VLÁKNA A TEXTIL

4

Volume 26.
December
2019

FIBRES AND TEXTILES

STU FCHPT

TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

Trenčianska univerzita Alexandra Dubčeka v Trenčíne
Fakulta priemyselných technológií v Púchove

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ZSVTS

CHEMOSVIT FIBROCHEM

Indexed in:
SCOPUS
Chemical Abstracts
World Textiles

ISSN 1335-0617
print version

ISSN 2585-8890
online version

Fibres and Textiles
Vlákna a textil

Published by

- Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology
- Technical University of Liberec, Faculty of Textile Engineering
- Alexander Dubček University of Trenčín, Faculty of Industrial Technologies
- Slovak Society of Industrial Chemistry, Bratislava
- Research Institute of Man-Made Fibres, JSC, Svit
- VÚTCH – CHEMITEX, Ltd., Žilina
- Chemosvit Fibrochem, JSC, Svit

Vydáva

- Slovenská technická univerzita v Bratislave, Fakulta chemickej a potravinárskej technológie
- Technická univerzita v Liberci, Fakulta textilní
- Trenčianska univerzita Alexandra Dubčeka v Trenčíne, Fakulta priemyselných technológií
- Slovenská spoločnosť priemyselnej chémie, Bratislava
- Výskumný ústav chemických vlákien, a.s. Svit
- VÚTCH – CHEMITEX, spol. s r.o., Žilina
- Chemosvit Fibrochem, a.s., Svit

Editorial office and distribution of the journal
(Redakcia a distribúcia časopisu)

Ústav prírodných a syntetických polymérov
Fakulta chemickej a potravinárskej technológie
Slovenská technická univerzita v Bratislave
Radlinského 9, 812 37 Bratislava, SK
Tel: 00 421 2 59 325 575
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Order and advertisement of the journal
(Objednávka a inzercia časopisu)

Slovenská spoločnosť priemyselnej chémie,
člen Zväzu vedecko-technických spoločností
Radlinského 9, 812 37 Bratislava, SK
Tel: 00 421 2 59 325 575
e-mail: marcela.hricova@stuba.sk

Order of the journal from abroad – excepting Czech Republic
Objednávka časopisu zo zahraničia – okrem Českej Republiky

SLOVART G.T.G, s.r.o. EXPORT-IMPORT
Krupinská 4, P.O.Box 152, 852 99 Bratislava, SK
Tel: 00421 2 839 471-3, Fax: 00421 2 839 485
e-mail: info@slovart-gtg.sk

Typeset and printing *(Sadzba a tlač)*

FOART, s.r.o., Bratislava

Journal is published 4x per year
Subscription 60 EUR

Časopis vychádza 4x ročne
Ročné predplatné 60 EUR

Evidenčné číslo MKCR SR Bratislava EV 4006/10

IČO vydavateľa 00 397 687

Fibres and Textiles (4) 2019
Vlákna a textil (4) 2019
December 2019

Content

THE FUTURE OF ORGANIC COLORED COTTON

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Abstract: *Organic fibers are produced without chemical fertilizer, pesticides and genetically modified seeds (GMO). They require more time, labor and cost as they need special care than conventional fibers. Organic fibers alone are not safe, as added finishes can have toxic-effects. Therefore, Global Organic Textile Standard (GOTS) includes environmental-ecological, social and economic aspects of the production such as: prevention of pollution, contribution to prevention of global warming, decrease of waste and recycling. The economic impacts include the cost value of the organic fiber production and selling. On the social level, the future of the production of organic fibers in the world depends on textile, agriculture and environment-ecology. As people are becoming more conscious about their health and environment by wearing organic textile products, especially cotton, they are willing to spend more to wear these organic textiles. This research paper will look into the organic colored cotton and its future.*

Keywords: *Organic fibers, organic textiles, colored cotton, environmental protection, pesticide.*

1 INTRODUCTION

Fibers can come from different sources, natural and synthetic. The natural textile fibers are extracted from either animal sources like mohair, wool and silk, or from vegetable sources like cotton, kapok, linen, ramie, hemp, jute and sisal. The man-made fibers, such as acetate and viscose, are usually extracted in the lab and their polymer is generated from a cellulosic source such as wood and linters. For example, silkool from Glycine max, kazein from milk, ardil from peanut, zein from maize, are all obtained from natural sources, however they're not generated in a traditional fiber structure, but with special treatments applied they can be extruded into fibers and then they will be known as regenerated-fibers. Polyvinylchloride, polyethylene, poly-propylene, polyamide, polyester, polyacrylonitrile, polybenzimidazole polymer etc. are synthetic fibers made out of synthetizing chemicals obtained from crude and then extruded into fibers through the spinnerets, after being treated with special treatments. Natural fibers are dated to 8000 B.C. and still are being used around the world; however, the regenerated and synthetic fibers have been produced subsequently in 19th century, since the industrial revolution, which has brought conjointly environmental pollution whereas industrial production has been enhanced by various industrial chemicals, like crude, coal and gas [1].

Cotton is the most generally used natural almost pure polysaccharide fiber round the world, with softness and breathability that have made it the world's most popular natural fiber. Cotton has a great wicking ability as it absorbs moisture readily, which makes cotton clothes comfortable in hot weather, while having high strength in soap solutions, which means they are easy to wash. Cotton in its natural state and never dyed at all, can be identified as entirely organic. And since the naturally colored cotton is natural, and more desired than the chemically died one, naturally colored cotton is gaining its popularity as companies seek more sustainable solutions [2].

Organic fibers are the special production of typical natural fibers that do not use chemical fertilizers; cyanogenic pesticides (insecticides, defoliants, herbicides or fungicides) and genetically altered seeds (GMO). Organic fibers follow conjointly a certification for organic fibers methods of production [3]. The objective of the production of organic fibers is to mainly protect the natural sources, in addition to people's health besides all living creatures and their maintainable life conditions [4]. Certification of organic fibers requires hard procedures such as ceasing the utilization of chemical fertilizers and pesticides no less than three years, followed by organic cultivation. Organic fibers consume solely permissible substances that should cover physically the areas of cultivation fields, by using organic fertilizers for the reason of the enrichment of soil organically etc. Cotton with naturally colored lint, aside from white, is often referred to as colored cotton. Naturally grown, colored and white linted cottons are found from ancient times. However, colored cotton is being utilized since 2500 B.C. Colored cotton variations were known under cultivation in Asia, predominantly the Indian subcontinent, central Asian Republics of former Soviet Union and China as well. India was popular in producing varieties of brown linted types of tree cotton (G. arboreum L.) known as Cocanada 1, Cocanada 2. However, the Red Northerns were under marketable cultivation primarily on black soils under special circumstances in some areas of Andhra Pradesh. The red linted colored cotton were predominant and in high demand because of their higher coloring qualities, especially its color fastness. The advancements and new regulations of dyeing techniques have contributed significantly. The cultivation of colored cotton became discouraged and virtually abandoned in the latter half of this century, as many linted colored cotton variations didn't gain popularity among growers and were not in high demand for many reasons, primarily because of short productivity per unit area, poor quality of fiber physical appearance and uneven distribution of colors. The demand to use cotton around the world is increasing and there is a big need to increase the production, as the population demands for products and clothing made out of cotton are increasing. The advancement of technology in the mills during the processes of spinning, weaving or knitting and sorting the various shades of cotton during the production and separating the shades and colors, in addition to the different treatments and synthetic dyes, all have made it easier to separate the superior fiber quality cotton from others. In many cases white linted superior quality types of cotton replaced the less quality colored cotton. Therefore, the agriculture of colored cottons continued in exclusivity as novelty niche cotton and was favored for its aesthetic qualities. Recently with the companies being more aware about sustainability and trying to avoid using textiles, that can harm the environment, colored cottons started to get more attention and started to receive more recognition as being environmentally friendly. As people became aware of the danger, toxicity and the pollution of synthetic dyes, which they have on the environment and humans, the interest in cultivation of organic colored cotton has increased considerably. The only way to grow eco-friendly cotton is by organically grow colored cotton without the harmful chemicals used in the dyes or during the dying processing itself [5].

2 NATURALLY COLORED COTTON

As naturally colored cotton has increased in popularity recently and many companies are using the neutral shades of colored cotton as fashionable and trendy colors in their fashion collections of apparel, many farmers are asked and in some cases are even paid not to produce the colored variety and to concentrate on the organic naturally colored cotton with the off-white shade as they are coming back into fashion. Many Spanish companies are cultivating cotton that grows naturally with the neutral like mocha, green and taupe (Figure 1). The nature of these organic colored cotton fibers can be subject to emerge in varied tones and for the colors to change after washes, and to fade with exposure to the sun. The naturally colored cotton found in small farms in Brazil, where every farmer owns his or her land and grow organic cotton using biodynamic growing practices, only to produce super quality organic colored cotton. Growing organic cotton starts with the seeds being free from any genetic modification or added chemicals and the fibers never dyed or chemically treated during the processing. One washing process to remove the vegetable fats derived from the weaving process is used during the process and nothing more.

Figure 1 Photo credit: organic cotton colors

During the talk at Texworld Paris in September 2017, Mr. Santi Mallorqui Gou said: "We are used to having a fabric and giving it 20 to 40 different treatments. From spraying, coating, softeners, anti-crease finishes, anti-microbial treatments, antiseptics and enzyme treatments, there's so much added to fiber and fabrics during finishing stages" [2]. As all these processes contain many chemicals which we don't know how they interact with the wearers. About 20 percent of fibers considered as waste because they are collected during the process of cleaning or being too short to turn into yarns, gets turned into accessories or paper to ensure that the loop is completely closed.

2.1 Companies producing exclusively organic colored cotton (NCC ECOBRANDS)

NCC ECOBRANDS produce organic colored cotton exclusively and the cotton is purchased from the company through a guaranteed system. Embrapa Cotton supports the plantation of the organic colored cotton and the labor is carried out by the Margarida Maria Alves settlement in the city of Juarez Távora (PB). The size of the plantation is around 18 hectares of land which depends on a rainfed agriculture system. The plantation does not use any pesticides or synthetic fertilizers. However, processing of the cotton takes place in the actual settlement.

Figure 2 Photo is the courtesy of NCC ECOBRANDS posted on May 12, 2016

During the processing a special machine separates the seed of the fiber, then the seeds stay in the settlement for a period till the next planting season, then the fibers go through the spinning process in Campina Grande and Joao Pessoa. Goats and Cattle goats are harvested, which makes another source of income for cotton producers as they feed on the remained vegetation. The plants remaining are usually removed by the farmers to clean the fields and prepare them for another season in the following year. Organic colored cotton made a huge appearance during the 41st São Paulo Fashion Week – SPFW, 2016, which is considered one of the biggest fashion weeks in the world. The corporation of Cotton Natural Color with the fashion designer João Pimenta resulted in an amazing collection of apparel emphasizing on the usage of sustainable raw material as he created the summer collection of 2016.

2.2 The Biodynamic Institute – IBD

The IBD works on issuing the certifications of the color cotton produced in Juarez Távora, proving that it is a purely organic product. For the certificate to be issued by IBD, many regulations and procedures have to take place including the verification if the planting of the cotton follows the labor laws and the Brazilian Forest Code. The IBD certification has a special advantage being internationally credible, as it is monitored by the International Federation of Organic Agriculture Movements (IFOAM – England); JAS (Japan); USDA (United States); DAR (Germany) and Demeter International [6].

2.3 Cotton producers in the world

Identity programs identify the world cotton production as it is increasing in the marketing channels around the world, by the program or initiative under which it is produced. There are four major identity cotton world production. They are: Better Cotton Initiative (BCI), Cotton made in Africa (CmiA), Organic and Fairtrade, which its production was estimated at 3.4 million tons in 2016/17 and that makes around 15% of the world total production of cotton [7]. The Fairtrade was estimated at 3.4 million tons in 2016/17, up from 2.6 million tons in 2015/16 and 2.1 million in 2014/15. The world cotton production under the four identity programs is increasing and BCI is targeting to account of 30% of world production by 2020. The four identity cotton programs totaled 8% of world cotton production in 2014/15 with BCI and CmiA combined scored 7.6% of the total production. 12% of the world's total cotton production were credited to the identity in the year 2015/16 and the score of 15% in the year 2016/17 with BCI and CmiA accounting for almost all.

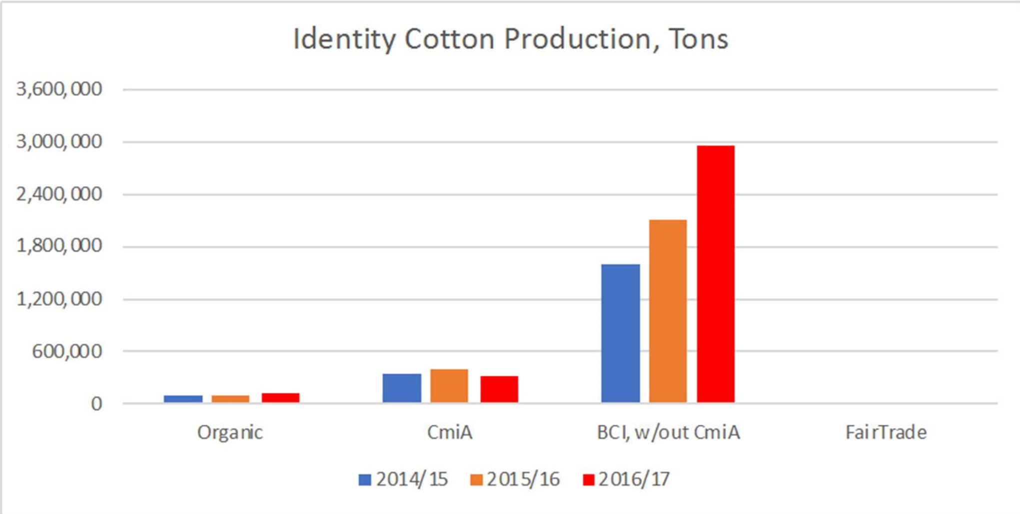

Figure 3 Identity cotton production from 2014-2017

Table 1 Production of BCI Cotton in 2016/2017

Production of BCI Cotton in 2016/17						
	ha	kg/ha	tons	% of total	farmers	tons/farmer
Australia	62 000	2 226	138 000	4	76	1 816
Brazil	607 000	1 730	1 050 000	32	195	5 385
China	401 000	2 324	932 000	29	51 746	18
CmiA	1 182 000	271	320 000	10	780 000	0.4
India	501 000	649	325 000	10	303 886	1
Israel	8 000	1 750	14 000	0	84	167
Kazakhstan	2 000	500	1 000	0	43	23
Madagascar	7 000	143	1 000	0	2 106	0.5
Mozambique	59 000	153	9 000	0	68 599	0.1
Pakistan	359 000	880	316 000	10	90 441	3
South Africa	7 000	571	4 000	0	553	7
Tajikistan	13 000	1 000	13 000	0	1 051	12
Turkey	16 000	1 875	30 000	1	342	88
USA	85 000	1 282	109 000	3	121	901
total	3 309 000	986	3 262 000		1 299 243	3
total less CmiA	2 127 000	715	2 942 000		519 243	6

2.4 World cotton production

The production of cotton is mainly grown commercially in around 80 countries in the world, even though the oilseeds, grain and oilseeds are grown in nearly every country. Approximately 2.5% of the world's fertile land is utilized to produce cotton. The estimated value of the world cotton production during the period of the month of August 2017 to the month of July 2018 accounted to be about $ 50 billion US dollars [7]. If we draw a comparison between the world cotton production and the world soybeans, maize, wheat or rice productions, we find that each accounted for a total of $130 billion US dollars to $160 billion US dollars. Therefore, cotton world production is not considered the largest crop in terms of land area or in production value. In addition, cotton is considered mainly a fiber crop and not a food crop. Therefore it is not associated with food security which is a main focus of government concern.

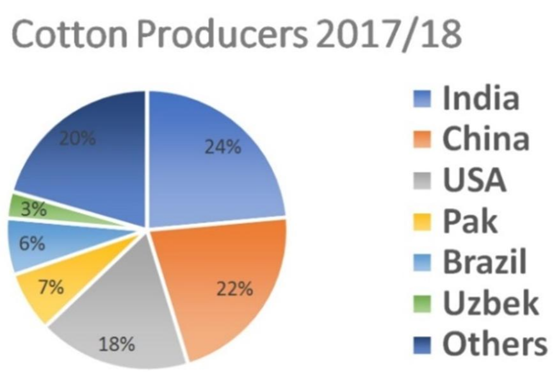

Figure 4 Cotton producers of 2017/18 with India being the most producers with 24%

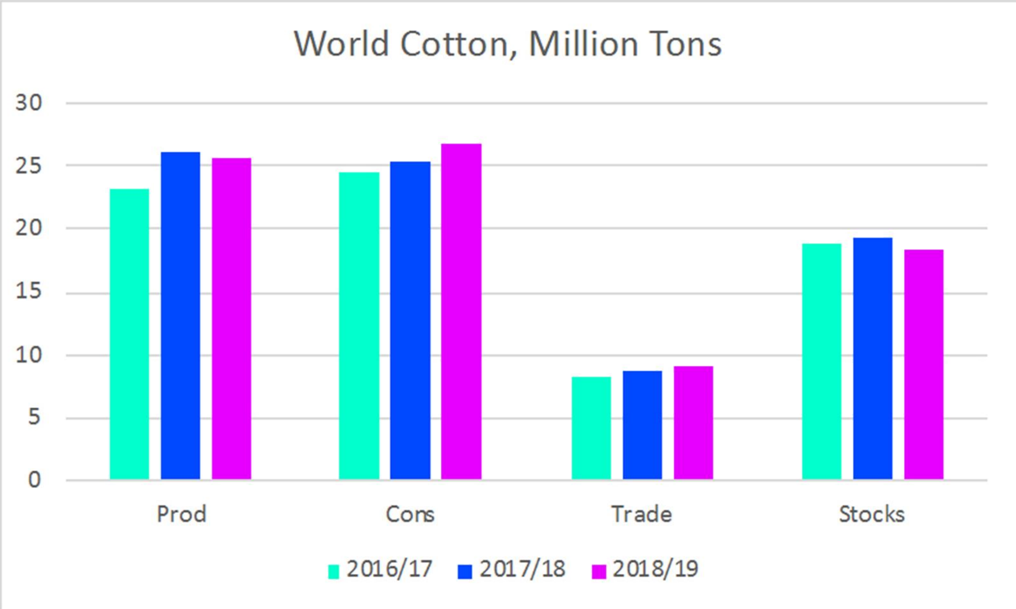

Figure 5 World cotton production in million tons

It was noticed that the world cotton production was increased to 26 million tons during the season which ended in July 2017. The production is expected to remain the same during the season starting in August 2018. The world cotton production forecast is predicting that the world cotton production in general will climb to approximately 27 million tons in the year 2018/19, which will mark a complete recovery prior to the recession period. However, the world trade in cotton is predicted to rise around 9 million tons, which will mark the highest number in few seasons ago. India, China and the United State of America take the lead accounting for about two-thirds of the world cotton production, whereas China, India and Pakistan account for a similar percentage of the world cotton consumption.

Figure 6 Cotton being cultivated by women in Pakistan scoring as the fourth country in the word production of 2019 with 1676 thousand metric ton. Photo is courtesy of Daily Record Report [8]

According the Daily Records report of January 2019 [8], the top ten countries in the world that produced cotton are India being ranked at number one with 5879 thousand metric ton, China as number two with 4953 thousand metric ton, United States of America as number three with 3738 thousand metric ton, Pakistan being number four with 1676 thousand metric ton, Brazil as number five with 1529 thousand metric ton, Australia as number six with 914 thousand metric ton, Uzbekistan as number seven with 811 metric ton, Turkey ranked as number eight with 697 thousand metric ton, Turkmenistan as number nine with 288 thousand ton and finally as number ten, Burkina Faso with 283 thousand metric ton.

2.5 About DNFI

The Discover Natural Fiber Initiative (DNFI), formed in January 2010 as an outgrowth of the International Year of Natural Fibers 2009, was declared by the United Nations General Assembly. The main drives of the existence of DNFI are to develop the welfares of the industries of all the natural fibers and to encourage the enlarged utilization of natural fibers in the world economy. Another important factor about DNFI is that it is a voluntary association with interests in promoting natural fibers through consultation and collaborations. The organization serves as a platform for an exchange of information by generating statistics about fiber production and their end uses. Another important goal of the organization is to raise awareness about the benefits of using natural fibers and how beneficial is that to the world economy and the consumers.

3 HOW MUCH OF THE WORLD'S CLOTHING IS MADE FROM COTTON?

60% of women clothing items contain cotton fibers according to cotton Inc. About 40% of women's clothing items are made from 100% cotton. However, a total of 75% of summer garments must contain cotton, whereas only 60% of winter wear has it and that proves that cotton is a must to have in the summer because of its wicking ability and its characteristics to make the wearer comfortable, able to breath and feels cool while wearing cotton in the hot weather. Cotton is an essential textile to have. 48% of women's knit blouses contain cotton. On the other hand, 75% of men's clothing contain cotton or cotton blend fibers, while 85% of men's garments are made using 100% cotton. Cotton is used to make variety of men's clothing items including: suits, dress shirts, underwear and men's casual clothing, including jeans and sweatshirts and also business wear [9].

3.1 Differences between conventional, organic, Pima and Egyptian cotton

The *conventional cotton* is the word that is commonly used to describe the cotton grown using modern farming methods. The latest technologies and newest methods of production are usually utilized to enable the most efficient ways of production with keeping the safety of the environment in mind and moving recently towards sustainability. Conventional cotton can be grown by using transgenic plant varieties (GMO) or in a greenhouse. Furthermore, the conventional cotton farming techniques are used all over the world. *Organic cotton* is a method of cotton farming that does not use pesticides and non-GMO seeds. This method takes a lot more water and land, resulting in less than one percent of the organic cotton grown globally. *Pima cotton* is an American type of cotton where its fibers are considered the longest type of staple fibers in ranging between 1/4 inches to 19/16 inches making Pima cotton fiber to be considered an extra-long staple cotton fiber in comparison to conventional cotton's fibers that measure to approximately 7/8 of an inch. The extra length of the cotton staples contributes into the creation of a much stronger yarn, softer and higher quality textile. *Pima cotton* is typically grown in California, Arizona, Texas and New Mexico. On the other hand, *Egyptian cotton* is luxurious and desired as it contributes to high-quality set of sheets usually offered by five start hotels. *Egyptian cotton* states that the cotton is grown in Egypt regardless of its fiber length. However, *Egyptian cotton* is known to have an extra-long staple fiber. In most cases can fiber's length exceed the length of *Pima cotton* that can result in a very soft and silky textiles [10].

4 THE INFLUENCE OF SALLY FOX ON THE COLORED COTTON INDUSTRY

Sally Fox has been an innovator of organic farming methods, rediscovering the ethics of the naturally colored cotton and her contributions to this industry have been appreciated as she cared to protect and save the environment. Fox began breeding brown and green cotton by choosing the best seeds to be able to produce the longest staple fibers and cultivate them year after year. Ultimately, Sally Fox succeeded in creating two major colored cottons that were able to be spun on a machine, as she was able to purchase a small land to grow the two naturally colored cottons. Sally was the recipient of Plant Variety Protection Certificates, which are equivalent to a patent. During the year 1988, only one acre of organically grown cotton existed in the United States and today over 20000 acres of organic cotton are available. Sally Fox received prestigious awards including the UNEP Award awarded to her in the year 1993 [11] and the Discover Magazine Award in 1994 for the sake of technological innovation. Green Housekeeping Award was given to Fox for Environmental Leadership

5 ADVANTAGES OF NATURALLY COLORED COTTON

The cotton that does not have the usual yellowish off-white color is usually referred to as colored cotton. It is mainly bred to have a different color than the traditional commercial one. The most popular colors grown are green, red and various shades of brown. The cotton's natural color is not likely to fade [9]. The naturally colored cotton is supposed to have originated in central and south America about 2000 years ago. Especially, the Mochica Indians can be credited with growing naturally colored cotton of many various hues that are preserved on the northern coast of Peru [12]. Not many colors are grown naturally today, mainly in addition to the green, red, light shades of brown, gray and chocolate brown may exist. The utilization of the naturally colored cotton has been blocked, mainly because of the industrial revolution, as the commercial off-white cotton was much cheaper to produce for mass production clothing items. Today, people have become more aware about the harm chemicals causing to both humans and the environment. The trend to use the naturally colored cotton has been revived and is being favored because of his low impact on harming the environment. If the colored cotton is already colored naturally, then there is no need to use synthetic dyes or harmful chemicals during processing and production. An important fact is that the natural colored cotton is unlikely to fade with the wash, like the fabrics colored with synthetic dyes.

Figure 7 Naturally colored cotton

Naturally colored cotton without any chemicals, synthetic dyes or any other treatments has been increasingly in demand and is becoming more popular mainly for being safe and environmentally friendly. The commercial off-white cotton is known to be the most pesticide-dependent crop in the world. Even though it only occupies around 3% of the world's farmland, but it consumes over 25% of the insecticides and 12% of the pesticides consumed worldwide. Around fifty-five countries rely upon cotton for a substantial percent of GDP. The residues after using the dyes are usually thrown into nearby rivers causing the contamination of the water and soil. Artificial dyes are eliminated when using the already colored cotton saving the environment. The World Bank predicts that 20% of water pollution originated because of the chemicals used from textile dyes. Seventy-two toxic chemicals in our water solely were identified to be related to textile dyeing. Using naturally colored cotton not only saves the health of humans, including farmers, but also saves to the environment and communities and in addition to reducing production cost. In comparison to the white cottons, naturally colored cotton fibers are shorter and economically less profitable. Even though the dying process cost is omitted from the cost of colored cotton production, but the cost of it is much higher than the cost of white cotton. Mills producing cotton using artificial dyes have reported cases of antagonistic effects on the skin and human health, such as allergies and itching of the skin and even cases of cancer. Furthermore, the washing after effects of the natural colored cotton is quite different from the synthetic dyed colors, as the dyed fabrics have tend to fade much faster while some naturally colored cotton improve in intensity with each wash.

5.1 Types of lint color

The main lint color of commercial cotton cultivation is often white. Brown and green colors are most common in the cultivated species. However, it was reported that some of the genotypes of USA and Russian Republics cotton collection included colored lint with shades of pink, red, blue, green and also dark grey close to black. Even though Sally Fox of Verses Ltd. Has claimed to developed multicolored lint with more than one color on the same lint strand. Genotypes with multi colored lint have not yet been made available to the researches and nor were produced on a large scale. The two main lint colors are green and shades of brown.

Brown color is considered the most common color among the colored cotton. It is available in different shades and ranges from light brown almost mocha color to an intense mahogany red. The names are given to the colors based on the intensity of the shades. For example: khaki, camel, brown, dark brown, chocolate brown, dirty grey, tan and red. Interestingly, the brown colored cotton stable fibers are longer than green. With intense exposure to sunlight the brown colored cotton fades but gradually and at a very slow rate [5].

Green colored cotton is the second significant commonly used lint color in cotton. The green color is not as common or available as the brown and comes only in two shades, light green and green. The green color fades much faster than the brown color with exposure to sunlight. The prolonged exposure to sunlight during the boll opening may lead to fading of the shade of green color and it may turn to white or off-white. An important finding by the central institute for cotton research Nagpur discovered that the colored cotton genotypes are poor in yield as they hold weak fiber properties in comparison with white linted cotton.

Wild species are considered a significant source of colored lint. Many of the wild species of genus Gossypium including assumed donors of present-day tetraploid cotton G.herbaceum race africanum and G.raimondii have colored lint. In addition to lint color some of wild species possess the ability to resist drought, insect pests' diseases and poses fineness and extra strength of their fibers.

