compared with similar structures of a similar country (Poland) and reference countries in this sector (Italy and Germany). As a result of these comparisons, the problem areas of the textile industry and related sectors of the economy are identified. The source of information for the analysis of cross-sectoral links was the data of the tables "input - output" [17].

3 RESULT

Since Ukraine’s independence, textile output has declined significantly, accounting for only about 22% of 1990 output in 2001. This drop in output was, in particular, caused by a significant reduction in household incomes and a sharp decline in government orders for professional clothing.

In 2008, the output of the textile industry of Ukraine reached almost 60% of the level of 1990, but in the following years again fell sharply, primarily under the influence of the global financial crisis (Figure 1).

Further dynamics of production in this segment of the national economy was unstable: a decline in 2014-2016 (to the level of 2004) and stable growth in the next two years. In 2018, the volume of sold products of the textile industry of Ukraine is 93.00% the level of 2006.

As a result of the negative dynamics of textile industry production, Ukraine lagged behind this indicator, in particular, from Poland 6 in times, from Germany – 21 in times, and from Italy (the leader among EU countries in this segment of the processing industry) – 73 in times. In 2017, Ukraine ranked the 21st among EU countries in terms of textile output [17].

The textile industry of Ukraine (both ITA and DEU) specializes in the manufacture of final consumption goods, the share of which in the structure of output (by consumption segments) in 2017 was 60.76%, and in 2015 even reached 82.90% (Figure 2). However, despite this specialization, the domestic market demand for textile products was covered to 87.22% of imports.

One of the main reasons for the high dependence of the national economy on imports of textile products everywhere to replace the textile industry is the low level of provision of domestic industries with their own intermediate products. At the same time, it is necessary to state the tendency to a certain decrease in the import dependence of the national economy on all segments of consumption of textile products. Thus, in 2017, compared to 2013, the share of imports in general consumption of textile products decreased by 11.87 pp (here and there - percent point), in particular in the final – at 2.75 pp., and in the intermediate – by 6.80 pp. (Figure 3).

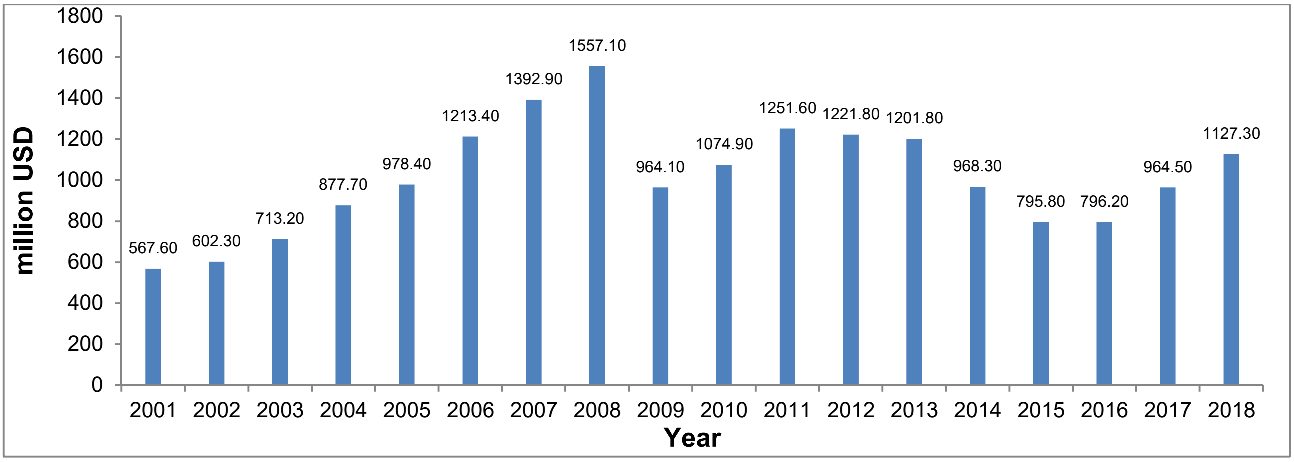

Figure 1 Volume of sold products of textile industry of Ukraine [million USD], Source: elaborated by the authors based on [18]

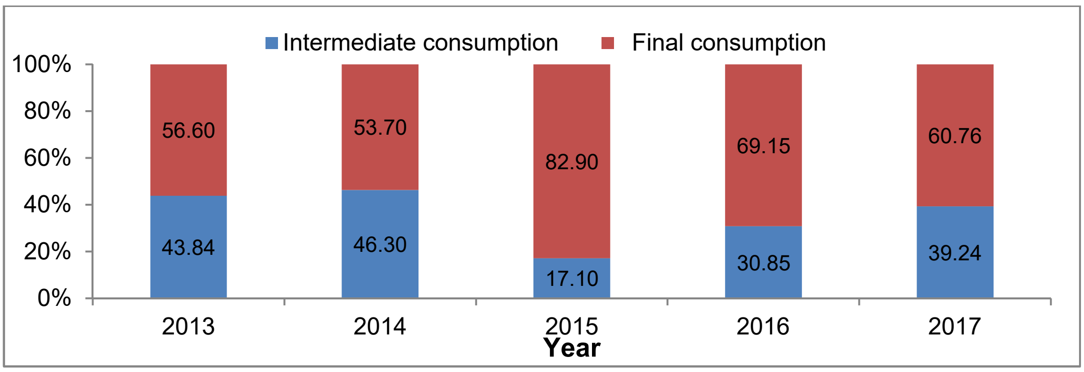

Figure 2 Structure of textile industry output in Ukraine (by consumption segments), Source: elaborated by the authors based on [19]

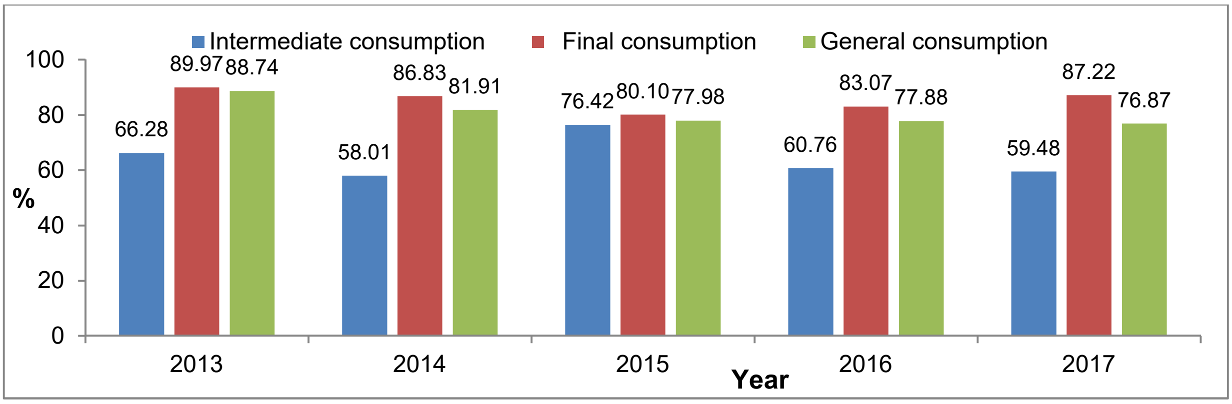

Figure 3 Share of imports in the consumption of textile products in Ukraine, Source: elaborated by the authors based on [19]

The dynamics of import operations is also positive: compared to 2013, the volume of imports to Ukraine of intermediate goods manufactured by textile industries decreased to 51.00% in USD, and final consumption - to 39.70%. Over the past five years, the total volume of Ukrainian imports of textile products (commodity groups 61-65) decreased to 42.00% [17]. This mostly concerned the import of textile clothing (-52.55%) and footwear (-55.55%).

Despite the tendency to reduce the level of import dependence of the Ukrainian economy by segments of consumption of textile products (intermediate and final), as well as despite a significant decrease in such imports, the absolute values of these indicators remained relatively high. At the same time, it should be noted that dependence on imports of textile products is inherent in the economies of most EU countries. For example, in Poland the share of imports in intermediate consumption of textile products is 63.45%, and in the final – is 69.24%. In Germany, the values of these indicators are at the level of 68.39% and 65.77%, while in Italy – is 32.11% and 27.04% [17].

Almost 80% of the EU textile industry's output is produced in 6 countries: Italy, Germany, Spain, France, the United Kingdom and Portugal [17]. It follows that not all countries have the potential (or priority) for the active development of the textile industry. This situation is due to both the problems of resource provision of specialized industries, and the existing structure of the world market of textile industry. However, despite the relatively (with EU countries) low output of domestic textile industry and its high dependence on imports of production resources (the fixed assets, raw materials and supplies), Ukraine has significant experience, qualified personnel, traditions and potential to increase the necessary raw materials, and hence – the finished products of these processing plants. This statement is argued by the gradual decrease in the level of import dependence of the national economy by segments of consumption of textile products.

At the same time, one of the main factors weakening the competitiveness of Ukrainian textile industry products in the domestic consumer market is the favorable conditions for the import of used clothing and other products. In particular, in 2018, 130.00 tons of second-hand clothes worth 154.98 million USD were imported to Ukraine, which is 38.87 thousand tons (or 57.47 million USD) more than in 2015 (Figure 4).

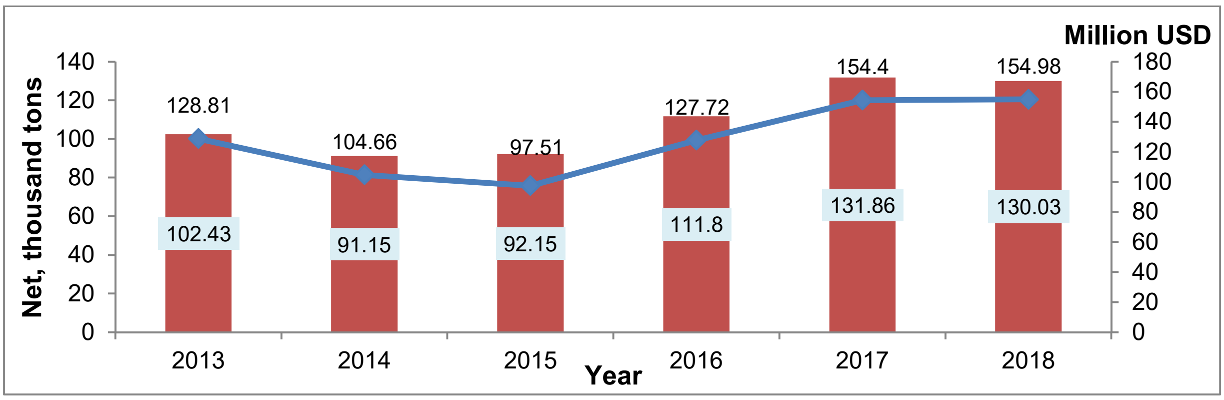

Figure 4 Volume of imports to Ukraine of second-hand clothes and the other products, Source: elaborated by the authors based on Clothing; worn and other worn articles [20]

Thus, in terms of imports of second-hand clothes and footwear, Ukraine ranked the 4-th (after Pakistan, Malaysia and Kenya) among 112 countries, while in 2013 – the 5th (128.80 million USD) among 157 countries after Russia, Pakistan, Malaysia and Poland [20].

In the structure of Ukrainian imports of ready-made clothing and footwear in 2018, the share of second-hand goods was 13.30% (vs. 17.10% in 2017 and 6.50% in 2013) (Figure 5). For comparison, in Poland this figure was 3.29%, and in Pakistan (the world leader in the import of used clothing) – 51.12%.

Thus, despite the relative proximity of Ukraine and Poland in the world ranking of importers of second-hand clothes and the other products in 2018, the share of such goods in the structure of Ukrainian imports of textile products was 10.01 pp. higher than in the Polish structure. Of course, the decrease in 2018 (compared to 2017) in the share of second-hand goods in the volume of imports of ready-made clothing and footwear in Ukraine at 3.8 pp. is positive, but in general the trend of this indicator is clearly negative.

At the same time, it should be recognized that in developing economies or transition economies (with relatively low incomes), the import of second-hand clothes can be useful because it provides access to cheap clothing and footwear for the poor. However, on the other hand, such imports significantly reduce the competitiveness (primarily in terms of price parameters) of domestic textile products in the domestic consumer market, and thus cause a decline in production.

Despite the high import dependence, Ukrainian textile industry is export-oriented – in 2017, 46.21% of manufactured textile and other products were sold on foreign markets (Figure 6).

That is, the domestic market of Ukraine consumed only 53.79% of domestic products, while import dependence in the segment of final consumption of textile goods amounted to 87.22% (see Figure 3). At the same time, compared to 2013, the share of domestic products sold on the domestic market increased 1.85 in times, and import dependence in the segment of final consumption of the textile products in Ukraine during this period decreased only by 2.75 pp.

Significant export orientation of textile and other textile industries with a high level of import dependence of the national economy in all segments of consumption of products of these industries indicates the presence of a high share of tolling operations in Ukrainian exports.

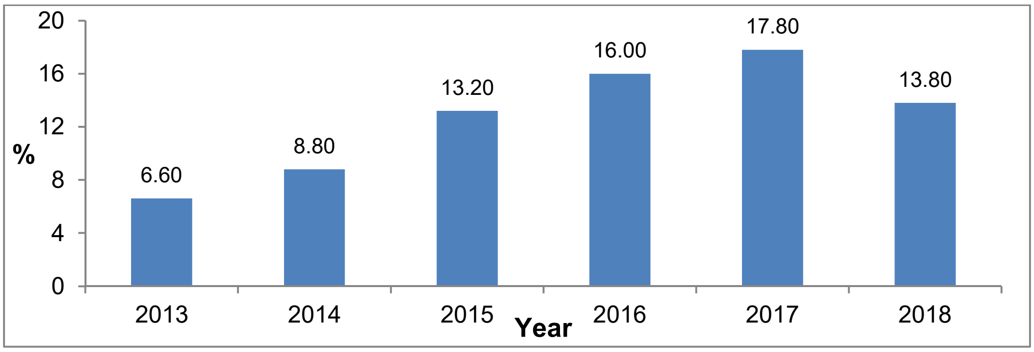

Figure 5 Share of second-hand goods in Ukrainian imports of finished clothes and footwear, Source: elaborated by the authors based on Clothing; worn and other worn articles [18]

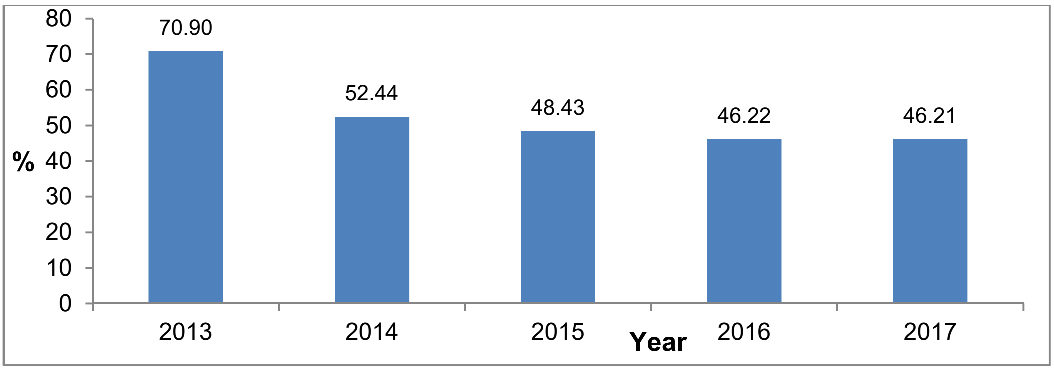

Figure 6 Share of exports in the production of textiles, clothing, leather and the other materials in Ukraine, Source: elaborated by the authors based on [18]

Table 1 Share of finished products made from toll raw materials in the export of textile industry of Ukraine [%], Source: elaborated by the authors based on [18]

Code UCG FEA*	Cargo group	2013	2014	2015	2016	2017	2018
VIII.	*The skins are raw, the skin is tanned*	*34.32*	*36.20*	*47.94*	*55.50*	*57.00*	*56.11*
41	skins	20.48	22.50	36.75	48.30	51.10	52.80
42	leather goods	66.03	79.30	74.68	81.90	83.90	84.03
43	natural and artificial fur	34.18	20.30	29.59	19.90	24.80	13.61
XI.	*Textile materials and textile products*	*74.14*	*76.30*	*76.45*	*79.20*	*76.00*	*74.60*
51	wool	30.49	16.90	15.24	51.90	48.10	49.42
52	cotton	20.63	17.70	52.96	37.00	36.70	41.82
53	other textile fibers	2.44	3.50	2.16	1.30	2.30	1.01
54	threads, synthetic or artificial	13.96	35.60	67.38	78.70	56.20	67.36
55	synthetic or artificial staple fibers	12.62	12.10	47.76	47.70	36.10	45.45
56	cotton	16.14	11.70	6.81	9.30	7.10	5.05
58	special fabrics	64.12	67.40	61.24	64.90	69.10	62.22
59	textile materials	1.20	2.10	3.89	6.90	9.20	10.21
60	knitted fabrics	76.59	75.10	74.53	78.80	87.00	88.60
61	clothing and clothing accessories, knitted	76.66	77.70	76.85	80.00	77.90	78.13
62	clothing and clothing accessories, textile	95.90	96.40	96.62	96.60	95.50	93.88
63	other finished textile products	61.71	69.20	68.90	75.90	73.70	76.02
XII.	*Shoes, hats, umbrellas*	*72.58*	*77.80*	*80.72*	*79.10*	*77.70*	*80.86*
64	shoes	74.46	79.80	82.97	82.40	80.30	84.84
65	hats	55.09	69.20	58.46	63.10	77.20	49.33
67	treated feathers and down	30.90	9.50	48.93	61.50	35.50	65.92

* UCG FEA – *Ukrainian Classification of Goods for Foreign Economic Activity*

Thus, in 2018, the export of commodity group VIII. Raw hides and skins, leather made up to 56.11% consisted of products made from toll raw materials, and compared to 2013, the value of this indicator increased by 21.89 pp (Table 1).

During the analyzed period, the share of such products in group XII exports also increased (at 8.28 pp.) shoes, hats, umbrellas. At the same time, in the export of textile materials and textile products (commodity group XI), the share of products made from toll raw materials, after growing in 2016 by 5.06 pp. returned to the level of 2013.

In general, it can be stated that there is an almost complete absence in the Ukrainian export of textile products of leather products, knitted fabrics and clothing (knitted and textile), as well as domestic shoes.

Thus, garment, textile and footwear enterprises located in Ukraine, but operating on a tolling basis, provide products not to Ukrainian consumers, but fill the foreign market and serve the economic interests of certain countries and business groups. The socio-economic effect for the national economy from the operation of such enterprises is only in the presence of a relatively small number of low-paying jobs (compared to neighboring countries, in particular, EU), budget revenues from contributions to the payroll, as well as consumption energy resources. At the same time, this situation indicates that the output of the domestic textile industry (in terms of both intermediate (or production) and final consumption), and thus the labor market and budget revenues can potentially increase significantly due to import substitution in the domestic market and qualitative improvement structure of exports, primarily by reducing the share of finished products made from toll raw materials.

The high level of import dependence and, at the same time, the export orientation of Ukrainian textile industry was reflected in the structure of its intersectional relations, in particular, in the use of textile and other products (in the intermediate consumption segment) by enterprises of other economic activities.

During 2013-2017, the largest consumers of the textile products in Ukraine were industries that belong to this type of industrial activity (textile, clothing, leather and the other materials), as well as the trade sector, furniture industry, public administration and defense (Table 2).

Thus, in 2017 in Ukraine 44.42% or 200.40 million USD products of textile industry for industrial purposes were consumed by enterprises engaged in the manufacture of textiles, clothing, leather and the other materials. At the same time, it should be noted that 95.65% (191.7 million USD) of the volume of these products was covered by imports (Table 3). For comparison, in Poland the textile industry used 28.61% of textile products and the others industries, of which imports covered 54.35%, and in Italy the values of these indicators were, respectively, 70.59% and 32.57% [17].

The second largest consumer of textile products in Ukraine is the trade sector, which in 2017 accounted for 8.87% or to 40.00 million USD, of which 34.96% (13.99 million USD) was covered by imports. In Poland, on the other hand, the second place in this structure belonged to the production of furniture with a share of 12.75%, of which 58.11% was provided by imports. In Italy, furniture production was also the second largest consumer of textile products, but with a share of 5.54%, of which 31.03% was covered by imports.

In Ukraine, in the structure of consumption of textile products for industrial purposes, the furniture industry ranked third with a share of 8.61% or 38.85 million USD, of which imports accounted for 28.94% (11.24 million USD). The relatively low share of imports in the consumption of furniture products of the textile industry is a sign of the potential of domestic textile and other industries in providing this segment. However, the realization and further increase of this potential requires appropriate conditions for the growth of demand for such products in the domestic market by furniture companies.

In general, the analysis of intersectional relations of the domestic textile industry and the level of import dependence of the national economy by segments of consumption of its products can be said that this type of industrial activity in Ukraine has significant potential to increase output not only for furniture. The expansion of the range of relevant specialized textile products and the other textile industries for: the production of rubber and plastic products; the production of vehicles, trailers and semi-trailers; the production of other vehicles; a public administration and defense, compulsory social insurance; a health care and social assistance.

Table 2 Share of the largest consumers of textile products in Ukraine (in the segment of intermediate consumption) [%], Source: elaborated by the authors based on [19]

Type of economic activity*	2013	2014	2015	2016	2017
Manufacture of wood, paper, printing and reproduction	32.21	34.08	48.05	45.30	44.42
Wholesale and retail trade; repair of motor vehicles and motorcycles	14.51	7.79	9.29	10.66	8.87
Manufacture of furniture; jewellery, musical instruments, toys; repair and installation of machinery and equipment	8.16	9.92	8.28	7.25	8.61
Public administration and defence; compulsory social security	4.60	9.33	7.38	5.68	6.77
Manufacture of wood, paper, printing and reproduction	1.39	1.96	0.83	4.45	3.96
Manufacture of food products; beverages and tobacco products	4.57	4.03	3.44	3.13	3.67
Transportation and storage	4.62	3.44	3.10	3.09	1.93
Accommodation and food service activities	2.09	1.26	0.71	1.21	1.73
Agriculture, forestry and fishing	1.06	1.39	1.30	1.18	1.62
Manufacture of rubber and plastic products	1.65	0.45	0.36	0.33	1.53
Other service activities	1.35	1.27	0.80	0.92	1.42
Electricity, gas, steam and air conditioning supply	1.73	2.57	1.44	2.16	1.34
Manufacture of basic metals	2.92	3.75	1.90	1.66	1.27
Construction	2.22	1.96	1.54	1.12	1.23
Mining of metal ores, other minerals and quarrying; provision of ancillary services in the field of mining and quarrying	1.57	1.70	1.16	1.44	1.17
Manufacture of chemicals and chemical products	1.65	0.77	0.63	0.41	1.09

*Type of economic activity *according to NACE activities – Statistical Classification of Economic Activities in the European Community*

Table 3 Share of imports in the structure of intermediate consumption of textile products in Ukraine [%], Source: elaborated by the authors based on [19]

Type of economic activity	2013	2014	2015	2016	2017
Manufacture of textiles, wearing apparel, leather and related products	99.91	99.08	87.98	94.64	95.65
Wholesale and retail trade; repair of motor vehicles and motorcycles	42.86	35.97	43.07	30.62	34.96
Manufacture of furniture; other manufacturing	47.68	40.25	69.59	36.90	28.94
Public administration and defence; compulsory social security	42.76	35.94	65.15	35.73	28.82
Manufacture of wood, paper, printing and reproduction	81.52	39.10	52.54	30.05	32.21
Manufacture of food products; beverages and tobacco products	93.05	35.83	60.57	30.94	25.23
Transportation and storage	42.62	35.40	59.01	31.02	47.41
Accommodation and food service activities	42.75	36.00	92.16	31.93	20.77
Agriculture, forestry and fishing	45.71	37.84	59.14	36.21	24.23
Manufacture of rubber and plastic products	92.66	41.67	96.15	40.63	8.20
Other service activities	42.70	36.63	70.18	35.56	21.76
Electricity, gas, steam and air conditioning supply	42.98	35.61	92.23	30.19	45.96
Manufacture of basic metals	42.49	35.79	94.85	31.29	40.13
Construction	42.86	35.90	65.45	30.91	27.21
Mining of metal ores, other minerals and quarrying; provision of ancillary services in the field of mining and quarrying	42.31	35.56	74.70	30.50	35.71
Manufacture of chemicals and chemical products	43.12	36.07	93.33	35.00	12.21
Total	***66.28***	***58.01***	***76.42***	***60.76***	***59.48***

An important argument in favor of this statement is a significant reduction in the level of dependence of these economic activity on imports of textile products, and especially the production of rubber and plastic products (by 88.00 pp. compared to 2015). In the other words, over the last 3 years there has been a significant increase in the share of products manufactured by domestic textile industries in the intermediate consumption of these type of economic activities that we can see in the Table 3.

One of the most important characteristics of the functioning of any type of processing industry is the structure of its intermediate consumption (or the structure of production and non-production costs) in the terms of products and services of the other economic activities. The production activities of the textile industry in Ukraine use the products of many economic activities, but the main suppliers of raw materials and components are: textile production, production of clothing, leather and other materials; production of chemicals and chemical products; wholesale and retail trade; supply of electricity, gas, steam and air conditioning. In 2017, these 4 economic activity accounted for a total of 70.74% (compared to 66.42% in 2013) of expenditures of the Ukrainian textile industry (Table 4).

During 2014-2017, significant changes took place in the sectoral structure of expenditures of the domestic textile industry. In particular, the share of textile, clothing, leather and other materials decreased at 8.54 pp., while the share of trade increased by 9.02 pp. Such structural changes are evidence of increasing the level of manufacturability (achieving a higher degree of processing of raw materials) of textile industries in Ukraine, and thus bringing them closer to EU standards. For example, in the sectoral structure of costs (intermediate consumption) of the Italian textile industry, the share of textile products, clothing, leather and other materials was 32.47%, and the trade sector accounted for 20.34%. In Germany, the values of these indicators were, respectively, 22.29% and 24.01%, and in Poland – 37.04% and 25.87% [21]. At the same time, the reduction in the cost structure of the Ukrainian textile industry of the share of agricultural products (by 2.38 pp. during 2014-2017) and, at the same time, the increase in the share of chemical products (3.12 pp.) indicates a decrease in production natural products, and instead – an increase in synthetic.

Despite the gradual approximation of the sectoral structure of expenditures of the textile industry of Ukraine to the level of the leading EU producers, the import dependence of domestic industries in the segment of intermediate consumption remains relatively high. Thus, in 2017, 95.65% (vs. 99.91% in 2013) of the textile products used in the production activities of Ukrainian textile and the other enterprises were covered by imports (Table 5). For comparison, in ITA the value of this indicator was 32.57%, DEU – 62.34% and POL – 54.35%.

An unconditional positive is the reduction of the level of the import dependence of Ukrainian textile industries in the segment of intermediate consumption of agricultural products to 30.21% (vs. 98.97% in 2014) and rubber and plastic products to 34.43% (vs. 90% in 2013).

Table 4 Types of economic activity, the products of which occupy the largest share in the cost structure of textile industry in Ukraine [%], Source: elaborated by the authors based on [19]

Type of economic activity	2013	2014	2015	2016	2017
Manufacture of textiles, wearing apparel, leather and related products	41.07	43.83	33.90	34.60	32.53
Manufacture of chemicals and chemical products	18.65	16.55	17.31	19.16	21.77
Wholesale and retail trade; repair of motor vehicles and motorcycles	0.37	8.77	8.43	9.06	9.39
Electricity, gas, steam and air conditioning supply	6.33	5.36	5.48	6.97	7.05
Transportation and storage	2.12	3.29	3.32	3.98	4.03
Agriculture, forestry and fishing	5.25	3.13	4.20	3.61	2.87
Manufacture of rubber and plastic products	6.37	4.02	4.66	2.96	2.41

Table 5 Share of imports in the costs of the textile industry in Ukraine (in terms of major suppliers (economic activity) of intermediate goods) [%], Source: elaborated by the authors based on [19]

Type of economic activity	2013	2014	2015	2016	2017
Manufacture of textiles, wearing apparel, leather and related products	99.91	99.08	87.98	94.64	95.65
Manufacture of chemicals and chemical products	23.08	42.34	37.95	36.56	45.53
Wholesale and retail trade; repair of motor vehicles and motorcycles	5.26	0.55	0.47	0.52	0.39
Electricity, gas, steam and air conditioning supply	0.00	0.00	0.00	0.00	0.00
Transportation and storage	35.45	15.20	15.43	41.29	46.52
Agriculture, forestry and fishing	78.68	98.97	58.92	32.61	30.21
Manufacture of rubber and plastic products	90.00	32.13	31.78	31.84	34.43
Total	***60.49***	***58.87***	***46.09***	***47.81***	***48.88***

Instead, the share of imports in the chemical industry used by textiles and the other domestic industries reached 45.53% (vs. 23.08% in 2013), which, in turn, indicates the problems of development of the chemical industry in Ukraine. In general, in 2017, the Ukrainian textile industry used 48.88% of imported resources in its activities (vs. 60.49% in 2013). For comparison, the import dependence of the textile industry in Italy was 21%, Germany – 31% and Poland – 37%.

Summarizing this block of research, we can state the tendency to reduce the level of import dependence of textile industries in Ukraine and the gradual approximation of the structure of its intersectional ties to the standards of EU countries, in particular Italy and Germany, which are leaders in the textiles, leather, clothing and footwear in Europe. At the same time, further development and raising the level of manufacturability of Ukrainian textile industry products requires strengthening the latter's integration with the trade sector. This is due to the fact that through the trade network, companies, on the one hand, purchase the necessary materials for production processes and components manufactured by the other foreign trade, and on the other – sell their products (wholesale and retail). However, the trade sector (and especially the retail sector) in Ukraine requires a radical "de-shadowing", legalization of all the operations. In addition, increasing the competitiveness of the domestic textile industry in the both domestic and foreign markets is impossible without import substitution in the segment of intermediate goods, raw materials, materials and components, especially fabrics.

4 CONCLUSIONS

The development of Ukrainian light industry constrains the presence of 3 key problems:

1) high dependence on imported raw materials, materials and components, in particular, fabrics (primarily cotton and linen), leather, wool, accessories, threads, as well as fixed assets;
2) low price competitiveness of domestic products in the domestic market, caused by favourable conditions for official and "gray" imports of used clothing and footwear, illegal domestic production, as well as smuggling of fabrics and finished products;
3) the concentration of a significant part of production (especially in the Western region) on the manufacture of products from toll raw materials.

Therefore, the priority task to ensure the development of domestic light industry is the restoration (with further increase) of raw materials for textile and other industries in Ukraine. To solve this problem, it is necessary to create or restore or modernize facilities (enterprises) for processing wool, flax, technical hemp, cotton, as well as for the production of artificial and synthetic fibres. Such capacities should be concentrated in regions that have favourable conditions for growing and harvesting these types of raw materials.

The second (no less important) task to overcome the problems of light industry in Ukraine and ensure its further development is to create competitive conditions for participants in the domestic market of textile and other industries. Solving this problem requires the development and implementation of appropriate regulatory, technical and personnel measures aimed at eliminating the flow of "gray" imports of clothing and footwear to Ukraine, as well as illegal domestic production. In other words, ensuring competitive conditions for participants in the domestic market of light industry products in Ukraine is impossible without the elimination of shadow trade in this segment of the economy. In turn, the legalization of trade, in particular, finished products of light industry, in the domestic consumer market provides for the mandatory introduction of registrars of settlement operations (including software) for all traders.

The practical implementation of such a task lies in the regulatory framework, and today the first legislative steps have already been taken in this direction, in particular, to improve (rationalize) the simplified taxation system. Thus, on September 20, 2019, the Verkhovna Rada of Ukraine adopted the Law of Ukraine "On Amendments to the Tax Code of Ukraine on De-Shading Settlements in the Sphere of Trade and Services" and the Law of Ukraine "On Amendments to the Law of Ukraine on Registration of Settlers trade, public catering and services" and other laws of Ukraine on de-shadowing of payments in the field of trade and services".

At the same time, an important step in overcoming the problems of domestic light industry is its protection from the effects of imports of cheap (especially Chinese) goods. This can be achieved by increasing (subject to conflict with WTO rules) rates of duty and VAT on imports of clothing, footwear, as well as raw materials, fabrics, accessories and other light industry products that have actual and future manufacturing potential in Ukraine. Another way is to substantiate and introduce indicators of the max value of customs duties on these imports from China and other non-EU countries.

Given the significant negative impact of imports of used clothing and footwear on the competitiveness of domestic light industry products in the domestic market, it is proposed:

- to establish proper sanitary control over the sale of second-hand goods;
- introduce mandatory sorting and certification, as well as a total ban on imports of certain (linen, etc.) types of second-hand goods;

- introduce licensing of traders in used clothing and footwear;
- to make appropriate amendments to the Tax Code of Ukraine, which would provide for a mandatory common taxation system for importers and sellers of used clothing and footwear, and in the future - for all importers without exception.

The development of light industry in Ukraine requires overcoming the negatives associated with the narrowing of opportunities for domestic producers due to the increase in the number of enterprises engaged in the processing of toll raw materials. The presence of such enterprises (in the form in which they operate now) from the standpoint of economic security is appropriate only in the short and medium term. In the future, these enterprises should be transformed in the direction of their integration into the Ukrainian economy. This can happen in two ways (or their synthesis):

a. opening of national productions for the production of products that can replace toll raw materials;
b. creation in Ukraine of enterprises for further processing (or use) of finished products made from toll raw materials at existing enterprises.

Thus, one of the priorities of the state industrial policy, in particular in the field of development of light industries producing on the basis of toll raw materials, should be the expansion of value chains created in Ukraine by supplementing them with new links. These can be joint ventures, however, the coefficient of localization of domestic (Ukrainian) potential should be at least 50%.

The strategy for the development of light industry should include reducing raw material exports and increasing the supply of high quality value-added products.

Further research in this direction will be aimed at developing econometric models for optimizing the structure of cross-sectoral links of the textile industry according to the criteria of efficiency and innovation.

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INVESTIGATION OF ANTIMICROBIAL PROPERTIES OF TEXTILE MATERIALS AFTER WASHING

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Abstract: *This work is devoted to the study of antimicrobial properties of cellulose-containing textile materials treated with new safe biocidal products of thiosulfonate structure. A resource-saving method of providing antimicrobial properties to cellulose-containing textile materials is presented. High antimicrobial activity of biocidal products after washing was established. The duration of action and expediency of their use in the textile industry are proved. It is shown that after 10 washes the treated tissues lose only 14-15% of antimicrobial properties.*

Keywords: *textile materials, biocidal treatment, washing, microorganisms.*

1 INTRODUCTION

It is known that one of the most common types of destruction of textile materials under the influence of the environment is their microbiological damage, which occurs due to the development of three main types of microorganisms: bacteria, actinomycetes and fungi. It is also known that on the surface of any textile fiber can be found microflora, which at high relative humidity and optimum temperature for its development is able to eventually absorb the fibers as a nutrient substrate and leads to their destruction [1-4]. Textile materials based on natural fibers, such as cotton, linen, and others, which are utilized by the saprophytic microflora in the nutrient cycle, are most prone to microbiological damage. And today the problem of microbiological stability of textile materials used in different climatic zones, especially with high humidity, in particular in marine areas, remains unsolved [5-7]. In the textile industry there is a continuous state of exploration for more advanced and environmentally friendly technologies, nanomaterials for antimicrobial treatment of cellulose-containing textile materials for various purposes. Although modern biocidal substances inhibit the growth of most microorganisms, they are not effective enough, and some of them are toxic and dangerous to humans and the environment [8]. Therefore, the issue of development of ecological textile materials with long-acting antimicrobial properties remains relevant and open.

Analysis of literature studies has shown that today there are several thousand names of biocidal substances on the world market. The main participants in the global market for biocides are BASF SE (Germany), AkzoNobel N.V. (Netherlands), Ashland Inc. (USA), Champion Technologies (USA), Cortec Corporation (USA), Clariant AG (Switzerland), LANXESS AG (Germany), Lonza Group Ltd (Switzerland), Nalco Holding Company (USA), Thor Group Limited (UK) and Troy Corporation (USA) [9].

The world leader is the Swiss company Sanitized AG, which has been producing biocidal substances for textiles, leather and plastics for universal and special purposes for 70 years. The most well-known and effective developments for the textile industry of this company are Sanitized T25-25 series of biocides - based on silver, which reduces the development and reproduction of micro-organisms and suppresses odors, and Sanitized T 96-21 - bacteriostatic preparation based on triclosan [10, 11]. The antibacterial agent triclosan is the basis of many biocidal substances that act on gram-positive and gram-negative flora. But in recent years, the possibility of widespread use of triclosan as an antimicrobial agent is the subject of debate due to the ability of the preparation in chemical transformations to emit dioxin, and today the regulations include non-recommended antimicrobial substances.

One of the most effective for bio-sustainable processing of textile materials is also a foreign preparation LSL in the form of an emulsion. It is resistant to high temperatures and gives tissues a significant bioprotective effect. However, the disadvantage of this preparation is a marked decrease in the stability of cotton fabrics after prolonged exposure to light weather.

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Increased antimicrobial activity has a textile material made of chemically refined linen fiber and contains the antiseptic drug iodpirone, which retains its softness and is widely used in the manufacture of special gaskets, bedding, and clothing. It retains antimicrobial properties to a number of micro-organisms, after five washes it contains 42% of the preparation, and after ten - 20% of its initial content. It is used as an antiseptic. Non-woven fabrics containing catamine AB + potassium iodide (alkyldimethylbenzylammonium chloride, cationic surfactant antiseptic) with high antimicrobial activity and resistance to wet treatments have been developed.

Kathon MW (USA) based on diazolines is considered to be a universal highly effective antimicrobial agent, which has been widely used in various industries. Methods for imparting antimicrobial properties to textile materials by introducing nitrofuran preparations into spinning solutions with their subsequent fixation in the fine structure of fibers during molding have also been developed. A significant place among them is occupied by guanidine compounds as physiologically active substances. Their bactericidal action is determined by their ability to bind to bacterial membranes, penetrate the cell nucleus and produce cellular enzymes [12]. But today it is classified as a toxic biocide.

Quaternary aluminium base salts (QAS) play a significant role as antimicrobial treatment. However, the number of critical publications on their use has increased. The authors note that some species of microorganisms have a natural resistance to QAS, others quickly acquire them, creating a biofilm that neutralizes active substances. In addition, there is a lack of activity of QAS against picornaviruses, pseudomonads, and mucoid strains of staphylococci [13].

California scientists have studied the biocides of 3-methylol-2,2,5,5-tetramethylimidazolidinone and 1,3-dimethylol-5,5-dimethylhydantoin and their compositions in different ratios for chemical modifications of textile cellulose. It has been found that the use of such compositions for cellulose treatment improves the strength and stability of biocidal functions of tissues treated with these drugs, in addition, these fabrics can withstand repeated washing and long shelf life [14].

Another achievement in this direction are cyclodextrins [3, 15], which are widely used for tissue treatment, because they due to their unique chemical structure show good absorption capacity, namely form complexes with various antimicrobial and other biologically active substances.

Nanotechnology also plays an important role in the development of antibacterial textiles. As a promising tool for creating highly stable, effective and environmentally friendly antibacterial textile coatings, sonochemistry was first used by applying inorganic nanoparticles (CuO, ZnO, MgO) to tissues without damaging the structure of textile materials [16-21]. The bactericidal properties of such textile coatings have been preserved after repeated washing, making them an alternative to known bactericidal preparations such as triclosan, various quaternary ammonium salts and other toxic compounds.

In particular, the work of textile materials with antimicrobial properties is devoted to many works of scientists who had found that the protection of natural textiles from biodegradation is possible due to the action of biocidal substances, and some of them even improve performance [22-31]. But, analyzing in general the properties of some biocidal products, we conclude that all of them have significant disadvantages: low weather resistance; short duration of action, high cost and insufficient resistance of the antimicrobial effect to washing. Another problem is the reduction of wear resistance during operation, in particular washing, during which the products are exposed to physico-chemical and mechanical factors. Therefore, we have a goal to obtain environmentally friendly textile materials with high long-acting antimicrobial properties, while maintaining quality characteristics.

2 METHODOLOGIES

The analysis of the Ukrainian market showed that the vast majority of fabrics for the production of overalls are cellulose-containing fabrics (cotton + polyester) - 68%, then for experimental studies selected 3 variants of textile materials (Table 1): option 1 - "Toctals Fabrics"); Option 2 - OJSC Ternopil Association "Texterno" (Ukraine); Option 3 - PJSC "Cherkasy Silk Factory".

Table 1 Characteristics of objects

Number option	Fiber content	Surface density [g/m^2]	Porosity [%]	Type of weave	Brands of dyes
1	100% cotton	245	41.2	twill	Straight orange Indosol
2	50% cotton 50% polyester	245	37.5	twill	Dispersive «Foron» RD-SN
3	35% cotton 65% polyester	220	30.6	twill	Optical bleach CBS-X (OBA 351)

As noted above, today the search for low-toxic biocidal products, which would not only solve the problem of protecting textiles and products from microbiological destruction, but also would improve their quality characteristics, is relevant worldwide. One of the new promising environmental developments in this direction today can be considered biocidal products of thiosulfonate structure, synthesized at the Department of Technology of Biologically Active Compounds, Pharmacy and Biotechnology of the National University "Lviv Polytechnic".

To protect cellulose-containing textile materials and clothing products from the negative effects of fiber-destroying and pathogenic microorganisms, we selected new biocidal preparations having the thiosulfonate structure: Ethylthiosulfanilate (ETS), Allylthiosulfanilate (ATS), Methylthio-sulfanilate (MTS), which exhibit a wide spectrum of antimicrobial activity and are non-toxic, and can be used for antimicrobial protection in various industries [32-35].

These biocidal products are effectively used as biocides to protect paints and varnishes; additives for protection against bio-damage of lubricating and cooling liquids; biocidal component of anti-corrosion composition for pipelines of circulating water supply systems, oil products, building materials and structures; algaecides for protection of surfaces, packaging materials, for sterilization of culture fluid in biotechnological productions, etc. [36].

Thiosulfonate biocides have not yet been tested in light industry, and we decided for the first time to experimentally investigate the antimicrobial properties of these drugs for textiles. This is dictated not only by the broad spectrum of action of thiosulfonate compounds, but also by the attempt to solve the problem of finding low-toxic and ecological biocides [34, 37]. These preparations, in our opinion, may be ideal for the terminology "environmental biocides", as they are also an active substance for the treatment of various skin mycoses and onychomycosis of the nails, competitive with nizoral and clotrimazole.

Antimicrobial treatment of cotton-polyester cloths was carried out at the Analytical and Research Testing Laboratory "Textile-TEST", Kyiv (Kyiv National University of Technology and Design). Samples of tissues were treated by water alcoholic solution (60/40) of ETS, MTS and ATS preparations in padding dyer at room temperature 18-20°*C* and relative humidity of the air 63-65%. Subsequently, these test specimens were pressed using padding dyer to a residual moisture content of 6-8% and dried at 70, 60 and 50°C. The concentration of ETS, MTS and ATS in water alcoholic solutions was 0.5%. Before all determinations of textile quality, fabric samples were being dried for 5-7 min [38].

The test samples were washed in a Bosch washing machine, bath module - 1:30 at a temperature of 40°C, rinsing - 3 cycles at a temperature of 21±3°C, dehydration - centrifuge according to the washing machine program, dried at room temperature. This mode of washing causes minimal damage to the fabric structure, but according to the developers it can be washed at temperatures up to 90° C and antimicrobial properties are not lost. Washing was carried out according to regulated standard methods [39]. In order to conduct rational experiments, research on the use of synthetic detergents was conducted not in the laboratory, but in real production conditions.

Experimental tests were conducted in the port of Odessa in the working conditions of 9 dockers-mechanics for one year. Workers' overalls were made from 100% cotton treated with ETS and MTS biocides, as they proved to be more effective. The workers worked in one shift under the same conditions. The monthly change of dockers was 15 days at night and during the day. Clothes were washed twice a month in a Bosh washing machine at a temperature of 60°C and synthetic detergent "Losk", squeezed at 800 rpm.

The guarantee error of the coefficient of variation (mc) was in the range of 1.5-2.5%. To determine the antimicrobial activity of textile materials we used certain strains of microorganisms that have a destructive effect on cellulose fibers. Studies of bacterial resistance and fungal resistance of tissue samples were performed according to standard methods. Sterile meat-peptone agar (MPA) for bacteria and wort agar (WA) for fungi were used for the experiment. The following types of microorganisms were used in the tests: *Escherichia coli, Staphylococcus aureus, Mycobacterium luteum, Candida tenuis* and *Aspergillus niger*. To do this, sterile agar medium cooled to 40-45°C was poured into Petri dishes, in which a suspension of microorganisms had been previously inoculated (microbial load: bacteria 109 CFU/ml; fungal spores 107 CFU/ml). The prepared samples were immersed in agar medium, cups with experimental and control samples were incubated in a thermostat for 24-48 hours at a temperature of 37°C for germination of bacteria and 48-72 hours at a temperature of 28-30°C for fungi.

3 RESULTS AND DISSCUSION

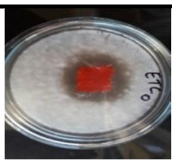
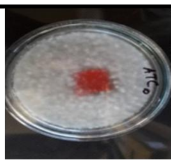
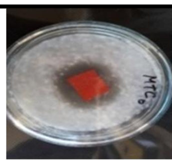
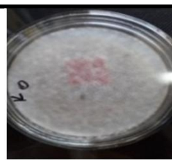
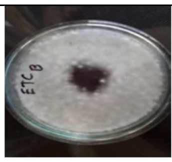
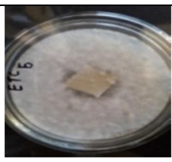
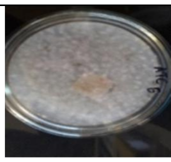
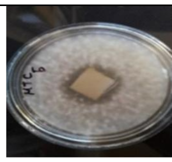
It is known that during washing the antimicrobial properties are lost and the duration of action of the preparations is reduced. Therefore, the aim of our work was to study the resistance of textile materials with biocidal treatment to repeated washing. Antimicrobial activity of textile materials treated with biocidal products ETS, MTS and ATS are shown in Table 2.

Table 2 Antimicrobial activity of cellulose-containing fabrics

Sample number	Fibrous composition	Type of processing	Zones of growth retardation of microorganisms* [mm]				
			Aspergillus niger	***Candida tenuis***	***Mycobacterium luteum***	***Escherichia coli***	***Staphylococcus aureus***
1	100% cotton	without processing	0	0	0	0	0
		ETS	40.0	69.0	49.0	28.0	34.7
			10.0	24.5	14.5	4.00	7.4
		MTS	44.0	56.0	67.5	35.0	32.0
			12.0	18.0	23.8	7.5	6.0
		ATS	20.0	50.0	43.0	25.0	33.7
			0	15.0	11.5	2.5	6.9
2	50% cotton 50% polyester	without processing	0	0	0	0	0
		ETS	27.0	65.0	39.0	0	32.6
			3.5	22.5	9.5		6.3
		MTS	22.0	58.4	43.0	0	31.7
			1.0	19.2	11.5		5.9
		ATS	0	49.0	43.7	0	31.4
			0	14.5	11.9		5.7
3	35% cotton 65% polyester	without processing	0	0	0	0	0
		ETS	29.0	67.5	39.0	0	27.0
			4.5	23.8	9.5		3.5
		MTS	38.0		45.0	0	26.0
			9.0		12.5		3.0
		ATS	0	50.0	40.0	0	28.7
			0	15.0	10.0		4.4

*includes the sizes of a fabric sample (20 mm) in the denominator - the zone of growth retardation of the sample.

As a result of the tests, it was proved that ETS, MTS and ATS selectively inhibit the activity of microorganisms (photos are presented in Figure 1). It was found that the delay of the growth zone of the selected test cultures of microorganisms depends not only on the preparation and its concentration, but also on the physiological group and type of microorganisms and fibrous tissue composition (corresponding ratio of cotton and polyester fibers). For example, the sample № 3 has a content of cotton fibers 35% and polyester 65%. For example, if the growth inhibition of *Mycobacterium luteum* and *Staphylococcus aureus* is affected by all selected preparations - ETS, MTS and ATS, but ETS inhibits only the growth of *Escherichia coli*. Gram-negative *E. coli* is the least sensitive to the action of three biocidal preparations, possibly due to the special structure of the cell wall. As for *Candida tenuis* - the zone of growth retardation is the largest - 67 mm in pure cotton fabric treated with ETS, but the same effect can be seen on samples treated with MTS and ATS. As for the fungus *Mucor*, this genus of fungi does not cause real decomposition of cellulose, but rather has the character of surface growth, but also reduces the physico-mechanical and physico-chemical properties of the fibers.