Table 2 Major economic and fiber characteristics of colored upland cotton

Lint color and accessions	Seed cotton yield [g/pt.]	Durations [days]	G.O.T. [%]	2.5% span length [%]	Maturity coefficient	Micronaire value	Strength '0' gauge [g/tex]	Uniformity ratio [%]
Dark Brown								
LC-1-1	50.2	165	33.2	23.4	0.89	3.1	38.0	54
Red 5-7	46.5	170	19.5	21.3	0.81	3.6	40.7	46
Conark (DB)	45.6	160	31.1	24.1	0.62	2.7	40.7	46
Medium Brown								
Extreme Okra Leaf	54.3	160	28.3	15.1	0.83	3.9	38.0	49
Parbhani American	68.7	165	35.1	14.8	0.83	4.5	35.0	53
Hirsutum Tashkent	39.2	160	32.3	20.0	0.78	3.6	36.5	51
Light Brown								
Kampala Colored	24.9	160	30.9	22.9	0.64	2.8	37.4	44
Nankin brown	63.7	160	31.5	20.0	0.76	3.4	34.6	51
LL 55-68-2	34.6	170	29.8	19.8	0.66	2.8	36.0	48
Khaki Color								
Khaki Colored	37.4	165	30.5	20.0	0.65	3.0	35.0	46
Light Green								
Arkansas Green	46.5	160	19.5	18.5	0.59	2.6	32.0	50
Green								
Intense Red Green	31.5	160	20.7	21.7	0.56	2.8	32.2	47
Commercial White								
LRA 5166 (Check)	126.0	165	35.0	25.5	0.71	3.6	44.5	51

Table 3 Economic and fiber characteristics of brown linted germplasm of desi cotton

Sl. No.	Accessions	Seed cotton yield/plant [g]	Duration [days]	G.O.T. [%]	2.5% span length [%]	Fibre strength [g/tex]	Micronaire value	Uniformity ratio [%]
G.arboreum								
1	Light brown	32.0	176	36.2	20.6	17.5	3.2	48
2	SP 3936 (A)	30.5	182	38.0	21.1	18.1	5.4	50
3	Malvensis	49.0	195	30.7	23.0	16.4	4.8	47
4	7869 Brown	28.0	186	37.5	24.0	19.0	4.9	50
5	Khaki color 8631	32.1	195	38.0	20.0	17.1	5.3	50

Table 4 Lint colours found in Gossypium species

Continent	Species	Genome	Lint color
America	G.aridum	D_4	brown
	G.armourianum	D_{2-1}	brownish
	G.darwinii	AD	brownish
	G.mustelinum	AD	brownish
	G.gossypioides	D_6	greyish
	G.harknessii	D_{2-2}	greyish
	G.laxum	D_9	tan
	G.lobatum	D_7	tan, white
	G.trilobum	D_8	tan
	G.lanceolatum	AD	white
	G.tomentosum	$(AD)_3$	red brown
	G.hirsutum	$(AD)_1$	brown, tan, white, green
	G.barbadense	$(AD)_2$	creamish, white
Africa	G.anomalum	B_1	brownish
	G.capitis-virdis	B_4	brownish
	G.somalense	E_2	brownish
	G.herbaceum	A_1	greyish, white
	G.longicalys	F_1	greyish
	G.triphyllum	B_2	tan creamy
Afro-Asia	G.arboreum	A_2	brown, tan, white
	G.stocksii	E_1	brownish
Arabia	G.areysianum	E_3	brownish, grey
	G.incanum	E_4	tan
Australia	G.australe	C_3	brownish
	G.sturtianum	C_1	brownish
	G.robinsonii	C_2	greyish
	G.sturtianum var.nandewarense	C_{1-n}	greyish

6 DISADVANTAGES OF NATURALLY COLORED COTTON

Some of the major disadvantages of naturally colored cotton include the limitation of colored cotton availability, in addition to the low yield potential, poor fiber characteristics and limited colors with the instability of colors and low market demand. The yield potential for colored cotton is currently very low, almost half of the white linted variations. Because of low demand, naturally colored cotton did not become as popular as the white cotton to be produced commercially. In fact, the low yield has acted as a blockade in the expansion of its cultivation and the cultivation of colored cotton has been limited to tribal areas and small lands only. Another major factor that makes the colored cotton undesirable is the poor fiber properties it processes compared with white cotton. The fibers are usually shorter in staple length and weaker. They also have low fiber maturity compared to white cottons. The weakness of the colored cotton fibers makes it difficult for spinning the fibers into yarns. In addition to the weakness of the fibers, colored cotton is available in limited lint colors, while the white cotton can be colored into any shade using the chemical dyes. The ability of the natural colored cotton to stay bright and intense is low, as the extensive exposure to sunlight fades the colors, especially the green, and turns it into almost white fiber. The brown colored cotton fades but slower than the green. Another disadvantage that the colored cotton processes is contamination. Growing of colored and white cotton in the vicinity will increase the chance of contamination of white linted genotypes with colored genotypes and vice-versa. For this reason, growing of white cotton in the field in which colored cotton was grown in the previous year may also lead to contamination. Colored cotton should be restricted to small areas only. Low market demand is another reason that limits the cultivation of colored cotton on a big scale. However, the demand of naturally colored cotton has increased in some European countries. It is recommended to develop marketing facilities before starting the cultivation of colored cotton on commercial scale. For example a written agreement should be drafted between the purchaser and the producer in order to facilitate the production of naturally colored cotton, as its demand is fairly limited.

7 CONCLUSION

Fibers can come from different sources, natural or synthetic. The natural textile fibers are extracted from either animal sources like mohair, wool and silk or from vegetable sources like cotton, kapok, linen, ramie, hemp, jut and sisal. The man-made fibers, such as acetate and viscose, are usually extracted in the lab and their polymer is generated from a cellulosic source such as wood and linters. For example, silkool from Glycine max, kazein from milk, ardil from peanut, zein from maize, are all obtained from natural sources, however they're not generated in a traditional fiber structure but with special treatments applied they can be extruded into fibers and then they will be known as regenerated-fibers.

Cotton is a very desirable fiber, as it has a wicking ability that makes the wearer feels cool and comfortable to wear during the summer. According the Daily Records report of January 2019 [8], the top ten countries in the world that produced white cotton are India being ranked at number one with 5879 thousand metric ton, China, United States of America, Pakistan, Brazil, Australia, Uzbekistan, Turkey, Turkmenistan, and ranked as number ten, Burkina Faso with 283 thousand metric ton.

Cotton in its natural state and never dyed at all, can be identified as entirely organic. And since the naturally colored cotton is natural, and more desired than the chemically died one, naturally colored cotton has been gaining popularity in recent years as companies started seek more sustainable solutions. However, to grow natural cotton many factors need to be taken into consideration, since the utilization of the naturally colored cotton has been blocked, mainly because of the industrial revolution, as the commercial off-white cotton was much cheaper to produce for mass production clothing items.

Today many companies are becoming aware of the concept of sustainability, since no chemical dyes are involved in the process. In Brazil the organic colored cotton is produced without any synthetic fertilizers and pesticides by the Natural Cotton Color Group NCC Ecobrands in the city of Juarez Távora (PB). The plantation takes up 18 hectares of land and the production system relies on a guaranteed purchase agreement between the NCC and the local farmers. In India, the Central Institute for Cotton Research of Nagpur and several State Agricultural Universities have taken up breeding programs for improvement of colored cotton.

Sally Fox, the American lady has been an innovator of organic farming methods, rediscovering the ethics of the naturally colored cotton, and her contributions to this industry have been appreciated as she cared to protect and save the environment. Fox began breeding brown and green cotton by choosing the best seeds to be able to produce the longest staple fibers, and cultivate them year after year.

Even though natural colored cotton is becoming more desirable by the consumers and many clothing companies, and fashion designers are going sustainable, natural colored cotton has many drawbacks, and limitations. Mainly naturally colored cotton has limited colors, shades of brown, green, grey, and chocolate brown. Fabrics created from naturally colored cotton fade with washes. The green color fades from the exposure of the sun, but improves its fastness and color intensity with each washing. Colored cotton fibers are weaker, shorter staple fibers than white cotton, which makes it difficult to spin into yarns, and if planted with the white cotton, will make the white cotton subject to contamination, that is why naturally colored cotton must be planted in separate small areas exclusively.

Because of short productivity per unit area, poor quality of fiber physical appearance, and uneven distribution of colors, colored cotton is not produced commercially. Even though, the demand of naturally colored cotton has increased in some European countries, and is desirable because of its natural color properties, without the chemical dyes, it is recommended to develop marketing facilities before starting the cultivation of colored cotton on commercial scale.

A written agreement should be drafted between the purchaser and the producer in order to facilitate the production of naturally colored cotton, as its demand is considered fairly limited in comparison to white commercial cotton that is a better quality, and can be dyed in any color following the fashion trends.

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EFFECT OF DIFFERENT WET PROCESSING STAGES ON PHYSICAL PROPERTIES OF COTTON WOVEN FABRICS

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Abstract: *This paper sheds light upon the influence of pretreatment as one of the most important wet processing stages on cotton woven fabric properties. Throughout this study a part of the woven fabrics were in a grey form while the second part of fabrics subjected to desizing and scouring and the third part subjected to desizing, scouring and bleaching respectively. All the pretreated fabrics will be compared to each other and to grey woven fabrics of the same characteristics. The findings of the experimental results revealed that physical and mechanical properties of woven fabrics have been influenced significantly with wet processing stages especially tensile strength, air permeability and tearing strength.*

Keywords*: wet processing, woven fabrics, physical properties, tensile strength, breaking elongation, air permeability.*

1 INTRODUCTION

Textile industry includes various and distinguished processes such as spinning, weaving, wet processing and garment industry. Wet processing includes pretreatment, dyeing and finishing processes. A pretreatment is a group of processes that precede fabric dyeing and comprises singeing, desizing, scouring and bleaching. These distinguished processes have a remarkable influence on fabric appearance and its physical properties.

Singeing is one of an important part of the pretreatment process. Its objective focuses on the elimination of loose fibers from yarn and/or fabric surfaces using burning-off. If the burning-off of the protruding fiber ends from yarn and/or fabric surface doesn't properly done, it will results in an unclear pattern, mottled and pilled fabric surface [1]. Singeing process was found to have a reducing effect on yarn hairiness by about 87%. However, it increases and reduces unevenness and imperfection values of spun yarns respectively for all counts [1]. Because of compact spinning eliminates hairiness significantly from compact spun yarn surface, the singeing process can be eliminated considerably [2-5].

The second processing step after singeing in pretreatment stages of cotton and blended woven fabrics is called desizing. The main goal of this process is to remove sizing ingredients from warp yarns of grey fabrics. After performing desizing, woven fabric become ready for processing in subsequent stages. According to the type of size ingredients, desizing process is executed using different methods [6-9]. Generally, desizing process can be done in many ways such as acid steep, rot steep and enzymatic. Because of its advantages such as eco-friendly, selectivity and speed, enzymatic is the most dominating and enzymes are used efficiently to remove sizing materials from fabrics, especially, which are sized with non-soluble starches [10-13].

Scouring is an essential pre-treatment of woven fabrics. The main object of this process is to obtain sufficiently hydrophilic fabrics. This is done by removal of pectins, waxes, hemicelluloses and other impurities present in the cotton fabrics [14]. Conventional scouring process of cotton fabrics is carried out using sodium hydroxide at 100°C temperature and alkaline medium, namely pH 10-12. Because of alkaline scouring consumes a large amount of water and energy, enzymatic scouring finds itself as an effective and efficient alternative for cotton fabric scouring. In general, scouring of cotton fabrics using enzymes is called bio-scouring. In this process, low temperature, i.e. 50-65°C and pH ranges between 7.9-9 are used [15, 16].

To remove the natural pigments of cotton fibers, bleaching is the process that follows scouring directly. Generally, cotton fabrics are mostly bleached using hydrogen peroxide (HP) in an alkaline path, i.e. pH 10-12 and at 100°C temperature. There is no ecological consideration in using hydrogen peroxide. But, because of a large quantity of water that are utilized to neutralize and rinse pretreated woven fabrics, a large quantity of energy and a large amount of salts produced, several types of enzymes and biotechnology were found to be good alternatives to hydrogen peroxide as a bleaching agent [17, 18]. For instance, pectinases were an efficient alternative to sodium hydroxide to remove non-cellulosic materials from cotton fabric surface. In this process a moderate temperature and a slightly alkaline medium are used. Also, the fiber surface doesn't deteriorate during this process [19, 20]. Peracetic acid was also found to be a good alternative to hydrogen peroxide. Because of its low concentration, low temperature, its degradability and slightly alkaline medium, it was also considered as an effective bleaching agent [21, 22].

Because of swelling of cotton fibers when treated with aqueous solution of sodium hydroxide, mercerization is mainly used to improve cotton fabric properties such as tensile strength, smoothness, dye affinity and dimensional stability [23, 24]. This treatment is generally carried out in slack or tight states. Mercerizing cotton fabrics in slack condition increases their stretch properties, whereas tight mercerization enhances tensile strength and luster properties. With mercerization, all these features stem from fiber swelling which in turn increases crystallinity, unit cell structure, accessibility, and fiber orientation, i.e. orientation of fibrils along fiber axis [25, 26]. Although there are a variety of chemical agents used for mercerization, caustic soda remains the best one [27, 28]. It was reported that hot and cold mercerization are the most commonly used types of mercerization. In normal type, woven fabrics are treated with caustic soda at 15-20°C temperature, while temperature can be raised up to 90°C in hot mercerization [29].

There are many research papers have been published [30-36] regarding the influence of weaving and spinning parameters on the cotton woven fabrics properties. By contrast, there are few numbers of them which examining the influence of pretreatments altogether on the woven fabrics properties. The effects of pretreatments on the cotton woven fabrics properties will be undertaken throughput this study

2 MATERIALS AND METHODS

Throughout this study, rapier weaving machines of model – was used to weave the grey fabric samples during this study. Warp and weft yarns of count 24 Ne and with 66 ends/inch and 58 picks/inch respectively were utilizes to weave the fabric samples. Egyptian cotton of type Giza 86, which is considered one of the best worldwide, was used to spin warp and weft yarns. After weaving, fabric samples were classified into three sections. The first section was left as it is, namely it did not subject to any pretreatments. The second fabric section subjected to desizing and scouring processes only. The third section of fabric samples subjected to desizing, scouring and bleaching processes respectively. The chemical and auxiliaries used to pre-treat the greige woven fabric samples were listed in Table 1. The temperature used for scoring ranges between 100 and 125°C, while for bleaching it reaches to 95°C.

Table 1 Chemicals and auxiliaries used in the pretreatments of woven fabrics

Chemicals and auxiliaries	amount [g/l]
alkali (NaOH)	5
soda ash	1
wetting agent	1
detergent	2
hydrogen peroxide (H_2O_2)	2

After weaving and pretreatments, fabric samples were left in a standard conditioned environment for one day at temperature 20±2°C and relative humidity 65±2%. After that these fabric samples were laboratory tested for their weight, breaking strength, breaking elongation, tearing strength and air permeability. For each property, five individual-readings were obtained and averaged. Tensile properties of fabrics under study were tested and assessed using Instron tensile tester of model 4411 (Instron Inc., USA) in accordance with ASTM standard D5035-11(2015) (strip method). Air permeability of griege and treated woven fabrics were evaluated using Shirely-Air permeability tester in accordance with ASTM standard D737-18. While according to ASTM standard D1424-09(2013), tearing strength of fabrics under study was also measured using Intensity tearing tester (Elmendorf). The mass per unit area of griege and treated woven fabrics were measured using a standard balance according to D3776M – 09a(2017).

2.1 Statistical analysis

In order to examine the significance impact of pretreatments on fabric characteristics, the Analysis of Variance of type One-Way (ANOVA) was implemented. The statistical analysis in this study was performed using SPSS statistical package version 25. The significance level, $0.01 \leq \alpha \leq 0.05$ was utilized to assess the significant influence of pretreatments on woven fabric characteristics.

3 RESULTS AND DISCUSSION

3.1 Fabric weight

The results of fabric weights at different pretreatment processes were displayed in Figure 1. The statistical analysis results were also listed in Table 2. From the ANOVA results, it is clear that pretreatment processes have a significant effect on fabric weight at 0.01 significant level. It can be seen from Figure 1 that fabric weight has increased progressively by wet processing. That is fabric weight has increased by desizing and scouring processes compared to grey fabric weight and that it continues to increase with the bleaching process. Scouring and desizing process led to increasing grey fabric weight by approximately 6% and this ratio has been raised to 11% at bleaching process. The positive influence of wet processing on fabric weight may be due to fabric shrinkage in weft direction because of this wet processing.

Table 2 ANOVA results of the effect of pretreatment processes on fabric weight

Variation source	SS	df	MS	F	P-value	F crit
Variation between groups	840	2	420	32.30769	0.000	3.885
Variation within groups	156	12	13			
Total	996	14				

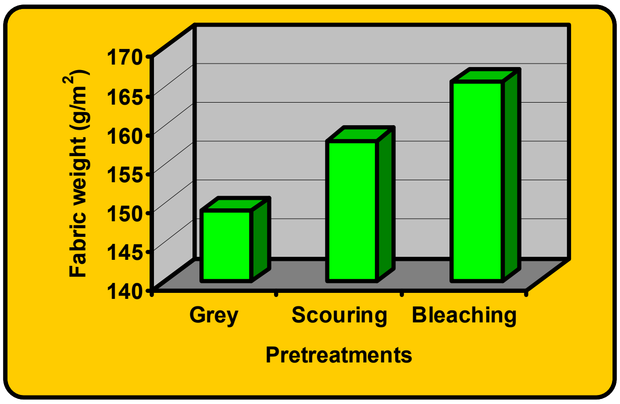

Figure 1 Effect of pretreatment processes on woven fabric weight

3.2 *Effects on fabric tensile strength*

Values of grey and pretreated fabrics' tensile strength were depicted in Figure 2. The statistical analysis results were also listed in Table 3.

Table 3 ANOVA results of the effect of pretreatment processes on fabric tensile strength

Variation source	SS	df	MS	F	P-value	F crit
Variation between groups	74.533	2	37.267	7.1667	0.009	3.885
Variation within groups	62.4	12	5.2			
Total	136.933	14				

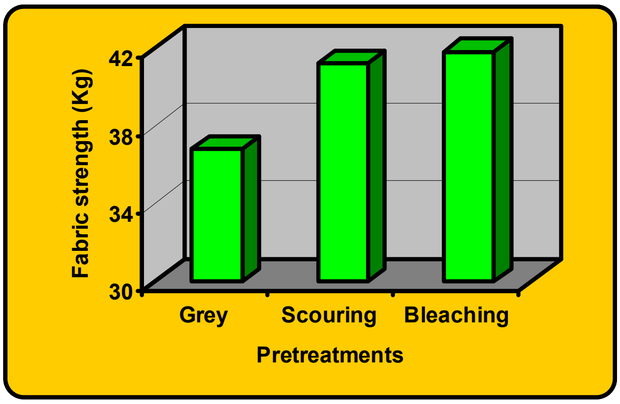

Figure 2 Effect of pretreatment processes on woven fabric tensile strength

From the ANOVA results, it can be seen that wet processing stages statistically significant influence the fabric tensile strength. An increasing trend was detected confirming that pretreatment processes have a positive influence on fabric tensile strength. The scouring process has a pronounced influence on the fabric tensile strength. While fabric tensile strength slightly increased due to the bleaching process. The average values of fabrics' tensile strength were 36.8 kg, 41.2 kg and 41.8 kg for grey, scoured and bleached fabric samples respectively. The increased breaking tensile strength of pretreated woven fabrics probably be ascribed to the reduction of internal stresses and to somewhat the de-convolution of the fibers in the woven fabrics due to the effect of caustic soda.

3.3 *Effects on breaking elongation*

Figure 3 shows the influence of pretreatment processes on breaking extension of woven fabrics. Statistical analysis results were listed in Table 4.

Table 4 ANOVA results of the effect of pretreatment on fabric weight

Variation source	SS	df	MS	F	P-value	F crit
Variation between groups	23.333	2	11.667	6.364	0.013	3.886
Variation within groups	22	12	1.833			
Total	45.333	14				

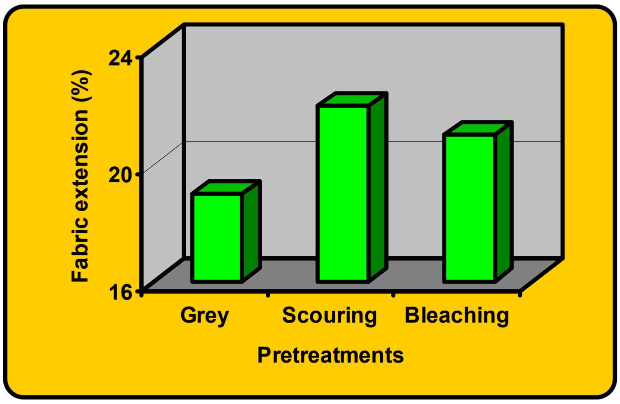

Figure 3 Effect of pretreatment on woven fabric breaking elongation

From ANOVA results it can be concluded that fabric breaking elongation has been affected significantly by pretreatment processes at 0.05 significant level. By contrast to tensile strength results, high breaking extension values were accompanied by scoured woven fabric samples, whereas the low ones were associated with the grey woven fabric. The statistical analysis proved that scouring process increased the breaking elongation of grey woven fabrics by about 15.8%, while the bleaching process diminished the breaking elongation of scoured woven fabric by less and non-significant value, i.e. 4%.

3.4 Effects on tearing strength

Figure 4 portrays the influence of wet processing stages on woven fabric tearing strength; and the findings of the statistical analysis were also introduced in Table 5. It was proved that pretreatment processes have a significant influence on fabric tearing strength. From this figure it can be observed that after wet processing, tearing strength of woven fabrics have been reduced significantly. The influence of the scouring process decreased tearing strength of greige woven fabrics by approximately 6.7% and continued to decrease the tearing strength up to 26.7% due to the impact of the bleaching process. The negative influence of wet processing on fabric tearing strength may be attributed to fabric shrinkage and compactness after wet processing which leads to diminishing the fabric tearing strength.

Table 5 ANOVA results of the effect of pretreatment processes on fabric weight

Variation source	SS	df	MS	F	P-value	F crit
Variation between groups	1036000	2	518000	62.16	0.000	3.886
Variation within groups	100000	12	8333.333			
Total	1136000	14				

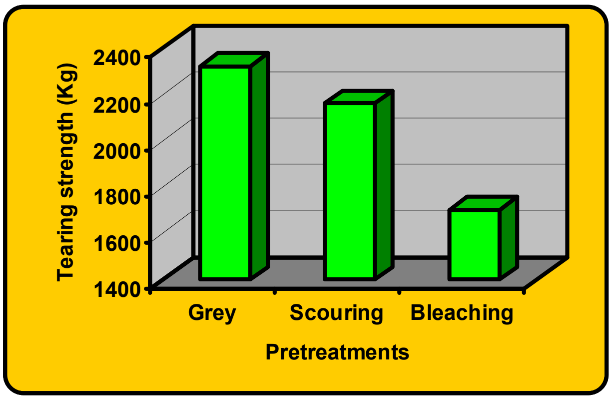

Figure 4 Effect of pretreatment processes on woven fabric tearing strength

3.5 Effects on air permeability

Air permeability values versus the types of wet processing are shown in Figure 5. Also, Table 6 represents the findings of the statistical analysis. From this figure and table, it can be observed that air permeability values of woven cotton fabrics were significantly affected by the different types of pretreatment processes. As shown in this figure pretreatment process has a negative influence on woven fabric air permeability. Grey fabrics were found to have high air permeability. By contrast, lower values of the air permeability were associated scoured with woven fabrics. The air permeability values of wet processed woven fabrics were 75, 28 and 32.5 $cm^3/cn^2.s$ for grey, scoured and bleached woven fabric respectively. The negative influence of pretreatment processes on fabric air permeability can be ascribed to increasing the fabric weight and thickness after these wet processes.

Table 6 ANOVA results of the effect of pretreatment processes on fabric air permeability

Variation source	SS	df	MS	F	P-value	F crit
Variation between groups	6747.658	2	3373.829	2090.944	0.000	3.88529
Variation within groups	19.36252	12	1.613543			
Total	6767.02	14				

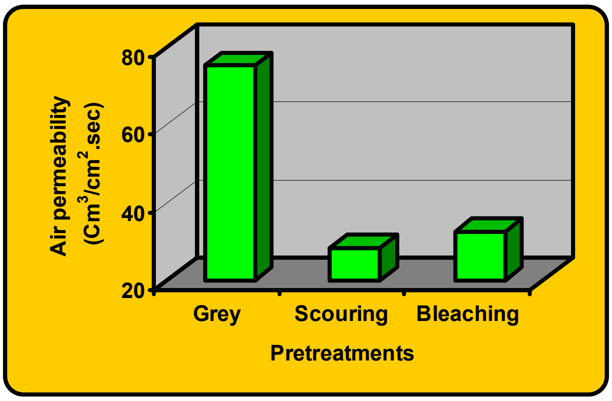

Figure 5 Effect of pretreatment processes on woven fabric air permeability

4 CONCLUSION

After each wet processing stage, the experimental results revealed that the physical properties of the woven fabric have been changed considerably. Due to fabric shrinkage after pretreatment processes, it was found that woven fabric properties have been affected significantly. The experimental results of this work can be summarized as follows:

- Due to shrinkage after wet processing, woven fabric weight and tensile strength have increased significantly. Whereas, the air permeability and tearing strength decreased considerably.
- Scouring process increased grey woven fabric weight by about 6%, while bleaching one increased scoured fabric weight by 4%.
- The influence of the scoring process on fabric tensile strength is more pronounced compared to the effect of bleaching one.
- The high breaking extension is associated by scoured fabrics followed by bleached and griege woven fabrics respectively.
- The air permeability of woven fabrics was reduced dramatically by introducing scouring and bleaching processes.

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A STUDY OF AIR PERMEABILITY INFLUENCES ON PATTERN CUTTING

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Abstract: *This paper is presenting part of the research for "Redefining Men's Shirt Pattern by means of Thermal Insulation, Water Vapor Permeability, Air Permeability and Body Movement". In this part, the research studies the effects of air permeability on four important parameters for clothing comfort and pattern cutting. The four parameters are the grain lines, aging fabric, wash and dry cycle of fabric and moisture content of the fabric. Results will be analyzed and be collected as one of the factors to create an ideal pattern for a men's shirt.*

Keywords: *air permeability, pattern cutting, grain lines, aging fabric, moisture.*

1 INTRODUCTION

Men's shirt is one of the important garment production in the industry. In 2018, the top men's shirt production country, the United State had produced 1034.51 million of pieces of shirts for men and boys, over US$ 23205.6 million in revenue [1]. This popular item which has been developed over a hundred of years ago [2, 3] by directly draping fabric onto the customer's body to obtain the clothing pattern [4, 5]. Later on, pattern drafting technique was developed and became the standard of pattern cutting [6, 7]. Until nowadays, even the shirt patterns have been changed for so many times according to the fashion trends; however, the basic pattern pieces and shapes are remaining very similar. Collar, collar stand, bodice front, bodice back, yoke, sleeve and cuff pieces are the basic elements to make up a shirt [8]. With the rapid and innovative invention in textile and fabric [9], developers and manufacturers need more than just a regular pattern shapes to satisfy and compatible with their high-end products. A new set of pattern that is not just offering the wearing comfort but is also concerning the breathability rate, movement comfort, thermal insulation and perspiration rate of the clothing that the traditional pattern may not offer.