Sample number	***Aspergillus niger***			
	ETS	**ATS**	**MTS**	**Control**
1				
2				
3				

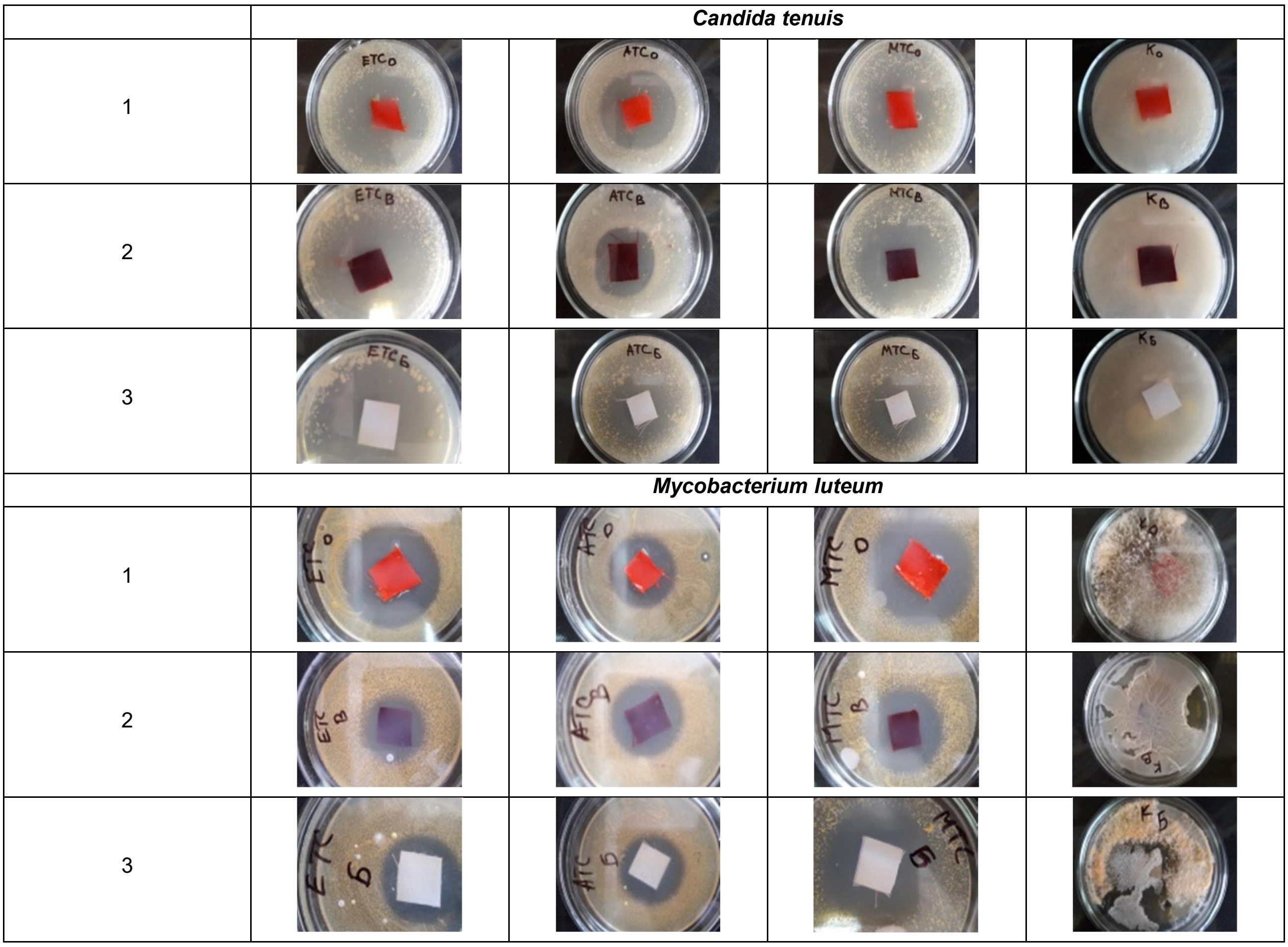


Figure 1 Photographs of experiments towards antimicrobial activity

The results of research again confirm that the most aggressive microorganism among fungi is *Aspergillus niger*, which causes a real breakdown of cellulose. The growth of colonies of fungi *Aspergilllus niger* is inhibited only by ETS and MTS. The best effect of biostability is achieved on pure cotton fabric. Antimicrobial activity was established experimentally after 1, 3 and 10 washes in water. The results of the resistance of biocidal products after repeated washing are clearly presented in Figures 2-4

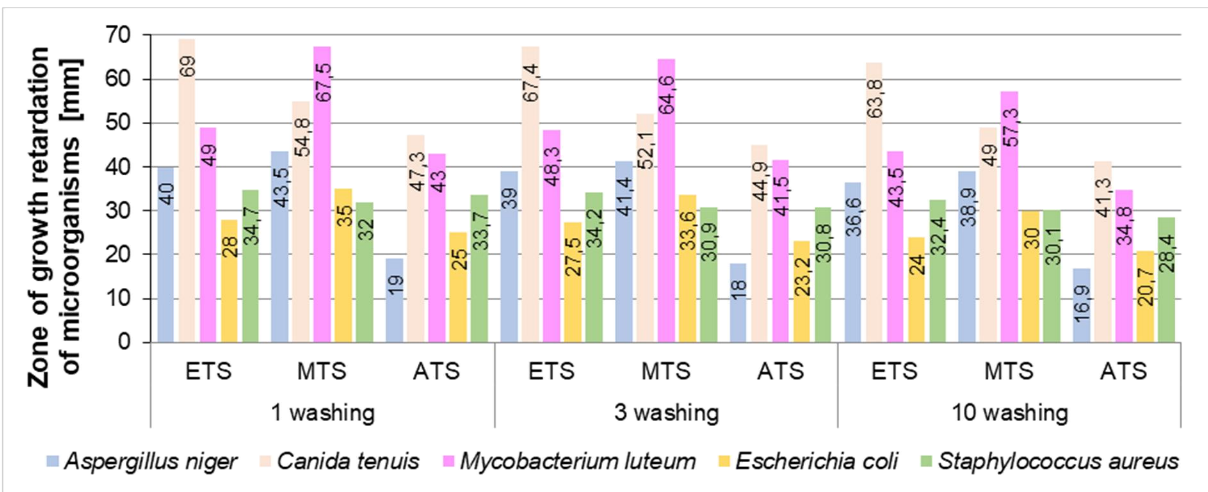


Figure 2 Resistance to antimicrobial activity var. 1 (**100% cotton**) after 10 washes

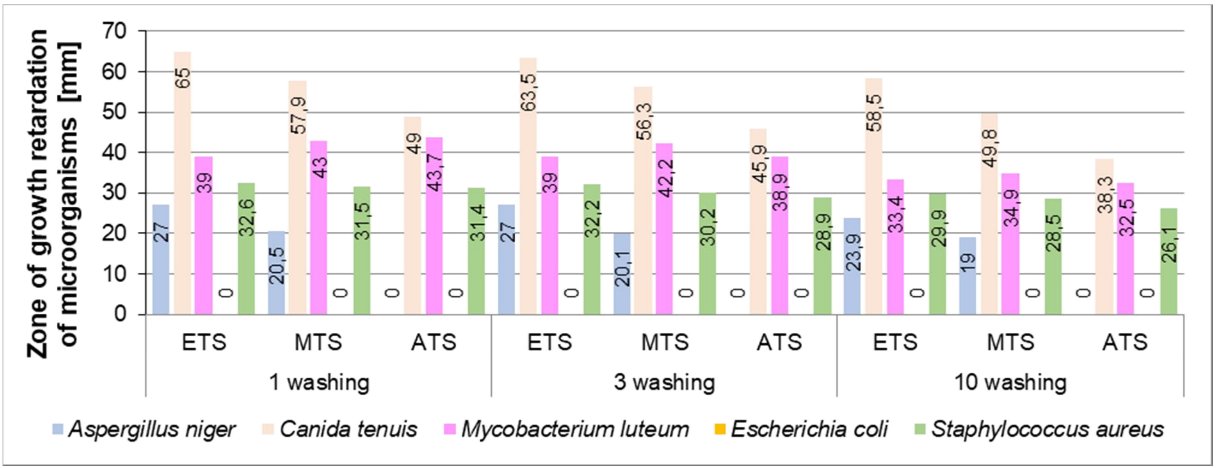


Figure 3 Resistance to antimicrobial activity var.2 (**50% cotton/50% polyester**) after 10 times washing

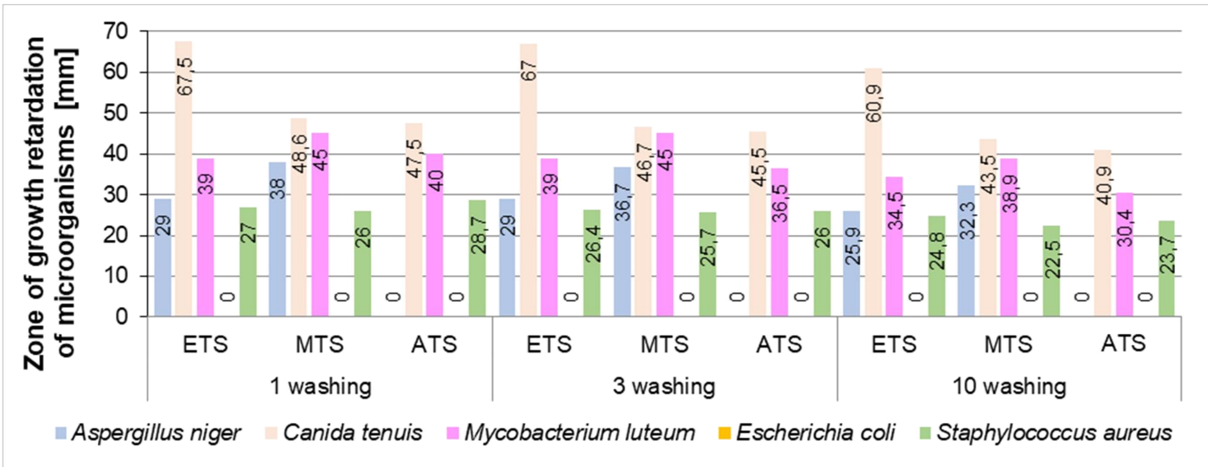


Figure 4 Stability of antimicrobial activity var.3 (**35% cotton/65% polyester**) after 10 times washing

The test results showed that the most effective of the three biocides after wet treatments in water was ETS, as the zone of growth retardation of microorganisms after 10 washes on all 3 variants of the studied samples decreased from 8.5 to 14% depending on tissue composition and microorganism. While in MTS this figure ranged from 11 to 15%, and the least effective in comparison was the biocidal product ATC, where the antimicrobial activity of the biocide after 10 washes decreased from 15 to 25%. But, in general, it can be stated that all biocidal products have high antimicrobial properties and can be effectively used in the textile industry. But in order to obtain a longer antimicrobial effect, ETS and MTS are recommended to use. Studies have also been conducted to determine the effect of biocidal treatment on the light fastness of textile materials with biocidal treatment. The results of studies [40] have shown that significant advantage of ETS, MTS and ATS preparations is the ability to inhibit the process of discoloration of dyeing on clothing textile materials, as well as in the process of light aging. It was also found that the preparations ETS, MTS and ATS, in addition to protection against light aging of paints, significantly inhibit light aging and the fibrous basis of the studied samples. It has been established that in the process of tissue irradiation, ETS, MTS and ATS preparations absorb part of the solar energy incident on the fabric and thus inhibit the process of discoloration of the dye present on it. This is due to the keratolytic properties of biocidal products. After washing, the migration of paint is not established. This is due to the keratolytic action of biocidal products, which are water-insoluble because the protective layers are lipophilic. In general, it can be argued that all biocidal products have a high enough resistance to wet treatments. After all, during washing in experimental variants of fabrics, the antimicrobial activity of ethyl biocide is lost by a maximum of 14% and methyl 15%, due to keratolytic properties and insolubility of these biocidal products. In order to determine the wear resistance of textile materials and products during operation, we conducted real tests in production conditions (Table 3).

Table 3 Antimicrobial activity of textile materials treated with biocidal products ETS and MTS in real operating conditions

Variants	Before 1 wash			After 1 year, after 24 washes		
	Aspergillus niger	***Candida tenuis***	***Mycobacterium luteum***	***Aspergillus niger***	***Candida tenuis***	***Mycobacterium luteum***
Without processing	0	0	0	0	0	0
ETS	40.0	69.0	49.0	8.6	9.4	7.3
MTS	44.0	56.0	67.5	5.3	5.7	6.0

These indicators once again confirm the feasibility of using these biocidal products and the effectiveness of impregnation of textile materials for the producing of overalls, because during operation in conditions of high humidity antimicrobial activity persists after repeated washes during the year. Due to the keratolytic action of biocidal products do not wash off quickly. Moreover, we aim for promising research on the creation of synthetic detergents with biocidal substances, taking into account the water-insoluble properties of biocidal products

4 CONCLUSION

1. Possibility and expediency of use in domestic textile production of thiosulfonate preparations ETS, MTS and ATS for antimicrobial treatment of cotton-polyester fabrics for their effective protection against destruction by cellulose-destroying and pathogenic microorganisms is studied. These biocidal products can be considered non-toxic and environmentally friendly.
2. The developed resource-saving method of providing antimicrobial properties to textile materials and products has shown an effective long-term effect in repeated washing, where the antimicrobial properties of cellulose-containing fabrics remain high enough after wet treatments.
3. The stability of adsorption of biocides on the surface of textile materials provides a long delay in the growth of microorganisms after 10 washes and is lost by 14% for ETS and 15% for MTS. Tests in real operating conditions have shown high activity of biocidal products after repeated washing (24 times a year) and long-term action and durability of textile products with antimicrobial properties.

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COLOR PERCEPTION ESTIMATIONS OF METAMERIC PAIRS UNDER DIFFERENT ILLUMINANCE LEVELS

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Abstract: *LEDs or light emitting diodes of the lighting class dominate both the indoor and outdoor lighting industries today due to their accuracy and consumer-friendly color temperature. In the context of color science, it is necessary to analyze both the spectral power distribution of lighting and the human characteristics of color perception under these lights. In this article, we provide estimates of the appearance of eleven metameric pairs under LEDs with four correlated color temperatures and six illuminance levels, using color difference formulas based on the CIELAB, CAM02-UCS, and CAM16-UCS models to verify our estimates. We followed ASTM D4086 standard visual methods for detecting metamerism and for estimating the magnitude of a metameric color difference. Our investigations found that color appearance models are more reliable than CIELAB in evaluating color difference under various LED conditions. CAM16-UCS more accurately predicted the color difference estimates between all three formulas. Our comparative study confirms that the variation in the estimates with the CCT and illuminance levels of the LED sources depends on the color appearance model used. The results also showed that in order to determine the color difference of metameric pairs, optimal conditions regarding the colorimetric properties of the samples and the variability of the observer should be considered separately. We noticed an increasing correlation trend with increasing illuminance. However, there was no such increase or decrease trend in CCTs. The trend of the STRESS change in the color appearance models showed the influence of the chromatic adaptation, but the establishment of adaptation patterns is far beyond the scope of this work. Although our research has had limitations on correlated color temperature and illuminance, we believe that it can be beneficial for the lighting application to ensure correct lighting decisions when assessing the color differences of metameric pairs.*

Keywords: *Correlated color temperature, illuminance, CAM02-UCS, CAM16-UCS, color difference formula.*

1 INTRODUCTION

To see color, you have to have light. Our eyes only can see the colors that are bounced off or reflected from the objects. With the change of light sources, colored objects appear differently. The emerging market of lighting industries and addition of new light sources increase the complexity of the scenario for color related field like dyeing and printing industries, paper industries, graphics, art, painting and architecture etc. A wide variety of electric lighting is in use today including incandescent, fluorescent, metal halide and light emitting diodes (LEDs). Recent progresses in illuminant technology, LED lights have taken the market by storm over the last few years, largely due to their high efficiency and affordability. According to 2018 data from The National Electrical Manufacturers Association (NEMA), LED bulbs account for about 65% of the consumer lamp market, followed by halogen incandescent, which account for about 28% of the market [1].

After almost three decades of the acceptance of the CIE (The International Commission on Illumination known as the Commission Internationale de l'Elcairage), in 1963 CIE defined new series of daylight illuminants (D55, D65, and D75) based on Judd et al. [2] approach and Simonds' [3] method. Recent CIE publication document 15.4 defined the standard spectral power distributions (SPD) of LED sources for color specification [4]. Since there is not a single LED lighting standard for color matching that map directly to available LED lamps on the market today, they are best utilized as an additional light source to gauge how the product may appear in an environment illuminated by a similar LED source. Nonetheless, it is perfectly possible to obtain different SPD's for light sources with the same CCT and thanks to metamerism [5-6].

Knowledge about the lighting quality such as spectral power distribution (SPD), chromaticity coordinates (*x, y* or *u', v'*), correlated color temperature (CCT), color rendering index (CRI), luminance, illuminance, and luminance and illuminance efficacy will allow the user to ensure the optimum lighting decisions. Different color difference formulas and color tolerance systems are widely utilized in industrial acceptability applications for that purpose. Color differences between pairs of colored samples depend on whether one or another light source is used and the capacity of the observers to make judgments of color difference. After the formulation of CIE L*a*b* color space in 1976, various advanced color difference formulas such as CMC [7], CIE94 [8], CIEDE2000 [9] has been formulated based on some experimental data sets namely RIT-DuPont [10], Witt [11], Leeds [12], BFD [13], and so on. In 2002, CIE adopted CIECAM02 color appearance model which was a revised version of CIECAM97s [14]. One of the major parts of the model is its chromatic adaptation transform, CIECAT02. Luo et al. later derived three uniform color spaces based on CIECAM02 namely CAM02-SCD, CAM02-LCD, and CAM02-UCS. However, the appearance correlates of CIECAM02, the lightness (*J*), colorfulness (*M*), and hue angle (*h*) form a uniform color space that can be used to calculate color differences, as long as a viewing condition is fixed. Later, Li et al. [15] developed, a new color appearance model called CAM16 based on a conical space to overcome the mathematical problems associated with CIE CAM02. Based on CAM16, they also developed a new chromatic adaptation transformation, CAT16 and a new uniform color space, CAM16-UCS.

According to CIE recommendations, a set of 'reference' viewing conditions must be fulfilled for color difference assessments e.g. D65 simulator at 1000 lux, normal color vision observers, object viewing mode, stimulus size of more than 4° subtended visual angle, color-difference magnitude of 0 to 5 CIELAB units and visually homogeneous sample structure [16]. The question then is the current color space and color appearance models optimum to predict absolute color, color difference and color changes as a result of changes in lighting conditions. The best way to visualize how color will react in different lighting conditions is to use a light booth. For our present work, we have used a lighting booth equipped with four LEDs of four different correlated color temperatures e.g. 6500 K, 5000 K, 4000 K and 2700 K. We have set up six luminance levels: 50 lx, 100 lx, 200 lx, 500 lx, 1000 lx and 1500 lx by control switch attached to the lighting booth.

The objective of the present work was to carry out a visual experiment involving color difference formula based on CIELAB, CAM02-UCS and CAM16-UCS in order to study the possible relationships between the correlated colour temperature or the illuminance level with the discriminatory capacity of a set of observers. The initial hypothesis is that there is no relationship between the CCT or the illuminance level of a light source with the color difference formulas itself. Another hypothesis is that the CCT or the illuminance level of a light source has no influence on color difference variability of the observers.

2 DATA ANALYSIS

2.1 Observer's variability assessment

An individual's color difference ability undoubtedly depends on the individual conditions. There are two forms of observer variability (i) intra-observer and (ii) inter-observer variability. The standardized residual sum of squares (*STRESS*) metric [17] is a statistical measure widely used in color research field to indicate intra or inter-variability of observers. The *STRESS* value can be calculated by using (1):

$$STRESS = 100.\sqrt{\frac{\sum(\Delta E_i - F_i \Delta V_i)^2}{(F_1^2 \Delta V_1^2)}}$$

and (1)

$$F_1 = \frac{\sum \Delta E_i^2}{\sum \Delta E_i \Delta V_i}$$

where: ΔE_i and ΔV_i are the computed and the perceived color difference for the *i* =1,…n sample pair respectively and F_1 is an adjusting factor between ΔE_i and ΔV_i .

The percent *STRESS* values are always between 0 and 100. Values of *STRESS* near to zero indicate better agreement between two sets of data. In color-difference studies, a *STRESS* value exceeding 35 is typically an indicator of the poor performance of the color difference formula [18].

After visual assessments, the grey scale number (GS) for each pair was transformed to the corresponding visual color difference (ΔV) by (2):

$$\Delta V = 26.36.e^{-GS/1.659} - 0.9532 \quad (2)$$

2.2 Color difference calculation with color appearance models

The equation for calculating color difference in color appearance models is represented as (3):

$$\Delta E = \sqrt{(\Delta J')^2 + (\Delta a')^2 + (\Delta b')^2} \quad (3)$$

With $J' = ((1+100C_1)*J)/(1+C_1*J)$; $M' = 43.86*\ln(1+C_2*M)$; $a' = M'\cos(h)$ and $b' = M'\sin(h)$ and $M = C.F_L^{1/4}$

Here *J*, *M*, *h* and *C are* the lightness, colorfulness, hue angle, and chroma values respectively. *ΔJ'*, *Δa'* and *Δb'* are the *J'*, *a'* and *b'* differences between the samples in a pair in color appearance model. The C_1 and C_2 coefficients based upon color appearance model having values 0.007 and 0.0228 respectively.

2.3 Metamerism index

The Metamerism index (MI) is a single number index that indicates how well two samples that match under one illuminant will match under another illuminant. The MI is calculated with the *ΔL, Δa*, and *Δb* values of a sample and a standard under a reference illuminant and a test illuminant. Usually the D65 illuminant (daylight) is used as the reference illuminant. Metameric differences (*ME*) for CIELAB color space and metameric differences by visual evaluation (*MV*) can be calculated by using (4) and (5) respectively:

$$\Delta ME = \sqrt{(\Delta L^*_{65} - \Delta L^*_{50})^2 + (\Delta a^*_{65} - \Delta a^*_{50})^2 + \\ +(\Delta b^*_{65} - \Delta b^*_{50})^2} \quad (4)$$

and

$$\Delta MV = \sqrt{(\Delta V_{65} - \Delta V_{50})^2} \quad (5)$$

where: $\Delta L_{65}*$ = lightness difference at daylight source D65; $\Delta L_{50}*$ = lightness difference at light source D50; $\Delta a_{65}*$ = red/green difference at daylight source D65; $\Delta a_{50}*$ = red/green difference at light source D50; $\Delta b_{65}*$ = yellow/blue difference at daylight source D65; $\Delta b_{65}*$ = yellow/blue difference at light source D50; ΔV_{65} = visual color difference at daylight source D65; and ΔV_{50} = visual color difference at light source D50.

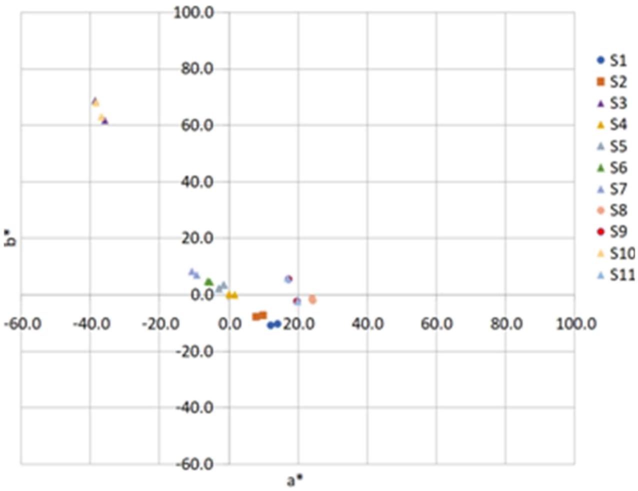
3 EXPERIMENTAL METHODS

In order to conduct a psychophysical experiment, four LEDs with six different illuminance levels from dark to very bright and eleven metameric sample pairs were selected. Figure 1 is representing the distribution of eleven metameric pairs in the *a*b** and *L*a** plane of CIELAB color space under Illuminant D65/2°.

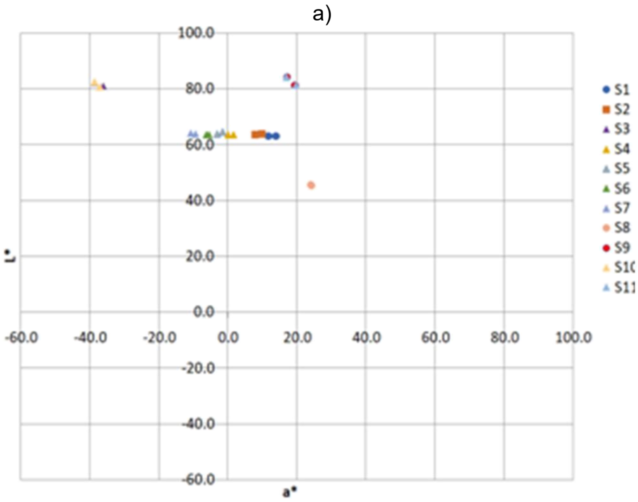
As we can see from both figures, sample pairs 1 to 7 are having almost constant lightness value (64.5 approximately). Sample pairs 8, 9 and 11 have similar chroma and hue whereas sample pairs 3 and 10 have high chroma value with nearly similar lightness. The mean color difference of the 11 metamers calculated under standard D65/2° were 3.8 *ΔE*ab* units.

The experiment was performed in viewing cabinet, whose interior painted with Munsell N7 spectrally neutral paint and has dimensions of 42 cm (width) × 74 cm (depth) × 74 cm (height). The cabinet had four LEDs with nominal CCT 2700 K, 4000 K, 5000 K and 6500 K. The experiment was divided into six phases to investigate the color appearance of the samples at different illuminance levels from dark to very bright (50 lx, 100 lx, 200 lx, 500 lx, 1000 lx and 1500 lx). The spectral power distribution and the luminance of the different configurations was measured with a Photo Research PR-740 spectroradiometer over a plaque containing pressed Barium Sulphate white standard produced by Merck placed in the centre of the bottom surface of the lighting cabinet. The SPDs and position of all light sources at six illuminance levels in *xy* diagram are shown in Figure 2 and in Table 1.

From the position of light sources in CIE *xy* chromaticity diagram in Figure 2, it can be seen that three LEDs such as 6500 K, 4000 K and 2700 K CCTs were located on the planckian locus whereas LED at 500 K CCT was located on the CIE daylight locus. All light sources have sufficiently high CIE Color Rendering Index (CRI) as shown in Table 1. Also it is noticeable from Table 1 that for all lighting conditions, maximum CCTs were found at 200lux.



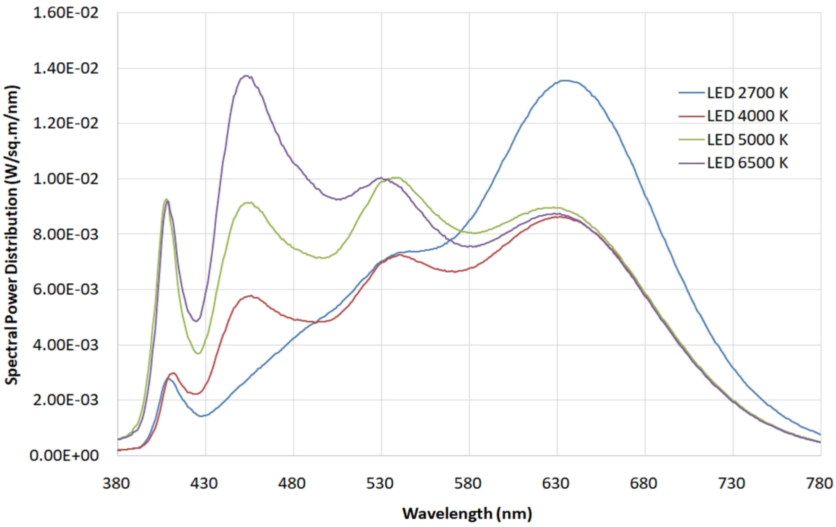
a)



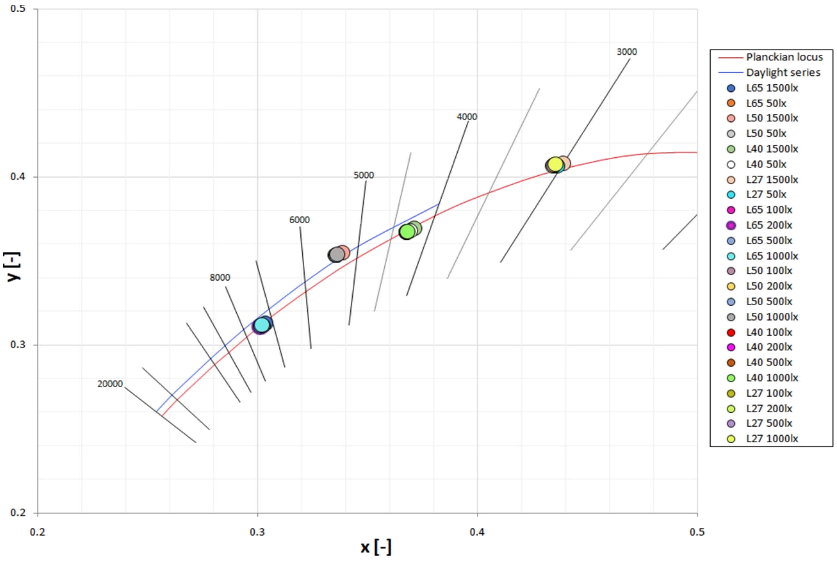
b)

Figure 1 Distribution of 11 sample pairs on *a*b** plane (a) and *L*a** plane (b) under standard D65/2°

Seven observers between 20 and 56 years of age were asked for the experiment. All 11 metameric pairs were presented to all observers in five consecutive sessions under four light sources and six illuminance levels. The observers were asked to adapt to the mid-gray interior of the cabinet for 2 minutes after each new lighting condition and illuminance levels. After adaptation, they were provided with the grey scale and sample pairs. Due to the determination method used in the experiment; the participants were required to evaluate and compare the sample pair with grey scale. Each participant was asked to determine a closest grey scale value according to his/her own perception. The distance between observers and sample was 50 cm.



a)



b)

Figure 2 SPD of four LEDs (a) and position of light sources in CIE xy diagram at different conditions (b)

Table 1 The parameters of the light sources

Nominal CCT [K]	Measured values	Illuminance level [lux]					
		50	*100*	*200*	*500*	*1000*	*1500*
6500	*x*	0.3023	0.3015	0.3014	0.3016	0.3020	0.3036
	y	0.3116	0.3112	0.3111	0.3113	0.3117	0.3128
	CCT [K]	7225	7279	7406	7388	7351	7233
	Luminance [cd/m²]	6.64	11.98	7.53	17.06	29.48	178.41
	CRI	93	93	93	93	93	93
5000	*x*	0.3361	0.3357	0.3356	0.3359	0.3363	0.3387
	y	0.3537	0.3535	0.3534	0.3536	0.354	0.3550
	CCT [K]	5254	5370	5374	5363	5345	5258
	Luminance [cd/m²]	8.18	14.47	8.97	19.92	33.67	198.22
	CRI	98	98	98	98	98	98
4000	*x*	0.3693	0.3677	0.3676	0.3678	0.3682	0.3712
	y	0.3678	0.3671	0.3671	0.3673	0.3676	0.3693
	CCT [K]	4176	4300	4304	4299	4290	4211
	Luminance [cd/m²]	4.82	8.53	5.33	12.19	21.18	136.23
	CRI	97	97	97	97	97	97
2700	*x*	0.4361	0.4346	0.4344	0.4347	0.4355	0.4390
	y	0.4066	0.4067	0.4068	0.4071	0.4075	0.4082
	CCT [K]	3034	3061	3064	3061	3050	2998
	Luminance [cd/m²]	4.72	10.34	6.53	14.78	25.67	157.56
	CRI	95	95	95	95	95	95

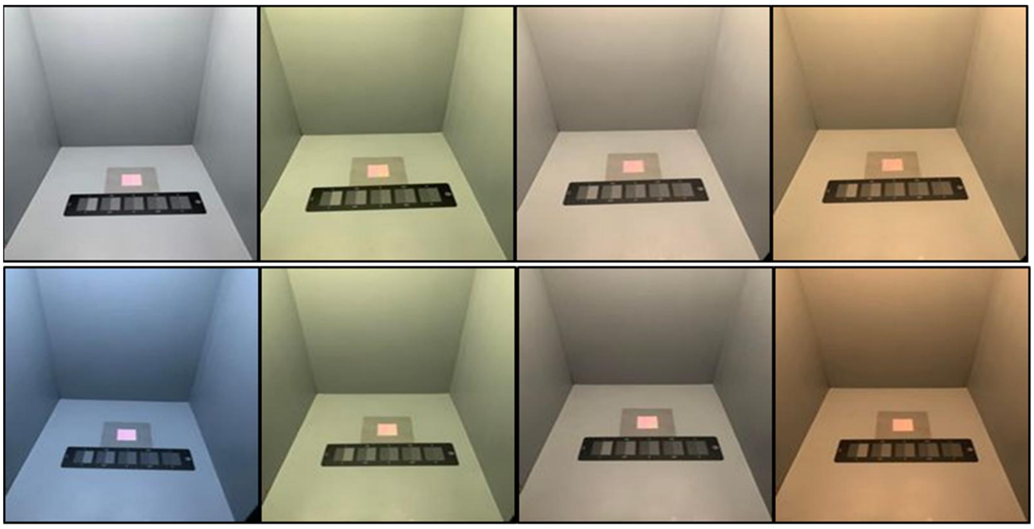


Figure 3 Position of a sample pair and the grey scale in the viewing cabinet at maximum (top) and minimum (bottom) luminance levels

The illumination: viewing geometry was always approximately 0°:45°. All the observers had normal color vision. All of the visual evaluations were conducted in a completely darkened room. In total 1200 assessment data were collected. Figure 3 is demonstrating the position of sample pair along with grey scale during visual assessment at different conditions.

4 RESULTS AND DISCUSSION

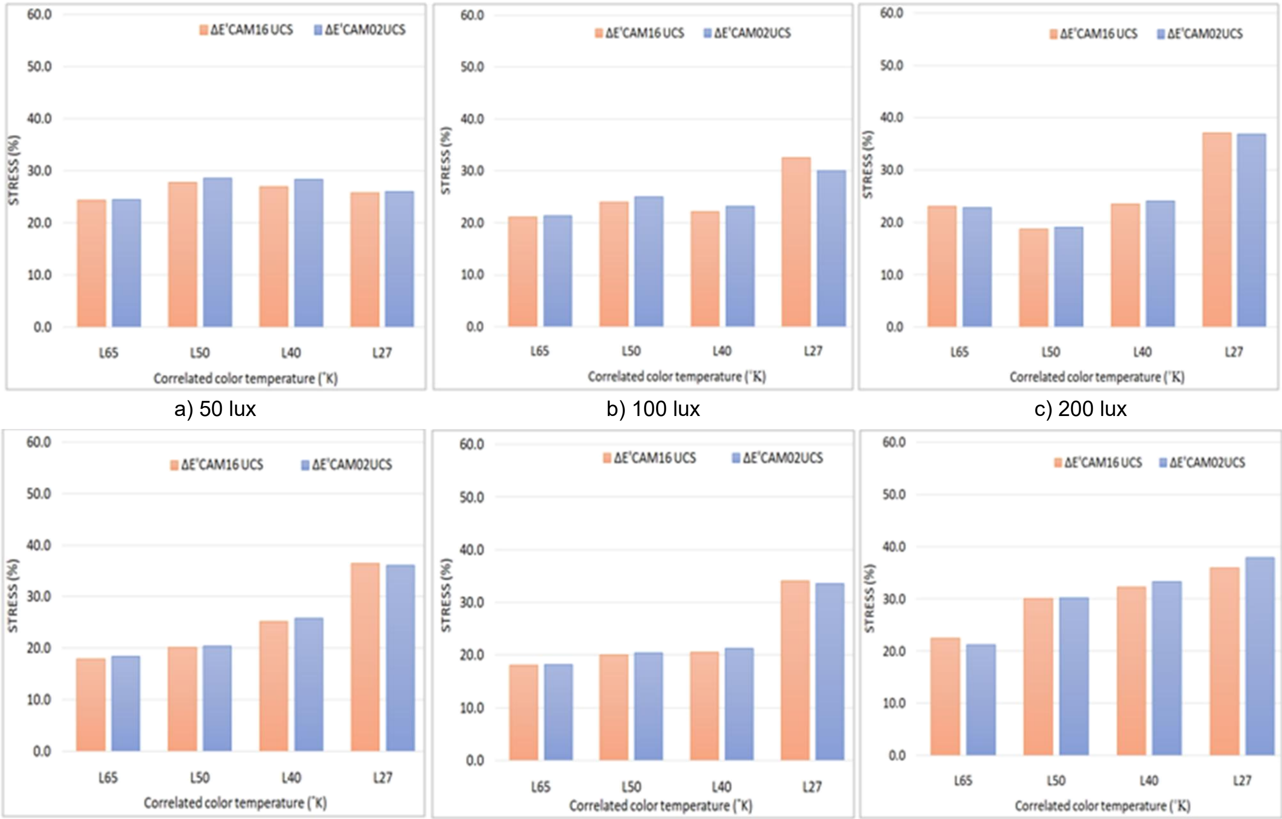
4.1 Performance of different color difference formula in terms of STRESS

Figure 4 shows the inter-observer variability in term *STRESS* as a function of the CCT for six illuminance levels: 50 lx, 100 lx, 200 lx, 500 lx, 1000 lx and 1500 lx. *STRESS* and correlation coefficient values for CIELAB color difference formula are listed in Table 2.

Table 2 STRESS and correlation coefficient (COQ) for CIELAB color difference formula

Illuminance [lux]	Parameter	6500 K	5000 K	4000 K	2700 K
50	COQ	0.87	0.68	0.70	0.79
	STRESS	28.72	47.20	42.88	29.54
100	COQ	0.82	0.72	0.79	0.82
	STRESS	34.06	42.54	34.15	32.94
200	COQ	0.83	0.81	0.83	0.83
	STRESS	34.36	35.36	32.77	36.13
500	COQ	0.89	0.83	0.83	0.84
	STRESS	27.48	34.51	33.17	34.99
1000	COQ	0.86	0.83	0.85	0.85
	STRESS	30.52	34.64	28.95	32.39
1500	COQ	0.72	0.64	0.70	0.73
	STRESS	41.33	48.88	42.51	32.97

Figure 4 and Table 2 illustrate that for all CCTs and for all illuminance levels, the inter-observer variability with regard to the *STRESS* units was lowest for the CAM16-UCS models than for the CIELAB color space. CAM02-UCS also showed a better correlation compared to CIELAB. This suggests that the CIELAB estimate of the color difference at different color temperatures and illuminance levels is not reliable when compared to color appearance models. Also, CAM16-UCS has shown better performance compared to CAM02-UCS due to the associated new chromatic adaptation transformation called CAT16, which is in line with the researchers' earlier results [15]. The trend of the *STRESS* change in the color appearance models shows the influence of the chromatic adaptation of the observers during the evaluation (the observers were asked to adapt to the medium gray interior of the cabinet for 2 minutes after each new lighting condition and illuminance), but the adaptation pattern is neither specific nor known. This comparative study confirms that the variation with the CCT of the LED sources depends on the color model used [19]. Since the applicable range of von Kries-type chromatic adaptation in terms of color temperature change is unknown or there is no particular trend of the effect of the degree of adaptation contained in the chromatic adaptation transformation (CAT) matrices on the estimate [19], it is necessary to validate the results for other datasets under LED sources. It is also worth mentioning that both color appearance models have the lowest *STRESS* values at illuminance 1000 lx. The lighting position at different illuminance levels for different CCTs remains almost the same and all LEDs have a very pure and sharp spectral power distribution, as can be seen in Figure 2. We consider our estimate to be reasonable, which can be justified or corrected by testing with other data sets or with multiple observers. In addition, the adaptation time of 2 minutes should be validated by future studies.



a) 50 lux b) 100 lux c) 200 lux

d) 500 lux e) 1000 lux f) 1500 lux

Figure 4 STRESS values for CAM16-UCS and CAM02-UCS at four CCTs: 6500 K (L65), 5000 K (L50), 4000 K (L40) and 2700 K (L27) for six illuminance levels: 50-1500 lux (a-f)

4.2 Effects of illuminance on visual difference and intra-observer's variability

Figure 5 shows the visual color difference within the samples as a function of illuminance, while Table 3 shows the mean intra-observer variability using *STRESS*.

It can be seen that samples 8 and 10 were highly variable with changes in illuminance and CCTs, while samples 4, 9 and 11 showed an average change trend with changes in conditions. Samples 1, 2, 3, 5, 6 and 7 showed negligible influence of the change in conditions. It can also be seen from Figure 5 that samples showed maximum variability in the ranking of visual differences at 2700 K within observers.

As can be seen from Table 3, the variability of the intra-observer gradually decreases with increasing illuminance up to 1000 lux. At 1500 lx the variability of the observer begins to increase.

In order to validate this increasing trend, it is necessary to continue experimenting with current samples with illuminance levels above 1500 lx. From Figure 5 and Table 3, it can be concluded that in order to determine the color difference of metameric pairs, optimal conditions with regard to the colorimetric properties of the samples and the variability of the observer should be considered separately.

Table 3 Average intra-observer's variability using *STRESS*

Illuminance [lux]	STRESS			
	6500 K	*5000 K*	*4000 K*	*2700 K*
50	18.57	16.02	18.13	13.77
100	16.01	13.83	13.57	12.15
200	11.34	8.74	13.13	7.06
500	7.67	8.69	9.02	9.68
1000	6.13	6.21	10.60	5.70
1500	14.21	12.28	11.59	10.87

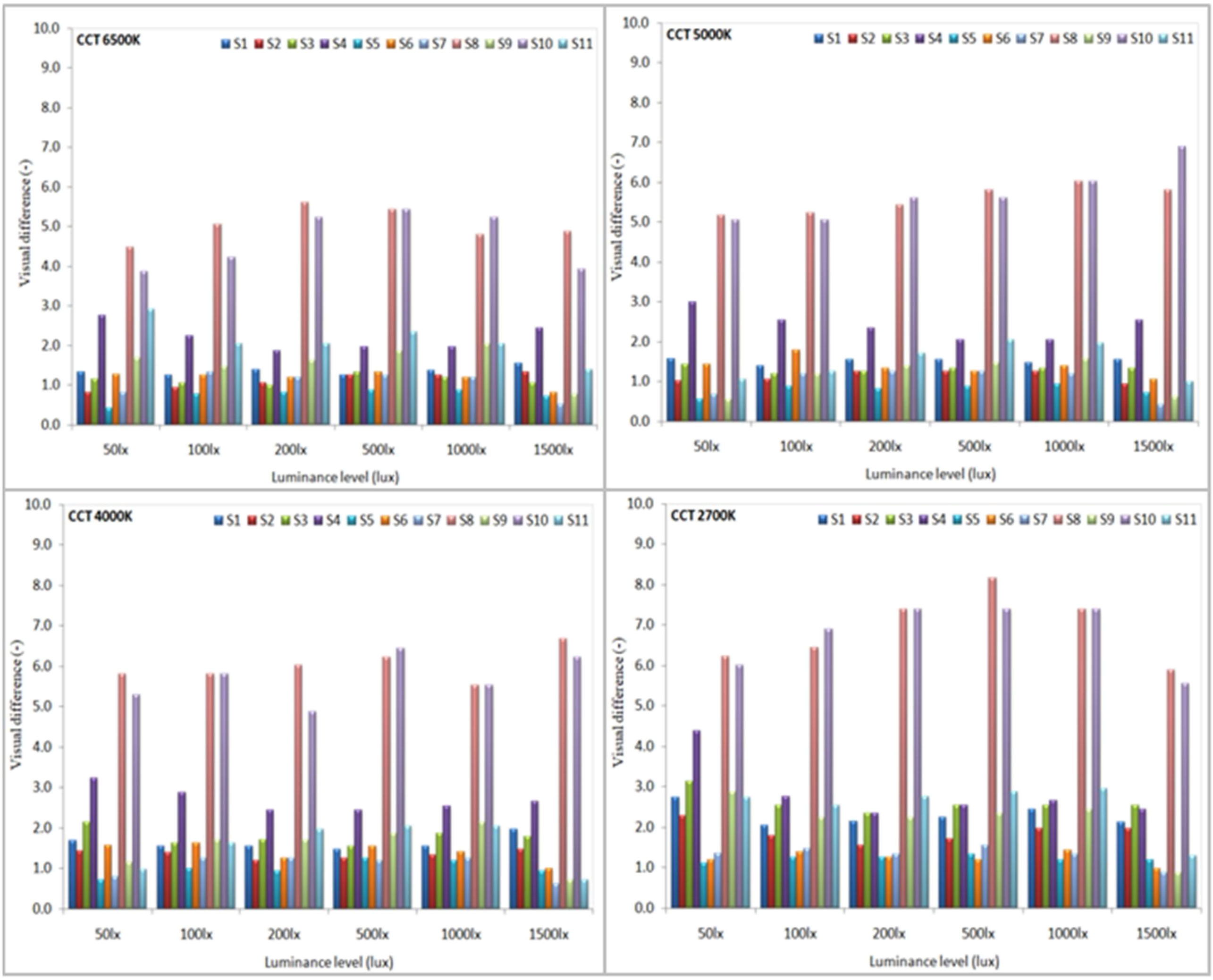


Figure 5 Visual color difference within samples at six illuminance level under four CCTs

4.3 Comparison of visual scales and colorimetric magnitudes

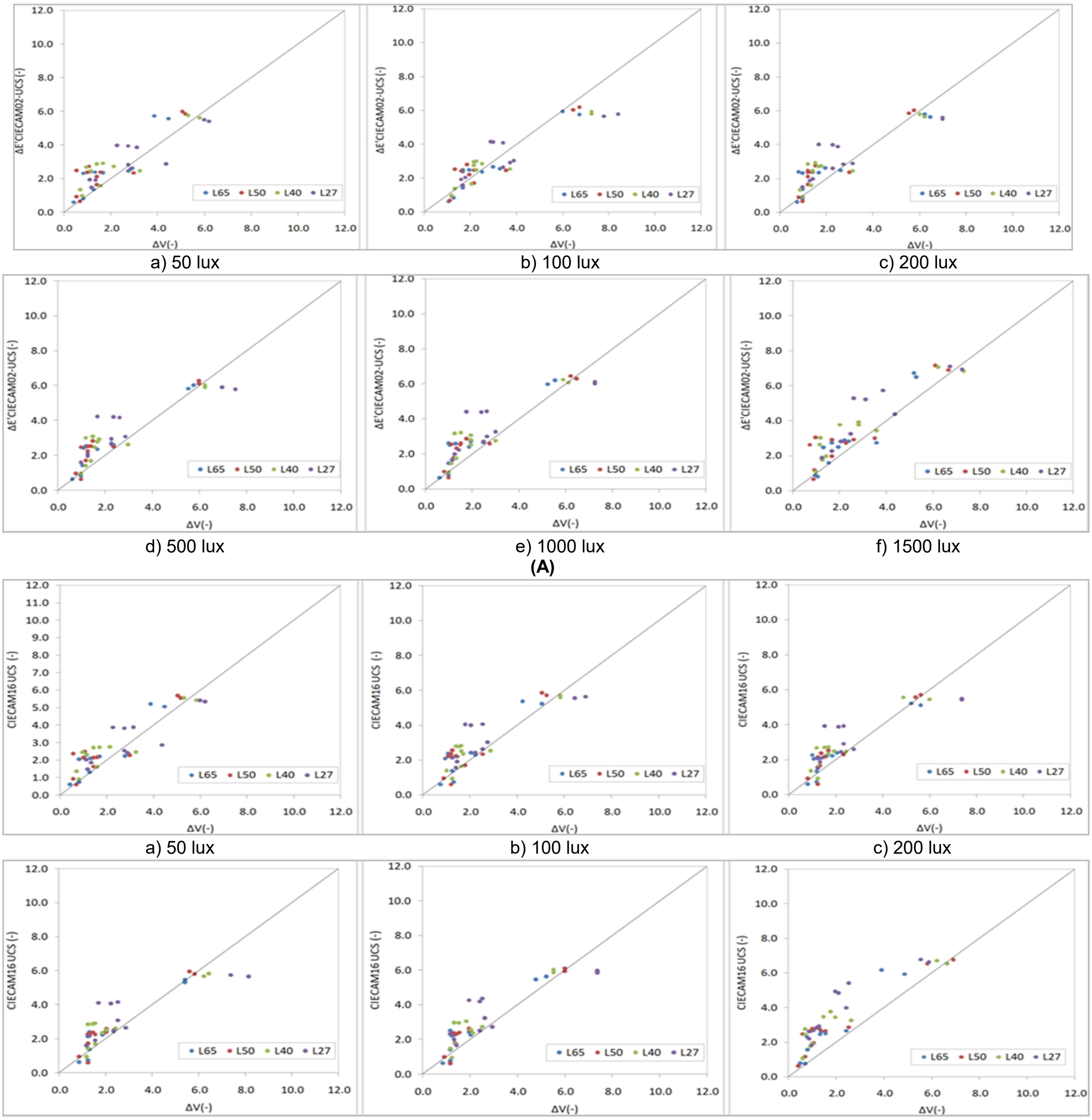
Figure 6 shows the correlation between the visual and calculated color difference in the CAM02-UCS and CAM16-UCS model as a function of the CCT for six illuminance levels: 50 lx, 100 lx, 200 lx, 500 lx, 1000 lx and 1500 lx. The correlation coefficient values for these two formulas are shown in Table 4.

Figure 6 (A) and (B) show that the CAM16-UCS formula performed better than the CAM02-UCS formula as expected. The central diagonal line with an inclination of 45° represents the ideal correlation between visual assessment and calculated color difference estimates. As can be seen from Table 4 together with Figure 6, the correlation increased with increasing illuminance levels. However, there is no such increase or decrease trend in CCTs. All estimates are on or near the ideal correlation line for both color appearance models.

Also, the calculated sizes of the color differences examined here were typically linear with the visual scales and excellent performance was found at 1000 lx for all CCTs that support the previous results from Sections 4.1 and 4.2.