In fact, a lot of articles had been published that were related to pattern improvement, breathability and wearing comfort. For examples, Hes researched on moisture absorptivity rate, water vapor permeability rate and the composition of woven shirt fabric and its influences on body cooling effect [10-12]; some articles tried to predict the air permeability rate related to woven fabric's mechanical properties [13, 14]. Musilova, Jang and Xu et al. were using computer software and men's body measurements to predict and to perfect men's shirt pattern and wearing ease [15-17]. However; all these researches are still based on the traditional pattern shapes and forms, not a new invention for the future needs and purposes.

This paper is part of a series of research to redefining men's shirt pattern through four major parameters which are thermal insulation, water vapor permeability, air permeability and mobility. The goal of this paper is to find out how air permeability related to men's shirt pattern. Air permeability or breathability was tested through grainlines, aged sample, wash/dry cycle and moisture content of the sample. Results were analyzed and would be combined with the other three parameters' results in order to create a better pattern shapes for men's shirt for the future usages.

2 EXPERIMENTAL PART

2.1 Materials

Three popular woven materials were chosen for the experiment which were:

1) 100% cotton, 139 g/m^2, thickness 0.43 mm, warp 26/cm, weft 24/cm;
2) 50% cotton/50% polyester blended, 153 g/m^2, thickness 0.44 mm, warp 26/cm, weft 24/cm;
3) 98% cotton/2% elastan blended, 110 g/m^2, thickness 0.27 mm, warp 42/cm, weft 34/cm.

Samples of 25x25 cm were cut from the materials for the grainline test, wash/dry cycle test, and moisture content test. Samples for the aged sample test were cut bigger; 31x31 cm for storage and easier to be found. All samples were basket weave and had been pre-washed, pre-shrunk and ironed flat to clean out the finishing before experiments.

2.2 Methods

Three materials were prepared for the experiment. Each material went through four groups of tests. They were:

Group 1 - grainlines test, this test served two purposes: a) to show the air permeability influences on the straight grain, cross grain and bias; b) to act as a reference/standard for other tests.

Group 2 - aged sample test, to find out any different from the grainlines test after materials were put in an open environment for a period of 6 months.

Group 3 - wash/dry cycle test, to find out any different from grainlines test after materials were gone through 3 times of washing, hang drying and iron flat cycle.

Group 4 - moisture content test, to stimulate samples when soaked with sweat and to find out the air permeability influences.

Samples from each material were tested three times by these four groups to get the mean value.

Fabric Breathability Test Machine was used for group 1, 2 and 3 tests. According to the standard of CSN EN ISO 9237, the air pressure was maintained at 100 Pa, testing head ring diameter was 50.5 mm and the tested surface area was 20 cm^2. For group 4, FX 3300 Air Permeability Tester III was used and the air pressure was set to 100 Pa for apparel materials. Results were analyzed in the conclusion.

3 RESULTS AND DISCUSSION

3.1 Group 1 - grainlines test

Samples were marked with direction arrow on the straight grain (weft) in back, cross grain (warp) in blue and bias (diagonal) in red (Figure 1). Test spots were randomly chosen and marked in a circle with 50.5 mm in diameter. Each spot went through 3 tests: straight grain, cross grain and bias. Only successfully test spots were numbered 1, 2 and 3. Some test spots were given unstable reading due to uneven weaving pattern (Appendix 1).

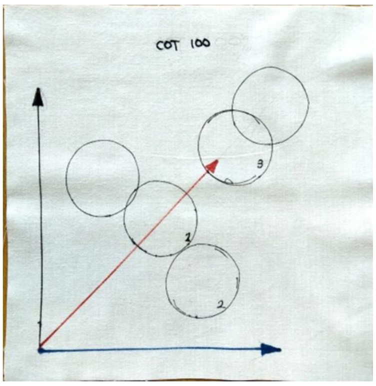


Figure 1 Sample of 100% cotton marked with grainline directions and the three successful circle tests

3.1.1 Grainline test result

Results in unit liter per minute (L/min) were converted into standard unit (mm/s) by the following formula:

$$R = qv/A*167 \quad (1)$$

where *qv* is the result in L/min from the Fabric Breathability Test Machine; *A* is the tested surface area 20 cm^2, 167 is a constant and the resulting unit is in standard mm/s.

Results are shown in Table 1 and Figure 2.

Table 1 Results of three materials from grainlines tests

Unit in mm/s	100% cotton	50% cotton 50% polyester	98% cotton 2% elastan
Straight grain*	256	245	346
Cross grain*	259	246	346
Bias*	257	244	346
Mean	257	245	346
SD	1.23	1.21	0.02

*arithmetic mean

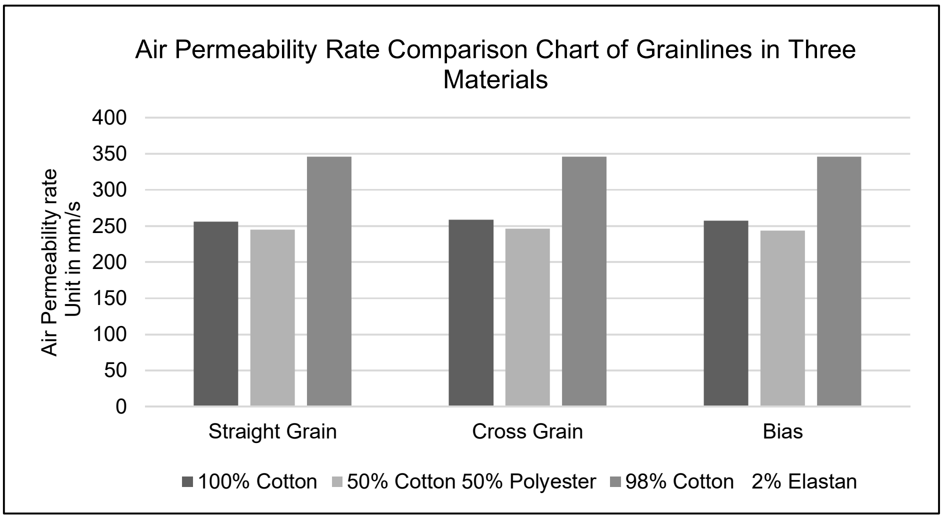


Figure 2 Comparison chart between three materials for the air permeability rate of grainlines

The results from Table 1 show that the air permeability rate from three samples of each material is highly similar through straight, cross and bias grainlines. Especially cotton/elastan blended, the results are identical. When comparing results between materials, cotton/elastan blended also has the highest air permeability rate; and the second is 100% cotton.

3.2 Group 2 - aged sample test

Three 31x31 cm samples were cut from each material, then put aside in the open area in the laboratory with no restrictions on any condition for 6 months, from 09/2017 to 02/2018. Weather, wind speed, humidity, heat and other unexpected conditions were changing every moment. After that, two spots were chosen randomly from each sample of the same material. Total six results were recorded from one material (Table 2, Figure 3).

Table 2 Air permeability rate results from aged sample test

Unit in mm/s	100% cotton	50% cotton 50% polyester	98% cotton 2% elastan
Mean	326	272	433
SD	59.81	16.03	89.15

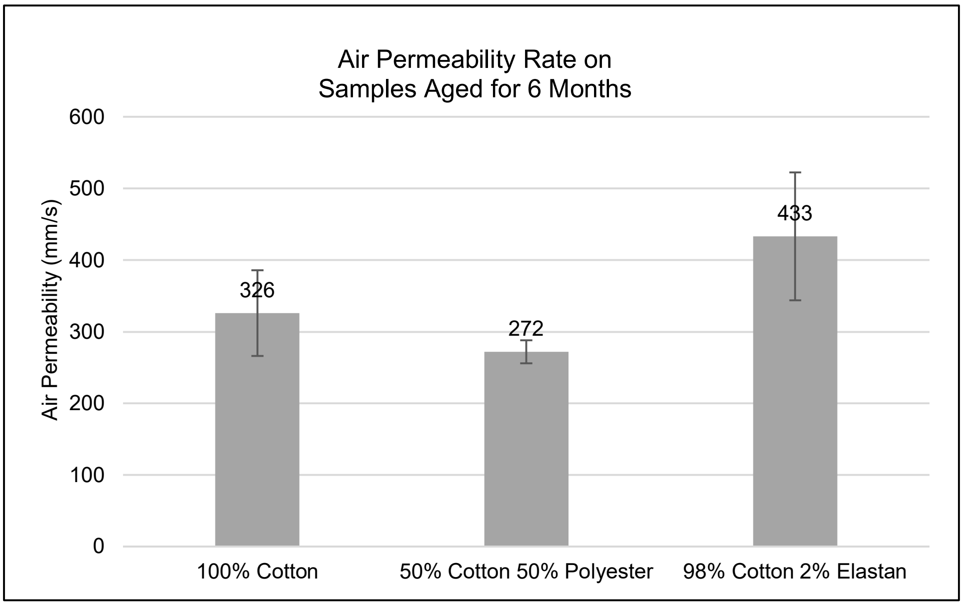


Figure 3 Aged sample test results

3.2.1 Aged sample test result

When comparing the mean values of the aged sample test results (Table 2) to the grainlines test results (Table 1); the air permeability rate increases in all three materials. This may cause by the expansion of the pores (spaces between wefts and warps) in the fabric due to being exposed in the open environment; temperature and humidity constantly changing all the time. Under natural heat expands, cold contracts conditions, it may affect the samples' mechanical structure. When looking at the enlarged pictures by Navitar micro camera Zoom 12X (Appendix 1, Figures a-i) and comparing the center reference sample column to the aged sample column on the right, pores are slightly bigger and less blocked pores than the reference column and the wash/dry cycle sample column.

3.3 Group 3 - wash/dry cycle test

Three 25x25 cm samples were cut from each material. Nine samples were in total. Each sample was tested twice and the mean value was recorded. Before tests, all samples went through 3 times of washing and drying cycle. Each cycle included one wash, one dry and one ironed flat. Washing condition was 40±°C in gentle cycle with mild detergent and tumble dry. Drying condition was hanging to dry naturally then ironed flat. Results are in Table 3 and Figure 4.

Table 3 Air permeability rate results from wash/dry cycle test

Unit in mm/s	100% cotton	50% cotton 50% polyester	98% cotton 2% elastan
Mean	275	249	464
SD	15.23	5.74	24.31

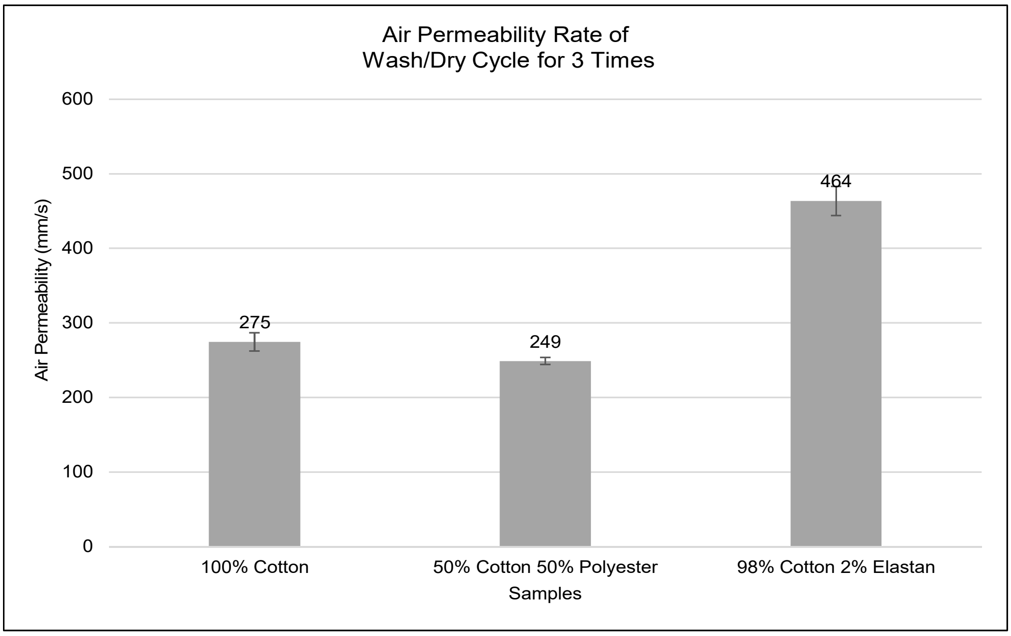


Figure 4 Wash/dry cycle test results

3.3.1 Wash/dry cycle test result

Comparing the results to grainlines test results in Table 1, a slight increase in all three materials. When comparing the results from the grainlines test (Table 1), aged sample test (Table 2) and wash/dry cycle test, (Table 3) altogether, it shows that the air permeability rate continues to rise up through wash/dry process and time (Table 4, Figure 5).

Table 4 Comparing results from grainlines, wash/dry cycle and aged samples of three materials

Unit in mm/s	100% cotton	50% cotton 50% polyester	98% cotton 2% elastan
Grainlines	257	245	346
Wash/Dry	275	249	464
Aged	326	272	433

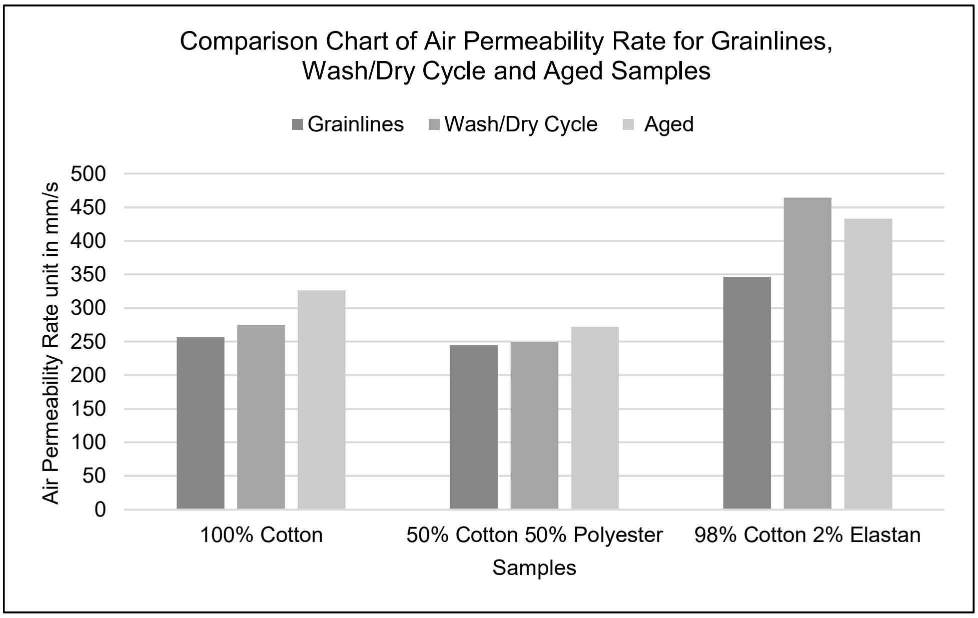


Figure 5 Comparison chart of air permeability rate of grainlines, aged, wash/dry cycle samples from three materials

3.4 Group 4 - moisture content test

FX 3300 Air Permeability Tester III was used for this group. The test area was a circle with a 20 cm^2 testing surface, EN ISO 9237 standard for apparel fabrics test was applied and the air pressure was set to 100 Pa. One 25x25 cm sample was cut from each material. Three samples are in total. Each sample was tested according to the following procedures:

1. The dry mass of each sample was weighted.
2. Each sample was soaked in water (stimulation of sweat), then towel dried. Noted that it was difficult to maintain the same moisture content.
3. Wet mass of each sample was weighted.
4. Calculated the moisture content by the following equation:

$$\textit{Moisture content [\%] = Wet mass - Dry mass/Dry mass*100} \quad (2)$$

5. Each wet sample was tested by following the order of directions in a pattern, a total of four patterns of directions from 1 to 4 (Figure 6). Each pattern contains nine testing directions. These four patterns were used to minimize error because the testing device continued to blowing air to the wet sample that would dry up the moisture content fast.
6. All three wet samples were tested by the same pattern of directions each time. After that, all three samples would go through from step 2 to step 5 until all four patterns of directions were done.

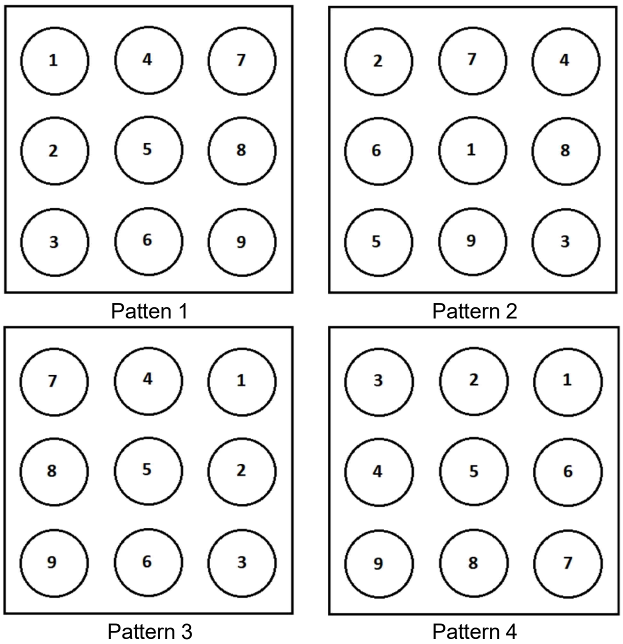


Figure 6 Four patterns of the order of directions were used to minimize error caused by the testing machine blowing out air drying the wet samples fast

3.4.1 Moisture content test result

From the results (Figure 7a-c) of three materials went through four patterns of directions, a similar trend has been noticed in all samples tests. The trend is when the moisture content is high, the air permeability is low and vice versa. This forms an inverted proportional relationship between air permeability and moisture content. Only in results from pattern 2 which took three to four seconds longer to finish the process than other patterns 1, 3 and 4; plus the directions on pattern 2 did not run in a continuous manner which affected the irregular drying time of the spots and caused error.

4 CONCLUSIONS

Air Permeability on grainlines (group 1)

Air permeability does not have any influence on straight grainline, cross grain nor bias grainline. Hence, it will not affect the clothing patterns that are being positioned on fabric for cutting. However, the grainlines still have a certain effect on wearing comfort; for example, bias cut clothing has more drapability than the cut on straight grainline or cross grainline even for woven fabrics because of better shearing and bending strength [18].

Air permeability on aged and wash/dry cycle (group 2 and 3)

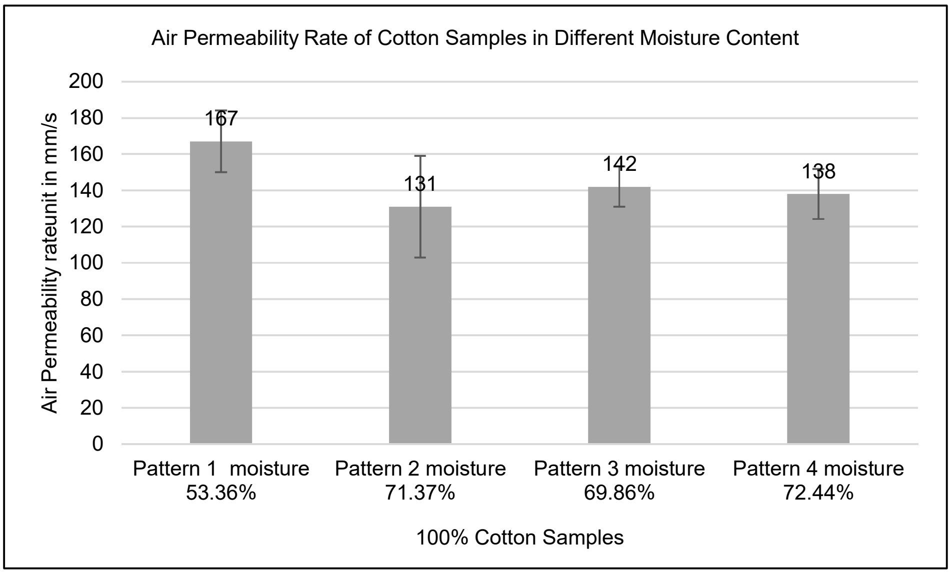
When fabrics are exposed to the environment, being used, washed and dried for some time, air permeability tends to rise up. This influence may be caused by the wear off or damaged of the materials that the pores of the materials enlarged and become more porous. When comparing the columns of the wash/dry and aged to the column of grainlines in Figure 8a-i, it is clearly shown that pores in the wash/dry and aged samples that are more open and clearer; less blocked by the fibers itself.

Air permeability on moisture content (group 4)

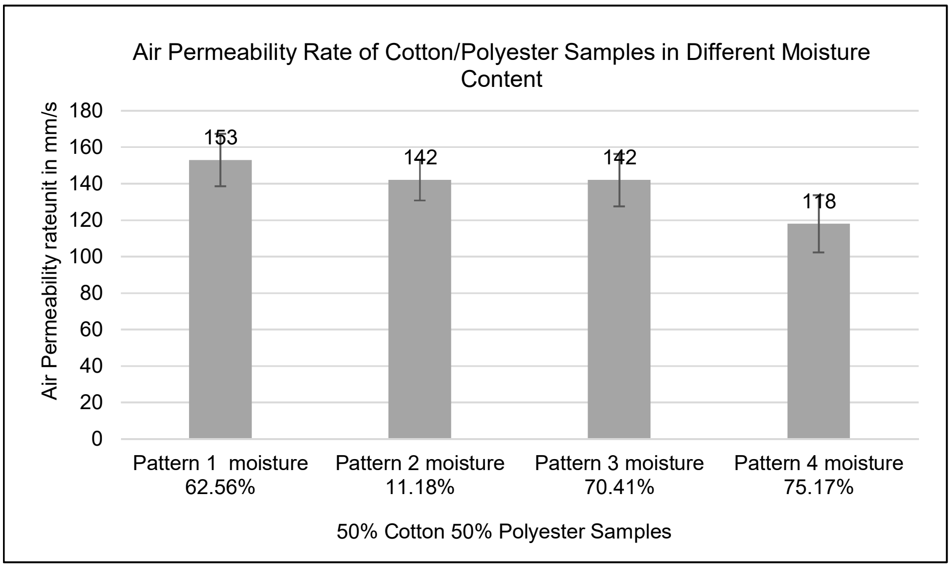
Air permeability is inversely proportional to the moisture content of the fabric. When the moisture content is high, air permeability will be low. When the moisture content is low, the air permeability will become high. It is because when the moisture content is high, pores of the woven fabric are blocked by water, allowing less air to go through the fabric and vice versa.

Pattern cutting is influenced by grainlines for its drapability effect which will affect the air flow between the skin and the clothing. Aging clothing and wash/dry process will increase the air permeability rate; however, high moisture content or sweat will decrease air permeability. Overall, air permeability will not directly influence pattern cutting.

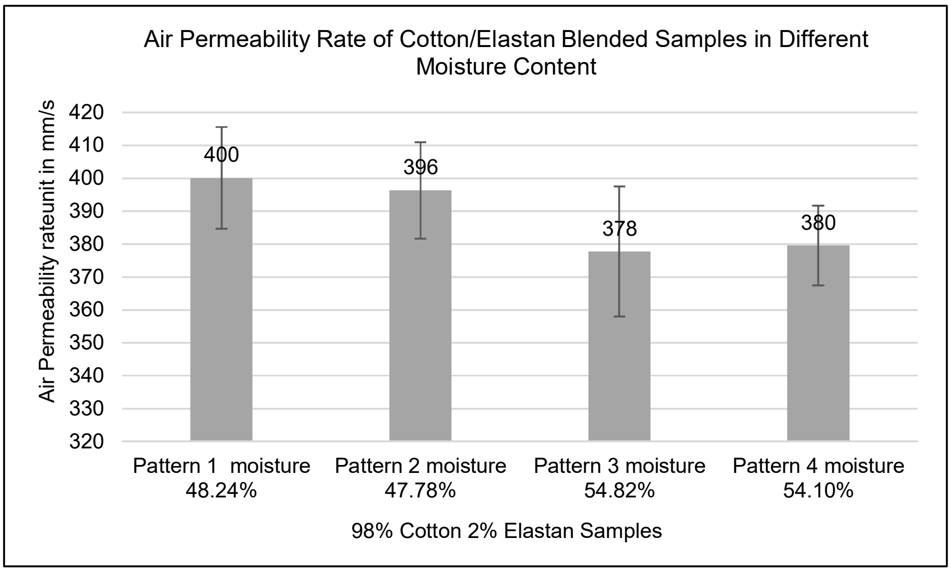
Acknowledgment: *Thank you Ing.Ph.D.Pavla Tesinova for showing me the operation of the Fabric Breathability Test Machine.*



a) Results from 100% cotton samples with different moisture content



b) Results from 50% cotton 50% polyester samples with different moisture content



c) Results from 98% cotton 2% of elastan samples with different moisture content

Figure 7 Air permeability rate results from three materials with different moisture content

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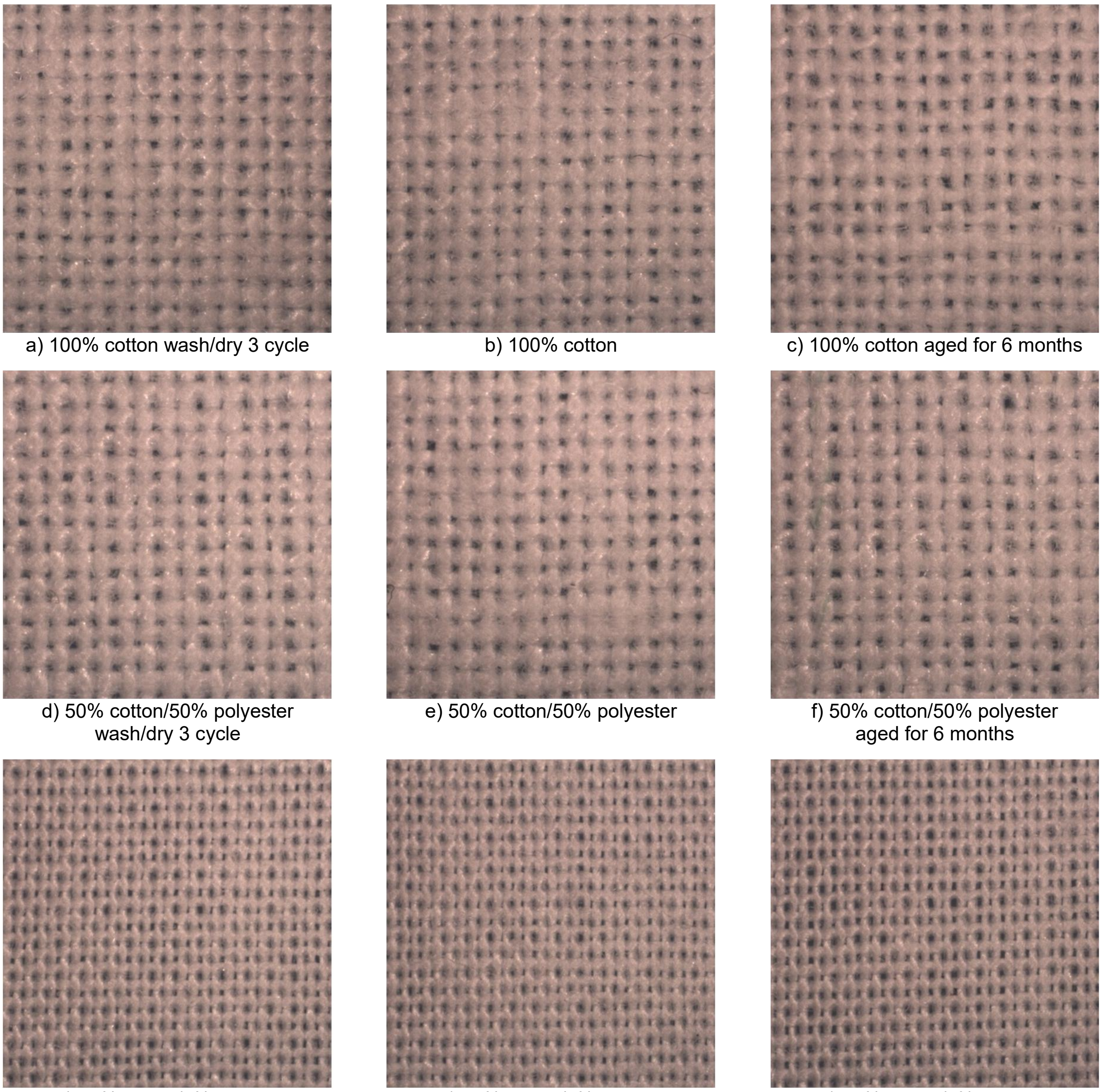
Appendix 1



a) 100% cotton wash/dry 3 cycle

b) 100% cotton

c) 100% cotton aged for 6 months

d) 50% cotton/50% polyester wash/dry 3 cycle

e) 50% cotton/50% polyester

f) 50% cotton/50% polyester aged for 6 months

g) 98% cotton/2% elastan wash/dry 3 cycle

h) 98% cotton/2% elastan

i) 98% cotton/2% elastan aged for 6 months

Figure 8 Left column are the samples which have been washed and dried for 3 cycles, middle column are the regulars for reference and the right column are samples that have been aged for 6 months. When compare the empty spaces (pores) between weft and warp threads, noticed that pores are getting bigger and wider in aged samples than the regulars. especially in cotton/elastan blend shows more spacing than the regular sample. The regular cotton sample has a lot of blocked spaces by its own fiber when it compares to the aged cotton samples. Photographs are taken by Navitar Micro Camera, zoom 12x

EFFECT OF UV WEATHERING ON THE COMFORT AND PHYSICAL PROPERTIES OF ABAYA CLOTHING

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Abstract: *Ultraviolet rays from the sun are the major reason to cause physical damage to the clothing in warm countries. The typical clothing "Abaya" worn in Arab countries are affected by this strong UV rays. In this research the properties like comfort, air permeability and drape property will be examined for the clothing before and after artificial weathering. Special accelerated artificial weathering machine form company "Atlas" will be used and the samples will be tested under repeated cycles of UV light. This accelerated weathering will give us a real condition of clothing after years of wearing under sun. The thermo-physiological properties of the fabric are analysed before and after weathering. The results show significant decrease in drape, air permeability and water vapour permeability, whereas a minor change is observed for the thermal resistance.*

Keywords: *Clothing, comfort, UV, comfort.*

1 INTRODUCTION

Climate has adverse effect on the material properties, which leads to product failure. The major reason of product failure is UV degradation of the material. In most cases the functionality and the durability of the product is significantly decreases due to natural weathering. Most of the product made from synthetic polymers possesses great functional properties but the effect of natural weathering is usually unavoidable [1-4]. In this research typical Middle East clothing for women (Abaya) is selected. The photo of standard Abaya is shown in Figure 1.