Table 4 Correlation coefficient for CAM02-UCS and CIECAM16-UCS

Illuminance [lux]	CAM02-UCS				CAM16-UCS			
	6500 K	*5000 K*	*4000 K*	*2700 K*	*6500 K*	*5000 K*	*4000 K*	*2700 K*
50	0.894	0.900	0.900	0.854	0.895	0.910	0.920	0.851
100	0.932	0.910	0.920	0.883	0.934	0.920	0.930	0.841
200	0.938	0.951	0.934	0.840	0.939	0.954	0.941	0.835
500	0.947	0.960	0.920	0.836	0.951	0.960	0.930	0.829
1000	0.948	0.957	0.931	0.850	0.949	0.961	0.938	0.841
1500	0.942	0.951	0.933	0.820	0.937	0.953	0.945	0.858



a) 50 lux b) 100 lux c) 200 lux

d) 500 lux e) 1000 lux f) 1500 lux

(A)

a) 50 lux b) 100 lux c) 200 lux

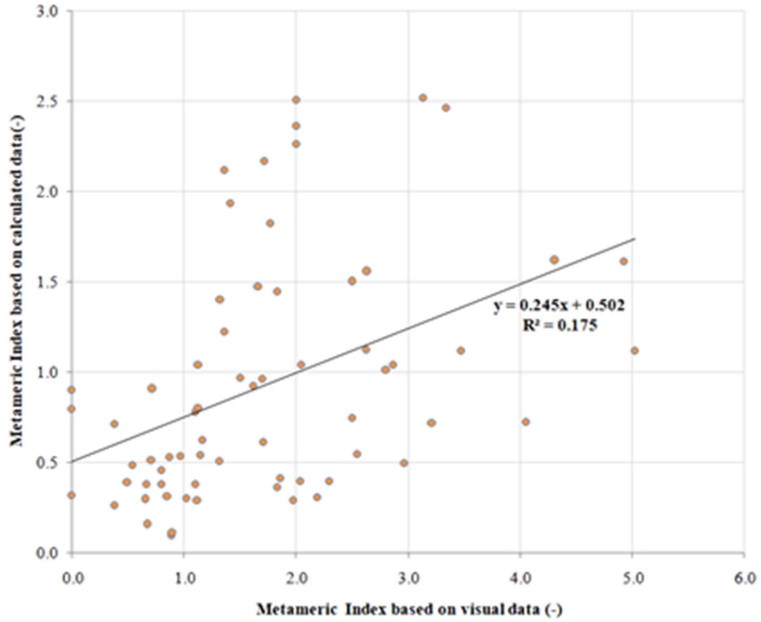
d) 500 lux e) 1000 lux f) 1500 lux

(B)

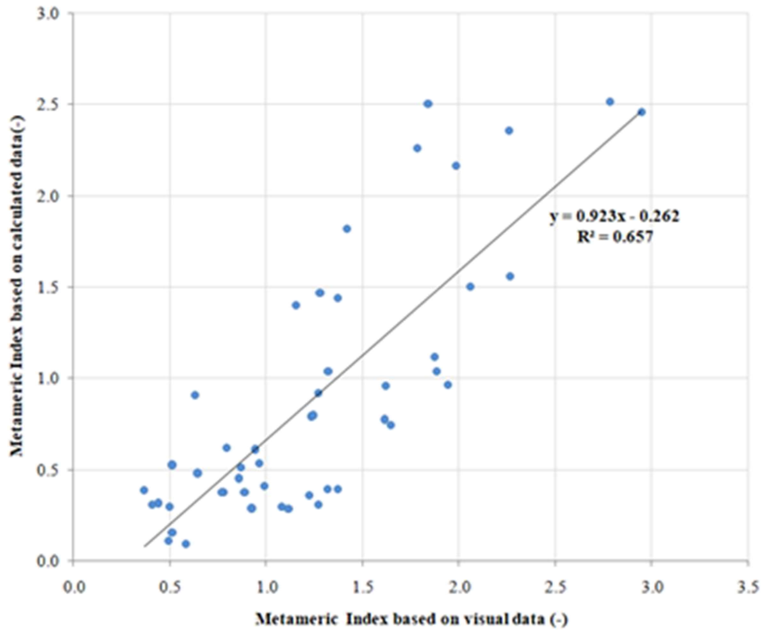
Figure 6 Comparison of visual assessment and calculated color difference in the (A) CAM02-UCS and (B) CIECAM16-UCS

4.4 Correlation between metameric color difference in visual evaluation and CAM02-UCS color space

Figure 7 shows the correlation between metameric color differences in visual assessment and the CAM02-UCS color space under all light sources and an illuminance of 1500 lx. Using data obtained from equations (4) and (5) we drew the graph in Figure 7. From Figure 7 it can be seen that when outlier data are taken into account, there is a very poor correlation. This may be due to difficulties in detecting low levels of metamerism of Samples 8, 9 and 11 as they contain optical brighteners. However, when the data excluded outliers, the correlation increased by a unit of 0.657, as can be seen from the right graph in Figure 7. This justifies that the selected light sources and illuminance levels were correct and meaningful to detect all degrees of metamerism.



a)



b)

Figure 7 Correlation between metameric color differences based on visual data and calculated data: a) all samples and b) excluding samples visually judged to be outliers. Samples were measured under all CCTs and an illuminance of 1500 lx

5 CONCLUSION

Four different LED sources with six illuminance levels were used to assess the appearance of the eleven metameric pairs. To test the validity of our estimates, we used three color difference formulas based on the CIELAB, CAM02-UCS and CAM16-UCS models. Based on our estimates, we have proven that color appearance models are more reliable than CIELAB in evaluating color differences under different LED conditions. CAM16-UCS more accurately predicted the color difference estimates between all three formulas.

Our comparative study confirms that the variation in the estimates with the CCT and the illuminance levels of the LED sources depends on the color model used. The results also suggested that in order to determine the color difference of metameric pairs, optimal conditions regarding the colorimetric properties of the samples and the variability of the observer should be considered separately. We were also able to substantiate that our chosen light sources and illuminance levels were correct and meaningful to detect all degrees of metamerism. We noticed an increasing correlation trend with increasing illuminance.

Although the optimization or modification of the model based on estimates is not analyzed in this work, we believe that this current work shows the importance of correct lighting decisions in evaluating the color differences of metameric pairs.

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FEATURES OF THE PRIMARY PREPARATION OF HEMP STRAW STALKS SUITABLE FOR OBTAINING CELLULOSE-CONTAINING MATERIALS AND PAPER

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Abstract: *The features of the primary preparation of hemp straw stalks suitable for obtaining cellulose-containing materials and paper are considered in the article. The primary processes of the preparation of hemp raw materials for pulp production, which include harvesting, storage of straw stalks, transportation, and primary processing of raw materials suitable for obtaining cellulose-containing materials, are described. Methods of shortening stems and fibers applied in the pulping process are studied in detail. Technological methods of shortening straw stalks of technical hemp and cleaning raw materials from grains and garbage impurities are mentioned. The necessity of applying the processes of stalks crushing and wet purification of chopped straw stalks of technical hemp is proved.*

Keywords*: technical hemp stalks, shortening of stem length, cleaning, cellulose materials, paper.*

1 INTRODUCTION

The main raw material of the pulp and paper industry for the production of pulp and paper is wood but taking into account the fact that the current state of the forest complex of Ukraine, according to the experts (Doskich V.), belongs, in particular, to the least forested countries, forest supply accounts for only 15.9%, so our country cannot provide the paper industry with its resources. Therefore, hemp can be one of the most practical renewable natural resources, which significantly reduces the cost of production of cellulose-containing products. Cultivation of industrial crops of technical hemp has high profitability of cultivation and processing. Hemp yields from a land unsuitable for agriculture are about 6 tons of pulp per hectare per year, which is several times more than the annual forest yield per hectare. A distinct advantage of hemp cultivation is an opportunity to obtain a large amount of hemp raw materials in a much shorter (4 months) period compared with the period of obtaining wood (50 years).

In European countries, paper manufacturers have already abandoned producing pulp from wood, and they mainly use annual fibrous materials: stems and fibers of cotton and bast plants: flax and hemp. The cellulose content in these plants varies widely from 70 to 96%, while the cellulose content in coniferous wood is only 45-58%.

Stems of technical hemp are used as the main raw material for cellulose production in European countries. A significant advantage of annual fibrous plants as raw materials for manufacturing cellulose semi-finished products, compared to wood, is their annual regeneration, though ten years is required for growing wood suitable for manufacturing cellulose semi-finished products.

However, the use of annual plants in the production of cellulose semi-finished products involves several time-consuming operations: harvesting, storage of straw stalks, transportation, and primary processing of raw materials suitable for the production of cellulose-containing materials. Therefore, this research is devoted mainly to eliminating shortcomings in the preparation of straw stalks of technical hemp for obtaining cellulose-containing materials.

2 MATERIALS AND METHODS

As an object of research work examines the stems of technical hemp straw, suitable for the production of cellulose-containing materials and paper. Technical help can be one of the most realistic renewable natural resources, that significantly reduces the cost of cellulose-containing products production.

The research was conducted using methods based on comparative and systematic analysis, generalization methods. Methods of stems and fibers shortening for the application of the boiling process are described in detail. Technological methods of shortening straw stalks of technical hemp and cleaning of raw materials from grains and garbage are given.

3 RESULTS AND DISCUSSION

The composition of pulp and paper production includes the production of fibrous semi-finished products, pulp and wood pulp, and their processing into various types of paper and cardboard.

Straw stalks of technical hemp are loose raw materials. 1 m^3 of this raw material without pressing weighs 30-40 kg, and 125-150 kg in pressed form. The most valuable in hemp plants are thin cells of bast fibers, the length of which reaches 1.5 mm. Compared to the chemical composition of coniferous wood, these plants have a lower content of lignin, 25 instead of 28, and a higher content of pectin 30 instead of 11. Comparative characteristics of pulps obtained from hemp and wood raw materials are given in the Table. 1.

Table 1 Comparative characteristics of pulp obtained from hemp and wood raw materials

Indicators	Stem of hemp straw	Larch
Alpha cellulose [%]	92.02	Maximum up to 94
Pentosans [%]	4.55	3.2
Ash [%]	0.48	0.2
Resin [%]	0.73	0.2
Lignin [%]	0.00	0.0
Copper number	0.92	1.4-1.8
Degree of brightness [%]	89.0	90-92
Viscosity [mP]	180-200	270-320

The fibers of cotton and bast crops such as flax and hemp are of particular interest to the pulp and paper industry. These fibers are much longer and stronger than wood pulp fibers. The length of cotton fibers reaches about 40 mm, linen 30 mm and hemp 25 mm. This is especially important in the production of high-quality paper of banknote range, in which the ratio of the length of the fibers to their cross-section in flax fibers is 1200 units, but in coniferous wood, this ratio is only 100 units. The strength and elasticity of bast fibers and cotton are distinct in the high content of the pulp. It is equal to 80% in bast flax fibers, 77% in hemp, and 90-96% in cotton. Table 2 shows the characteristics of technical and elementary fibers of the basic bast crops.

Analyzing this table, it can be inferred that most characteristics of the elementary fibers of flax, hemp and cotton are close to each other and can be considered as an additional source of raw materials for different areas. The properties of technical fibers are determined by the properties of elementary fibers, as well as the chemical composition of encrustants and adhesive agents [1-3].

Under production conditions, the processes of obtaining cellulosic materials from bast crops, depending on the reagents used are divided into three groups: acid, alkaline, and combined.

The first group includes the sulfite method, which is the most common. Sulfate and partially sodium methods have an industrial significance in the second group of alkaline methods.

According to the combined method, pulp and semi-chemical pulp are obtained by processing vegetable raw materials with acidic and then alkaline reagents. This process includes the chlorine-alkaline method. It has a consistent effect of alkaline solutions and chlorine in an acidic environment on the stalks of annual plants.

According to the acid method, the plant material is affected by chemical reagents, which include acidic and neutral salts of sulfuric acid (sulfites), and in some cases, sulfuric acid itself. Thus, if sulfuric acid and its acid salts (bisulfites) are present in the cooking liquor, sulfite pulp or semi-chemical pulp is obtained as a result of processing. When a solution of sodium bisulfite salt of sulfuric acid is applied to plant raw materials without free sulfuric acid, bisulfite semi-chemical pulp is obtained. In the neutral-sulfite preparation process of pulp or semi-chemical pulp, cooking liquor containing a mixture of two chemical compounds such as sodium sulfite and sodium carbonate is used.

When processing vegetable raw materials by alkaline methods, the composition of the cooking liquor includes various chemical components such as sodium hydroxide using the sodium method, and a mixture of sodium hydroxide and sodium sulfide using the sulfate method.

Table 2 Characteristics of technical and elementary fibers of annual crops

Name of characteristics	Fibre		
	hemp	flax	cotton
Length of technical fiber [mm]	700-1500	500-750	-
Linear density of technical fiber [tex]	8-40	5-8	-
The average length of elementary fiber [mm]	15-25	15-26	22-45
Maximum length of elementary fiber [mm]	65	130	45
The size of the cross-section of elementary fibers [mm]	14-50	12-20	1-2
Average linear density of elementary fibers [mtex]	220-440	200-350	130-220
Specific density [g/cm^3]	1.48-1.50	1.43-1.50	1.47-1.50
Tonin index [mm^2]	0.13-0.29	0.11-0.22	0.09-0.15
Average coefficient of prosenchyma *	600-1000	1000-1500	-
The average extensibility at breaku [%]	2.2-3.0	2.2-2.8	6.9-7.2

*The coefficient of prosenchyma is a number that characterizes the ratio of the length of elementary fiber to its cross-section

For the production of pulp or semi-chemical pulp by the combined method, cooking liquors containing such reagents as sodium bisulfite, sodium hydroxide, soda ash, and others are used.

Sulfite and sulfate processes are of priority importance for the production of paper, cardboard paper, and products derived from vegetable cellulose. Bisulfite and neutral-sulfite methods are also used.

Regardless of the method of the production of pulp or semi-chemical pulp, all efforts should be directed to the production of these semi-finished products with specified chemical and mechanical properties and with a high yield.

When crushed wood is cooked or treated with a solution of chemical reagents (cooking liquor) at high temperature and pressure, it is delignified. So, most of the lignin dissolves, the wood cells are separated, and fibrous technical cellulose is obtained. To achieve a high yield of cellulose-containing materials from the straw stalks of technical hemp it is necessary to conduct a thorough initial preparation of raw materials to obtain a homogeneous mass before the process of delignification.

The technological cycle of the production of cellulose semi-finished products from annual plants is described in known literature sources [4-10]. Preparation of straw of annual plants consists of two operations: shredding and cleaning. Straw choppers used in industry, similar in design to agricultural, differ mainly in capacity. On a special table, piles of raw materials are untied, and the dressing material (metal or film) is removed. The straw is fed by a conveyor into a straw chopper equipped with rotating knives. The length of the chopped straw depends on the number of cuts, which in turn is determined by the rotating speed and the number of knives. As the number of cuts increases, the chopped straw becomes shorter and more uniform. The theory of obtaining chopped straw is similar to the theory of cutting wood and is expressed by the same mathematical dependencies. Accordingly, the length of the chopped straw should be as long as possible. However, to increase the degree of purification of straw and the uniformity of its cooking, attempts are made to bring the length of the chopped straw to a few centimeters [8].

Fibers from straw stalks of annual plants, as well as wood, have a definite orientation. But since the straw stalks are fed to the straw chopper blades in a disoriented state, the increasing length of the cut increases the unevenness of the chopped straw. Chopped straw is even ideally less uniform than wood chips. Longer chopped straw easily becomes compressed and downy with difficulty, which complicates its cleaning (dedusting, removal of metal impurities, removal of grain and shive).

Wood chips during cooking become uniformly saturated with chemicals. When cooking straw stalks, fast and uniform saturation of chemicals into the chopped straw occurs only if the stalk is cut between two joints (Figure 1). In this case, the wall of the plant cell both outside and inside comes into contact with cooking chemicals. If the stalk is not cut between two joints, then part of the stalk remains closed, and the chemicals come into contact with plant tissue only externally, as a result, the saturation is slower. Cooking chemicals penetrate through the inner walls of the plant faster than the outer ones. There are no joints in the straw stalks of technical hemp, so the cooking liquor penetrates into the hemp chaffs more uniformly than in the stems of wheat and bamboo.

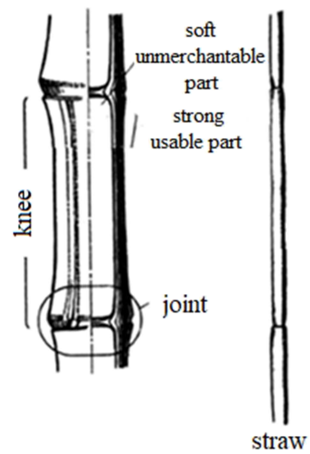

Figure 1 The structure of the straw stalk of annual plants

The uniformity of chopped straw is important for filling the continuous digests. Shorter chopped straw provides more uniform and dense filling and the formation of a pressure-tight that increases the tightness of the pressure fryer. In this regard, apparatuses for additional shredding of the chopped straw were designed.

Figure 2 shows a straw chopper that provides maximum length of the chopped straw of 30-50 mm. The minimum length of the chopped straw is 12-18 mm. For pneumatic feeding of the chopped straw to the first stage of cleaning and sorting, the straw chopper is equipped with an air blower. The pneumatic system sizes should ensure the concentration of the chopped straw in the system is not more than 200-250 g/m^3 of air, because at higher densities the chopped straw easily becomes compressed, which leads to clogging of the system.

At the first stage of cleaning, there is a preliminary dedusting of the chopped straw. For this process, the apparatus for cleaning and sorting the chopped straw is equipped with a cyclone, inside of which two brushes for cleaning the chopped straw from dust rotate.

The chopped straw under the action of gravity enters the drum with beats, which are equipped with needles, where the grains are separated from the straw. At the same time dust is formed on the surface of the chopped straw. Then with the help of an electromagnet metal impurities are removed. For this process, the chopped straw is distributed in a vibrating singeing plate with a magnet. This method enables extracting most of the metal impurities, which are the remnants of the metal wire used for tying bales, from the chopped straw. Usually, a second electromagnet is turned on for more thorough cleaning of the chopped straw. Then the dedusting and removal of crushed straw in a drum sorter, similar in design to a single-hull drum sorter for chips take place.

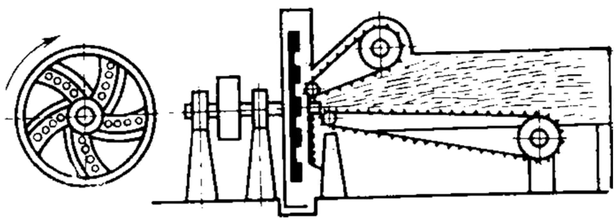

Figure 2 The existing technological scheme of the shortening of straw stalks of technical hemp

Grains and joints are removed with the help of an air separator at the next stage of cleaning. The chopped straw is blown into vacuum channels, where grains and chopped straw that have higher specific gravity than the chaff fall down and fall on vibrating screens. This process can be considered as the third stage of dedusting. Another air separator is installed for a more thorough separation of grains and chopped straw from the chopper. The grains can also be further sorted, which improves the use of sorting waste. The scheme of the sorting system is shown in Figure 3.

From the straw chopper, the chopped straw is fed pneumatically or by a belt conveyor for further processing. The energy consumption for pneumatic transportation of the chopped straw is greater than the transportation of chips. This is because, firstly, the density of the transported material, as indicated above, should be in the first case as low as possible, and secondly, the shop for preparing the chopped straw due to high fire risk should usually be at a sufficient distance from other industrial buildings. Usually, the shop is located directly next to the straw warehouses. In addition, the transportation of straw bales is much more expensive than the transportation of chopped straw.

Some attempts have been made to facilitate the cutting, cleaning, and sorting of straw. In 1959, at the symposium of the European Liaison Committee for Pulp and Paper (EUSERA) on straw processing, Achison [9] proposed the technology of shredding straw in a hydrobeater. Wet cleaning of straw by this method is the same principle as wet cleaning of waste paper.

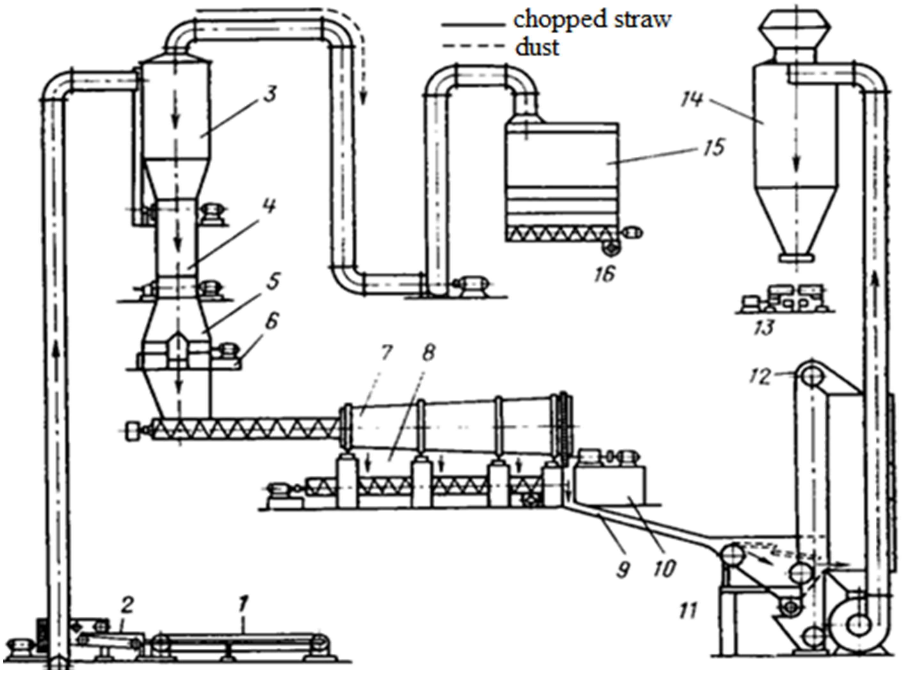

Figure 3 Preparation and cleaning of chopped straw from straw stalks of technical hemp: 1 - untying of piles; 2 - straw chopper; 3 - preliminary dedusting; 4 - duster; 5 - shake apparatus; 6 - magnetic drum separator; 7 - vibration sorting; 8 - straw waste; 9 - conveyor; 10 - elevator; 11 - removal of grains; 12 - separation of grains; 13 - conveyor for chopped straw; 14 - cyclone; 15 - dust collection; 16 - dust removal

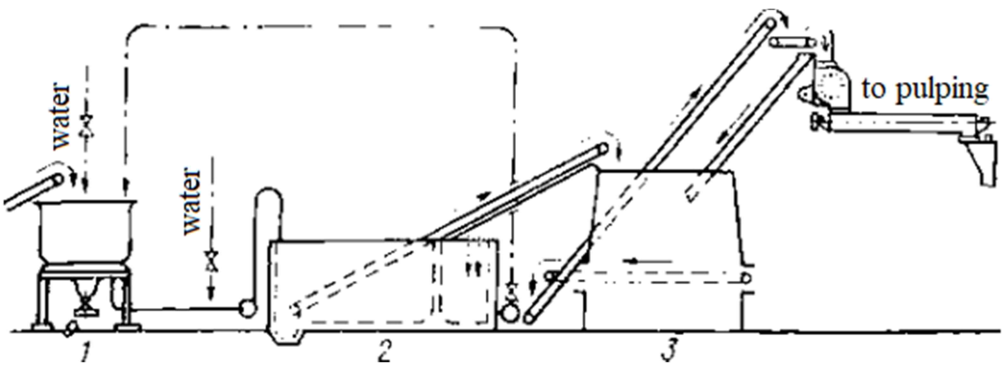

Figure 4 Wet method of cleaning the chopped straw: 1 - hydrobeater; 2 - tank; 3 - hopper

The proposed technology has particular advantages in the processing not only straw but, for example, corn stalks, as it enables removing parenchymal fibers. In the 1930s, attempts were made to separate parenchymal cells of a hydrophobic nature from the chopped straw by mixing them with water; in this case, when a proper concentration is reached, the hydrophobic particles are gathered on the water surface, from where they are easily removed. Since the design of the hydrobeater and the vortex motion of its content, starting during operation, provided a good effect of separation of hydrophobic substances only, this method was not further developed. The scheme of the described system is shown in Figure 4. Wet cleaning makes it easier to remove dust. That is why in the dry method of cleaning after filtering the air and separating the dust generated in the system, it should be precipitated with water (or circulating water). For this purpose, special fans are used, through the axis of which water is sprayed [11].

Removal of straw dust from preparatory shops is necessary for sanitary and hygienic purposes as it can cause, among other diseases, silicosis. Cleanliness for the enterprise can be maintained only at the high efficiency of dedusting. The importance of this problem is easy to determine, given that the dust content in the straw of cereals is 1-1.2%, in rice straw - 5%, morover 30-40% of it is comprised of inorganic substances, of which 80% is SiO_2.

4 CONCLUSION

Based on theoretical studies of the primary preparation of plant stalks for obtaining cellulose-containing materials, it can be concluded that the straw stalks of technical hemp at the first stage of preparation for pulping require shortening to a certain length, thorough cleaning from dust, metal and seeds. The most suitable way to clean the crushed stalks of technical hemp, in our opinion, is a wet method of cleaning chopped straw.