Figure 1 Standard Middle Eastern woven ABAYA

1.1 Factors that affect weathering of material

Many factors influence the functionality of material under different climatic condition, in general its usually solar radiation, temperature and moisture. But some other factor like pollution makes it more worst. The list of factors effecting weathering can be described as [4-6]:

- water
- pollution
- temperature
- sunlight
- physical interaction
- air impurities

The sun is the source of the radiation energy naturally. The energy can be described by following equation:

$$E = h.C/\lambda \quad (1)$$

where h is Planck constant, C is velocity of light in vacuum and λ is wavelength.

1.2 Ultraviolet light wavelength

The UV spectrum of solar light consists of 3 regions [5-8]:

UVA: The wavelength is between 315 to 400 nm and it is source of polymer damage

UVB: The wavelength is between 280-315 nm, it causes severe polymeric damage

UVC: the wavelength is between 100-280 nm, it is filtered out by the atmosphere.

1.3 The effect of UV on materials

Photo degradation is closely connected with the UV light, the absorbed UV energy higher than the bond energy of the polymer causes the breakage of the bonds and impact significantly on the overall life time of the materials [9-11].

The textile garments are made from multiple thin layers of polymers, stitched together with polymeric threads. The overall life time, durability and comfort of the garment is highly affected by the climate. This naturally weathering reduces the overall look, comfort properties and the durability of the garment [12-16].

1.4 Types of weathering [17]

There are 2 major kinds of weathering:

1) Natural weathering

The natural weathering is performed naturally available condition around the word. Usually tropic regions are used for high humidity condition, Deserts for extreme UV radiation condition and European regions for cold and UV conditions. The temperature and humidity depends on the region used for testing. The sample is placed at a 15° angle for maximum sunlight facing.

2) Artificial lab weathering

Besides natural weathering, several test methods have been developed using artificial light sources to provide accelerated test procedures. All methods are based on the regular observation of characteristics reflecting an ageing process such as mechanical properties or visible characteristics. The artificial weathering is done either on natural weathering stations or artificial accelerated weathering chambers.

Because there is a need for more rapid evaluations of the resistance of materials to weathering than can be obtained by outdoor exposure tests, devices with artificial light sources are generally used to accelerate the degradation. These sources include filtered long arc xenon, fluorescent, metal halide lamps and carbon arc. Less commonly used light sources include mercury vapor and tungsten lamps. These laboratory accelerated weathering tests are sometimes and perhaps more appropriately, referred to as artificial weathering [16-17].

2 OBJECTIVES OF THE RESEARCH

The main objectives of the research were to analyze the following comfort properties of clothing before and after artificial weathering. The tested properties include:

- Drape test
- Air permeability
- Water vapor resistance
- Thermal resistance

3 METHODOLOGY

Six different Abaya clothes (3 woven and 3 knitted) were tested before and after artificial UV weather for air permeability water vapor resistance, drape percentage and thermal resistance by testing machine. For the weathering of samples we used the Atlas UV weathering machine, 15 hours of the Atlas UV weathering machine is equal to 1 month of outside UV weathering and to get 1 year weathered sample we put our samples for 7 days in to the machine by ATLAS UV2000 (ISO 11507).

Air permeability was measured by device FX3300 using standard ISO 923 and the water vapor resistance was measured using the Atlas Sweating Guarded Hot Plate using standard ISO11092.

The details of woven samples are given in Table 1 and the details of knitted samples are given in Table 2.

Table 1 Abaya woven fabric composition

Fabric	**1**	**2**	**3**
Composition	**100% PES**	**100% PES**	**60/40% PES/CO**
Weave design	twill	satin	plain
Thickness [mm]	0.58	0.15	0.5
Fabric mass [g/m^2]	205	80	140
Warp yarn count [tex]	15	5	10
Weft yarn count [tex]	14	5	18
Ends/cm	60	100	60
Picks/cm	40	40	54

Table 2 Abaya knitted fabric composition

Fabric	**1**	**2**	**3**
Composition	**100% Nylon**	**50/50% Wool/Nylon**	**100% Wool**
Knit design	interlock	single jersey	single jersey
Thickness [mm]	1.1	0.72	0.5
Fabric mass [g/m^2]	320	120	154
Yarn count [tex]	19	17	18

4 RESULTS AND DISSCUSION

The samples were tested before and after artificial UV weather for air permeability water vapor resistance, drape percentage and thermal resistance by standard test procedures.

4.1 Drape test results

Drape test is performed on all samples (before and after UV) using standard BS EN 9073.

It is observed as shown in Figures 2 and 3, that UV weathering has significant loss of drape ability of woven as well as the knitted fabric. The effect can be because of the adverse effect of the UV on the surface of the man-made fibers. Finally causes the stiffness of the material.

Drape is important property while choosing Abaya. As comparison to both the graphs it can be stated that the effect is more for the knitted fabric as compared to the woven. It might be due to fact that the woven fabrics are already tightly packed as compared to knitted fabrics.

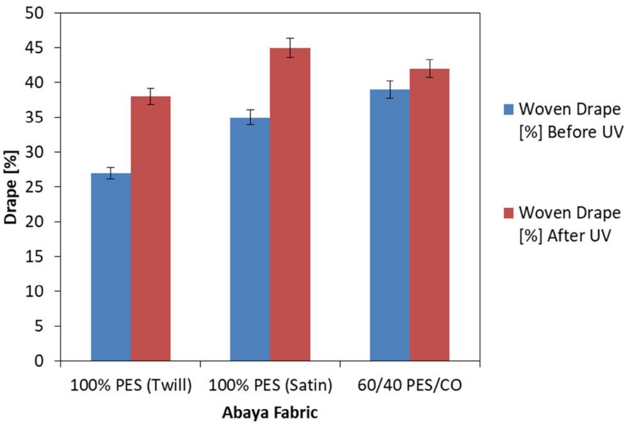

Figure 2 Effect of UV on drape of woven ABAYA

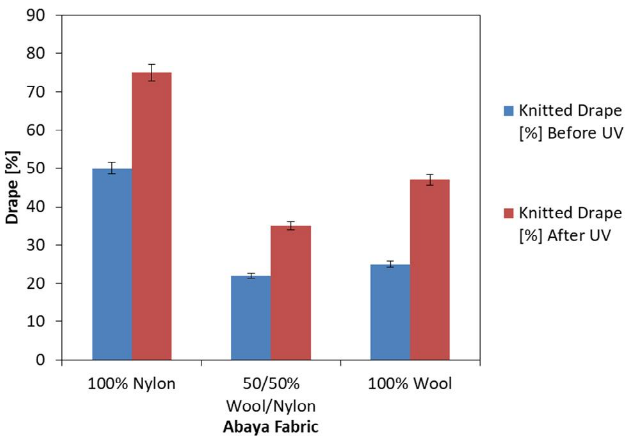

Figure 3 Effect of UV on drape of knitted ABAYA

4.2 *Air permeability*

Air permeability is very important factor for the Abaya clothing, It is seen form Figures 4 and 5, that the air permeability of both knitted and woven fabric is significantly decrease after UV weathering. The UV weathering causes the damage on the surface of the fabric and this rough structure and broken fibers may have decreases the flow of air.

The air permeability of Abaya is one of the most important factor as less permeability will cause the wet microclimate and discomfort. It can be seen that PES twill structure is much more permeable and shows less impact even after weathering.

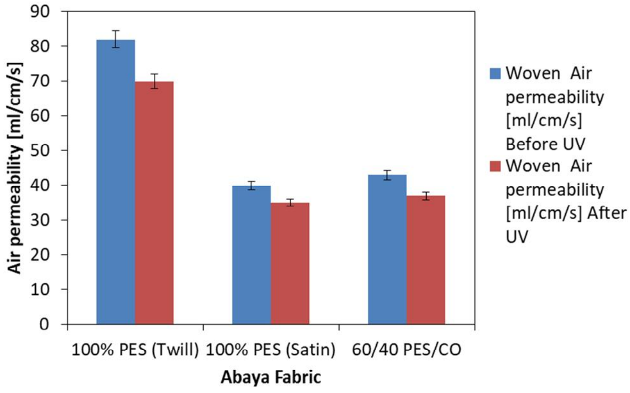

Figure 4 Effect of UV on air permeability of woven ABAYA

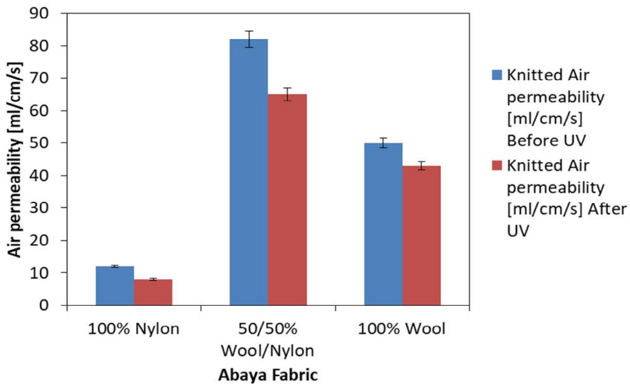

Figure 5 Effect of UV on air permeability of knitted ABAYA

4.3 *Water vapour resistance*

The water vapour permeability is very important property while choosing the clothing. It is seen in Figures 6 and 7, that the UV has great influence on increasing the water vapor resistance of the fabric. It is mainly due to the roughness and damage of the surface and hinders the flow of moisture. It is also possible that broken fibers and cracks may have made new channels for the flow of water vapors.

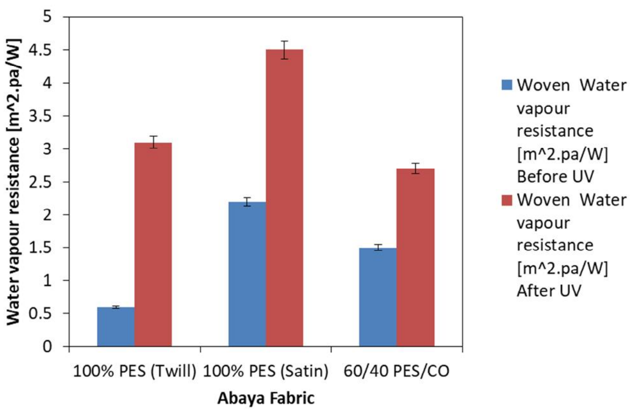

Figure 6 Effect of UV on water vapour resistance of woven ABAYA

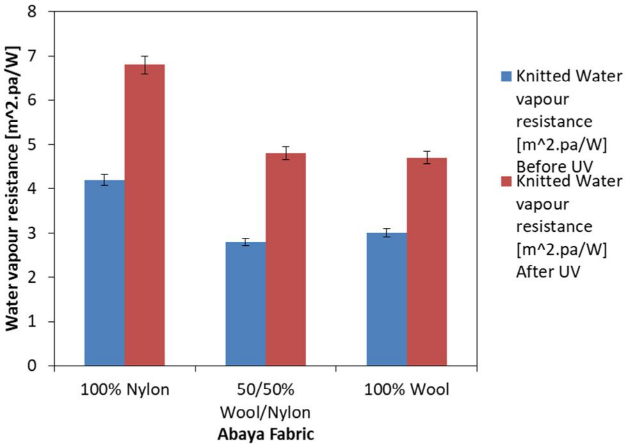

Figure 7 Effect of UV on water vapour resistance of knitted ABAYA

Water vapor resistance was much more impacted for the woven fabrics after UV weathering, which can be due to fact that knitted fabrics have more tendency for open channels after degradation.

4.4 Thermal resistance

The thermal resistance of Abaya clothing is important specially when worn in hot environment. It is seen in Figures 8 and 9, that the UV has great influence on increasing the thermal resistance of the fabric. It is mainly due to the roughness and damage of the surface and keep more air pockets and causes increase in thermal resistance.

Thermal resistance is crucial for the Abaya, when worn specially in hot climates. Woven fabrics are much impacted after UV weathering, which can be because of the trapped air spaces inside woven structure after degradation.

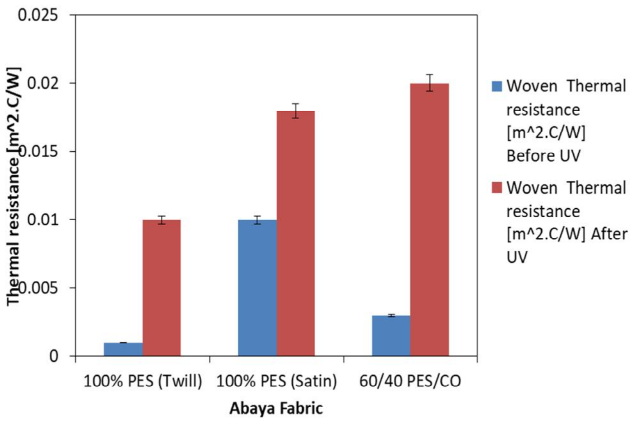

Figure 8 Effect of UV on thermal resistance of woven ABAYA

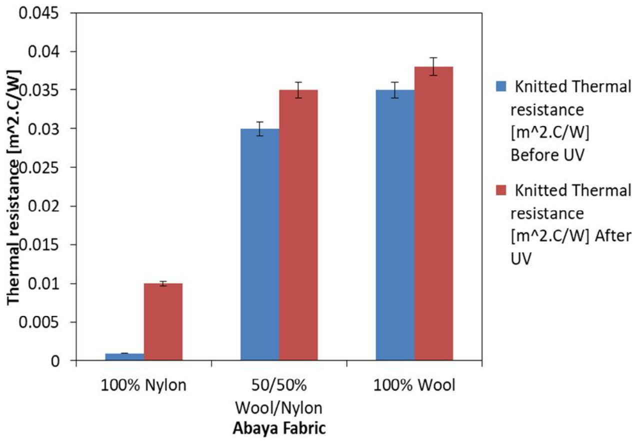

Figure 9 Effect of UV on thermal resistance of knitted ABAYA

5 CONCLUSION

It is concluded from this research that the UV has adverse effect on the Abaya clothing and causes significant decrease in drape, air and water vapor permeability of the Abaya clothing. These all properties are essential for choosing the comfortable clothing especially in hot and humid environment.

It is also observed that

- UV has similar impact on woven and knitted fabrics.
- The Abaya made from cotton and wool shows better performance, that is less water vapor resistance even after UV weathering.
- The UV weathering as adverse impact on the performance of the textile clothing. Also it affected the aesthetic property of garment specially the color, but this was not part of the current research.

Future works

In future following research will be studied.

- UV absorber coatings and textile covers to protect Abaya from weathering.
- Accelerated weathering with condensation can be useful for predicting the Abaya life time in different parts of the world.
- Accelerated weathering equivalent to 2 or 3 years can be useful in knowing the life time of garments.

Acknowledgement: *This Project was funded by the Deanship of Scientific Research (DSR) at King Abdulaziz University, Jeddah, under grant no. G- 101-253-39. The authors, therefore, acknowledge with thanks DSR for technical and financial support.*

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CHANGES IN EDUCATION FOR TEXTILE PRODUCTION IN THE INDUSTRIALISATION PROCESS

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Abstract: *This study deals with the issue of the changes in the professional training of those who participated in textile production during the industrialisation process in the second half of the 19th and early 20th century, when the mechanised factory mass production overshadowed the traditional forms of production and final treatment of textiles based on handiwork. It introduces the newly forming education possibilities, the birth of the system of textile education, the attitude of both the state and non-state officials and, last but not least, also the students of textile schools. In the first part of the study we will present the general tendencies based on knowledge from the Cisleithanian part of the Habsburg Monarchy, while the second part presents a more detailed insight into textile education on the territory of the so-called Austrian Silesia from the mid-19th century until the First World War.*

Keywords: *education, schools, students, industrialisation, Cisleithania, Silesia, 19th century, 20th century.*

1 INTRODUCTION

Training for textile production in the period until the early 20th century is not a commonly dealt with topic among researchers, which, in fact, applies to the entire sphere of professional training. Even the classical works by J. Gruber [1], O. Kádner [2] or Z. Černohorský [3], which today's authors still refer to, reserved only minimal space for textile schools. In addition, this space was given mainly to institutions where Czech was used as the language of teaching. What attracts even less interest is the research of the ties between education and various modernisation processes taking place in the Central European area roughly from the mid-18th century. The role of education in the industrial revolution and industrialisation processes is no exception, as it was taken into account more only by foreign researchers. For the territory of the Austrian part of the Habsburg Monarchy (Cisleithania), which this study is focused on, we can, from this aspect, point out especially the inspirational and factually beneficial works written by the Austrian authors H. Engelbrecht [4], J. Schermaier [5] and K. J. Westritschnig [6]. The last two authors paid more attention even to the development of textile schools. Within the possibilities of its limited extent, this study intends to pursue three aims:

1) to outline the development of textile schools in the Cisleithanian part of the Habsburg Monarchy until the First World War;
2) to show the transformation of the organisation of these schools and the teaching in the context of changes brought about by the industrialisation process, which developed rather diffidently in the conditions of the Bohemian Lands from the 1820s;
3) to introduce the general trends on the example of Austrian Silesia (in its borders in 1742–1918) and the local educational institutions.

The limited extent of the study causes that its character is more of an input text, the introduction of the basic aspects and introduction into the problem. In conclusion of the introductory input we should add that the text omits the basic competencies which primary school pupils gained in the monitored period as part of lessons on sericulture and the so-called women's handicraft (embroidery, knitting, etc.). As important as the knowledge and skills gained in this way were for those concerned, they could be applied only in the relevant households and family farms.

2 THE TRANSFORMATION OF TEXTILE PRODUCTION DURING THE INDUSTRIAL REVOLUTION AND INDUSTRIALISATION

Much has already been written about the fact that the Bohemian Lands were a traditional base of textile production in the Cisleithanian part of the Habsburg Monarchy. Even more than for the Middle Ages this applied for the later periods. In the pre-industrial era textile production was an important production area, from which a large part of the local population profited and on which it was existentially dependent. In the conditions of the Bohemian Lands two sectors with a long tradition played a key role in this period: linen and woollen fabric production. These were produced from thread supplied either from rural areas or bought at foreign markets. The fabric was mainly intended for sale at local markets or, exceptionally, at supraregional markets. While at first the weaving and final treatment (bleaching, dying, etc.) of both aforementioned types of fabric was concentrated into towns, during the first half of the 18th century the centre of production in the case of flax weaving was transferred into the countryside, specifically into submontane and mountain border areas in North and North-East Bohemia and Silesia, and the neighbouring North Moravian regions [7-10]. Flax spinning and cloth weaving had the form of cottage industry here (in the households of direct manufacturers, predominantly handiwork with the use of simple hand tools), intended both for one's own consumption and for the market (including taking part in supraregional and foreign trade), which was, in practice, realised through the so-called merchant or putting-out system or, alternatively, as part of the scattered manufactory [11]. In any case it was an important secondary source of the agricultural population's livelihood in periods of vegetation rest, which, together with engaging women and children in labour, was another sign typical of the process of the so-called proto-industrialisation [12]. What played an important role here was the exemption of flax spinning and cloth weaving from the shackles of guild regimentation and their proclamation as free trades in the mid-18th century, which also concerned wool processing and the steadily more used cotton. While flax spinning and weaving (though not the final treatment) typically had the form of scattered rural cottage industry, the production of woollen cloth was traditionally concentrated into towns, where, right until the onset of industrialisation, it was the domain of guilds (e.g. Jihlava, Brno, Bielsko), and, from the 18th century, in some places even of the newly established manufactories (Horní Litvínov and others).

Besides both traditional branches of textile production, in the late 18th century cotton industry started to assert itself in the Habsburg Monarchy, despite the Monarchy's initial efforts to restrict it. In the 19th century cotton industry became the lagship of the industrial revolution and industrialisation. It was precisely in the cotton industry (namely in spinning and the final treatment of the cloth /printing/), fully dependent on the import of the indispensable material from abroad, where the changes borne by the industrial revolution asserted themselves the fastest: the mechanisation of work and factory mass production. This secured the field a decent competition advantage. While the transfer to centralised machine production in both aforementioned branches of the cotton industry was in fact complete by the mid-19th century, cotton weaving remained the domain of work on hand-looms for a long time afterwards [13]. This was also the case of the wool industry, where machine spinning also asserted itself before the mid-19th century, but in weaving the traditional and mainly guild organised forms of production still prevailed. Although mechanical looms started to be introduced in the wool industry as early as the 1830s, it was only after the mid-19th century that they prevailed in the centres of modern wool production in the Bohemian Lands (the Brno and Liberec regions) [14]. The reasons for the slower advancement of the mechanisation of weaving lay in the relatively high purchase price of a mechanical loom and the need for a source of energy, whether hydraulic or steam.

The slowest advancement of processes brought about by the industrial revolution can be observed in the linen industry, which was already stagnating in the first half of the 19th century as a result of the loss of foreign markets during the continental blockade and the competition of the more easily processed and demanded cotton [15]. This was the reason why some regions converted from processing linen to processing cotton, which manifested itself e.g. in the Liberec and Šluknov regions, in the surroundings of Frenštát pod Radhoštěm, or in the Frýdek and Místek regions [16]. Machine flax spinning prevailed only in the 1850s, while mechanical weaving started to gradually assert itself only from the late 1870s. During the second half of the 19th century the linen industry, inhibited by the resistance of a backward form of weaving, was steadily losing its importance as opposed to the dynamically developing types of textile production, especially the progressive cotton industry, which was also supported by changes in the demand for textile goods and the decline of interest in products made from linen fabric. Last but not least we can also mention the consequences of the liberalisation of economic activities, losses of tariff protection and the detrimental impact of the economic crisis in the 1870s. What was crucial was that the above-mentioned was not only an economic problem, but in the last decades of the 19th and early 20th century it had also become a serious social and political problem, for at the end of the monitored period tens of thousands of people were still existentially dependent on textile production that was technologically backward, uncompetitive as far as quality and price were concerned, and that predominantly operated as a cottage industry. The crisis of the cottage industry in general, in our case mainly flax weaving, carried with it the political risk of pauperism while increasing the undesirable depopulation tendencies in the affected regions [17, 18]. As lax as the initial attitude of the Austrian state towards this problem was, e.g. in comparison with Germany, facing this challenge in the late 19th century was inevitable, on the central as well as the provincial and regional level. As we will see below, a crucial link in this crusade were the efforts to increase and change the qualification of cottage weavers. In other words, what gained importance both in considerations and specific actions was vocational education, which had until then been ignored. Those that were also forced to react to the changing qualification requirements in the second half of the 19th century were guilds, or later, after their abolition in 1859, trade communities, professional associations and even the owners of the still existing non-factory forms of mass production (manufactories). Finally, in the second half of the 19th and early 20th century, new technologies had taken over even in factories, even though in the lowest stages of production a short initial training to teach the workers (especially women and children) how to operate the machines was enough. As a result, education was not only a means of supporting the dynamically developing textile industry based on machine production in centralised factories, but it also provided aid to a relatively large number of people who represented the traditional forms of textile production, which, at the time, were already without good prospects.

3 TEXTILE EDUCATION IN THE CISLEITHNIAN PART OF THE HABSBURG MONARCHY UNTIL THE FIRST WORLD WAR

Ever since the Middle Ages there basically existed two ways how to gain knowledge and skills usable in textile production (spinning, weaving, final treatment of the cloth): at home and in field-oriented guilds. In the first case experience was passed on from generation to generation; from today's perspective it was a strictly individual approach based on demonstrations, trying out the individual parts of the process and exercising parental authority. We can doubt the systematic nature and depth of such a presentation, as well as its ability to innovate the educational content. In this respect a more advanced form of education took place in guilds, where the obligations, responsibility and qualification were graded as part of the classic triad apprentice – journeyman – master, which survived (though under different conditions) even the end of the guild organisation in 1859. What was typical for both traditional forms of textile education was the specialisation of each individual on a specific part of the work process (spinning, weaving, etc.) and that these forms significantly influenced the competencies of workers in textile production until the end of the monitored period [19].

The first textile schools (from today's perspective more resembling courses) were established only in the 18th century, ranking among the very oldest vocational institutions in the Habsburg Monarchy. Some of them were established as part of manufactories, which, from 1770, were allowed to have their own apprentices. These schools aimed not only to expand the qualification of the workers, but also to unify the working procedures and quality of the final products. We can also mention the inspiring deed in the form of industrial education at elementary schools, which, in the late 18th and early 19th century, spread mainly in Bohemia thanks to Ferdinand Kindermann. It was an interesting means linking educational, disciplinary and social goals, which, however, slowly declined during the first half of the 19th century mainly due to a lack of finances, learning space, qualified teachers and too many students in the classes [20, 21].