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DETERMINATION OF TENSION FOR ARAMID AND CARBON YARNS WHILE WEAVING INDUSTRIAL FABRICS

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Abstract: *Resulting from researches conducted to determine tension for para-aramid, meta-aramid, and carbon multifilament yarns during their contact with the operative parts of the weaving looms as part of the industrial fabrics formation process, we have found out that in threading areas the tension is increasing driven by variation of values of the friction forces in the contact area. It has been proven that tension degree of para-aramid, meta-aramid, and carbon multifilament yarns before industrial fabric formation area is influenced by (1) tension before cylindrical guide surface of an operative part, (2) radius of the cylindrical guide surface curve of the operative part, (3) contact angle between yarns and cylindrical guide surface of an operative part, (4) mechanical, physical and structural properties of para-aramid, meta-aramid, and carbon multifilament yarns. It allowed (yet at the initial stage of design of technological process of industrial fabric formation) to determine para-aramid, meta-aramid, and carbon multifilament yarns tension before formation area depending on (1) form of threading line for yarns at the weaving loom, (2) mechanical, physical and structural properties of para-aramid, meta-aramid, and carbon multifilament yarns and industrial fabrics. The paper contains experimental research of interaction of para-aramid, meta-aramid, and carbon multifilament yarns and cylindrical guide surfaces of the operative parts of automatic weaving looms. Based on experimental researches regression dependencies have been obtained between para-aramid, meta-aramid, and carbon multifilament yarns tension value after cylindrical guide surfaces of the operative part and (1) tension before cylindrical guide surface of the operative part, (2) radius of the cylindrical guide surface curve of the operative part, (3) contact angle between yarns and cylindrical guide surface of the operative part. Consecutive application of these regression dependencies allows to determine para-aramid, meta-aramid, and carbon multifilament yarns tension before industrial fabrics formation area. Analysis of regression dependencies allowed to find out values of technological parameters when para-aramid, meta-aramid, and carbon multifilament yarns tension before industrial fabrics formation area will be of minimum value. It will allow to minimize tension of para-aramid, meta-aramid, and carbon multifilament yarns while manufacturing resulting in (1) yarn breakages reduction, (2) better productivity of weaving looms due to reduced stoppage time, (3) improved quality of manufactured industrial fabrics. Therefore, we can argue that suggested technological solutions are practically attractive. In view of this, it is reasonable to say that it is possible to directionally regulate the process of para-aramid, meta-aramid, and carbon multifilament yarns tension change while manufacturing industrial fabrics on the weaving looms through selection of values of guides' geometrical parameters.*

Keywords: *industrial fabrics, para-aramid multifilament yarns, meta-aramid multifilament yarns, carbon multifilament yarns, tension, contact angle, guide's curve radius.*

1 INTRODUCTION

Yarns tension on the weaving looms and knitting machines [1-3] is a determining factor for evaluation of the density of fabric and knit formation process. The papers [4-7] show that tension of polyethylene, polyamide, and basalt multifilament yarns consists of the threading tension and additional tension arising due to frictional forces between yarns and surfaces of guides and operative parts of the weaving loom which have cylindrical form or one close to it. The value of friction forces depends on the material of yarn and guide [2], curve of guides surfaces and operative parts of the weaving looms and knitting machines [4, 6], actual contact angle between the yarn and cylindrical guide of the operative part [2, 3, 5-6], mechanical, physical and structural properties of the multifilament yarns, as well as tension before the guide [1, 7].

Simulation of the warp yarns manufacturing process at the weaving loom involves research of the process of interaction between warp yarns and cylindrical guides of the operative parts which imitate surfaces of back rest [8-14], separating rod of yarn break detector, heddle eyes of heald frame for automatic [12], shuttleless looms when manufacturing single-layer and multilayer fabrics [8, 10].

When a yarn passes all guides consecutively, from the input area to the area of fabric formation, it leads to step-type increase in tension [14]. Output parameter of tension after the previous guide will be equal to input parameter for the following guide, which allows to use recursion to determine tension before single-layer and multilayer fabrics formation area [6, 8, 9, 14]. That sort of interaction occurs during similar technological processes [15, 16].

Simulation of warp yarns manufacturing process at the weaving loom involves research of the interaction process between warp yarns and cylindrical surfaces imitating the surfaces of the back rest, the separating rod of yarn break detector, heddle eyes of heald frame for automatic shuttleless pneumatic rapier looms [4, 5, 8]. Increase in measuring accuracy of para-aramid, meta-aramid, and carbon multifilament yarns tension and possibility to ensure metrological self-control are facilitated by use of redundant measurements method. This method ensures independence of measurement result from parameters of conversion function and their deviations from nominal values [17-19]. While planning the experiment it is necessary to consider direction of relative shifting of friction surface [20, 21], yarn sliding speed or guide surface movement speed [22, 24], curvature radius of cylindrical surface [17, 18, 25]. Taking into account that para-aramid, meta-aramid, and carbon multifilament yarns are used as warp yarns bending rigidity can be ignored [2, 13].

To carry out experimental researches aimed at determining para-aramid, meta-aramid, and carbon multifilament yarns tension after the guide's surface the special strain-gauge unit is to be designed. The paper [7] emphasizes the necessity to consider that if the value of multifilament yarns throwing greater the value of its bending rigidity will also be greater. Bending rigidity significantly influences the value of the actual contact angle between the yarn and the guide's surface. It was confirmed in papers [4, 5] while carrying out research of conditions of interaction between polyethylene, polyamide, and basalt multifilament yarns and guide's surface.

Results of experimentally determined (with the help of special units) tension of multifilament yarns were provided in the papers [4-6, 8-14].

Design of the experimental unit estimates the accuracy of the obtained results, while determining yarn tension. The papers [23-24] show the scheme for determination of the yarn tension. In this scheme the cylinders with big radii are used as guides. Among its drawbacks is impossibility to simulate real conditions of interaction between the yarn and guide and operative parts of looms with large curvature. The same drawbacks come with experimental unit with revolving cylinder [25].

2 MATERIALS

Industrial fabrics from aramid and carbon multifilament yarns are widely used in different industry fields (Figure 1). It can be explained by their unique physical and mechanical properties. Aramid fabrics are used to manufacture overalls for military men, lifeguards, firemen, metallurgists. They are also used to produce clothes, battle dress uniform, bullet-proof vests, helmets, harness. Aramid fabrics are highly resistant to mechanical stress and able to hold its shape during the whole period of usage. Strength of aramid fabrics is greater than steel strength. The weight of aramid fabrics is small. They are weighing less than fiberglass materials and are able to retain protective properties at very high temperatures.

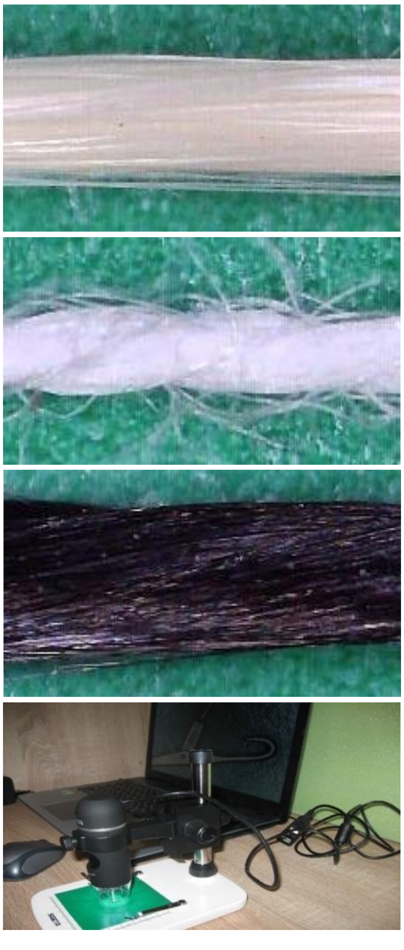
All aramid fibers have extra thermal protection. Meta-aramid fabrics (Figure 1a) are extra strong. Para-aramid fabrics (Figure 1b) provide extra protective properties.

Carbon fabrics (Figure 1c) is the basis in manufacture of carbon fiber reinforced plastic and all-carbon composites. They are used in chemical industry, oil refining industry, metallurgic industry, pulp-and-paper industry and other industry fields. They are suitable for insulation, heating elements, gas filters, liquids and melts, as well as for encapsulation of different compounds. They also may be used as current consuming elements and electrodes for electrochemical processes, as well as fiber fillers to produce chemically stable composites with polymer and carbon matrixes. This material is heat-resistant, electrically conductive, multifunctional, and resistant to corrosive environment.

a) b) c)

Figure 1 Industrial fabrics: a) Kevlar from para-aramid multifilament yarns 44 tex; b) Nomex from meta-aramid multifilament yarns 40 tex; c) fabric from carbon multifilament yarns 30 tex

Para-aramid and meta-aramid multifilament yarns were chosen as warp yarns to manufacture technical aramid fabrics. Carbon multifilament yarns were chosen for carbon technical fabrics. To conduct the experiment, the following yarns were taken: extra strong para-aramid multifilament yarns 44 tex (Figure 2a); meta-aramid multifilament yarns 40 tex providing extra thermal protection (Figure 2b); carbon yarns H-30 with thickness 30 tex (Figure 2c). They are used to produce insulation, heating units, gas filters, liquids and melts, as well as encapsulation of different compounds. We have chosen aramid and carbon yarns of approximately the same thickness. To determine diameters of the chosen yarns we used Sigeta USB digital microscope expert (magnification 10x-300x) (Figure 2d).



a)
b)
c)
d)

Figure 2 Yarns for experiment: a) para-aramid multifilament yarn 44 tex; b) meta-aramid multifilament yarn 40 tex; c) carbon yarn H-30 with thickness 30 tex; d) Sigeta USB digital microscope expert (magnification 10x-300x)

3 EXPERIMENT

Three types of multifilament yarns were chosen to conduct the experiment. Series PA: para-aramid multifilament yarns 44 tex. They used as warp yarns to produce extra strong fabrics, and then used to sew workwear, military apparel. They may be added to the makeup of composite materials and used for reinforcement of cable products. Series MA: meta-aramid multifilament yarns 40 tex. They are used as warp yarns to produce overalls for metallurgy, firefighting, welding, and fabrics suitable for canvas top for vehicles transporting asphalt and other high temperature cargos. Series CA: carbon multifilament yarns 30 tex. They are used as warp yarns to produce insulation, heating units, gas filters, liquids and melts, as well as encapsulations of different compounds.

For each series PA, MA and CA to determine joint influence between slack side tension of warp yarn P_0, radius of cylindrical guide R, nominal value of contact angle φ_P and tight side tension of warp yarn P in the paper has been planned and implemented second order orthogonal design for three factors [8-14]. General form of regression equation is as follows:

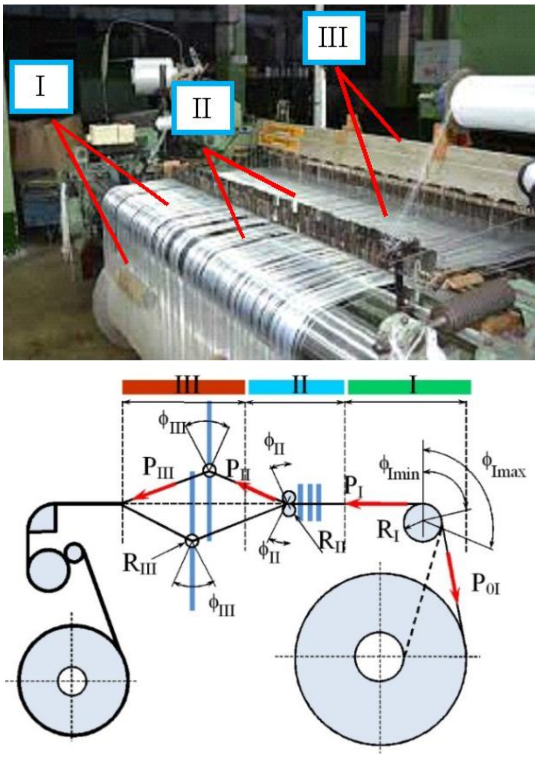
$$P = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + \\ + b_{13}x_1x_3 + b_{23}x_2x_3 + + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad (1)$$

Range of factors variations in equation (1) is determined by actual conditions of manufacturing of para-aramid, meta-aramid, and carbon multifilament yarns at the weaving looms. Threading line of warp yarns is divided into three areas: I - area from point of warp yarn coming off the beam up to the dropper mechanism; II – area of warp yarn entry to the dropper mechanism up to the heald frame; III – area from warp yarn exit from dropper mechanism up to the fell of the fabric (Figure 3a, 3b). In the I area para-amid, meta-aramid, and carbon multifilament yarns contact with back rest. In the II area para-amid, meta-aramid, and carbon multifilament yarns contact with dropper separating mechanism. In the III area para-amid, meta-aramid, and carbon multifilament yarns contact with heddle eyes of heald frame.

As a result of the implementation of the experimental plans for each series of PA, MA and SA and for each zone I, II and III, were taken 10 analytical measurements for 30 threads. For this experimental unit guide rollers with a working surface of 60 mm are used. The average tension values were taken for different moments of formation of fabric elements on looms.

The influence of the beating of the weft thread and shed formation on the deformation of para-aramid, meta-aramid and carbon complex threads was taken into account by selecting the value of the input tension in the cell.

Factor x_1 is a value of threading tension in the I area and up to back rest for weaving looms (Figure 3a, 3b). Depending on the type of warp yarns: PA - for para-aramid multifilament yarns P_{0I} = 38 cN; MA - for meta-aramid multifilament yarns P_{0I} = 26 cN; CA - for carbon multifilament yarns P_{0I} = 32 cN.



a)

b)

Figure 3 Weaving loom: a) warp yarns threading areas of the weaving loom; b) warp yarn threading scheme at the weaving loom

Factor x_2 - a cylinder radius (imitating back rest surface) in the I area, and for different looms it ranges from R_I = 63 mm to R_I = 32 mm. Factor x_2 - a cylinder radius (imitating surface of the left separating rod in the dropper mechanism) in the II area, for different looms it ranges from R_{II} = 9 mm to R_{II} = 3 mm. Factor x_2 - a cylinder radius (imitating surface of heddle eyes of heald frame) in the III area, for different looms it ranges from R_{III} = 1.1 mm to R_{III} = 0.5 mm.

Factor x_3 - nominal value of the contact angle between the yarn and the cylinder (imitating back rest surface) in the I area, and for different looms it ranges from φ_{IP} = 110° at maximum diameter of the beam to φ_{IP} = 90° at minimum diameter of the beam. Factor x_3 - nominal value of the contact angle between the yarn and the cylinder (imitating surface of the left separating rod in the dropper mechanism) in the II area, and for different looms it ranges from φ_{IIP} = 76° when shed is opened for maximum to φ_{IIP} = 0° when shed is closed. Factor x_3 - nominal value of the contact angle between the yarn and the cylinder (imitating surface of heddle eyes of heald frame) in the III area, and for different looms it ranges from φ_{IIIP} = 41° with open shed to φ_{IIIP} = 0° with closed shed.

At the first stage we determine tension in the I area after the beck rest. Table 1 shows matrix of second-order orthogonal design for three series PA, MA and CA.

Table 1 Matrix of second-order orthogonal design for three series PA, MA and CA for the I area

№	Factors					
	Input tension		Curvature radius		Contact angle	
	x_1	P_{0I} [cN]	x_2	R_I [mm]	x_3	φ_{IP} [°]
1	+1	48	36	42	+1	65
2	-1	28	16	22	+1	65
3	+1	48	36	42	-1	35
4	-1	28	16	22	-1	35
5	+1	48	36	42	+1	65
6	-1	28	16	22	+1	65
7	+1	48	36	42	-1	35
8	-1	28	16	22	-1	35
9	-1.215	26	14	20	0	50
10	+1.215	50	38	44	0	50
11	0	38	26	32	-1.215	32
12	0	38	26	32	+1.215	68
13	0	38	26	32	0	50
14	0	38	26	32	0	50
15	0	38	26	32	0	50

Connection between denominated and coded values of the I area for para-amid, meta-aramid, and carbon multifilament yarns is as follows:

series PA

$$x_1 = \frac{P_{0I} - 38}{10}, x_2 = \frac{R_I - 50}{15}, x_3 = \frac{\varphi_{IP} - 110}{10} \quad (2)$$

series MA

$$x_1 = \frac{P_{0I} - 26}{10}, x_2 = \frac{R_I - 50}{15}, x_3 = \frac{\varphi_{IP} - 110}{10} \quad (3)$$

series CA

$$x_1 = \frac{P_{0I} - 32}{10}, x_2 = \frac{R_I - 50}{15}, x_3 = \frac{\varphi_{IP} - 110}{10} \quad (4)$$

At the second stage we determine tension in the II area after the left separating rod in the dropper mechanism. As an input tension P_{0II} we take output tension of para-amid, meta-aramid, and carbon multifilament yarns after the I area P_I. Table 2 shows matrix of second-order orthogonal design for three series PA, MA and CA.

Table 2 Matrix of second-order orthogonal design for three series PA, MA and CA for the II area

№	Factors					
	Input tension		Curvature radius		Contact angle	
	x_1	P_{0II} [cN]	x_2	R_{II} [mm]	x_3	φ_{IIP} [°]
1	60	48	52	+1	8	+1
2	36	20	28	+1	8	+1
3	60	48	52	-1	2	+1
4	36	20	28	-1	2	+1
5	60	48	52	+1	8	-1
6	36	20	28	+1	8	-1
7	60	48	52	-1	2	-1
8	36	20	28	-1	2	-1
9	33	17	25	0	5	0
10	63	51	55	0	5	0
11	48	34	40	-1.215	1	0
12	48	34	40	+1.215	9	0
13	48	34	40	0	5	-1.215
14	48	34	40	0	5	+1.215
15	48	34	40	0	5	0

Connection between denominated and coded values of the II area for para-amid, meta-aramid, and carbon multifilament yarns is as follows:

series PA

$$x_1 = \frac{P_{0II} - 48}{12}, x_2 = \frac{R_{II} - 5}{3}, x_3 = \frac{\varphi_{IIP} - 45}{35} \qquad (5)$$

series MA

$$x_1 = \frac{P_{0II} - 34}{14}, x_2 = \frac{R_{II} - 5}{3}, x_3 = \frac{\varphi_{IIP} - 45}{35} \qquad (6)$$

series CA

$$x_1 = \frac{P_{0II} - 40}{12}, x_2 = \frac{R_{I}I - 5}{3}, x_3 = \frac{\varphi_{IIP} - 45}{35} \qquad (7)$$

At the third stage we determine tension in the III area after the heddle eyes of heald frame. As an input tension P_{0III} we take output tension of para-amid, meta-aramid, and carbon multifilament yarns after the II area P_{0II}. Table 3 shows matrix of second-order orthogonal design for three series PA, MA and CA.

Table 3 Matrix of second-order orthogonal design for three series PA, MA and CA for the III area

№	Factors					
	Input tension		Curvature radius		Contact angle	
	x_1	P_{0III} [cN]	x_2	R_{III} [mm]	x_3	φ_{IIIP} [°]
1	+1	70	58	64	+1	1.4
2	-1	42	26	32	+1	1.4
3	+1	70	58	64	-1	0.6
4	-1	42	26	32	-1	0.6
5	+1	70	58	64	+1	1.4
6	-1	42	26	32	+1	1.4
7	+1	70	58	64	-1	0.6
8	-1	42	26	32	-1	0.6
9	-1.215	39	23	29	0	1
10	+1.215	73	61	67	0	1
11	0	56	42	48	-1.215	0.5
12	0	56	42	48	+1.215	1.5
13	0	56	42	48	0	1
14	0	56	42	48	0	1
15	0	56	42	48	0	1

Connection between denominated and coded values of the III area for para-amid, meta-aramid, and carbon multifilament yarns is as follows:

series PA

$$x_1 = \frac{P_{0III} - 56}{14}, x_2 = \frac{R_{III} - 1}{0.4}, x_3 = \frac{\varphi_{IIIP} - 22}{18} \qquad (8)$$

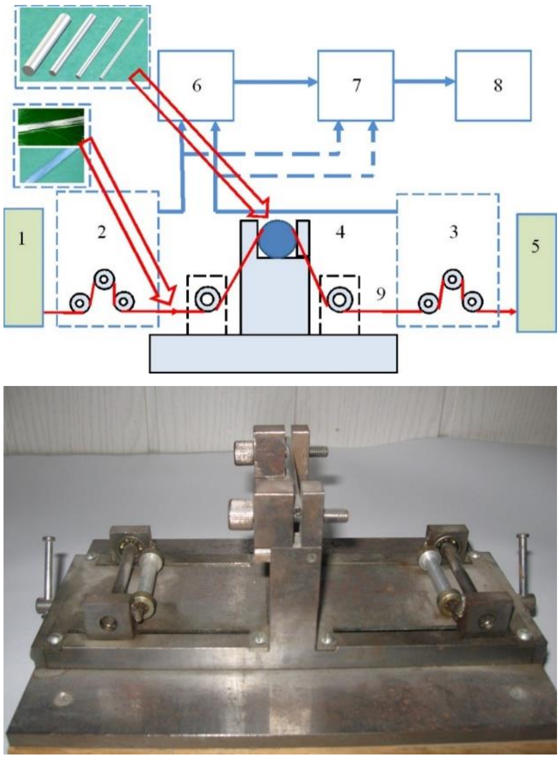
series MA

$$x_1 = \frac{P_{0III} - 42}{16}, x_2 = \frac{R_{III} - 1}{0.4}, x_3 = \frac{\varphi_{IIIP} - 22}{18} \qquad (9)$$

series CA

$$x_1 = \frac{P_{0III} - 48}{16}, x_2 = \frac{R_{III} - 1}{0.4}, x_3 = \frac{\varphi_{IIIP} - 22}{18} \qquad (10)$$

Figure 4a) shows principal scheme of the experimental unit. The first unit 1 is one for supply and tensioning of para-amid, meta-aramid, and carbon multifilament yarns. Input tension was created using tensioner. The second 2 and the third 3 units are designed for metering tension of slack side and tight side of the para-amid, meta-aramid, and carbon multifilament yarns 9. They have two rollers, which are installed in the bearings on the stationary axles. The third roller is installed on the cantilever fitted beam in a way that inner ring of the bearing fixed on it, and the roller which contacts with para-amid, meta-aramid, and carbon multifilament yarns is rigidly fixed with outer ring of the bearing. Friction forces in bearings we can ignore. Warp yarn were threaded into pulley in a way that slack and tight sides were places by both sides of right triangle.



a)

b)

Figure 4 Scheme of the experimental unit: a) principal scheme: 1 - the yarn threading unit; 2 - metering unit for slack side tension of the yarn; 3 - metering unit for tight side tension of the yarn; 4 - unit for simulation of interaction conditions between the yarn and guides and operative parts of the textile machinery; 5 - yarn receiving unit; 6 - amplifier; 7 - analogue-to-digital converter ADC; 8 - PC; 9 - the yarn; b) central metering unit

Affected by para-amid, meta-aramid, and carbon multifilament yarns tension central bar has been bending, which has resulted in variations in resistance of strain-gauge indicator. These variations have been registered at the corresponding channel of the amplifier 8ANCH-7M. Lateral and longitudinal dimensions of the beam have been chosen such that free-running frequency of the beam has been 1400 Hz. This frequency goes beyond frequency of the highest tension component way more. Figure 4b) represents central metering unit 4 of the experimental unit. This metering unit is intended for simulation of interaction conditions between the para-amid, meta-aramid, and carbon multifilament yarns 9 and cylindrical guides. Two slider pairs, on which aluminium rollers are fixed in rotation bearings, are installed on the foundation in the horizontal grooves. The position of the slider pairs with respect to the central fixed bracket is changed with the help of two screw pairs by turning the two levers on the left and on the right. The central, fixed vertical bracket serves to secure the cylinder guides of different diameters, needles of knitting machine, heddles. The fastening is carried out by two screw pairs and clamping bars.

The para-amid, meta-aramid, and carbon multifilament yarns 9 speed was varied due to a fixed ratio round belt transmission – unit 5 (Figure 4a). Driving pulley of the transmission is rotated by AC motor that was firmly fixed to the foundation of the main measurement system. Analogue signals from the 3rd and 4th units measuring yarn tension is being received by the amplifier 6 or by analogue-to-digital converter 7, enabled as a multifunction board L-780M with signalling processor ADC 14 bit/400 kHz having 16 differential input analogue and output digital channels, which is connected to the PCI-connector of the PC 8.

4 RESULTS AND DISCUSSION

As a result of implementation of designs of the experiment (Tables 1-3) for each series PA, MA and CA and for each area **I**, **II** and **III** the 10 parallel measurements have been conducted, and their average values are represented in Table 4.

Using known method for determining coefficients in regression equation (1) for second order orthogonal design [8-14], considering dependencies (2-10), the following regression dependencies have been obtained:

For the I area:

series PA - para-aramid multifilament yarn 44 tex

$$P_I = 3.22 + 0.93P_{0I} - 0.008R_I - 0.036\varphi_{PI} + \\ +0.00013P_{0I}R_I + 0.0033P_{0I}\varphi_{PI} + 0.00008R_I\varphi_{PI} - \\ -0.00009P_{0I}^2 - 0.00003R_I^2 + 0.00015\varphi_{PI}^2, \quad (11)$$

series MA - meta-aramid multifilament yarn 40 tex

$$P_I = 1.29 + 0.96P_{0I} - 0.003R_I - 0.009\varphi_{PI} + \\ +0.00008P_{0I}R_I + 0.0021P_{0I}\varphi_{PI} + 0.00003R_I\varphi_{PI} - \\ -0.0001P_{0I}^2 - 0.000002R_I^2 + 0.00004\varphi_{PI}^2, \quad (12)$$

series CA - carbon yarn H-30 with thickness 30 tex

$$P_I = 1.90 + 0.94P_{0I} - 0.005R_I - 0.017\varphi_{PI} + \\ +0.0001P_{0I}R_I + 0.0027P_{0I}\varphi_{PI} + 0.00002R_I\varphi_{PI} - \\ -0.00014P_{0I}^2 - 0.00002R_I^2 + 0.00007\varphi_{PI}^2. \quad (13)$$

Table 4 Results of tension determination for each series PA, MA and CA and for each area: I, II and III

Exp №	Warp yarn output tension *Pi*, cN								
	Para-aramid multifilament yarn 44 tex			Meta-aramid multifilament yarn 40 tex			Carbon yarn H-30 with thickness 30 tex		
	i=I	*i*=II	*i*=III	*i*=I	*i*=II	*i*=III	*i*=I	*i*=II	*i*=III
1	65.44	73.85	83.21	44.72	55.48	65.30	54.78	62.02	73.44
2	38.36	44.44	50.03	19.98	23.19	29.34	28.84	33.50	36.79
3	65.21	76.84	93.87	44.61	56.97	70.85	54.59	63.81	80.15
4	38.22	46.26	56.50	19.93	23.83	31.87	28.74	34.47	40.18
5	62.16	62.26	76.05	43.14	49.24	61.34	52.41	53.58	68.01
6	36.41	37.37	45.67	19.26	20.53	27.52	27.57	28.86	34.08
7	61.99	64.68	85.18	43.06	50.52	66.22	52.28	55.06	73.76
8	36.31	38.84	51.19	19.22	21.07	29.74	27.49	29.66	36.92
9	34.67	37.64	45.90	17.16	18.64	25.72	25.61	27.91	32.85
10	66.32	71.69	85.74	46.30	55.79	68.06	56.04	61.27	75.76
11	50.41	59.91	74.99	31.70	39.59	51.24	40.77	47.64	59.66
12	50.60	54.22	63.35	31.79	37.02	45.69	40.91	44.34	52.83
13	48.98	49.33	62.20	31.07	34.64	45.08	39.78	40.83	51.74
14	52.09	60.74	69.66	32.44	40.07	48.79	41.94	48.81	57.01
15	50.51	54.68	65.83	31.75	37.23	46.89	40.85	44.59	54.32

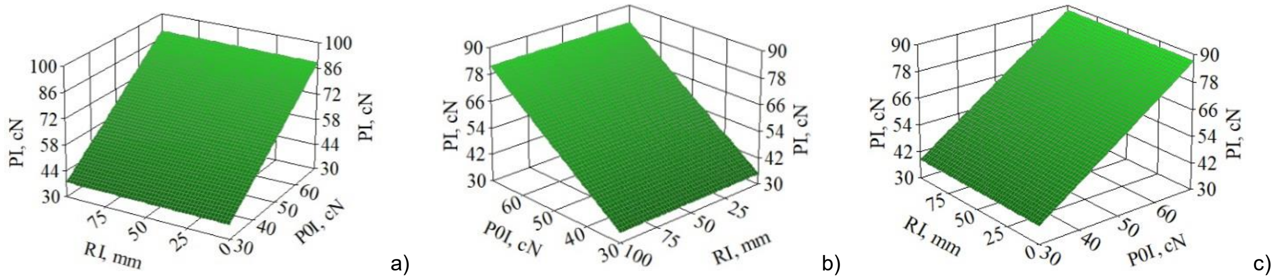


Figure 5 Graphical dependencies of the warp yarns tension for the I area of the weaving loom: a) - para-aramid multifilament yarn; b) - meta-aramid multifilament yarn; c) - carbon yarn H-30

Adequacy of obtained regression dependencies has been verified with SPSS program for statistical processing of experimental data [8-14].

For the II area:

series PA - para-aramid multifilament yarn 44 tex

$$P_{II} = -1.72 + 1.27P_{0II} - 1.31R_{II} + 0.014\varphi_{PII} - -0.007P_{0II}R_{II} + 0.0027P_{0II}\varphi_{PII} - 0.0011R_{II}\varphi_{PII} - -0.0023P_{0II}^2 + 0.12R_{II}^2 - 0.00008\varphi_{PII}^2, \quad (14)$$

series MA - meta-aramid multifilament yarn 40 tex

$$P_{II} = -5.32 + 0.65P_{0II} - 0.20R_{II} + 0.15\varphi_{PII} - -0.001P_{0II}R_{II} + 0.009P_{0II}\varphi_{PII} - 0.0003R_{II}\varphi_{PII} - -0.0025P_{0II}^2 + 0.002R_{II}^2 - 0.0007\varphi_{PII}^2, \quad (15)$$

series CA - carbon yarn H-30 with thickness 30 tex

$$P_{II} = 2.17 + 1.09P_{0II} - 1.18R_{II} + 0.007\varphi_{PII} + +0.005P_{0II}R_{II} + 0.002P_{0II}\varphi_{PII} - 0.0005R_{II}\varphi_{PII} - -0.0013P_{0II}^2 + 0.07R_{II}^2 - 0.00004\varphi_{PII}^2. \quad (16)$$

For nominal value of the contact angle $\varphi_{PII} = 45°$ in the center of experiment, using dependencies (14-16), Figure 6 represents response surfaces for the II area.

For the III area:

series PA - para-aramid multifilament yarn 44 tex

$$P_{III} = 10.39 + 1.33P_{0III} - 23.88R_{III} + 0.05\varphi_{PIII} - -0.17P_{0III}R_{III} + 0.003P_{0III}\varphi_{PIII} - 0.04R_{III}\varphi_{PIII} - -0.0002P_{0III}^2 + 12.13R_{III}^2 - 0.00003\varphi_{PIII}^2, \quad (17)$$

series MA - meta-aramid multifilament yarn 40 tex

$$P_{III} = 5.88 + 1.18P_{0III} - 11.27R_{III} + 0.02\varphi_{PIII} - -0.11P_{0III}R_{III} + 0.002P_{0III}\varphi_{PIII} - 0.02R_{III}\varphi_{PIII} - -0.00015P_{0III}^2 + 5.69R_{III}^2 - 0.00001\varphi_{PIII}^2, \quad (18)$$

series CA - carbon yarn H-30 with thickness 30 tex

$$P_{III} = 6.84 + 1.20P_{0III} - 13.64R_{III} + 0.25\varphi_{PIII} - -0.12P_{0III}R_{III} + 0.003P_{0III}\varphi_{PIII} - 0.026R_{III}\varphi_{PIII} - -0.00019P_{0III}^2 + 7.00R_{III}^2 - 0.00002\varphi_{PIII}^2. \quad (19)$$

For nominal value of the contact angle $\varphi_{PIII} = 22°$ in the center of experiment, using dependencies (17-19), Figure 7 represents response surfaces for the III area.

Adequacy of obtained regression dependencies has been verified with SPSS program for statistical processing of experimental data [8-14].

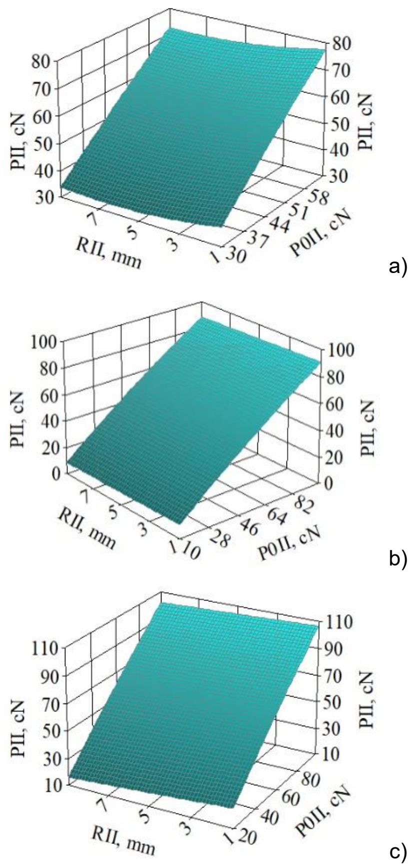


Figure 6 Graphical dependencies of the warp yarns tension for the II area of the weaving loom: a) - para-aramid multifilament yarn; b) - meta-aramid multifilament yarn; c) - carbon yarn H-30

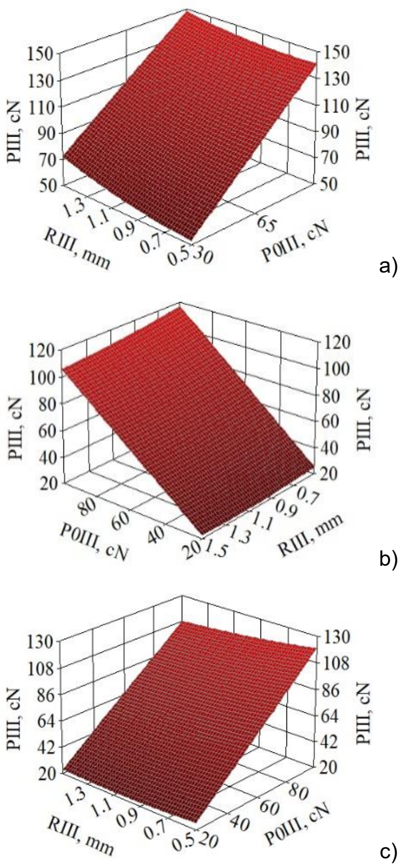


Figure 7 Graphical dependencies of the warp yarns tension for the III area of the weaving loom: a) - para-aramid multifilament yarn; b) - meta-aramid multifilament yarn; c) - carbon yarn H-30

It is of interest to obtain dependency of para-aramid, meta-aramid, and carbon multifilament yarn tension and radius of cylinder with fixed value of input tension. This value of tension corresponds to the center of the experiment (Tables 1-3) for each type of yarn.

Regression dependencies (11-13) for the I area rearranges as follows:

series PA - para-aramid multifilament yarn 44 tex (tension in the center of the experiment 38 cN)

$$P_I = 50.22 - 0.006R_I - 0.00002R_I^2, \quad (20)$$

series MA - meta-aramid multifilament yarn 40 tex (tension in the center of the experiment 26 cN)

$$P_I = 31.67 + 0.0028R_I - 0.00008R_I^2, \quad (21)$$

series CA - carbon yarn H-30 with thickness 30 tex (tension in the center of the experiment 32 cN)

$$P_I = 40.32 + 0.0063R_I - 0.00002R_I^2, \quad (22)$$

Regression dependencies (14-16) for the II area rearranges as follows:

series PA - para-aramid multifilament yarn 44 tex (tension in the center of the experiment 48 cN)

$$P_{II} = 60.27 - 1.17R_{II} + 0.12R_{II}^2, \quad (23)$$

series MA - meta-aramid multifilament yarn 40 tex (tension in the center of the experiment 34 cN)

$$P_{II} = 34.29 - 0.26R_{II} + 0.002R_{II}^2, \quad (24)$$

series CA - carbon yarn H-30 with thickness 30 tex (tension in the center of the experiment 40 cN)

$$P_{II} = 47.36 - 0.99R_{II} + 0.07R_{II}^2, \quad (25)$$

Regression dependencies (17-19) for the III area rearranges as follows:

series PA - para-aramid multifilament yarn 44 tex (tension in the center of the experiment 56 cN)

$$P_{III} = 88.29 - 34.57R_{III} + 12.13R_{III}^2, \quad (26)$$

series MA meta-aramid multifilament yarn 40 tex (tension in the center of the experiment 42 cN)

$$P_{III} = 57.42 - 16.24R_{III} + 5.69R_{III}^2, \quad (27)$$

series CA carbon yarn H-30 with thickness 30 tex (tension in the center of the experiment 48 cN)

$$P_{III} = 67.19 - 19.97R_{III} + 7.00R_{III}^2. \quad (28)$$

Figure 8 represents graphical dependencies reflecting influence of guide's radius on para-amid, meta-aramid, and carbon multifilament yarns tension for the I area, that have been obtained with the use of dependencies (20-22).

Figure 9 represents graphical dependencies reflecting influence of guide's radius on para-amid, meta-aramid, and carbon multifilament yarns tension for the II area, that have been obtained with the use of dependencies (23-25).

Figure 10 represents graphical dependencies reflecting influence of guide's radius on para-amid, meta-aramid, and carbon multifilament yarns tension for the III area, that have been obtained with the use of dependencies (26-28).

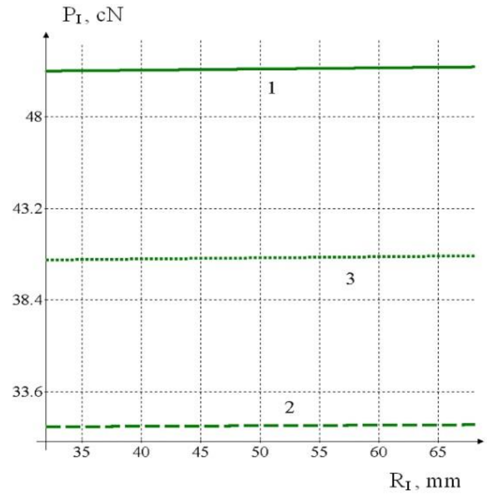


Figure 8 Dependency of para-aramid, meta-aramid, and carbon multifilament yarn tension after the I area: 1 - for series PA; 2 - for series MA; 3 - for series CA

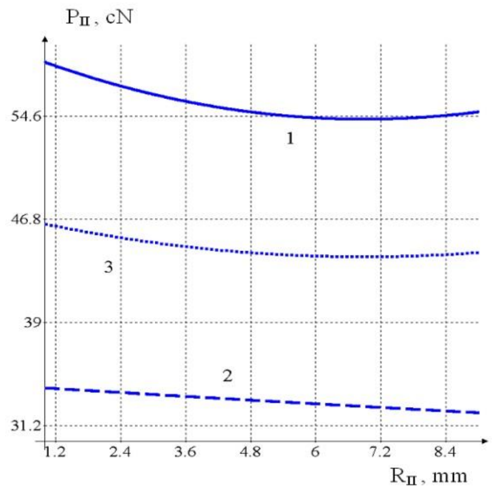


Figure 9 Dependency of para-aramid, meta-aramid, and carbon multifilament yarn tension after the II area: 1 - for series PA; 2 - for series MA; 3 - for series CA

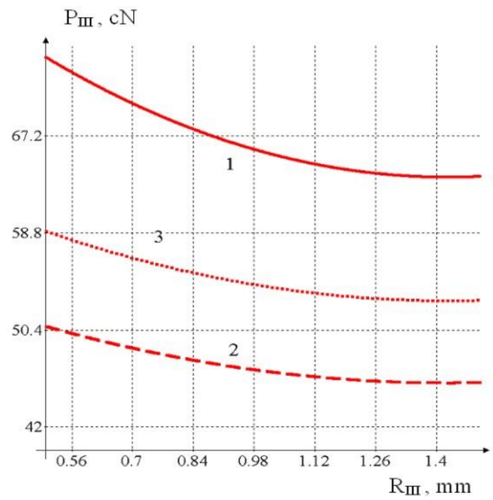


Figure 10 Dependency of para-aramid, meta-aramid, and carbon multifilament yarn tension after the III area: 1 - for series PA; 2 - for series MA; 3 - for series CA

Analysis of the above graphical dependencies allowed to find extreme points with minimum para-aramid, meta-aramid, and carbon multifilament yarns tension for the II, III areas. This permits to bring up a question of optimization of geometrical dimensions of guides and operative parts of the weaving loom.

Using regression dependencies (11-19) we determined values of para-aramid, meta-aramid, and carbon multifilament yarn tension in the III area before the fell of the fabric for different moments of fabric element formation at the weaving looms. The value of distortion of para-aramid, meta-aramid, and carbon multifilament yarns during shedding, as well as during battening and removal of fabric was taken into account as the value of input tension in the I area.

Analysis of graphical dependencies (Figure 11) has allowed to establish that the most dense conditions of fabric formation will be for series PA during manufacturing of Kevlar fabric, where para-aramid multifilament yarns are used as warp yarns 44 tex. This can be explained by the high value of the coefficients of tensile rigidity and bending rigidity.

Obtained results may be used to optimize technological process of weaving, when it will be possible to determine density of the fabric formation process yet during initial stage.

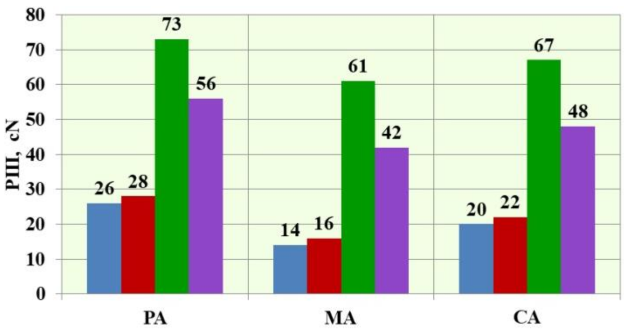


Figure 11 Histogram of warp yarns tension P_{III} before the fell during industrial fabric formation: PA - Kevlar from para-aramid multifilament yarns 44 tex; MA - Nomex from meta-aramid multifilament yarns 40 tex; CA - fabric from carbon multifilament yarns 30 tex; ■ - threading tension of warp yarns; ■ - warp yarns tension working with closed shed; ■ - tension of warp yarns with fully opened shed; ■ - tension of warp yarns during battening

5 CONCLUSIONS

As a result of integrated experimental researches, for para-aramid, meta-aramid, and carbon multifilament yarns were obtained regression dependencies between value of yarn tension after the guide and yarn tension before the guide, radius of guide's surface curve, and contact angle. It has been proven that tension degree of para-aramid, meta-aramid, and carbon multifilament yarns before industrial fabric formation area is influenced by:

1) tension before cylindrical guide surface of the operative part,
2) radius of the cylindrical guide surface curve of the operative part,
3) contact angle between yarns and cylindrical guide surface of the operative part,
4) mechanical, physical and structural properties of para-aramid, meta-aramid, and carbon multifilament yarns.

In the paper three series of experiments has been implemented for the I, II, III threading areas for para-aramid 44 tex, meta-aramid 40 tex and carbon multifilament yarns 30 tex.

The I area corresponded to small curved guide, when the radius of the guide is much longer comparing to the estimated radius of the yarn cross-sectional view. At the same time para-aramid, meta-aramid, and carbon multifilament yarns tension before the guide varies within the limits of $14\,cN \leq P_{0I} \leq 50\,cN$, value of radius of the guide surface curve varies within the limits of $32\,mm \leq R_I \leq 68\,mm$, value of the contact angle between the yarn and guide surface varies within the limits of $98° \leq \varphi_{PI} \leq 122°$.

The II area corresponded to medium curved guide, when the radius of the guide is commensurate with radii of different guides of the weaving looms. At the same time para-aramid, meta-aramid, and carbon multifilament yarns tension before the guide varies within the limits of $17\,cN \leq P_{0II} \leq 63\,cN$, value of radius of the guide surface curve varies within the limits of $1\,mm \leq R_{II} \leq 9\,mm$, value of the contact angle between the yarn and the guide surface varies within the limits of $3° \leq \varphi_{PII} \leq 88°$.

The III area corresponded to large curved guide, when the radius of the guide is commensurate with radii of the para-aramid, meta-aramid, and carbon multifilament yarn cross-sectional view. At the same time para-aramid, meta-aramid, and carbon multifilament yarns tension before the guide varies within the limits of $23\,cN \leq P_{0III} \leq 73\,cN$, value of radius of the guide surface curve varies within the limits of $0.5\,mm \leq R_{III} \leq 1.5\,mm$, value of the contact angle between the yarn and the guide surface varies within the limits of $1° \leq \varphi_{PIII} \leq 44°$.

Due to the above it is now possible, (still at the initial stage of the technological process design) with the use of recursion, to determine para-aramid, meta-aramid, and carbon multifilament yarns tension before the fabric formation area which depends upon geometrical and design parameters of the machinery and its physical and mechanical characteristics.

Obtained results may be used to improve technological processes of the textile industry.

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THE PROCESS OF MAKING BATIK AND THE DEVELOPMENT OF INDONESIAN *BAKARAN* MOTIFS

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Abstract: *Batik is one of the original handicrafts recognized by UNESCO as Indonesia's cultural heritage. Therefore, this research aims to explore the development of good quality innovative Indonesian batik designs for Micro, Small Medium Enterprise (MSMEs). This is practice based research with data collected through observation and interviews. The result showed that the designs of Bakaran motifs contain elements of the Pati city history, Central Java, Indonesia. The making of batik motif in this research also went through digitalization process for the efficiency of making the next batik. Therefore, the international community is expected to determine the beginning and ending process used by Micro, Small Medium Enterprise (MSMEs) craftsmen in producing good quality batik. Further research needs to be carried out to explore the development of batik Bakaran designs using Druju (Acanthus ilicifolius) flower motifs.*

Keywords: *batik Bakaran, batik motif, Druju (Acanthus ilicifolius) flower, craft.*

1 INTRODUCTION

Batik as an ancient Indonesian art has been recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as the country's cultural heritage. Historically, batik was popularized by the kings of Islamic Mataram when cloths of various cultural exchanges were used for palace decoration. Furthermore, the Dutch artists were interested in it, and in 1892 they encouraged the manufacturers to produce batik in Europe [1]. Therefore, batik is increasingly developing in the western world and is well known globally. Over the year, the uniqueness of the motifs and designs has attracted some world leaders, thereby making it an alternative to fashion trends in the global market [2]. Batik, as a symbol of Indonesian culture is used to describe regions inside and outside Java, such as Solo, Cirebon, Pekalongan, Lasem, Yogyakarta, Pati, etc. [3]. Batik Bakaran is one of the potential local cultures as Micro, Small Medium Enterprise (MSMEs) in Pati [4]. The power of culture symbolizes the original society of the batik, and this unique feature makes it one of the new trends in global fashion today. According to Mulyanto et al. [5], batik cloth can be made as fashion product which attracts the interest of many people. One of things that become a good or bad reason of a batik shirt can be seen from its batik motif arrangement. The unique original nature is highly pronounced when exploring the characteristics of the design and the motifs. Apart from that, a variety of unique and innovative designs made Indonesian batik inseparable from an aesthetic impression and popular in the international market. Unfortunately, the trend of wearing batik is also inseparable from societal reality because users do not know much about the manufacturing process and the stages involved. Generally, the design process in batik consists of the design and coloring stages. In the design stage, aesthetic elements are put forward, however it is necessary to improvise during innovation to ensure it is in line with the progress of the times without destroying the message and cultural meaning. Therefore, this research aims to understand the working process of batik Bakaran craftsmen in creating design innovations.

This research aims to describe the process of making Indonesian batik due to the unique characteristics associated with the manufacturing process. These include the use of traditional tools and the inadequate education of the craftsmen, with the majority still in high school, while the elderly did not exceed elementary school. This research focuses on the process of batik Bakaran because it is one of the famous motifs in Indonesia. According to Kusumawardani, batik is a prospective opportunity in developing Micro, Small Medium Enterprise (MSMEs) in Pati [7]. Its uniqueness lies in the crack motif [8].

The industry in Bakaran started in 1977 when a maker named Bukhari Wiryo Satmoko founded the "Tjokro" known as the "batik business" [9]. Since its popularity in Pati in mid-1997, batik has become synonymous with the role of women as craftsmen [10]. This ancient art work on cloths is made by women in their homes or better known as home industry businesses [11]. At that time, the work ethic of women with their patients and persevering character encouraged the timeless traditional batik Bakaran business [12]. However, this coastal batik varies from others in terms of brightness and boldness, with the incorporation of darker colors, such as brown and black [13]. The fundamentals pattern is based on the Middle and Coastal motifs and known as the Middle Stream because the Bakaran Wetan village introduced it as part of the Majapahit Kingdom [14]. Due to its attractiveness, batik Bakaran has penetrated international markets such as the United States and Canada [15]. One of batik Bakaran motifs which would be made was coming from *Druju* flower. *Druju* plant had latin name *Acanthus ilicifolius.* According to Tomlinson, this plant is classified into Acanthus ilicifolius L, Genus: Acanthus, Family: Acanthaceae, Ordo: Lamiales, and included into Plantae Kingdom [16]. There was another research about *Druju* flower motif, in the research conducted by Rohmah et al., only investigated the potency of Bakaran batik and short discussion about *Druju* flower as contemporary batik motif [17]. In the study conducted by Astuti only investigated the origin and the content of *Druju* flower motif aesthetic value which obtained full support from the local government of Pati Regency, Indonesia [18]. In the research by Septiana et al. [19], the various aesthetic elements of *Druju* flower batik motif, as one of batik Bakaran traditional motifs, were introduced. This research was different from the previous research which had been conducted. This research was conducted on the ideas of planning of batik motif making from the beginning until the final step. Beside that the motif designed was the exploration result of the original plant. Then this research was also a collaboration conducted by the author with the craftsmen to create the new motif. There was significant difference between the existed *Druju* flower motif and *Druju* flower motif to be developed. In the previous motif design obtained in Astuti, *Druju* plant was not pictured clearly, and put side by side with the bird motif without its main head, but less specific on describing *Druju* plan in real, especially if seen from distance, and the brown color seemed dominating in that motif [19].