Finally let us recall the engagement of the Austrian state in the form of initiating the establishment of independently run spinning (wool, cotton, flax and hemp), weaving and bobbin lace schools in royal towns in 1755–1770. They proved successful especially in Bohemia and their character was partially that of several-week-long production workshops intended primarily for youngsters aged 7–15, orphans, poor children and the offsprings of artisans who had not yet mastered the trade; however, even artisans already practising their trade could improve there. Their establishment was connected with the growing competition in the textile product market as well as with spinning and weaving being declared the so-called free trades, which meant, among other things, that they were not subject to the guild organised system of professional training. The purpose of these schools was to improve textile production in the sense of improving the quality and competitiveness of the textile products. According to the state authorities, weaving schools, for example, were to teach weavers how to achieve fine fabric and how to produce the so-called commercial linen, fine and attractive (fashionable) goods [22].

The ambitions to help textile production in this manner came up against certain limits in practice, which lay mainly in that the engagement of the state was restricted only to the initiation level. What was lacking were standardised curricula, a sufficient number of qualified teachers and the essential material support. This was the reason why a number of courses/schools often did not last very long [23].

The indicated educational alternatives of training workers for textile production remained, in essence, identical even in the early stages of industrialisation in the first half of the 19th century. What was typical was the considerable heterogeneity of schools in their quality, focus and facilities, the absence of a general conception and state support, and the persistence of two main lines of education: within guilds and outside them. While on the educational level we cannot speak of any progress, the opposite was true of the situation in the textile production itself, in technology, the organisation of work, and in the transport and trade possibilities. The changes launched and sometimes even completed in textile production in the first half of the 19th century became more intensive after this century had reached its midpoint. The results were increased pressure on the price and quality of the goods, the rationalisation of the work organisation and managing the growing paperwork. The demands on qualification grew and changed with time, which, in the interest of preserving competitiveness and securing existence, needed to be reacted to adequately. The textile producers themselves realised this much sooner than the state administration. The first impulses to institutionalise the actual professional training, intended to help face the new challenges, therefore came from the 1840s to the 1870s from none other than these producers and their organisations (guilds or, after 1859, professional organisations and associations). Even the local governments and the newly established Chamber of Commerce and Industry (*Handels- und Gewerbekammern*) joined in these self-help efforts. Specifically, this included mainly establishing weaving schools, as the mechanisation of spinning in the prospective branches (cotton and wool industry) was already so widespread in the mid-19th century that with most workers it sufficed to train them in using the corresponding machines. The phase of the final treatment of the cloth was similarly progressive as well.

The first independently run textile schools were opened in Vienna, Liberec, Brno and Bielsko, all thanks to artisan associations. Besides their focus and founders, these schools were also linked by the German language of teaching. Vienna was a specific case, for as part of the existing technical school a weaving school was opened in 1847, which, however, soon closed down. It was renewed only in 1871, focusing at first on teaching its students drawing and designing patterns, while from 1882 it became a more widely conceived educational institution (lessons of weaving, knitting, drawing patterns, etc.) with the name *Lehranstalt für Textilindustrie* [24]. The weaving school in Liberec was established in 1852 by the local drapers' guild, while the Chamber of Commerce and Industry accompanied the establishment of the weaving school in Brno in 1860. The fourth school of this type, which we will describe in more detail in the next chapter, was opened in the early 1860s in the Silesian Bielsko. In the 1850s and 1860s the four aforementioned schools were the only independently running institutions in the Cisleithanian part of the Monarchy which focused on textile education. The number of textile schools remained frozen practically until the early 1870s when the state finally became more noticeably engaged in this educational segment. The first foray of the new founding wave was the establishment of a weaving school in Ústí nad Labem in 1869.

However, let us return briefly to one of they key centres of the Cisleithanian textile production – to Brno. On its case we can document a different way of educating workers employed in textile production that was newly asserting itself in a time when independently run vocational schools were lacking, i.e. in the 1850s and 1860s. What we have in mind are Sunday and evening courses, which were being established as part of the so-called *Realschulen*. They were schools which, in the aforementioned two decades, had the character of technically oriented secondary schools. Just to illustrate: until the school year 1866/1867, 55 of these schools were established in the Cisleithanian part of the Monarchy [25]. And it was as part of these schools that the popular Sunday and evening courses for artisans, sometimes referred to as *Abend- und Sonntagsschulen*, were opened. What was important was that in the areas where textile production was concentrated, these courses were well attended by persons working in the textile industry (mainly apprentices, journeymen and, sporadically, masters), causing the lessons to be partially adapted to them. In Brno such a course was established as part of the local *Realschule* in November 1852 with the cooperation of the local government, industrialists and Brno's artisan guilds. Brno's Sunday and evening school consisted of a preparatory and vocational department. The latter was further divided by branches into four separate courses, where one of them, planned for two years, was intended specially for spinners and weavers. The lessons focused mainly on refining the students' ability to draw patterns and on thoroughly acquainting the students with the Jackquard loom. Let us add that in some other departments of the school it was possible to develop the competencies for textile production: the so-called free-hand drawing (*Freihandzeichnen*) and drafting was the content of the preparatory course, while dying was taught in the department of chemistry. In addition, it was possible to attend even lectures which stood outside the specialised departments: e.g. on accounting, mechanical engineering and civil engineering. It should be added that the Czech language was starting to assert itself in the lessons, which was, however, conditioned by the ethnic composition of the students. This consequently helped those students who did not have a sufficient command of German to get a better fixation and understanding of the presented facts. The example of the Brno school shows that these Sunday and evening courses were well attended. Already in the first year of its existence 1,278 students were enrolled there, from which more than 1/3 were textile producers, mainly weavers [26].

It was only the 1870s that can be considered the real founding period of textile schools. In the Cisleithanian part of the Monarchy a number of schools were opened in that time, so by the early 1880s the Austrian school statistics already registered 30 educational institutions of this kind [27].

By looking at their structure we have come up with the following findings:

1) they were usually small schools with a maximum of several tens of students (exceptions with more than 100 students: Krnov, Brno, Šternberk, Varnsdorf, Rumburk, Aš and Wien) and only a few teachers (usually from 1 to 4);
2) the placement of the schools corresponded to the importance of textile production in the individual lands and regions. A total of 23 schools were located in the Bohemian Lands (Bohemia – 15, Moravia – 5, Silesia – 3); these schools could largely be found in the border regions of North and North-East Bohemia, North Moravia and Silesia;
3) a branch-regional differentiation of the schools was applied. While the typical schools for the Hereditary Austrian Lands were bobbin lace schools (*Spitzenklöppeleischulen*), the Bohemian Lands were dominated by classic weaving schools (*Webeschulen*);
4) the ethnicity of students attending the schools in the Bohemian Lands corresponded with the placement of the schools and the population characteristic of the individual regions. Most schools were dominated by students whose mother tongue was German; the only exceptions were the institutions in Lomnice nad Popelkou, Polička, Jilemnice and Prostějov. The placement of the schools and composition of their students subsequently corresponded with the predominantly German language of teaching;
5) the statistics did not register all schools (courses) focused on training for textile production. Corporate schools, for instance, were demonstrably absent, which we will illustrate on the example of the school in Jeseník in the following chapter.

There are two reasons why the founding boom of textile schools took place precisely in the 1870s. The first of them was the unsustainability of the existing unsystematically organised education of workers in the textile industry, especially weavers, which was underlined even more by the economic crisis that took place after 1873. The dismal situation was registered both by those employed as weavers and by their employers. It was precisely the organisations of artisans (producers) and industrialists (employers) that became the driving force of establishing textile schools. The second reason was the change in the approach of the, until then, inactive state, which, besides economic motives, also pursued social-political goals, i.e. using its educational policy to try and eliminate the risk of pauperism and potential social unrest. In this period the state generally started to engage more in the field of professional training, textile education included. In this case the engagement of the Ministry of Trade was essential, as it supported the establishment of new schools by means of subsidies. As a result, this activated those considering the establishment of a school even more. Textile schools fell within the competence of the Ministry of Trade itself until as late as 1882, when the Ministry of Cult and Education took them into its management. Let us add one characteristic aspect of the state engagement in the field of textile schools from the 1870s: putting schools under state management or, alternatively, the direct establishment of schools by the state. This pursued two main objectives. Firstly the state's motive was to secure a basic network of textile schools. Secondly, in the interest of maintaining the quality and competitiveness of the domestic textile production, the state's ambition was to control this segment of education and to form it to its liking, which, however, was realised only in the following decades.

Although in the 1870s the number of textile schools was growing dynamically, what remained a long-term problem was their different organisation, quality, educational content and, last but not least, the different educational goals of the individual institutions. In the following section we will focus on the largest group of textile schools, i.e. weaving schools. In late 1880 and early 1881 their total was 21, all of them located on the territory of the Bohemian Lands. Most of them were two-year institutions with lessons taking place during the day. Schools with only a one-year day school could be found in Brno and Liberec, while Sunday or evening courses were held at schools in Aš and Moravský Beroun [28]. We can only speak of a really systematic care of weaving schools with the aim of unifying their organisation and curriculum in the period when the superintendence of these schools had been taken over by the Ministry of Cult and Education. It must be added that this process was neither simple nor fast and direct. This is confirmed by the fact that this process was only completed in the early 20th century. The first important step on the way to the systemisation and unification of textile education was the issuing of the so-called normal curriculum (*Normal-Lehrplan*) for the teaching of free-hand drawing (*Freihandzeichnen*) and technical drawing at two-year weaving schools in 1884. Five years later (1889) came a bigger intervention with the issuing of the so-called normal curriculum and instructions for technology studies at two-year schools with day-to-day courses and in one-year evening and Sunday courses, which set the spectrum of compulsory subjects and their number of lessons per week [29]. What can be referred to as an intervention of crucial importance was the issuing of the so-called normal curriculum in 1901, which comprehensively covered all education taking place at weaving schools. Based on this curriculum, effective until a new regulation was issued in 1910, education at weaving schools could be divided into four groups of subjects: professionally theoretical (technological) subjects, drawing, professionally practical education (almost 1/3 of all lessons) and generally industrial and trade subjects. It was precisely in the removal of deficiencies in trade competencies and in the intensification and expansion of technical education where the path to the improvement of production and the sales of textiles was believed to lie [30].

We have stated that the total number of weaving schools in the early 1880s was 21. By the school year 1913/1914 this number had increased to 34 (including schools with departments for knitters and spinners), whereas the total number of state schools on the eve of the First World War was 30 (29 in the Bohemian Lands and 1 in Vienna) and non-state schools 4 (all in Galicia). The base of these schools were one- to two-year schools with day-to-day courses, which were, based on the possibilities and local preferences, joined by other courses and departments. These often included for example evening and Sunday trade courses, courses of mechanical weaving, special courses for drawing designs, the study of promissory notes, etc. It will probably not be surprising that most state weaving schools for which the relevant dates are available were schools with the German language of teaching. However, from the late 19th century there was a considerable increase even in the number of schools with the Czech language of teaching. In this period, the traditional Czech schools in Lomnice nad Popelkou, Prostějov a Jilemnice were joined by schools in Frenštát pod Radhoštěm, Rychnov nad Kněžnou, Humpolec, Náchod, Dvůr Králové nad Labem, Strakonice and Ústí nad Orlicí. By the First World War the ratio of German and Czech schools therefore settled at 20:10 [31]. Considering both the material and the organisational (an extraordinarily high number of affiliated courses) and capacity aspect, there was one school that stood out above all others – the school in the centre of the textile industry in Liberec. Let us add that the advancement of the industrialisation process also manifested itself in the need to establish institutions where one could gain higher vocational education in the textile industry. In the Cisleithanian part of the Monarchy this was possible at the German schools in Aš, Brno and Bielsko. While at the turn of the 20th century (1899 and 1903 respectively) the first two institutions transformed from the original weaving schools into four-year higher vocational schools for the textile industry (*K. k. Lehranstalt für Textilindustrie*; the school in Aš with special emphasis on commercial education), the school in Bielsko was, already in the early 1880s, incorporated into the local reorganised state technical school. At these three schools there studied mainly the middle technical and white-collar cadres and foremen (weaving, spinning and final treatment). However, there were also various courses affiliated to them, which provided education to other interested parties, namely in spinning, weaving, knitting, final treatment and trade subjects (e.g. accounting).

It now seems appropriate to ask what the role of weaving schools in the late 19th and early 20th century actually was. In the mid-1880s the purpose of these schools was aptly described by a contemporary, Eduard Magner, the then ministry official and specialist on the issue of textile production. According to Magner it was necessary to distinguish between the purposes of schools based on whether hand or mechanical weaving was concerned. In the case of hand weaving he stressed that weaving schools should not prolong the battle of cottage weavers with the constantly spreading machine weaving. The schools' primary task was to commence and facilitate the transition to mechanical weaving by explaining the substance of the matter, rejecting shallow work and providing direct instructions for mechanical weaving. If needed, the students of these schools were to be reoriented into a production area where no machines were used – artistic weaving in the broadest sense of the word. In the case of mechanical weaving, which was to become a part of school education in regions with a developed production of this type, the education included both that of highly qualified workforces (fitters, foremen, etc.) for factory mass production and the so-called preliminary education (*Vorbildung*) of blue-collar employees for mechanical weaving [32]. In the late 19th and early 20th century weaving schools had to reflect the structural changes in textile production, namely the process of the mechanisation of cloth weaving. While the numbers of hand-looms were decreasing considerably, the numbers of mechanical looms were growing dynamically. For weaving schools to become a functional part of the industrialisation process they first had to be adequately equipped. In practice this meant not only a revision of the curriculum (strengthening the theoretical knowledge regarding machines and the practical training in operating them) and the corresponding training of the teachers, but also providing the schools with the necessary premises and technologies. Specifically, this meant mainly the acquisition of costly looms. Progress in this respect was evident. While as late as 1885 of the 29 weaving schools only 5 were equipped with mechanical weaving workshops, in 1909 they could be found in 30 of the 32 schools. The only exceptions were schools in Horní Benešov and Lanškroun, where at this time the latter had already launched the process of installing mechanical weaving. The above-mentioned does not mean that the graduates of weaving schools which lacked mechanical looms did not have the opportunity to expand their knowledge in this respect. If they were interested, they could make use of scholarships enabling them to study at schools which had already had mechanical looms installed. For example for the graduates of schools in Horní Benešov and Rýmařov there existed scholarships for studying mechanical weaving at the school in Krnov [33]. It should be added that the investments in the acquisition of mechanical looms for schools resulted in a considerable increase of the budget of this educational segment. While the state spending on textile schools amounted to a total of 115,500 Gulden in 1884, in 1906 it was already 971,780 crowns [34].

It would be too much of a simplification and very far from the real state of things if we evaluated the state of textile education in the early 20th century strictly positively. Despite the demonstrable progress there was also dissatisfaction both with the organisation and content of the lessons and with the employment possibilities of textile school graduates. This is documented by, among other things, the negotiations that were part of the so-called Central Commission of the advisory body for questions of education within the Ministry of Cult and Education (later the Ministry of Public Works, under whose competence textile schools had fallen before the First World War) from 1902 and 1904. As the so-called normal curriculum for weaving schools from 1901 was classified as insufficient, it was agreed to draw up a new reform programme. It is essential that this was preceded by a detailed analysis of the existing situation at schools and a questionnaire survey targeted at industrial corporations and organisations, complemented by findings about the situation at similar educational institutions abroad. The actual outcome of the reform efforts was the issuing if a new curriculum in 1910, whose content we will deal with in more detail below on the example of Silesia.

What we find interesting is the information which resulted from the conducted analysis, as it gives evidence of the state of Cisleithanian textile schools and their students at the turn of the 20th century. In a presentation at the meeting of the Central Commission on 5th November 1909 it was introduced to those present by the proposer of the reform, Wilhelm Hamann, and we consider it useful to briefly present here the main findings [35]. In connection with the prevailing dissatisfaction with the lessons, qualification profile and employment possibilities of the graduates, Hamann recommended two possible alterations in the organisation of schools:

1) preserving the existing purpose of the schools, i.e. providing broad-spectrum education, which would require extending the studies by at least another year;
2) a specialisation of the schools, which would reflect the professional, local and individual needs.

As part of the statistical survey a valuable analysis was conducted of the students and graduates of schools for the textile industry for the school years from 1893/1894 to 1902/1903. Although some schools are lacking data for certain criteria, this set of data (covering a total of 8,400 persons) can be considered as sufficiently informative about the composition of textile school students and the employment possibilities of their graduates. Based on the presented data, textile schools accepted 99% of the applicants, while the rest were usually rejected due to lack of places. More than ¾ of the students for whom we have the relevant data were accepted between the ages of 14 and 16. This corresponds with the findings about the previous education of the accepted students, as most of them (approx. 82%) came to textile schools straight from elementary schools (more than a half from the so-called *Bürgerschulen*). Around 13% of students transferred to textile schools from the lower years of Austrian *Gymnasien* and *Realschulen*. The textile school students usually lacked previous professional experience in the field, which was the case of 87% of individuals. The rest had usually had one- to two-year professional experience, and it was only exceptionally that students with longer previous professional experience came to the schools. The data about the territorial origin give clear evidence that textile schools were mainly filled with students straight from the locations or, alternatively, regions of the corresponding schools (60%). This finding is rather well reflected in the fact that the schools could be found in places where the production activities of this industry were concentrated, and where there existed a demand for professional workers, whether for the positions of producers or clerks. The social origin of textile school students reflected the self-recruitment tendencies of workers in the textile industry only partially – around only 39% of students had at least one parent employed in the textile industry. Almost ¼ of students were the offsprings of various sole traders, while the parents of 38 % of the students did not fall into any of the above-mentioned categories. It should be added that the situation at the individual schools often varied in this respect. A special statistical survey was devoted to textile school graduates, where the corresponding set of data for the monitored period included almost 7,000 persons. The results showed that on average there were approximately 11 graduates for one school and school year. Although even in this case the situation at the individual schools was different, the presented data indicate that the major part of the graduates found employment in their home country (90%). Around 82% of the graduates remained active in the textile industry, while the remaining 18% found other jobs. The purpose of textile schools and the advancement of mechanisation in textile production are confirmed by the ratio of graduates who found employment in enterprises with machine and hand production. At the turn of the 20th century this ratio was 72:28. From those who remained in textile production, 61% were technical employees, 15% did administrative work in trade and 16 % worked as independent producers. The remaining graduates pursued, within the textile industry, mainly related trades or a teaching career, or continued studying at higher vocational schools [36]. On the one hand the conducted analysis showed the wide-ranging employment possibilities of the graduates, but on the other also the fact that most of them occupied lower positions than for which they were predestined by the education mediated by textile schools. In other words, in practice the graduates did by no means use the qualification potential which they had gained at the textile schools. That is exactly why Hamann proposed to take the path of rationalising and specialising the education. Practically the schools were to be divided into two main stages: a one-year lower stage (general weaving and technical education) and a higher stage (specialisation in technology, drawing /both one-year-long courses/ or trade /half a year long/). The ntrance conditions were also to be altered (newly the schools required a minimum age of 16, the completion of the lower stage of a vocational school and a minimum professional experience of one year), where exceptions were allowed only during the five-year transition period following the launching of the reform. Furthermore, emphasis was placed on changes in the system of the financial support of students and teacher training (special courses were added and study trips were supported). Let us add that the proposed changes were approved by the Central Committee in November 1909, which used them as the base for its proposal to the Ministry of Public Works about the reorganisation of textile schools, which was carried out in practice based on Ministry Decree no. 442/18-XXIa of 5th May 1910 [37]. This document was the last more noticeable intervention into textile education until the end of the existence of the Habsburg Monarchy.

4 SILESIAN TEXTILE SCHOOLS AND THEIR STUDENTS

In the monitored period Silesia was a land where textile education had a special economic significance. The most important branch was traditionally the production of linen fabric, which found its buyers both at local and foreign markets. Just like in the wider Central European linen region, decentralised production forms also dominated in Silesia. Especially in the period of vegetation rest, spinning flax employed tens of thousands of persons here. This also partly applied in the case of weaving linen fabric, where the local weavers were either organised in guilds or worked outside them. While for the linen production in Silesia a decentralised form of production was typical (mainly the Jeseníky, Javorníky and Frýdek regions), the local wool production concentrated into towns. Besides guilds it was also centralised manufactories which gained significance here, whose products were, from the end of the 18th century, starting to replace products made by guild masters. Until the mid-19th century cotton production was only marginally important in Silesia, though around the middle of the century it quickly started to assert itself mainly in the Frýdek region, to the detriment of the traditional linen production (completed in the 1870s) [38].

From the 1850s the share of the textile industry in the total value of the local industrial production was gradually declining in Silesia (1855: 64%, 1880: 51%). However, until the early 20th century textile production still remained an important production sphere, which provided a living to tens of thousands of people in the land. Those branches that maintained the most important position within textile production were the wool industry (a 67% share in 1880) and the linen industry (a 21% share in 1880). The growth of the cotton industry in Silesia, slowed down by the Civil War in the USA, was renewed in the 1870s, and in 1880 the cotton industry already shared by 10% in the Silesian textile production [39].

In the second half of the 19th century Bielsko became the most important centre of the Silesian wool industry, overshadowing – together with the neighbouring Galician Biała – the other centres of the local wool production such as Krnov, Opava, Bílovec or Odry [40]. The example of the linen industry in Silesia gives evidence of regional differentiation taking place as part of industrialisation, as mechanical looms found their way into this branch much more slowly in the eastern part of the land than in the western one [41]. In addition, the composition of the linen production changed considerably: originally it was pure linen fabric that dominated the production of linen goods (mainly the so-called smooth fabric); however, gradually the share of mixed fabric (the so-called half-linen) grew. In connection with the increasing demand for fashionable fine fabric, the production of damask and moleskin in Silesia started to grow [42].

Just like in other lands, despite the progress in the industrialisation process and the ever more popular factory mechanised production, in the late 19th and early 20th century scattered cottage industry still played an important role in Silesia. That is why in this period the crisis of the domestic industry came to be a burning issue, whose solution became the subject of negotiations of Silesian political elites. From a large part this was a problem connected precisely with textile production, especially with the still insufficiently mechanised weaving. It was therefore no coincidence that the regions most hit by the crisis included the weaving regions of Zlaté hory, Jeseníky, Bruntál, Odry and the Frýdek part of Silesian Beskydy. One of the solutions to the crisis was seen in the producers associating into organisations and in the related care regarding the weavers' education and training [43].

Similarly to Bohemia or Moravia, even in Silesia traditional methods were first applied in textile education: education at home or in guilds. Also in this land the establishment of spinning schools occurred; these schools, however, never became too widespread here. An example of this can be the spinning school in Jablunkov for rural flax spinners from the surrounding areas [44]. In connection with the fact that with the advancement of industrialisation the hand production of thread was quickly losing its importance, in the mid-19th century the establishment of new spinning schools in Silesia was stopped [45]. The support of establishing educational institutions designed in a more modern way was therefore directed to weaving, which was even more evident after the increase in competition given by the liberalisation of economic activities and the abolishment of the guild organisation in 1859. The first ever weaving school in Silesia was a school established in the first half of the 1860s in the traditional centre of cloth production, Bielsko. In the previous chapter we have stated that it was one of the oldest schools of its kind in all of Cisleithania. However, the school was somewhat atypical. From 1862 the local weaving masters first ran a three-month weaving course here with evening classes. However, in connection with Bielsko a school is usually mentioned only from 1865, probably in relation to the standardisation of its management and lessons [46].

Other weaving schools were opened in Silesia only in the 1870s in Krnov (1875), Bruntál (1877), Jeseník (1879) and Horní Benešov (1880). Except for Bielsko, these schools were concentrated into the western part of the land, a region with a cottage linen industry tradition (only in Krnov wool production was important). The concentration of the establishment of schools into the 1870s was not coincidental, as it was a reaction to the changes induced by the economic crisis in the labour and goods market as well as in the position of the cottage textile producer. The intention of the founders was clear: to produce quality goods rationally, effectively and in compliance with the period taste and demand. What all schools had in common was the German language of teaching and the non-state initiative accompanying their birth. Those who played the key role here were those who were engaged in textile production directly: the weaving masters and their organisations.

A specific case is a school opened in today's Jeseník (author's note: previously Frývaldov). It was an educational institution established by the local company Regenhart & Raymann, which focused on the production of smooth fabric, handkerchiefs and table linen. In this way the enterprise, which combined factory production with the cottage weaving industry on hand-looms, reacted to the dissatisfaction with the professional training of apprentices in weaving flax. The local school, which had more of a character of apprentice workshops, was attended by boys over the age of 14, who had completed the compulsory school attendance. Studying at this school was free of charge, just like the lodgings, meals and clothing. After one year of studies the apprentices were even paid a wage. Investment in education was strategic and advantageous for the enterprise in the long run. There was no need to train or retrain new workers, or to eliminate some unsuitable work habits the workers had adopted earlier. All this gives indirect evidence of the fact that the distribution of adequate professional training in the late 1870s was insufficient in the region, as well as the focus and quality of extracurricular educational activities. By introducing their own education the enterprise formed a workforce to its liking, of the appropriate quality and specialisation. This is also documented by the fact that approximately over 60% of this small school's graduates (in 1879–1890 the school accepted 169 apprentices) finally found employment in the company itself [47].

We have provided information about the purpose of the school in Jeseník above. What was generally emphasised in the other schools was systematic and basic theoretical and practical weaving education. At first the schools in Bielsko a Krnov focused on weaving woollen goods, which corresponded with the needs of production in the related locations and neighbouring regions. In contrast, the schools in Bruntál and Horní Benešov predominantly taught how to weave flax and cotton fabric (artistic weaving), though the lessons also partly focused on weaving silk and sheep's wool [48]. However, as we will see below, weaving schools – including the affiliated courses – were not restricted only to teaching weaving. The extent of the presented knowledge and skills was considerably wider and included e.g. drawing patterns or subjects usable in business activities (accounting, trade-focused arithmetic). The purpose of the schools was therefore not only education aimed at running one's independent weaving trade or updating the students' knowledge in this field, but also the education of various kinds of employees in textile enterprises (from common workmen, pattern drafters, handlers, clerks and foremen to masters) [49, 50].

The development of the individual weaving schools in Silesia, despite its specific forms, copied certain general trends of the development of weaving education in other lands. Besides the changes in the content of the lessons and the composition of the students, which we will discuss below, we have in mind mainly organisational transformations, changes in the relationship between the state authorities and these schools and the question of financing. For instance, for many years the schools in Krnov and Horní Benešov had functioned as private schools, financed by their founders. Those who helped to fill the income aspect of their budget were other authorities: municipalities, Opava's Chamber of Trade and Commerce, the land or the state. They became state schools only in 1884 and 1893 respectively. A separate chapter is the institute in Bielsko. The local weaving school was originally of a private character and those that contributed to it at the beginning, besides the Ministry of Trade, were the Silesian Land Diet, the municipalities of Bielsko and Biała, drapers' associations in both municipalities and the local *Gewerbeverein*, and from 1880 even Opava's Chamber of Commerce and Trade. In the school year 1882/1883 it merged with the local reorganised technical school, though under special conditions – at first the state provided it only with subsidies, without taking over all obligations. This model lasted until the end of the monitored period. In contrast, the school in Bruntál was established by the Ministry of Trade, while the corporate school in Jeseník was left entirely to its own devices. While Opava's Chamber of Commerce and Trade was not, with the exception of the school in Krnov, an active supporter of weaving education in Silesia until the very end of the 1870s, from the early 1880s it contributed to all institutions with the exception of Jeseník. From as early as the 1870s the support of Silesian weaving education was therefore of a broad-spectrum and long-term character, which underlines the importance of this economic sector for the local population and its elites. It should be added that not even after being transferred under state management did the existence of weaving schools get by without the support of the land, municipalities, Opava's Chamber of Commerce and Trade, or other donors [51].