In this research, the author collaborated with craftsmen, created *Druju* flower motif described specifically because of exploring the real *Druju* plant. Besides, by utilizing the technology development the making of this motif was also conducted digitally in order to ease the process of making the next batik, and to protect the right design ownership.

2 THEORETICAL REVIEW

Etymologically and terminologically, batik is a series of words *mbat* and *tik*. *Mbat* in Javanese is interpreted as *ngembat* or throwing repeatedly, while *tik* comes from the word *titik* (dots). Therefore, the process of making batik is associated with throwing dots repeatedly on cloth [20-22]. Batik has been around for a long time, and even the motif has appeared several times in the carvings of the temple walls [3]. Its popularity has existed since the era of the kings of the archipelago, or feudalism, as art with plant and abstract characteristics, although its scope was only limited to the palace [23].

Batik Bakaran Pati is one of the numerous batiks that have been developed in Indonesia to date. It is a typical batik from Pati manufactured in the Bakaran Village, Juwana sub-district [24]. Visitors are allowed to choose from various motifs of interest, both classic and contemporary, with varying color choices. Compared to written batik produced in other areas, the characteristic of Bakaran lies in its spontaneous, bolder, and freer motifs [25]. Some of the motives include *Padas Gempal*, *Gringsing*, *Bregat Ireng*, *Truntum*, etc [26].

One of the most distinctive characteristics of batik is its continuous use in traditional techniques, such as in the manufacture of making written batik [27]. However, it still has high artistic value and is customarily used for clothing and as a means of supporting ceremonies [28]. However, this does not rule out the fact that it has become a fashion in general. It is a commodity that is in high demand by the global market. Meanwhile, the processing time taken by the craftsmen to create batik with traditional techniques has an average of 110-115 hours, starting from the design to the washing stage [29].

Generally, batik craftsmen start to reflect on the artistic ideas that are enthusiastic or stubborn to create [30]. After finding an artistic idea in the form of a batik design, they start with the design process either manually or using machines (technology) [31]. At the design application stage, the craftsmen start writing batik using *canting* [32]. Furthermore, the coloring is also carried out in a traditional stage, namely by dyeing it to produce the desired color. In the last stage, the craftsmen carry out color-locking, which is finished by drying the cloth [33].

3 METHODOLOGY

This research was a practice based. Creation research usually integrated creative process, aesthetic as the part of a research [34]. The uniqueness of an art creation and design cannot be equated with the theoretical concept in another research, even though probably the concept could be used but in certain limitation. There were three general factors in art creation and design such as; the initial inspiration, information collection, selection, experiment, articulation, perfection, generalization, human response, and the result of art work. In an art creation or design, the methodology is not only the framework but also involving intuition, and emotion existed in the researcher which also determined good or bad design or work. Many art and design research had different procedures but the most important they can tell the process [35].

Several stages are involved in the process of making batik Bakaran, including finding artistic ideas, the design, manufacture and final stage. This is an practice based research research carried out through collaboration between the authors and batik craftsmen, with the task of creating a batik cloth divided using a high-quality Bakaran motif. Collaboration and assignments were reflected on the mind map (Figure 1). The research focuses on 3 processes in making batik, namely the idea, design and batik manufacturing stages, which are expected to be able to explain all the processes in making batik Bakaran at MSMEs in Indonesia. The stage of searching for aideas and the stage of design were conducted by both researchers because they had experience in the field of art and design creation, while the stage of making batik was done by the craftsmen because they had the batik experience.

Data collection was obtained through observation and interviews. Interview was conducted to the opinion of Batik expert named Sudarwanto who was a practitioner and instructor of a college in Indonesia. The interview was conducted with the purpose to find out the guidelines of making batik. This research was carried out in January 2021 in the Pati area, Central Java, Indonesia.

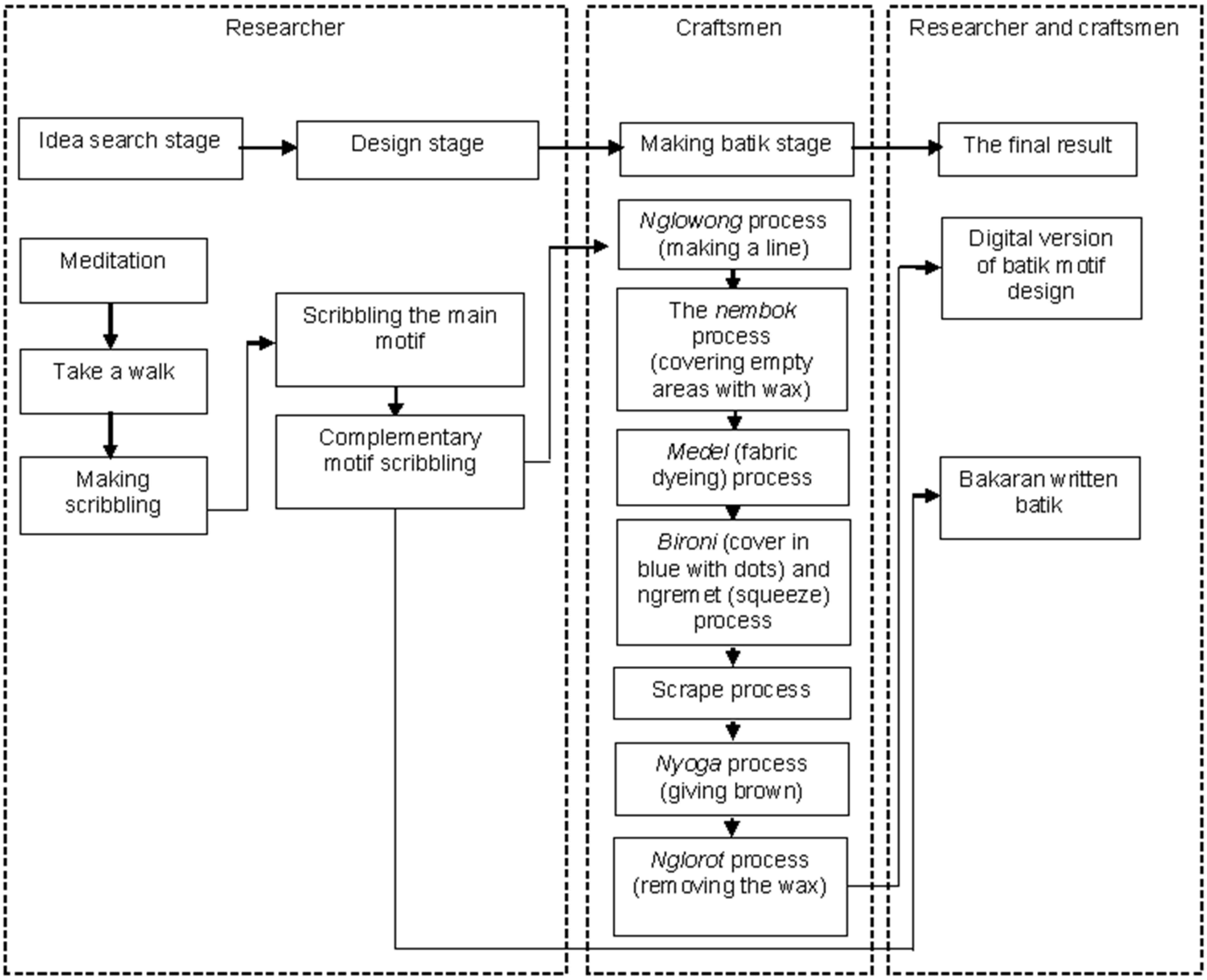

Figure 1 Mind map

Table 1 The profile of the batik craftsmen collaboration

No	Name	Age	Occupation	Years of Service	Expert
1	Bukhari	70	Owner of UD. Tjokro *Batik* Tulis	39 years	Making batik
2	Aan Sudarwanto, S.Sn.,M.Sn	50	Lecturer of Indonesia Art Institute Surakarta	15 years	Batik craft

The authors collaborated with Mr. Bukhari, a batik craftsman and owner of the UD. Tjokro Batik Tulis located at Jl. Mangkudipuro 196 Bakaran Wetan Village RT 2 RW 2, Juwana District, Pati Regency, Central Java to carry out this research. Mr. Bukhari is the owner of the first largest traditional batik business in Bakaran Wetan Village, which has been established since 1982. Therefore, for the past 39 years of existence, the company has been producing traditional hand-written batik with 20 employees, 12 of which have worked at UD. Tjokro Batik Tulis, while the other 8 work from their homes. This business produces 30-40 pieces of batik cloth with a fabric size of 90 cm wide and 3 m long. Some of the produced batik motifs are the *gandrung* and *udan liris*. Currently, there are 6 batik craftsmen in the UD. Tjokro Batik Tulis, with the products marketed in many cities in Indonesia including Jakarta, Semarang, Solo, Surabaya, Yogyakarta, Bali, Kalimantan and Sumatra. The process of making batik was conducted by Mr. Bukhari who was highly experienced, but in the process of making batik was not apart from the authors' assistance.

During the interview, Mr. Aan Sudarwanto explained that the trait of Bakaran batik is strongly related to the legend of Nyai Ageng Danowati. Bakaran batik had five classic motifs; they were the beginning of Bakaran batik creation. The five motifs were *Druju*, *Limaran*, *Magelati*, *Gandrung*, and *Sidorukun*. Mr. Aan Sudarwanto also added, Bakaran batik with good quality could be seen from the cloth used as its main material. Primis cloth was assessed to be more superior than Prima cloth because it has softer fiber. To obtain high art value, the working of Bakaran batik used manual ways, until the craftsmen could express the feel, emotion, and their ability in batik cloth. Superior batik Bakaran motif also can be seen from its tidiness and the picture pattern in batik motif, both described the craftsmen's skill in doing batik.

4 DISCUSSION

4.1 Idea search stage

Based on interviews with batik craftsmen, manufacturing batik still requires a search for ideas, which is philosophically known as *sêmêdi* (meditation), *mlaku-mlaku* (take a walk), and *orat-oret* (scribbling) in Javanese.

4.1.1 Sêmêdi (meditation)

Sêmêdi means traditional people generally carry out meditation in reflecting on themselves and focusing their minds to determining an idea. It refers to a retreat in a solitary place for meditation that connects the mind vertically to the Creator. *Sêmêdi* is a distinctive term associated with how Buddhists worship [36]. In the teachings of other religions, it is also a way of contemplating God, in Islam it is known as *dzikir* [37]. Initially, it was known as the methods used by a person to carry out a rigid or *saklêk* concentration of mind because it is part of traditional and religious rites [38]. Generally, in the context of the indigenous peoples' scope, someone with *sêmêdi* simply performs self-reflection or daydreams to explore visual experiences. In other words, *sêmêdi* or simple meditation carried out provides a place for someone to reflect and think deeply [39].

4.1.2 Mlaku-mlaku

Apart from *sêmêdi*, in search of ideas, the authors also carried out a process of *mlaku-mlaku,* which is a Javanese term that means traveling. However, in this context, *mlaku-mlaku* refers more to observations made by a person to collect visual exploration that meets many things, which are absorbed and carried out by the reviewer using the concept of thought. In this case, the journey taken to gain a lot of experience by meeting people in the social environment includes [40] conducting discussions and getting new things. Therefore, it is very likely for someone to get new experiences later then become a collection of concepts. This is one of the attributes generally carried out in studies associated with idea generation. Apart from meeting people in a social environment, one can also see various objects (living or dead) in form or ornament. Therefore, an idea arises through the observation of animals, plants, or even inanimate objects.

Figure 2 *Druju* (*Acanthus ilicifolius*) plants

This research uses plant motifs because Indonesia as an archipelago is rich in plants, including the *Druju (Acanthus ilicifolius*) flower, which is only found in swamps, estuaries between rivers, and the sea in Juwana, Pati, Central Java. Due to this peculiarity, these flowers are used as batik Bakaran motif in Pati, Central Java, and as a traditional medicine to treat coughs.

4.1.3 Orêt- orêt

To fulfil the process of searching for ideas when someone has taken the visual exploration with *mlaku-mlaku*, the casting carried out by scribbling or in Javanese terms it is called *orêt-orêt*. In this case, it comprises of two things, the first is the locking of ideas, while the second is the search process.

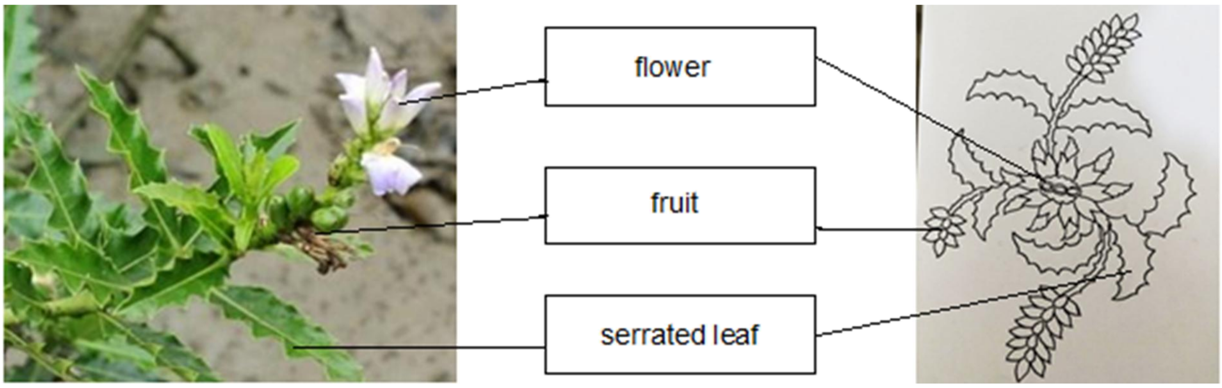

Figure 3 *Druju* (*Acanthus ilicifolius*) flower scribbling

To scratch a person, abstract lines and shapes are created, which leads to design innovation. When ideas have started to be discovered, the authors are allowed to outline it through scratching, scraping, *orêt-orêt*. On the other hand, it is also intended for someone still at the stage of looking for ideas. Through *orêt-orêt*, it is possible to get inspiration and innovation from a design idea. Furthermore, it provides new experiences in design principles; therefore artistic ideas always emerge in creating certain design prototypes [41]. Meanwhile, *orêt-orêt* means many things, despite being abstract from one's mind. Therefore, it is possible to find a design idea through this pattern, even when it locks into pre-existing ideas.

This research draws a doodle of *Druju* (*Acanthus ilicifolius*) flowers using 120 gsm of drawing paper and a black marker according to the pattern and structure. There are several characteristics of this flower, including sharp edges, basic curved shapes, as well as oval and compound fruit. Its leaf structure differs from other plants and is shaped like serrations.

4.2 Design stage

Design as a container for creative ideas aims to achieve beauty or aesthetic angle using the main and complementary motif sketch. At the sketching stage, a rough outline or design of artwork is conducted. Drawing a sketch serve as preparation for a large piece of art or simply for understanding the appearance of an object. At the designing motifs stage, this research uses digital techniques with the Adobe Illustrator CS6 application.

4.2.1 Sketch of the main motif

Figure 4 is the result of the main motif sketch with the motive characterized by the structure of the *Druju* plant, both flowers, fruit, and leaves.

4.2.2 Sketch of complementary motifs

Batik comprises main and complementary motifs used to fill the fields and beautify the batik Bakaran. In Figures 4 and 5 this research makes the main and complementary motifs of digital versions submitted to craftsmen later made as motifs on burnt batik. Furthermore, the making of this digital version is expected to be an alternative for creating printed batik using a machine system.

Figure 4 Sketch of the main motif

Figure 5 Sketch of complementary motifs

4.3 Making batik stage

The search for ideas needed for the batik motif pattern design in this research is given to the batik craftsmen. The making stage of the batik is carried out in four ways, namely by writing in *canting*, which is commonly called written batik, printing with a stamp called batik cap, tied with a rope or thread called batik *Ikat* or *jumputan*, and by printing it on a screen called batik print. Batik Bakaran is a popular hand-written technique in Pati, Central Java, with a prolonged production process. This is because it is carried out manually with each sheet is inscribed on both surfaces because this includes traditional written batik, which is different from printing techniques. In the making of this *Druju* motif used primis cloth that had soft fiber characteristic until the candle/night could stick well. The cloth used was with size length 115x115 cm; this size was used to make the table cloth. Candle used in the process of making batik consisted of three candle types namely klowong candle, blok/wall candle, and broken/retak candle.

The stage of making batik Bakaran consists of several processes, including:

4.3.1 Nglowong process

This is the process of making a line in accordance with the image that has been made on the cloth. It requires tools and materials in the form of pencils, cloth, *canting*, and wax. The *canting* with wax is used to outline the pattern of the image with *prim is* chosen to make a standard table cloth because of its good quality size with tight and regular fibers that do not easily stretch/spread. This process is called *nglowong*, which is a term for the traditional batik-making process. Before the *nglowong* process is carried out, a drawing pattern is made on paper using a pencil, then it is written using *canting*, and the wax adjusts the shape. The *nglowong* process takes one day to acquire maximum results.

Figure 6 The *nglowong* process

4.3.2 Nembok process (covering the part with wax lines)

Nembok is the process of blocking empty lines using a special wax with dark brown and thick colors. This process makes use of *canting*, a brush, and special wax. It blocks areas from other colors and is processed by *canting*. However, to hasten the procedure, the process is carried out with a sweeping brush while ensuring the cloth's wax is blocked. This starts with the close part to the motif lined, which is then blocked on another part till all the parts are covered with wax. It only takes a few minutes to block the batik Bakaran cloth.

Figure 7 The process of *nembok*

4.3.3 Medel process (coloring)

Medel is the process of adding a dark blue base color to the parts of images that are empty or unblocked on a cloth. This process uses tools and materials in the form of buckets, gloves, synthetic dyes, and water. Furthermore, it uses naphthol powder and dark blue indigosol liquid dyes. Both are used because they are synthetic therefore, they have a brighter color, and last longer with numerous color variations. The dye mixed with water for one Bakaran batik cloth of the *medel* process uses about 20 g of dye with 10-15 l of water. The *medel* process is carried out after the *nembok* process by dipping the blocked cloth into the color mixture until a homogenous effect is obtained.

Figure 8 *Medel* process

4.3.4 The process of bironi and ngremet

Mbironi is a traditional batik term after the *medel* process. Meanwhile, the *ngremet* (squeeze) process is carried out on the part of the cloth that is blocked and then kneaded until it looks cracked to make it easier to obtain a *soga* color. The tools needed in this process are buckets, dyes, and water. In this process, the staining is carried out with *soga* (dark brown) color, with a mixture of 20 g of *soga* color and 10-15 l of water. This process is performed by dipping the cloth into the color mixture then kneading it until the blocked part looks cracked and the cloth is *soga* color then drained.

Figure 9 The process of *mbironi* and *ngremet*

4.3.5 Scrape process

Kerok is the process of removing the wax from the cloth that needs to be colored. It is carried out using a tool in the form of a small plate or scrap with the wax-covered part of the pattern scraped-off. This process lasts only a short time until the wax that sticks to the fabric is lost.

Figure 10 The scraping process

4.3.6 Nyoga process

Nyoga is the process of giving a dark brown color to the cloth. The word *nyoga* comes from the Soga tree *(Peltophorum pterocarpum)*, which means when the skin is used as a dye it tends to produce a natural *soga* (brown) color.

Figure 11 *Nyoga* process

The tools and materials needed for this process are buckets, gloves, and *soga* dye. The dye mixture used is 20 g of dark brown color with 10-15 l of water. This process is carried out briefly by dipping the scraped cloth into the *soga* dye mixture until the cloth is dark brown.

4.3.7 Nglorot process (removing the wax and boiling)

Nglorot is the final process used to remove the wax in the cloth with boiling water. The tools and materials needed in this process are pot, furnace, water, and caustic soda. The use of *Sodium hydroxide (NaOH)* mixed with water at a rate of 10% serves to make the wax dissolve quickly. The amount of water used depends on the pan, although it is usually up to about 15 cm from the top to avoid overflowing. This process starts by making a mixture of water and caustic soda then boiling it on the stove. Furthermore, the cloth that has gone through the *nglowong* until *the nyoga* process is put into a pot filled with boiling water until all the wax is lost. After all the wax is lost, the cloth is rinsed using clean water and then aerated to dry.

Figure 12 *Nglorot* process

5 RESULTS AND DISCUSSION

The basis of this research is collaboration between authors and batik craftsmen. In the early stages, this research designed the batik motif in both manual and digital versions. The motif development in this research still maintained *Druju* plant as the typical motif of Bakaran batik. *Druju* flower motif is the original motif of Bakaran batik which has been existed since the era of Majapahit Kingdom; she was Nyai Ageng Danowati [19]. The selection of *Druju* plant as the main motif was because this plant could be easily found around the swamp of Juwana area, Pati. The findings of *Druju* plan was begun by some people from Majapahit Kingdom who searched for protection, until one of them named Ki Dhukut found a swamp and there were many *Druju* plants in it. Then it was made as a region which is now well known as Juwana [42]. Afterward, the craftsmen made a batik process from *primis* cloth with the batik Bakaran developed in 2 versions, namely the digital motif design and batik made from *primis* cloth.

Figure 13 is a digital version of the batik motif made as an alternative to the written batik production. This version of the batik Bakaran motif is an alternative for traditional batik craftsmen that need to digitize batik motifs and are expected to produce printed batik made using a mechanical system. The development of MSME batik craftsmen is very necessary, considering that the manufacturing technique only uses the written batik during this time. The craftsmen that do not master technology are unable to digitize batik motifs. The digital version of the batik motif tends to later make it easier for permits to register copyright or patent rights with the government.

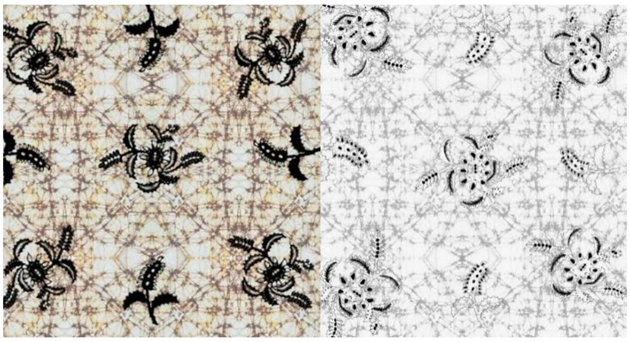

Figure 13 Digital batik motif design

Figure 14 is the final result of the batik-making process that produces batik Bakaran with floral motifs. This research uses the *Druju* flower motif to preserve the ancestral heritage of the Bakaran Juwana village. In this batik, there is a *Druju* flower motif which is related to the legend of the Bakaran batik maker, Nyai Ageng Danowati, an expert in the Majapahit kingdom era. One of the batik motifs created by Nyai Ageng Danowati is the *Druju* flower motif. This research makes black batik motifs because the color signified elegance, dignity, and personality in ancient times. This is also reinforced by the characteristics of the *Druju* flower batik with black and white colors, which have contrasting properties of light and dark [43]. The *soga* color chosen symbolizes traditional batik, which tends to have black, white, and brown colors. There are motifs such as veins that stick out to add aesthetic elements, variations, and uniqueness in this batik. In general, batik Bakaran is priced at 175 000 IDR to 1 500 000 IDR, depending on the material and width of the cloth with a processing time of 2-3 days for the size of a tablecloth 1 yard.

Many craftsmen of batik MSME made batik motifs from existed pictures by copying the previous cloth and the available batik pattern in the market. They also developed the motif from the result of existed batik cloth. In this research, the making of batik was started by analyzing the object directly from the structure of *Druju* plant then continued by making the sketch, then made into batik with *Druju* flower motif. Another difference from *Druju* motif in this research was obtained in the process of digitalization, where many of batik MSME did not used digital design yet. Digital design is beneficial to accelerate the working process, easing the archive file management on the design ownership.

Figure 14 Batik Bakaran

6 CONCLUSION

The surrounding environment inspires the process of making traditional batik motifs. For example, the batik Bakaran motif was inspired by the *Druju* flower found in swamps, rivers, and estuaries of the sea and Juwana River, Pati. The motifs pictured in Bakaran batik were the creation result of the existed legend in Bakaran area. Those motifs were strongly correlated to the figure named Nyi Ageng Danowati, a batiker of Majapahit Kingdom who lived in Bakaran village. What becomes the typical of Bakaran batik is that it has five traditional motifs namely *Druju*, *Limaran*, *Magelati*, *Gandrung*, and *Sidorukun*. These five motives were the creation of Nyai Ageng Danowati. Besides that, what becomes the specific trait of Bakaran batik is in the process of its creation that goes through mbironi process namely giving the blue color before given another color. This research aimed to conserve *Druju* flower motif as the original motif of Bakaran. Beside to conserve the original motif of Bakaran batik, the making of batik motif in this research also went through digitalization process for the efficiency of making the next batik. This research also thoroughly explained the process of making Bakaran batik from the beginning started from determining the idea, designing, until the process of doing the batik by exploring *Druju* flower motif directly from its original plant to obtain specific picture of *Druju* flower motif in Bakaran batik. The development of batik motif design results is expected to help enrich various types. This research only focuses on the process used by batik MSME craftsmen in Indonesia to create batik globally, from the idea-searching, design, to the making stages. Further research is expected to review the process of making batik both in terms of production and materials.

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