As the years went by weaving schools were undergoing organisational changes, which met both the current needs of textile production in the respective locations and regions and the conceptions of the state, which was becoming ever more influential in this educational segment. What can be referred to as the unifying elements of changes was the specialisation of the schools, the expansion of the study options with various courses, and gradually also the state controlled unification of the curriculum. All this depended, to a certain extent, not only on sufficient demand, but also on the spatial and financial possibilities of the schools, and the number and composition of their teaching staff. As an example we can name the school in Bruntál, which at first functioned as a one-year school with day-to-day tuition of weaving, to which a two-year evening course was connected. In the 1890s the school already offered a two-year day school, further divided into departments for drawing patterns and weaving. In addition, like at other Silesian schools, there existed a two-week preparatory course as a part of this school, intended, before the beginning of the school year, for those lacking previous professional experience in the field. Besides this the school offered a one-year evening and Sunday course, which was compulsory for the weaving apprentices from Bruntál. The school maintained the outlined organisation even in the early 20th century with the difference that it had expanded its offer of evening and Sunday courses. Besides the so-called advanced educational course (*Fortbildungskurs*) for weaving, three other special educational courses were held as part of the school: 1) the study of bindings and decomposition for weavers, 2) mechanical weaving, 3) trade subjects. To this we also have to add a hall with lessons of drawing that was open to the public outside the standard lesson times [52].

At weaving schools theory and practice were to be interwoven in a suitable way. A glance into the curriculum of these schools gives evidence of the fact that this was indeed happening. We have stated that at first the education at weaving schools was not unified, i.e. there were no differences in the extent or content of the lessons at the individual schools. We can illustrate the organisation of the education in the early 1880s on the example of the school in Krnov. At this time the school was divided into three main parts:

1) a two-year day school for future independent producers, company managers and masters;
2) a two-year evening and Sunday course for foremen, artisans and workmen;
3) a preparatory course for apprentices.

Education in a day school included a total of 35 lessons per week, 21 of which were devoted to practical weaving in each year. The remaining part was formed by theoretical presentations about decomposition (4 lessons), composition (2 lessons), technical drawing (*Manufakturzeichnen*) (4 lessons), the study of fabrication and calculation (2 lessons) and the study of tools and calculation (2 lessons). Education in the evening course consisted of two subjects with a total of four lessons per week (decomposition with calculation, composition with the study of tools). Lastly, in the preparatory course, whose attendance was compulsory for the local draper apprentices, three subjects were taught: practical weaving (2 lessons per week), simple mathematics (1 lesson) and the study of tools (1 lesson). Let us add that besides the aforementioned subjects the so-called mercantile subjects (accounting, trade-focused arithmetic) were already taught at the school at that time. They were given a time space of two lessons per week and were attended by students of the second year of the day-to-day and evening courses. Besides them these subjects were also open to anyone who was interested outside of school (naturally for a fee) [53].

The importance of professional experience at weaving schools was a general phenomenon. Even the data for the school in Bielsko from the early 1890s confirm that. This educational institution, with respect to the connection with a prestigious state industrial school, was the best evaluated of all weaving schools as the most favourable place to study when taking into account its facilities and the composition or, alternatively, qualification of the local teaching staff. What was typical of this school from the very beginning was the high number of lessons per week and the specific composition of subjects. Chemistry, physics, machine and pattern drawing, geography, German or accounting were all a part of the school's curriculum. The result was a high number of lessons per week which, for both years of the day school, included 45 lessons. Special emphasis was placed on teaching drawing (free-hand, geometric, designing, technical), which was taught, in the individual semesters, from 10 to 18 lessons per week. The progressively decreasing number of drawing lessons was replaced with a growing number of lessons of practical weaving, which increased from 3 lessons in the first semester up to 16 lessons in the final semester [54].

An example of a school in Silesia where only hand weaving was taught was, in the early 20th century, the one-year institution in Horní Benešov. The teaching here was based on the so-called normal school curriculum from 1901, although the number of lessons rather differed from this regulation. What followed from this was that the above-mentioned regulation was designed for two-year schools. Thus, for one-year educational institutions certain corrections were necessary to achieve the adequate qualification profile of their graduates. For instance, in the school year 1907/1908 a total of 42 lessons per week were taught here, which were distributed among these eleven subjects: the technology of spinning (the study of the material), the technology of hand weaving, the study of the binding of fabric, the analysis and calculation of fabric, free-hand drawing and pattern drawing, drafting and projections, technical drawing, practical hand weaving (using the Jacquard loom and dobby), trade-focused arithmetic, trade documents, and the study of promissory notes (taught together with accounting) [55].

In conclusion of the brief introduction of the curricula of Silesian weaving schools, let us mention in short what the impact of the weaving education reform from 1910 on the organisation of education was. Let us document the above-mentioned on the school in Krnov in the school year 1910/1911 [56]. In compliance with the reform the local school was divided into two main parts: 1) general vocational weaving schools (one year long), 2) special vocational schools (further divided into the technological /one year long/ and trade department /one semester/). All departments were connected by the same number of lessons per week, which were 42 lessons. The purpose of the general school, where the entrance was conditioned by a certificate documenting the completion of compulsory school attendance and by the minimum age of 14 (at the same time with the preference of those with professional experience in the textile field), was to provide general practical and theoretical weaving-technical education usable in the local textile production. Professional experience both in hand and mechanical weaving also played a crucial role here. It took up exactly 1/3 of the weekly lessons. Taking into account both hand and mechanical weaving also manifested itself in theoretical subjects. Students spent more than 1/4 of the lessons in a total of four subjects devoted to various types of drawing, which were traditionally highly emphasised at industrial and especially at weaving schools. In the curriculum of general schools, these subjects were complemented by the study of materials, binding, decomposition and the technology of the final treatment. The entrance into a special school, whose purpose was to provide special vocational education of a technological and business orientation in the textile field, was conditioned by the graduation from a general vocational school. In the technological department of the special school almost the same space remained for the practice of both hand and mechanical weaving; however, a certain reduction affected the other subjects, especially drawing. The created space was used for teaching the study of machines, technology of spinning, civics, trade and craftsmanship, and the strengthening of technical drawing. In the half-year trade department the major part of teaching was formed by subjects usable in practical business practice. Exceptional space was given to accounting (10 lessons per week), trade- and craft-focused arithmetic (6 lessons) and to trade documents taught alongside business geography (5 lessons). From other subjects which formed the spectrum of competencies usable in business let us mention the study of business and promissory notes, stenography and calligraphy. Several lessons per week (9 lessons in total) were devoted to subjects of a technological orientation: the technology of spinning, decomposition, the study of binding and the technology of the final treatment.

What played an important role at weaving schools were field trips, i.e. illustrative demonstrations of the practical use of materials and machines during regular enterprise operation. As an example we can mention the field trips carried out at the school in Horní Benešov. For instance, at the turn of the 20th century its students visited, under the supervision of the teachers, the Moritz Hansel & Söhne company, Julius Ricker's mechanical cotton and flax weaving mill, Göbel & Komp's match factory in Moravský Beroun, Josef Kohlmeyer's flax weaving mill, Josef Glammer's bleaching plant in Horní Benešov, J. Grohmann's spinning mill of linen thread, Adolf Richter's glassworks and R. Rudolf's lace factory in Leskovec nad Moravicí [57, 58].

The weaving schools (sections with day-to-day courses) in Silesia were attended exclusively by boys. The overall data for the turn of the 20th century, presented in W. Hamann's work, show us that the characteristics of the occupants of Silesian institutions were rather different from the average of all of Cisleithania, where significant differences existed even among the individual Silesian schools. While the schools in Horní Benešov and Bruntál were usually attended by the graduates of *allgemeine Volksschulen* (77 and 68% respectively), in Bielsko these graduates formed only 11% and in Krnov 38% of newcomers. On the other hand, the graduates of *Bürgerschulen*, who prevailed across all of Cisleithania, participated in the composition of the Silesian schools in the range of only 10% (Krnov) to 32% (Bielsko). The school in Bielsko was atypical by its high attendance of former *Gymnasien* students (14%) and the graduates of lower *Realschulen* (37%) which exceeded the Cisleithanian average many times. The above-mentioned reflected not only the higher prestige of the school but also, in comparison with other Silesian institutes, its somewhat different purpose. The majority of students entering the day-to-day form of weaving school studies lacked previous professional experience, which corresponded with the situation in other lands. This was the most evident in the case of Horní Benešov (91%) and the least evident in Bruntál (60%). If the students from Bielsko had one-year professional experience at the most (28%), then approximately 1/5 of their Bruntál counterparts had already been professionally active for three or more years before entering the school, which significantly exceeded the average rate in Cisleithania (4%). Thus, at the turn of the 20th century, the day-to-day weaving schools served primarily to educate a new qualified workforce, not to increase the qualification of those who were already professionally active. That was, after all, the purpose of various evening and Sunday courses [59].

The number of students in the Silesian weaving schools did not usually exceed several tens in the individual years. The only exception was the institution in Krnov, whose number of students often exceeded one hundred and sometimes even oscillated around 150. In general it applied that the majority of the occupants of weaving schools was formed by the students of evening and Sunday courses, i.e. professionally active individuals, who wanted to use the school to increase their qualification. The composition of their students was mainly based on the composition of the population of the respective locations and regions. The school in Horní Benešov, 95% of whose students were individuals born in this town, corresponded with the character of a regional vocational school the most. In contrast, the school in Krnov, where the locals together with the inhabitants of other municipalities of the Krnov political district represented, in the same time segment, approximately 57% of the students, was of supraregional significance. With a few exceptions, the attendants of weaving schools were individuals from a German-speaking Catholic milieu, joined at some of schools (Bielsko, Krnov) mainly by Protestants. It seems that the profession of the father played a crucial role in the choice of school, as roughly half of the students of weaving continued the family tradition, while another 1/4 of the students came from the families of sole traders specialising in different trades and crafts [60, 61].

With the graduates of the Silesian weaving schools it applied that most of them found professional engagement in the land where they had graduated. These schools were therefore beneficial for Silesia, as, after all, between 73% (Bielsko) and 91% (Horní Benešov) of these schools' graduates found employment here. With the exception of the school in Krnov, usually approximately ¾ of those who successfully passed through the Silesian weaving institutions remained active in the textile field. A larger part of them (approximately 60%) filled various positions in textile companies, which corresponded with the Cisleithanian average. Less frequently the graduates managed to assert themselves as independent producers. It happened the most often in the case of the former students of the school in Bielsko (26%) and the least in the case of their counterparts from Krnov (13%). Another more significant place of employment was administrative practice in textile business (book accounting), which, for the most part, concerned the graduates from Bruntál (20%), while the graduates from Bielsko used this opportunity the least (6%). From other professions let us mention teaching, which, however, was only pursued by individuals [62].

5 CONCLUSIONS

There is no doubt that, during the industrialisation process, vocational education for textile production was an important part of the professionally-educational system. What is also undeniable is the significance of textile professional training in connection with the changes brought about by industrialisation, despite the fact that the role of textile education was demonstrably ambivalent. On the one hand, the specialised schools and courses supported the transfer to mechanisation and centralised factory mass production, but on the other they helped those whose existence was dependent on traditional cottage industry with the use of simple tools and handicraft to adapt to the changed conditions in the labour and goods market.

With respect to the advancement of industrialisation, the transformation of weaving education played a crucial role. The attention of all interested parties was focused precisely on establishing vocational schools and courses specialised in this way. In this case the state started to be engaged relatively late. It took its first steps towards the conceptual grasp of the support and organisation of weaving schools only under the economic, social and political pressure of the 1870s. We can say that by the outbreak of the First World War the state took control of this educational segment, which allowed it to realise its unification and, above all, to form it to its liking. Practically this manifested itself mainly by the transfer of schools into the state's management and by the issuing of generally effective curriculums. A sign of the fact that even on the eve of the First World War there was dissatisfaction with the state of weaving schools and the employment possibilities of their graduates was the striving for reform, which was put into effect at schools in 1910. Generally it can be said that in the late 19th and early 20th century the significance of classical day schools increased at the expense of evening/Sunday courses, despite the fact that these courses were still well attended and played a significant role in the further education of those who were already professionally active.

In many aspects the Silesian example confirmed the general Cisleithanian trends (e.g. the importance of non-state authorities in the process of the establishment and development of schools), but in some cases the local specifics (the composition of students, the employment of graduates, etc.) were manifested. Also in Silesia the question of the crisis of the cottage industry became a hot topic, within which the local political elites also discussed the support of weaving schools. It should be added that in this case certain limits, brought by contemporary nationalism, were reached. As an example we can mention the obstacles which were laid at the Silesian Land Diet during the approval of scholarships for studies at the weaving school with the Czech language of teaching in Frenštát pod Radhoštěm, which was well attended even by Czech and Polish students from the Cieszyn region [63].

Acknowledgement: *The study was created as part of solving the grant GAČR, registration no. 18-04624S Education, Economy and Society in 1848–1914: The Socioeconomic Context of the Development of the Professionally-Educational Infrastructure in Austrian Silesia.*

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DISTRIBUTION OF THE SIZES OF MICROCAPSULES IN TWO-PHASE EMULSIONS FOR TREATMENT OF TEXTILE MATERIALS

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Abstract: *The article is devoted to the study of two-component emulsions intended for processing textile materials, taking into account the distribution of microcapsules in the nano-range of sizes. It is noted that the effect of reducing emulsion droplets can be achieved with the use of modified magnetite nanoparticles. The developed methods for determining the main characteristics of two-phase emulsions allow to determine in the express mode their main characteristics. An asymmetric representation of the particle size distribution function has been proven, 70% of which remain invisible in the optical spectrum. The specific results of the distribution of particles in an emulsion with nanoparticles of unmodified magnetite are given.*

Keywords: *Textile materials, nanotechnology, magnetite, two-component emulsion, microcapsules.*

1 INTRODUCTION

Nanotechnologies are confidently entering to the textile processing industry. The textile industry is a promising direction for the development of nanotechnology using composites, fibers, capsules, emulsions as nanoparticles [1].

Nanotechnologies can change the characteristics of textile materials [2], improve their technological and environmental quality.

Article [3] describes a new sector of cosmetic textiles. The creation of cosmetic textiles is associated with the technology of emulsion microencapsulation. This study discusses the development of cosmetic textiles and microencapsulation technologies, taking into account its historical past, significant advantages, microencapsulation techniques and recent applications in the textile industry.

In a number of papers [4], the importance of microencapsulation of emulsions for processing fabrics with the aim of increasing strength, stability after washing and resistance to abrasion is substantiated.

The work [5] describes the process of formation of microcapsules in an emulsion with dual functionality, which may have prospects for use in creating intelligent textiles or fabrics.

The study [6] is devoted to the development of methods for producing microemulsions, providing microcapsules in the nanometer range. Such emulsions allow the creation of textile materials for the manufacture of special protective clothing.

The process of creating microencapsulated emulsions is recognized as relevant for the creation of textiles with the possibility of thermal control [7].

The results of direct observation of nanoparticles in a liquid medium using a transmission electron microscope are proposed in [8].

In [9], an attempt was made to use an optical microscope equipped with a digital camera and a narrow-band filter to obtain images of emulsion droplets at the oil-water interfaces under the assumption of the presence of nanoscale particles.

The study [10] describes the formation of microbubbles encapsulated in water using microfluidic approaches. By adjusting the ratio of water consumption and oil, you can control the number of encapsulated microbubbles in water droplets of micrometric size.

Emulsions are widely used in various fields, including medicine, cosmetology and textile industry. The most common method of stabilizing emulsions is the use of surface-active emulsifiers. But recently more and more attention of researchers has been attracted to the pickling of emulsions stabilized by solid nanoparticles.

One of these stabilizers are additives, which are based on magnetite nanopowder (MNP).

The factor that determines the stabilizing properties of solid powders is the wetting of their surface with components of an emulsion, which can be regulated by treating their surface with hydrophilic or hydrophobic modifiers.

Previous studies have shown that the introduction of unmodified magnetite nanoparticles into various products leads to the appearance of the last water-holding and fat-retaining properties [11]. Studies have shown that magnetite nanoparticles (like molecules of surface-active substances) have diphilic properties, showing affinity for both polar media and non-polar media.

The nature of the interaction of liquids with the surface of solid materials is manifested in the wetting or non-wetting of the corresponding solid surfaces with corresponding liquids. The quantitative characteristic of the wetting process is the wetting angle Θ.

2 EXPERIMENTAL PART

Determination of the wetting angle was carried out by the sessile drop method - an instantaneous photograph of a drop applied to the surface of compressed magnetite powder [12].

The structure and size of the emulsion droplets were studied using an optical microphotographic apparatus.

The type of emulsion was determined by adding the oil-soluble dye Sudan III.

The basis of the material - nanopowder Fe_3O_4 (MNP) and its forms, modified with calcium oleate (MNP-M-1) and sodium oleate (MNP-M-2) were synthesized using the same methods [13].

Emulsions were prepared by intensive mechanical mixing using a rotating propeller agitator.

In order to test the hypothesis of the presence of diphilic properties in magnetite, the wetting angles of water droplets (Figure 1a) and the dye (Figure 1b) deposited on the surface of compressed magnetite were determined. The obtained values: Θ_{water} = 45° and Θ_{dye} = 60° confirm the presence of affinity in magnetite for both water and dye. In this case, the affinity for water is manifested to a somewhat greater extent.

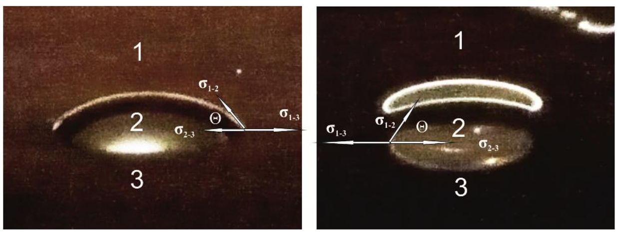

Figure1 Determination of wetting angle: a drop of water (a) and dye (b) on the surface of compressed MNP

The stabilizing effect of magnetite nanopowder treated with hydrophobic and hydrophilic modifiers on the emulsion of an oil dye with water was studied.

Primary information about the type of emulsion can be obtained by the nature of the behavior of the emulsion droplets in different environments. Figure 2 shows images of emulsion droplets stabilized by MNP-M-1 (a) and MNP-M-2 (b) on the surface of an oil dye. In the first case, a drop of the emulsion wets the surface of the oil and spreads over it, which indicates the formation of a w/o emulsion. In the second example drop of the emulsion does not wet the surface of the oil, trying to get a shape close to spherical, which indicates the formation of an o/w emulsion.

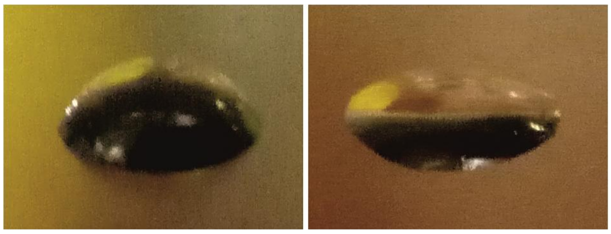

Figure 2 A drop of emulsion (a) and oil dye (b) on the surface of compressed MNP

A comparison of photomicrographs of emulsions stabilized by a conventional hydrophobic stabilizer (calcium oleate) and MNP-M-1, the surface of which was pre-modified with the same stabilizer, shows that in both cases w/o emulsions are formed, the introduction of magnetite contributes to a much thinner emulsions (Figure 3). A similar picture is observed in the case of emulsions of sodium stabilized by oleate and MNP-M-2 modified by the same stabilizer with the only difference that the resulting emulsions are of type o/w (Figure 4).

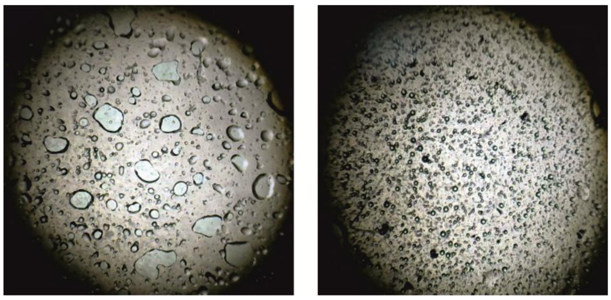

Figure 3 A drop of emulsion (a) and oil dye (b) on the surface of compressed MNP

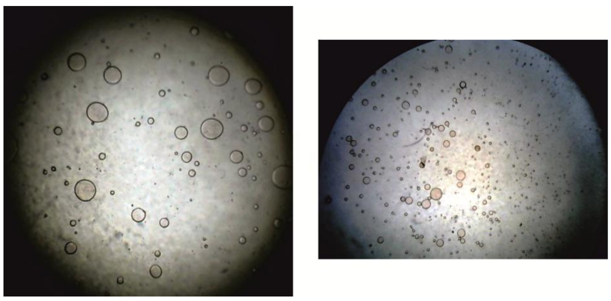

Figure 4 Micrographs of the emulsion stabilized with sodium oleate (a) and MNP-M-2 (b), magnification 40x

It should also be noted that o/w emulsion droplets have a much more regular spherical shape.

The photomicrographs made it possible to estimate the size of the emulsion droplets of Tables 1 and 2.

Table 1 The size of the emulsion droplets w/o

Stabilizer	Calcium Oleate	MNP-M-1
Particle size [μm]	60-15	9-3

Table 2 The size of the emulsion droplets o/w

Stabilizer	Sodium Oleate	MNP-M-2
Particle size [μm]	55-25	20-10

Longer mechanical treatment of the emulsion leads to the formation of complex emulsions (Figure 5). Their droplets of much smaller sizes can only be studied at high magnification.

Figure 5 Micrograph of a complex emulsion w/o/w stabilized by MNP-M-2, magnification 1000x

Table 3 The size of droplets of a complex emulsion w/o/w

Type of drops	Primary emulsion	Secondary emulsion
Particle size [μm]	4-2	0.25-0.15

The obtained results do not allow to determine directly such characteristics of a two-phase emulsion as the average particle size, the number of particles, the density of their location in the drop. Optical microscopes used for express methods cannot fix particles with sizes smaller than 250-300 nm, while at the same time real microscopic studies require a lot of processing time.

3 JUSTIFICATION OF THE BASIC LAWS OF THE DISTRIBUTION OF NANOPARTICLES

At our disposal there are photos of emulsion with particles of different sizes. The optical microscope allows to control the objects provided by the length of the light wave, that is, more than 200 nm. In our images (Figure 5), the smallest objects have a size of about 200 nm, smaller objects spill over and become invisible. The analysis of the size distribution of objects shows that the number of particles with a smaller size is larger than with big one. It is logical to assume that the visible number of particles reveals a part of the ascending branch of the total particle size distribution.

The purpose of our study is to justify the law of particle size distribution based on the data captured by an optical microscope, to determine the most probable particle size, the minimum size, and the density of their propagation.

For convenience, the size of the particles will be determined in hundreds of nanometers, that is visible particles are recorded in the range >2.

An attempt to use the normal distribution of Gauss unfortunately leads to a contradiction (Figure 6).

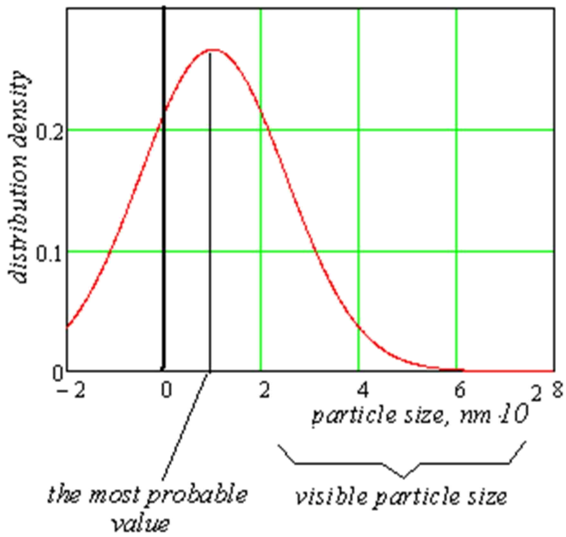

Figure 6 Normal distribution of particle size

Distribution of this type (symmetric) requires the presence of particles with negative dimensions, which is impossible. Given that the desired distribution should be asymmetrical, we will try to use the distribution of Weibull, which can be represented by an expression:

$$p(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}} \tag{1}$$

Unknown parameters of β, α are still unknown.

Possible type of distribution is presented in Figure 7.

We will choose three intervals of size within the limits that we observe in the photograph: 200-350 nm, 350-500 nm, 500-650 nm (in our definitions 2-3.5, 3.5-5, 5-6.5)

The middle of each interval is denoted by the letters $x_3<x_2<x_1$. The number of particles included in each interval is counted separately and is denoted $n_3<n_2<n_1$.

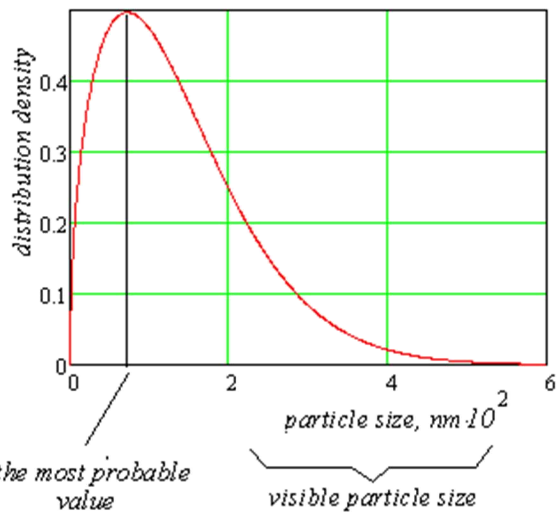

Figure 7 Weibull distribution for particle size

The total number of particles in the drop is N, the size of the interval of dimensions - Δ.

Then the probability density for a single interval can be defined as:

$$p_i = \frac{n_i}{N\Delta} \tag{2}$$

Then we can write a system of equations:

$$\begin{cases} \dfrac{n_1}{N\Delta} = \dfrac{\alpha}{\beta}\left(\dfrac{x_1}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x_1}{\beta}\right)^{\alpha}} \\ \dfrac{n_2}{N\Delta} = \dfrac{\alpha}{\beta}\left(\dfrac{x_2}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x_2}{\beta}\right)^{\alpha}} \\ \dfrac{n_3}{N\Delta} = \dfrac{\alpha}{\beta}\left(\dfrac{x_3}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x_3}{\beta}\right)^{\alpha}} \end{cases} \tag{3}$$

Thus, we obtain three equations with three unknowns N, β, α.

One unknown can be eliminated by dividing the third and second equations on the first:

$$\begin{cases} \dfrac{n_2}{n1} = \left(\dfrac{x_2}{x_1}\right)^{\alpha-1} e^{\frac{x_1^\alpha - x_2^\alpha}{\beta^\alpha}} \\ \dfrac{n_3}{n1} = \left(\dfrac{x_3}{x_1}\right)^{\alpha-1} e^{\frac{x_1^\alpha - x_3^\alpha}{\beta^\alpha}} \end{cases} \tag{4}$$

To both equations we impose the action of a natural logarithm. We'll get it:

$$\begin{cases} \ln\left(\dfrac{n_2}{n_1}\right) = (\alpha-1)\ln\left(\dfrac{x_2}{x_1}\right) + \dfrac{x_1^\alpha - x_2^\alpha}{\beta^\alpha} \\ \ln\left(\dfrac{n_3}{n_1}\right) = (\alpha-1)\ln\left(\dfrac{x_3}{x_1}\right) + \dfrac{x_1^\alpha - x_3^\alpha}{\beta^\alpha} \end{cases} \tag{5}$$

We move the term with the parameter β to the left, while dividing the second equation by the first, this parameter will disappear. We get the equation:

$$\frac{x_1^\alpha - x_3^\alpha}{x_1^\alpha - x_2^\alpha} = \frac{\ln\left(\frac{n_3}{n_1}\right) - (\alpha-1)\ln\left(\frac{x_3}{x_1}\right)}{\ln\left(\frac{n_2}{n_1}\right) - (\alpha-1)\ln\left(\frac{x_2}{x_1}\right)} \tag{6}$$

In this equation, one unknown is the parameter α. It is difficult to solve this equation analytically. For a graphical solution we will construct separately graphic dependences for the right and left parts (Figure 8). The intersection point shows the solution of the equation.

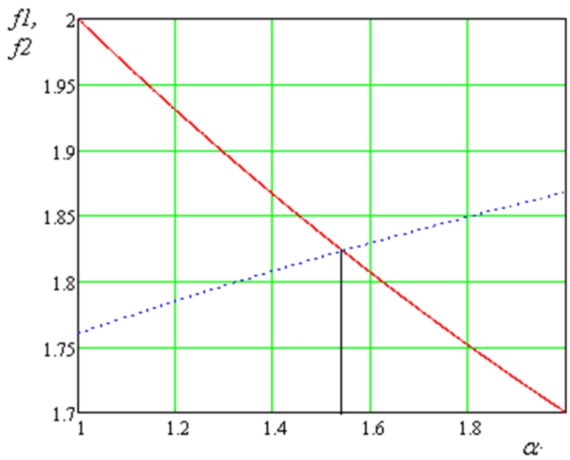

Figure 8 Definition of the parameter α

For this case $\alpha \approx 1.54$.

Then the parameter β can be found from one of the two equations of the second system:

$$\beta = \left(\frac{(\alpha-1)\ln\left(\frac{x_3}{x1}\right)\cdot\left(x_1^\alpha - x_3^\alpha\right)}{\ln\left(\frac{n_3}{n_1}\right)}\right)^{1/\alpha} \tag{7}$$

The total number of particles in a drop is determined, according to one of the equations of the first system:

$$N = n_1 \frac{\beta}{\Delta\alpha}\left(\frac{\beta}{x_1}\right)^{\alpha-1} e^{\left(\frac{x_1}{\beta}\right)^\alpha} \tag{8}$$

For the obtained values, the location of the distribution curve is clarified. As a result, the distribution curve will be described by the equation:

$$p(x) = \frac{\alpha}{\beta}\left(\frac{x-c}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x-c}{\beta}\right)^\alpha} \tag{9}$$

and have a graphic representation of Figure 9.

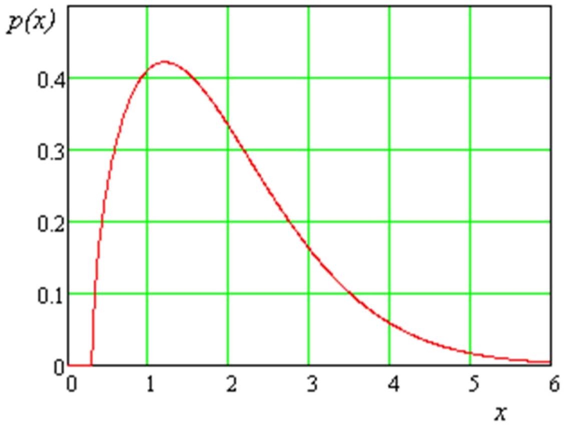

Figure 9 Real particle size distribution

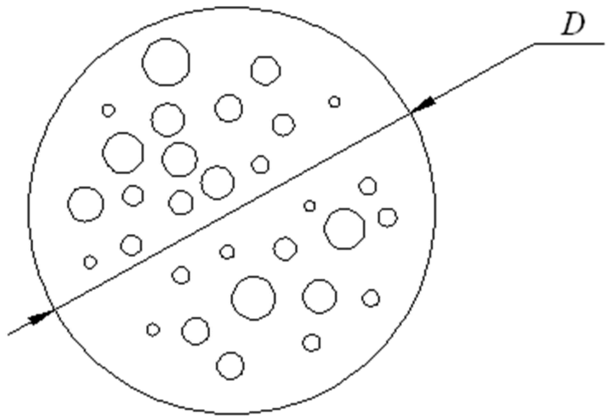

Figure 10 The location of particles in the area

For our case, the found parameters are N = 182, β = 1.78, α = 1.54, c = 0.38. Based on the found parameters you can find the most probable particle size. For this we take the derivative of the last expression:

$$\frac{dp}{dx} = \frac{\alpha}{\beta^{\alpha}}\left(\begin{array}{l}(\alpha-1)(x-c)^{\alpha-2} - \\ (x-c)^{\alpha-1}\cdot\alpha\dfrac{(x-c)^{\alpha-1}}{\beta^{\alpha}}\end{array}\right)\cdot e^{-\left(\frac{x-c}{\beta}\right)^{\alpha}} \tag{10}$$

The maximum on the curve corresponds to the zero of the derivative, from which it is possible to find the diameter that corresponds to the greatest probability:

$$x_m = \beta\left(\frac{\alpha-1}{\alpha}\right)^{1/\alpha} \tag{11}$$

For this case x_m = 120 nm. In this case, a plane image was investigated. In this image, the number of particles equalled N. The density of particles in a drop (Figure 10):

$$\gamma = \frac{4N}{\pi D^2} \tag{12}$$

The conditionally statistical diameter of the zone occupying a single particle can be defined as:

$$d = \frac{D}{\sqrt{N}} \tag{13}$$

We introduce the hypothesis that during transitioning to volume observation, the average statistical diameter of a separate particle remains the same as the diameter of a planar particle.

The conditionally statistical diameter of the zone occupying a single particle can be defined as:

$$d = \frac{D}{\sqrt{N}} \tag{14}$$

We introduce the hypothesis that during transitioning to volume observation, the average statistical diameter of a separate particle remains the same as the diameter of a planar particle (Figure 11).

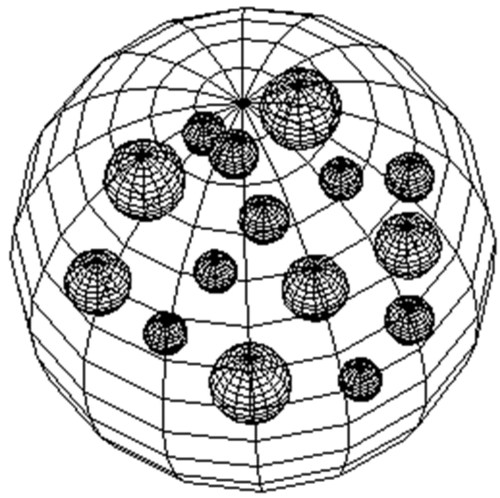

Figure 11 The location of the particles in volume

We shall consider the spatial shape of a large spherical drop with volume:

$$V = \frac{\pi D^3}{6} \tag{15}$$

Then the volume of the zone occupying a separate particle:

$$v = \frac{\pi d^3}{6} = \frac{\pi D^3}{6N^{3/2}} \tag{16}$$

The total number of particles in a spherical drop will be equal:

$$M = N^{3/2} \tag{17}$$

Then the average volume density:

$$\rho = \frac{6N^{3/2}}{\pi D^3} \tag{18}$$

The obtained methods allow us to determine the real parameters of complex emulsions based on the use of microphotographs.

4 CONCLUSION

The use of dyes in the form of emulsions increases the efficiency of applying dyeing to fibers of various nature. It has been established that for dyeing fibers of natural synthetic and artificial origin containing hydrophilic functional groups, it is advisable to use w/o emulsions containing water-soluble dyes. While for dyeing synthetic hydrophobic fibers, o/w emulsions with oil soluble dyes are more effective.

Reducing the size of the droplets of the emulsion contributes to a deeper penetration of the dye into the pores of the fiber. This effect can be achieved by using various stabilizers, in particular modified magnetite nanoparticles.

Even more effective from the point of view of the depth of penetration and the strength of fixing the dye on the fabric is the use of complex emulsions, the type and size of the droplets of which can be adjusted by using various stabilizers and production conditions.

The developed methods for two-phase emulsions allow the express mode to determine their main characteristics. An asymmetric representation of the particle size distribution function is proved, 70% of which remain invisible in the optical spectrum. Simulation by an asymmetric distribution method allows determining the minimum particle size, the most probable size, the average number of particles and the volume density of particles in a drop.

Specific results of particle distribution in an emulsion with nanoparticles of unmodified magnetite:

The minimum particle size is 38 nm, the most probable particle size is 120 nm, the average number of particles in a drop is 180, the density of particles in a drop is 15 particles/μm^2 and the volumetric density of particles in a spherical drop is 73 particles/μm^3.

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STUDY OF THE INFLUENCE OF PREPARATION OF KNITTED FABRIC ON THE SURFACE AND SUPRAMOLECULAR STRUCTURE OF COTTON FIBER

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Abstract: *The main goal of this research is to study the effect of preparation methods (alkaline boiling, basic combined boiling and bleaching technology, developed preparation technology) on the surface structure of cotton fibers and changes in the supramolecular structure of cellulose. The surface of the cotton fibers was examined using a scanning electron microscope and the supramolecular changes were studied by radiography. The results of the study of surface and supramolecular structure of cotton fibers explain the increase in the sorption ability of the knitted fabric, which was prepared according to the developed technology.*

Keywords: *preparation, cotton knitted fabric, fiber surface, supramolecular structure.*

1 INTRODUCTION

Preparation is an important technological stage of cotton knitted fabric finishing. It is at this stage that the basic properties of the textile material are formed, which provide not only the quality of the subsequent dyeing and final treatment, but also the hygienic properties of the finished products. These are primarily sorption properties that cotton knitwear gets after the removal of natural and technological impurities in the conditions of the preparation process. Sustained whiteness is another of the basic properties that a knitted fabric gets after preparation and is an important quality indicator of this range of textile materials.

The classic preparation technology of the cotton knitted fabrics includes boiling and bleaching, which are carried out sequentially. The boiling is carried out in an alkaline or neutral medium in the presence of surfactants. Alkaline solutions of hydrogen peroxide are most often used for bleaching [1, 2].

Currently, technology of the cotton knitwear preparation aimed at reducing time, temperature and water consumption. For this purpose, intensification of the preparation processes using physical, biological and chemical methods is carried out.

Physical methods include the use of gamma radiation [3], supercritical carbon dioxide [4], ozone [5] and atmospheric pressure plasma treatment [6]. The use of physical methods of exposure provide an opportunity to carry out the process with a reduction in water consumption or even in an anhydrous environment with a reduced temperature and a reduction in the duration of the process. It should be noted that the limited use of these intensification methods is due to the need for additional high-tech equipment.

Biological intensification methods suggest the use of enzymes that have an eco-friendly character in cotton knitwear preparation technology [7-9]. Their application is complicated by the need for strict control of the preparation process conditions.

The simplest and most effective way to intensify the technology of boiling and bleaching of cotton knitwear is the use of chemicals that can speed up the process of removing associated impurities of cotton and give the cotton textile material capillarity and whiteness at low treatment temperature [10-13].

A promising direction of resource saving is combination of boiling and bleaching [14-17]. According to the results of previous studies, the combined preparation technology of cotton knitted fabric was developed [18, 19]. It has been established that the developed preparation principle for cotton knitted fabric promotes the maximum removal of wax-like and colored substances from textile material and, as a result, increases capillarity and whiteness. The strength of knitwear decreases slightly. This became possible due to the application of the previously developed highly effective surfactants composition, which allows to combine the operations of boiling and bleaching and to carry out the preparation process at a reduced temperature of 80°C.

As a result of the research [20], it was established that the developed preparation technology affects the sorption kinetics and the fixation degree of the reactive dyes by cotton knitted fabric. The developed preparation method has advantages in comparison with the base one, which consist in the combination of boiling and bleaching. The reduction of the processing temperature from 100°C to 80°C ensures efficiency of the developed technology. One of the reasons for the increase in dyes sorption by cotton fiber can be its damage due to excessive oxidation of cellulose of textile material with hydrogen peroxide during bleaching or during undesired oxidative destruction of the substrate by oxygen of the air during boiling [21]. As a result, the polymer chains of cellulose are broken and the degree of polymerization reduces. At the supramolecular level, the degree of crystallinity decreases and the volume of amorphous regions increases. This in turn causes an increase in the sorption capacity of the fiber, including in relation to dyes. It should be noted that the obtained colors on a cotton substrate that was damaged during the preparation process are characterized by reduced resistance to physical and chemical influences, despite the intense sorption of the dye. In addition, the textile material loses strength, which is exacerbated during the operation of finished products.

2 THE GOAL OF THE STUDY

The goal of the work is to study the changes in the surface and supramolecular structure of cotton fiber cellulose under the influence of the developed preparation technology of knitted fabric.

3 MATERIALS AND METHODS

Study was carried out on grey cotton rib knitted fabric 1×1 with surface weight 150 g/sm^2. Preparation of knitted fabric was carried out under the conditions given in Table 1.

The textile auxiliaries used are Ultravalon TC, Albafluid CD, Albaflow FFC-01, Clarite by Huntsman NMG and Oxipav A1214C.50 by LLC Research and Production Association NII PAV. The surfactant composition contains in a certain ratio Ultravon TC as a wetting agent, Albafluid CD as an anticrease agent, Albaflow FFC-01 as a defoamer and Oxipav A1214.50 as a detergent.

Micrographs of the cotton fibers surface were obtained using a JSM 6060 LA (Jeol, Japan) scanning electron microscope after preliminary deposition of a thin layer of gold by the cathode method using a JFC-1600 instrument.

The amorphous-crystalline structure of cotton knitted fabric samples was investigated by wide-angle X-ray diffraction using a DRON-4-07 diffractometer. The X-ray optical scheme of the specified diffractometer was made to pass the primary X-ray beam through the thickness of the sample under study according to the Debye-Scherrer method. The studies were carried out in monochromatic CuK_{α}-X-rays (wavelength λ=0.154 nm) using a Ni-filter.

The size of the crystallites was estimated using the Scherrer method [22, 23] by determining the value of L in the direction of the angular position of the singlet maxima and then obtaining the average value of $\langle L \rangle$. First, the angular half-width (1/2β)×2 of the left and right parts of the diffraction maxima was determined at $2\theta_m$=14.8° and $2\theta_m$=22.6° respectively with the subsequent calculation of the average value.

$$L=K\cdot\lambda\cdot(\beta\cdot cos\theta_m)^{-1} \quad (1)$$

where K is a constant that is associated with the form of crystallites (with an unknown form of crystallites K=0.89) and β is the angular half-width (width at half height) of the clearest singlet diffraction maxima.

Table 1 Cotton knitted fabric preparation conditions

Preparation method	Preparation conditions
Base technology	*Boiling:* TF-129B (washing agent) – 2 g/l; Albafluid CD (anticrease agent) – 0.8 g/l; Soda ash – 1.5 g/l. Treatment at 80°C for 20 min. Hot washing. *Bleaching:* Ultravalon TC (wetting agent) – 1.1 g/l; Albafluid CD (anticrease agent) – 0.8 g/l; Albaflow FFC-01 (defoamer) – 0.5 g/l; Clarite (hydrogen peroxide stabilizer) – 0.4 g/l; Hydrogen peroxide 60% w/w – 1.5 g/l; Sodium hydroxide – 1.5 g/l. Treatment at 98°C for 20 min. Hot washing, neutralization, hot washing, drying.
Developed technology	Surfactant composition – 1.5 g/l; Hydrogen peroxide 60% w/w – 1.5 g/l; Sodium hydroxide – 1.5 g/l. Treatment at 80°C for 20 min. Hot washing, neutralization, hot washing, drying.
Alkaline boiling	Ultravalon TC (wetting agent) – 1 g/l; Sodium hydroxide – 5 g/l. Treatment at 100°C for 20 min. Hot washing, neutralization, hot washing, drying.

The estimation of the relative crystallinity level of the structure (X_{cr}) of cotton knitted fabric samples was carried out according to the method given in [24]:

$$X_{cr}=Q_{cr}\cdot(Q_{cr}+Q_{am})^{-1}\cdot 100 \quad (2)$$

where Q_{cr} is the area of diffraction maxima, which characterize the crystal structure and ($Q_{cr}+Q_{am}$) is the area of the entire X-ray diffractogram in the 2θ interval, in which the amorphous-crystalline structure of the samples is observed.

4 RESULTS AND DISCUSSION

Earlier studies [18-20] established that as a result of preparation according to the developed principle, the knitted fabric gets high sorption properties with relation to reactive dyes and the resulting colors are characterized by high resistance to light.

The reason for the increase in the sorption ability of cotton fibers in relation to dyes can be a change in the molecular and supramolecular structure. As a result of the influence on the molecular structure of cotton fiber, cellulose is damaged and degree of polymerization decreases, which affects the strength of the textile material. A change in the supramolecular structure of cotton fiber cellulose does not affect fiber strength [25]. For example, a change in the supramolecular structure of cellulose during mercerization does not reduce the degree of polymerization of cellulose, but increases its sorption ability [26, 27].

It was found that the cotton knitwear after preparation according to the developed technology does not lose strength and the sorption of reactive dyes increases at the same time.

The presented micrographs of the cotton fibers surface (Figure 1), obtained using an electron scanning microscope, confirm the preservation of the knitted fabric structure.

The results of microscopic examination of the fibers surface structure showed that the surface of cotton fibers after preparation by the studied methods (Figures 1b-1d) does not undergo changes as compared with the surface of the original grey fiber (Figure 1a).

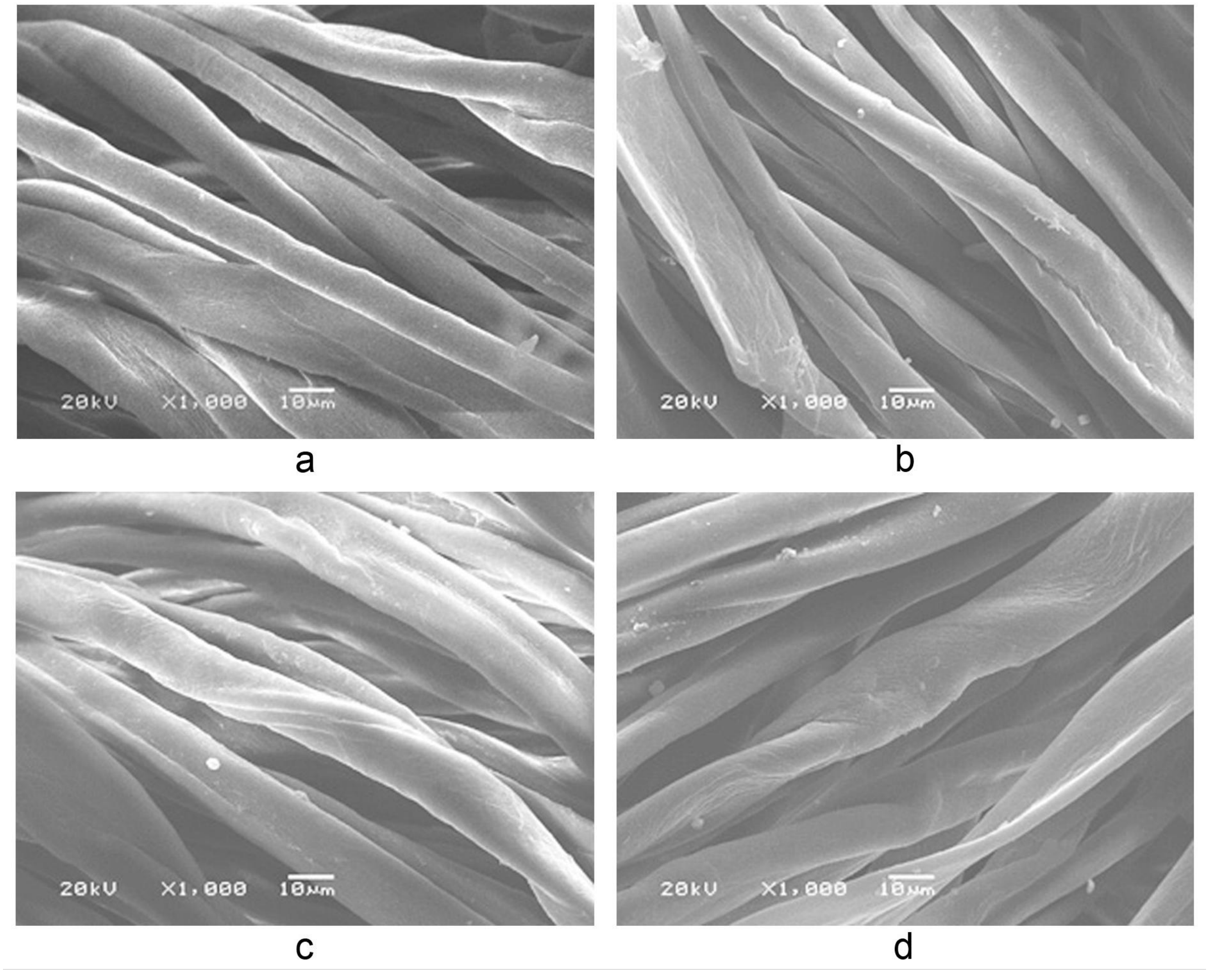

Figure 1 Micrographs of cotton fiber samples: a) gray, b) base technology, c) developed technology, d) alkaline boiling

Thus, it is necessary to investigate the supramolecular structure of cotton knitwear prepared by the developed technology. Radiographic study is one of the ways to study the supramolecular structure of textile materials [26]. The received roentgenograms of the cotton knitted fabric samples prepared in the different ways are presented in Figure 2.

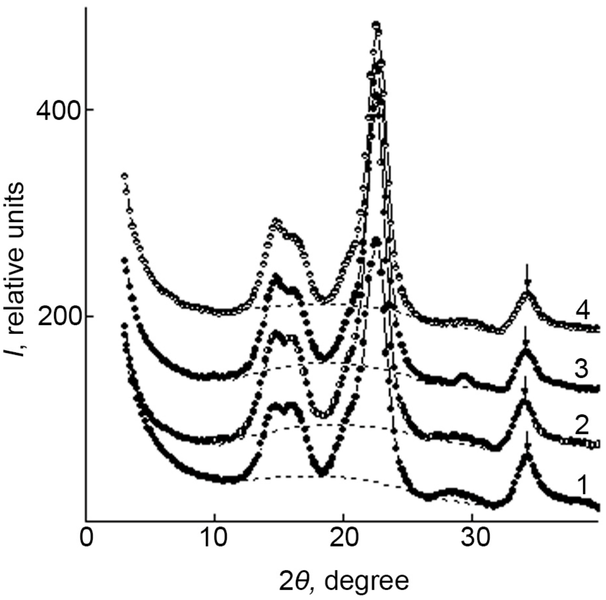

Figure 2 Wide-angle X-ray diffractograms of cotton knitted fabric samples: 1) gray, 2) base technology, 3) developed technology, 4) alkaline boiling

When analyzing X-ray diffractograms of knitted fabric (Figure 2), it was revealed that all samples have an amorphous-crystalline structure with a high level of crystallinity of more than 75%. This is evidenced by the presence of three main groups of diffraction maxima against a background of an imaginary diffraction maximum of diffuse type – amorphous halo – with the angular position of their peaks from $2\theta_m$=18.5° to $2\theta_m$=20°, which are shown by dotted lines. This is a doublet maximum with apexes at $2\theta_m$=14.8° and 16.0°, an asymmetric multiplet maximum with apex at $2\theta_m$=22.6° and a low-intensity singlet maximum, the angular position of the apex of which depends on the preparation method of sample and is in the range of angles X-ray scattering $2\theta_m$=34.2…34.4° (in Figure 2 it is indicated by an arrow).

It should be noted that a slight change in the angular position of the low-intensity singlet maximum, shown by an arrow at $2\theta_m$=34.2…34.4°, is observed regardless of the preparation method for the studied samples compared to the grey one.

The most noticeable changes on the diffractograms of cotton knitwear occur in samples prepared according to the developed technology (curve 3) and by the method of alkaline boiling (curve 4). At the same time, there is a change in the ratio of intensity of the components of doublet maximum at $2\theta_m$=14.8° and 16.0°, a change in the shape and intensity of the diffuse maximum, which is in the interval 2θ from 26.6° to 31.8° on the diffractograms. In addition, a diffraction maximum of a discrete type appears at the diffraction curve 3 of the knitted fabric sample prepared according to the developed technology at $2\theta_m$=29.4°. This leads to an increase in the area of the amorphous halo and indicates an increase in the amorphous fraction of cellulose in the specified sample. This fact explains the increase in the sorption ability of the cotton knitwear sample, which was prepared according to the developed technology.

Next, the sizes of crystallites <*L*> in the studied samples were calculated. To do this, we first determined the angular half-width $(1/2\beta)\times 2$ of the left and right sides of the diffraction maxima at $2\theta_m$=14.8° and $2\theta_m$=22.6° with the subsequent calculation of the average value. The results are presented in Table 2.

The results of determining crystallite sizes <*L*> in the volume of the cotton knitted fabric samples and the values of $L_{14.8°}$, $L_{26.6°}$ indicate that large and possibly defective crystallites have grey knitwear and knitwear prepared by the basic technology. For samples of cotton knitwear, prepared by the developed technology and by the method of alkaline boiling, the presence of smaller ordered crystallites is characteristic.

Table 2 The parameters of the amorphous-crystalline structure of knitted fabric samples depending on the preparation method

Samples	Crystallite size at $2\theta_m$=14.8°, $L_{14.8°}$ [nm]	Crystallite size at $2\theta_m$=22.6°, $L_{26.6°}$ [nm]	Average crystallite size, <*L*> [nm]
Gray knitted fabric	4.8	6.1	5.4
Base technology	4.8	5.8	5.3
Developed technology	4.6	5.7	5.1
Alkaline boiling	4.5	5.6	5.1

The results of calculating the relative crystallinity level X_{cr} of the cotton knitted fabric samples under study are presented in Figure 3.

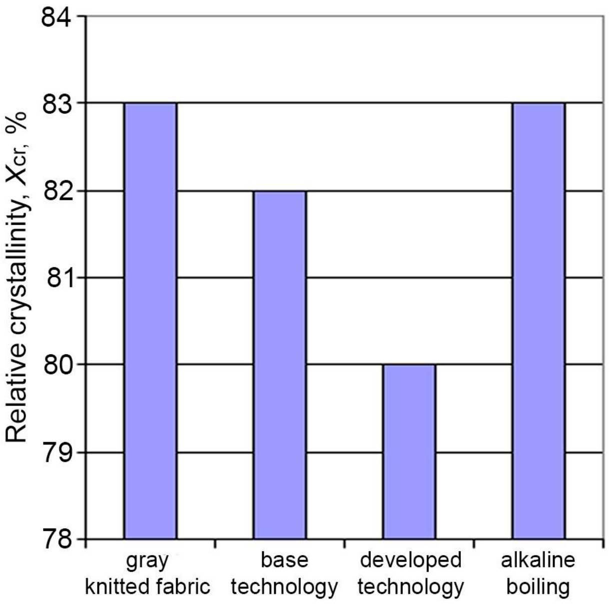

Figure 3 The relative level of crystallinity of cotton knitted fabric samples: 1) gray, 2) base technology, 3) developed technology, 4) alkaline boiling

The relative crystallinity of the structure of cotton knitted fabric samples was evaluated in the range of 2θ from 11.6° to 40.0°, in which the amorphous-crystalline structure of the samples under study are observed. It was established that the value of the relative crystallinity level X_{cr} of the studied samples is about 80% regardless of the preparation method (Table 2). The smallest crystallinity level X_{cr}=80% has a sample prepared according to the developed technology and the highest crystallinity level X_{cr}=83% has a grey knitted fabric.

Thus, X-ray studies of the amorphous-crystalline structure of cotton knitted fabric samples showed that they have a highly crystalline structure, which varies depending on the method of samples preparation.

Moreover, for curves 3 and 4 (the developed technology and alkaline boiling, respectively), the ratio of intensities of the components of doublet maximum and the angular position of low-intensity singlet maximum are observed, which is indicated by the arrow. In addition, there is a change in the shape and intensity of the diffuse maximum, which on the diffractograms is in the range of 2θ from 26.6° to 31.8° and also appears on its background a diffraction maximum of discrete type at $2\theta_m$=29.4° for sample 3, prepared by the developed technology.

5 CONCLUSIONS

With the help of SEM, it was determined that the preparation according to the methods under study does not damage the cotton fiber surface. On the diffractograms of knitted fabric samples after preparation, there is a slight increase in the intensity and integral value of scattering. The preparation of knitwear according to the developed technology causes a change in the nature of diffraction curve and an increase in the area of amorphous halo, which indicates an increase in the amorphous share of cellulose in the specified sample.

A quantitative analysis showed that the parameters of fibers diffraction of cotton knitwear that was prepared by the developed technology and by the method of alkaline boiling are characterized by the presence of smaller sized ordered crystallites. The relative level of crystallinity at the same time is the lowest among the studied preparation methods in comparison with the grey knitted fabric sample.

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EFFECT OF THE YARN STRUCTURE ON THE TENSION DEGREE WHEN INTERACTING WITH HIGH-CURVED GUIDE

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Abstract: *The research of the yarn structure effect on the tension degree when interacting with guides and operative parts of weaving looms and knitting machines, which have a high curve in the area of contact with the yarn, has established the mechanism of the yarn tension increase after it passes the guide due to a change in the guide's curve radius and friction forces in the contact area. It has been proved that the increase in tension is explained by a change in the angle between the yarn and the high-curved guide. At the same time, the actual angle for filament yarn and spun yarn will be higher than the nominal one due to yarn diameter deformation in the contact area, while the angle for monofilament yarns will be less than the nominal one due to the bending modulus. Based on the experimental research, regression relationships between the output tension and the radius of guide surface curve were obtained for polyamide filament yarns of various twists and monofilament yarns. The analysis of the research results made it possible to establish ultimate values of the guide curve radius at which tension will have minimal degree. This will enable minimization of the yarn tension during its processing on the production equipment. This leads to a decrease in yarn breakages, an increase in the production equipment performance by reducing its downtime, improving the quality of the fabric and knitted garments produced. This suggests a practical value of the proposed technology solutions. The latter, in particular, are related to determining optimal geometric dimensions of guides and operative parts of weaving looms and knitting machines, at which the output tension will have the minimal required degree. Therefore, there is a good reason to claim the possibility of guided management of the process of changing the yarn tension in weaving looms and knitting machines by choosing geometrical dimensions of high-curved guide for specific yarn types.*

Keywords: *monofilament yarns, filament yarn, yarn tension, high-curved guides, braid angle, radius of the guide curve.*

1 INTRODUCTION

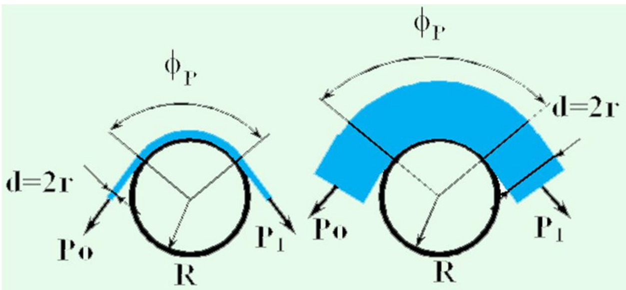
To date, the range of natural-fiber filter fabric produced by the textile industry does not always meet production requirements. In addition to filter fabrics, many industries use non-ferrous metal mesh as a filter material, which, like natural-fiber fabrics, are non-durable when used. This leads to reduction in the performance of equipment, increase in downtime associated with the replacement of used filters, and this, in turn, leads to an increase in the net cost of the products produced.

Modeling of the yarn processing process in weaving looms and knitting machines is made in order to study the process of yarn interaction with the operative part surfaces in the production equipment [1-3, 7, 10, 13, 14]. The shape of the operative part surfaces is similar to the cylindrical surface [4]. Therefore, when carrying out the experiment, cylindrical rods of different diameters were used as guide way surfaces [4, 5].

Figure 1 shows the diagrams of yarn interaction with a cylindrical guide way. In the first case (Figure 1a), the diameter of the cylindrical guide D substantially exceeds the yarn diameter d:

$$D >> d,\ D = 2R,\ d = 2r \tag{1}$$

where R is the radius of the cylindrical guide and r is the radius of the yarn cross section [2, 5].



a) b)

Figure 1 Diagrams of yarn interaction with a cylindrical guide way: a) the case when the diameter of the cylindrical guide way substantially exceeds the yarn diameter; b) the case when the diameter of the cylindrical guide way is comparable to the yarn diameter

In the second case (Figure 1b), the diameter of the cylindrical guideway is comparable to the yarn diameter [1, 4].

This type of interaction takes place when the yarn comes into contact with the heddle eye surfaces of weaving loom frames (Figure 2a), when it comes into contact with the surfaces of knitting machine needles (Figure 2b - polyamide filament yarn 29 tex; Figure 2c - polyamide filament yarn 29x2 tex).

The yarn tension *P* after the cylindrical guide for the case when *D>>d* is determined by the formula [1-3]:

$$P = P_0 e^{\mu \varphi_P} \tag{2}$$

where *P* is the yarn tension behind the cylindrical guide, P_0 is the yarn tension in front of the cylindrical guide [2], μ is the constant of friction [1, 3], φ_P is the nominal value of the angle between the yarn and the guide [4, 5].

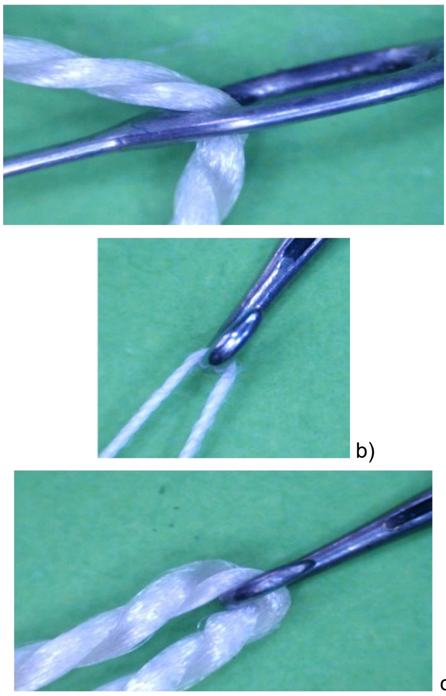

a)
b)
c)

Figure 2 Yarn interaction with operative parts of weaving looms and knitting machines: a) yarn interaction with heddle eye surfaces of weaving loom frames; b) yarn interaction with the surface of knitting machine needles (polyamide filament yarn 29 tex); c) yarn interaction with the surface of knitting machine needles (polyamide filament yarn 29x2 tex)

Figure 3 shows the diagram how the yarn tension behind the cylindrical guide depends on the cylindrical guide radius. The formula (2) does not consider actual conditions of interaction between the yarn and the cylindrical guide when the diameter of the cylindrical guide surface is comparable to the diameter of the yarn *D* ≈ *d* [1, 4, 5].

In this case, it is necessary to consider the yarn diameter deformation in the contact area. Furthermore, the tension degree has impact on the bending modulus. It is obvious that the increase in tension is explained by a change in the braid angle between the yarn and the high-curved guide.

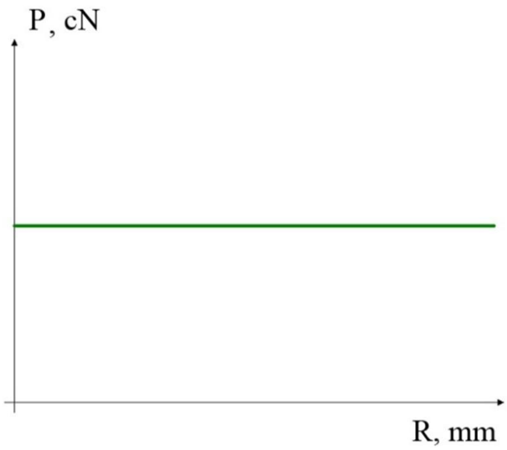


Figure 3 Relationship between the yarn tension behind the cylindrical guideway *P* and the cylindrical guideway radius *R*

At the same time, the actual angle for filament yarn and spun yarn will be higher than the nominal, due to the yarn diameter deformation in the contact area, while the angle for monofilament yarns will be less than the nominal due to the bending modulus. The bending value for filament yarns and spun yarn depends on the degree of their twist [6].

When the yarn twist increases, it's bending modulus increases too. This can be explained by the fact that with an increase in twist, specific pressure between individual filaments increases, which leads to an increase in friction forces that prevent elementary fiber movements during flexure.

Thus, the challenge remains urgent as to determine the effect of the yarn structure on the tension degree behind the guide surface, when the condition is met. When creating a design of the experiment, it is necessary to consider the direction of the relative shift of the friction surfaces [3, 5], the yarn tension before the guide way [8, 11, 12, 15], the structure of the yarn [5, 8, 9], the value of the nominal angle between the yarn and the guide surface [1, 2, 4, 5]. The bending modulus for monofilament yarns and filament yarns, which have different twists, is a crucial factor when determining the degree of tension [1, 3, 6]. Such restrictions required the development of a conceptually new experimental setup pattern, which differs from those designed earlier [2, 3, 16].

2 MATERIALS

Polyamide filaments were selected as raw materials for the experiment. These filaments are the same as those used to produce filter fabric and mesh. Filter fabrics made of polyamide filament yarns and monofilament yarns have a number of advantages over natural-fiber fabrics and non-ferrous mesh. Mesh made with polyamide monofilament yarns, unlike mesh made with non-ferrous metals, has a stronger durability, is resistant to corrosion, can be cut more efficiently and is much cheaper.

For industrial testing, raw materials and equipment were used to carry out experiments in the production environment of "TECHNOFILTER" Mechanical Fabric Factory, Private Joint-Stock Company. Filter mechanical fabrics and meshes of are widely used in mining, sugar, dairy and chemical industries.

For the first set of experiments (variant 1) polyamide monofilament yarn 36.3 tex was chosen, with the diameter of d=2r=0.200 mm, the bending modulus of B=14.0 cN/mm^2. Figure 4a shows a general view.

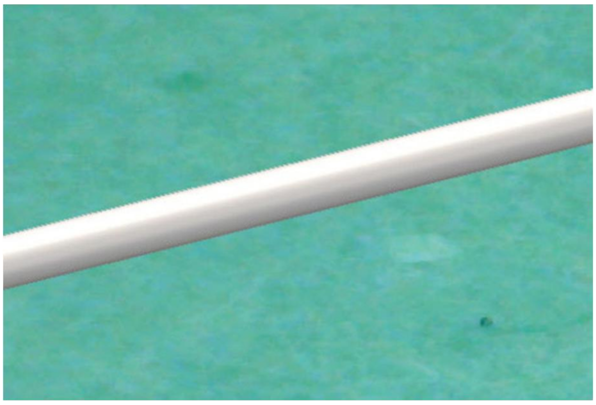


Figure 4 Diagrams of polyamide monofilament yarn 36.3 tex, with the diameter of d=2r=0.200 mm, the bending modulus of B=14.0 cN/mm^2

One of the factors that influences the yarn tension is its twist and specific pressure between individual filaments, which result in an increase in friction. When the yarn twist increases, it's bending modulus increases too. This can be explained by the fact that with an increase in twist, friction forces increase, which prevents elementary fiber movements when bended. So the minimum value of the bending modulus for polyamide filament yarn 29 tex equals to 1.3.10^{-5} cN/mm^2, when the twist tends to zero, and the maximum value equals to 11.2 cN/mm^2, when the twist reaches a critical value and the yarn breaks. The yarn bending modulus value has its impact on the actual value of the angle of the guide surface, the value of which determines the yarn tension. That is why, three series of experiments for polyamide filament yarns of various twist were carried out.

For the second series of experiments (variant 2), polyamide filament yarn 29 tex was chosen, which consisted of 80 filaments, flat twist Kr=100 twists/meter, the nominal diameter d=2r=0.199 mm, the bending modulus B=2.6.10^{-5} cN/mm^2. Figure 5 shows a general view of the yarn.

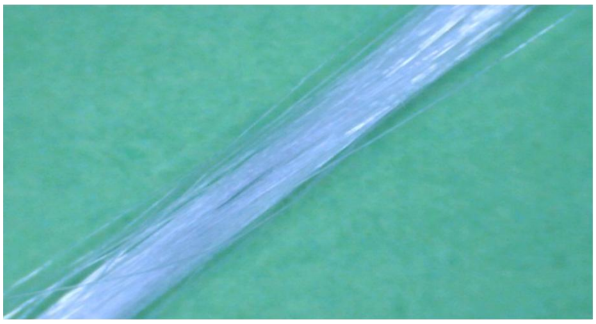


Figure 5 Diagram of polyamide filament yarn 29 tex consisting of 80 filaments, flat twist Kr=100 twists/meter, the nominal diameter d=2r=0.199 mm, the bending modulus B=2.6.10^{-5} cN/mm^2

For the third series of experiments (variant 3), polyamide filament yarn 29 tex was chosen, which consisted of 80 filaments, flat twist Kr=400 twists/meter, the nominal diameter d=2r=0.200 mm, the bending modulus B=4.0.10^{-2} cN/mm^2. Figure 6 shows a general view of the yarn. The value of the bending modulus for the polyamide yarn of medium twist is 1,000 times higher than that of the flat-twisted polyamide yarn [6].

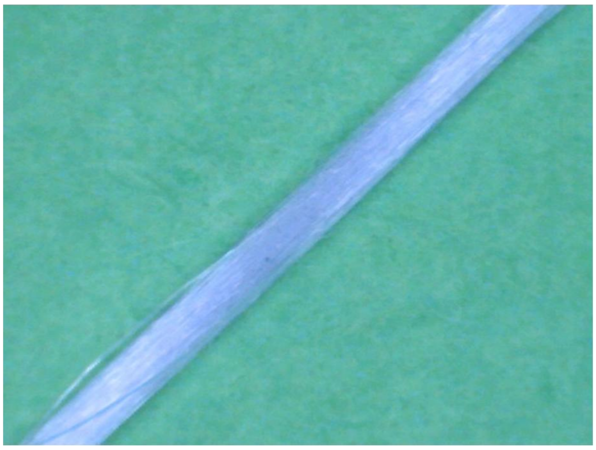


Figure 6 Diagram of polyamide filament yarn 29 tex consisting of 80 filaments, flat twist Kr=400 twists/meter, the nominal diameter d=2r=0.200 mm, the bending modulus B=4.0.10^{-2} cN/mm^2

For the fourth series of experiments (variant 4), polyamide filament yarn 29 tex was chosen, which consisted of 80 filaments, flat twist Kr=800 twists/meter, the nominal diameter d=2r=0.208 mm, the bending modulus B=0.22 cN/mm^2. Figure 7 shows a general view of the yarn.

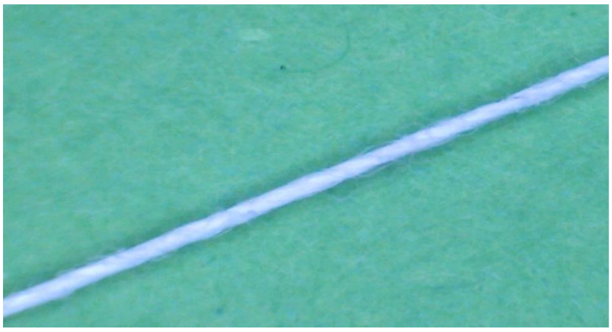


Figure 7 Diagram of polyamide filament yarn 29 tex consisting of 80 filaments, flat twist Kr=800 twists/meter, the nominal diameter d=2r=0.208 mm, the bending modulus B=0.22 cN/mm^2

The four variants used yarns with almost equal diameter made of the same material (polyamide), but with a different structure: monofilament yarn; filament yarn.

3 METHODS

For each of the 4 yarn variants, an orthogonal second-order plan for three factors was designed and implemented in the paper [4, 5]. The general view of the regression equation to determine the joint effect of the yarn tension prior it goes to the cylindrical guide P_0, the radius of the cylindrical guide R and the nominal value of the angle φ_P on the yarn tension behind the cylindrical guide P, is as follows:

$$P = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + \\ + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2. \tag{3}$$

The range of factor variation in the equation (3) was determined by the actual yarn processing conditions. In the blinded values: the yarn tension before it goes to the cylindrical guide P_0 was indicated as x_1; the cylindrical guide radius R was indicated as x_2; the nominal value of the braid angle between yarn and guide φ_P was indicated as x_3.

Values and interval of variation of the yarn tension before the yarn goes to the cylindrical guide way P_0 and the cylindrical guide way radius R are determined based on the conditions of interaction with the cylindrical guide surface. Two main criteria may be distinguished here. Let's analyze them in detail.

The first criterion refers to the choice of such an acceptable degree of the tension P_0 of bending resistance of the yarn before it reaches the guide surface, which will ensure the necessary angle for the cylindrical guide. Figure 8 shows the designed diagram.

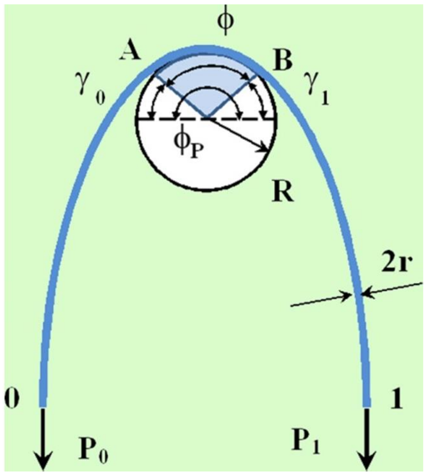


Figure 8 Design diagram to determine an acceptable degree of the tension P_0 of bending-resistant yarn before the guide surface

The equation below shows the relation between the tension P_0 of the yarn before the cylindrical guide surface, the bending modulus B, the radii of the cylindrical guide surface R and the yarn r, the angle γ_0 by which the actual braid angle φ is reduced due to the flexural resistance of the yarn, is reduced due to the bending resistance of the yarn [3].

$$\cos\gamma_0 = 1 - \frac{B}{2P_0(R+r)^2} \tag{4}$$

Let's find the bottom limit of the degree of the tension P_0 of the yarn before the cylindrical guide surface. It is obvious that at the degree of $\gamma_0=\pi/2$, the nominal angle φ will equal to 0 (Figure 8). Then using the equation (4), the following inequality is obtained:

$$P_0 > \frac{B}{2(R+r)^2} \tag{5}$$

It is quite obvious that the degree of the tension P_0 of the yarn before the cylindrical guide should be selected with the equation (5) in mind. Figure 9 shows graphic relationship between the value of P_0 and R for polyamide monofilament yarn (variant 1), for polyamide filament yarn (variants 3 and 4). The highlighted area in Figure 9 corresponds to the range of radius variation R of the cylindrical guide, under which the condition $D \approx d$ is met. The analysis of these relationships shows that to get into this interval, the tension degree P_0 should be higher than 20 cN for monofilament yarn (variant 1). For polyamide yarns (variants 3 and 4) the tension should be higher than 5 cN. For variant 2, the value of the nominal angle will be ensured by the tension less than 5 cN.

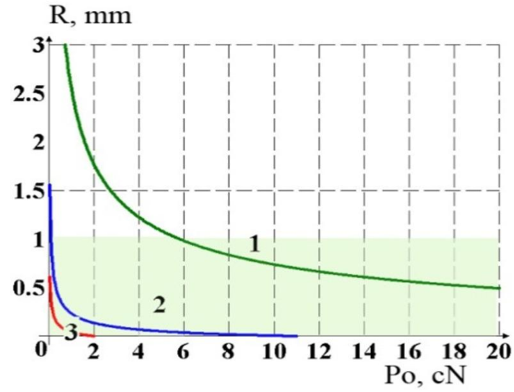


Figure 9 Relationship between the radius of the guide curve *R* on the tension P_0 of the yarn: 1) polyamide monofilament yarn; 2) hard-twisted polyamide filament yarn; 3) medium-twisted polyamide filament yarn

In view of the above, two series of experimental research were implemented. In the first series, for variants 1-4, the degree of tension P_0 of the yarn before the cylindrical guide in the middle of the experiment corresponded to 30 cN. In the second series, for variants 2-4, the degree of tension P_0 of the yarn before the cylindrical guide in the middle of the experiment corresponded to 10 cN. In the middle of the experiment, the radius of the cylindrical guide curve for the first and second series was equal to 1 mm. In the middle of the experiment, the nominal value for the angle φ_P for the first and second series equalled to 135°. Table 1 shows a second-order orthogonal matrix for the first series of the experiments for polyamide yarns (variants 1-4).

Table 1 Second-order orthogonal matrix for the first series of the experiments for polyamide yarns (variants 1-4)

№	Factors					
	Input tension		Radius of the guide curve		Braid angle	
	x_1	P_0 [cN]	x_2	*R* [mm]	x_3	φ [°]
1	+1	32	+1	1.3	+1	145
2	-1	28	+1	1.3	+1	145
3	+1	32	-1	0.7	+1	145
4	-1	28	-1	0.7	+1	145
5	+1	32	+1	1.3	-1	125
6	-1	28	+1	1.3	-1	125
7	+1	32	-1	0.7	-1	125
8	-1	28	-1	0.7	-1	125
9	-1.215	27.6	0	1.0	0	135
10	+1.215	32.4	0	1.0	0	135
11	0	30	-1.215	0.6	0	135
12	0	30	+1.215	1.4	0	135
13	0	30	0	1.0	-1.215	123
14	0	30	0	1.0	+1.215	147
15	0	30	0	1.0	0	135

The correlation between the open-label and blinded values for the first series of experiments for polyamide yarns (variants 1-4) is as follows:

$$x1 = \frac{P_0 - 30}{2}, \quad x2 = \frac{R - 1.0}{0.3}, \quad x3 = \frac{\phi - 135}{10}. \tag{6}$$

Table 2 shows a second-order orthogonal matrix for the second series of the experiments for polyamide yarns (variants 2-4).

Table 2 Second-order orthogonal matrix for the second series of the experiments for polyamide yarns (variants 2-4)

№	Factors					
	Input tension		Radius of the guide curve		Braid angle	
	x_1	P_0 [cN]	x_2	*R* [mm]	x_3	φ [°]
1	+1	12	+1	1.3	+1	145
2	-1	8	+1	1.3	+1	145
3	+1	12	-1	0.7	+1	145
4	-1	8	-1	0.7	+1	145
5	+1	12	+1	1.3	-1	125
6	-1	8	+1	1.3	-1	125
7	+1	12	-1	0.7	-1	125
8	-1	8	-1	0.7	-1	125
9	-1.215	7.6	0	1.0	0	135
10	+1.215	12.4	0	1.0	0	135
11	0	10	-1.215	0.6	0	135
12	0	10	+1.215	1.4	0	135
13	0	10	0	1.0	-1.215	123
14	0	10	0	1.0	+1.215	147
15	0	10	0	1.0	0	135

The correlation between the open-label and blinded values for polyamide yarns (variants 2-4) is as follows:

$$x1 = \frac{P_0 - 10}{2}, \quad x2 = \frac{R - 1.0}{0.3}, \quad x3 = \frac{\phi - 135}{10}. \tag{7}$$

Figure 10 shows the diagram of the experimental unit. Its set-up is described in detail in the paper [4, 5]. The distinction is that unit 4 of modeling the conditions of interaction with guides and operative parts of textile machines includes a set of cylindrical rods, the diameter of which equals to the diameter of the guides and operative parts of textile machines.

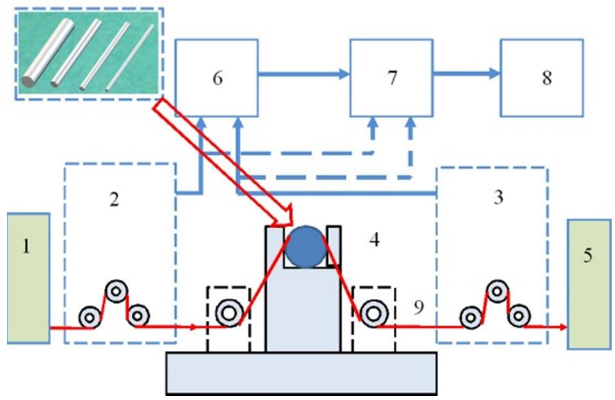


Figure 10 Diagram of the experimental unit: 1) filament feeder unit; 2) unit for measuring the yarn tension's slack side; 3) unit for measuring the yarn tension's slack side; 4) unit for modeling the conditions of interaction with guides and operative parts of textile machines; 5) yarn receiver unit; 6) driver; 7) analog-to-digital converter ADC; 8) personal computer; 9) yarn.

The value of the radii of the guides and polyamide filament yarns, their structure was determined using USB Digital microscope Sigeta (Figure 11).

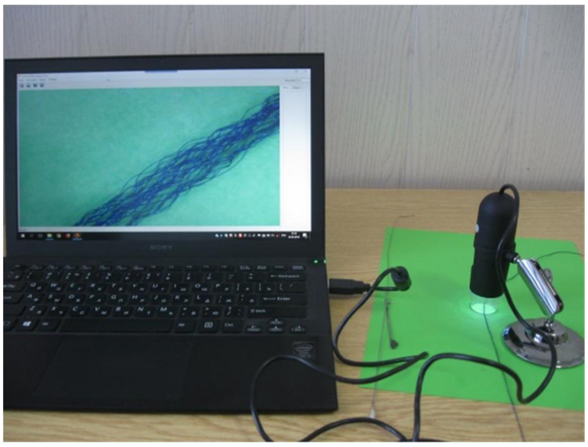


Figure 11 Set-up to determine the radii of the guide way and polyamide filament yarns

4 RESULTS AND DISCUSSION

As a result of implementation of second-order orthogonal designs for three factors (Tables 1-2) for the first series (variants 1-4) and the second series (variants 2-4), about 10 parallel measurements were performed. Its mean values are shown in Tables 3 and 4.

Using the known method of determining the coefficients in the regression equation (3) for the second-order orthogonal plan [4, 5], taking into account the relationships (6), the following regression relationships were determined:

The first series for *27.6 cN* ≤ *P_0* ≤ *32.4 cN*:

for polyamide monofilament yarn 36.3 tex (variant1):

$$P_1 = 3.27 + 0.72P_0 - 9.29R - 0.14\varphi + 0.53P_0R + \\ +0.01P_0\varphi + 0.16R\varphi - 0.02P_0^2 - 6.44R^2 - 0.001\varphi^2, \quad (8)$$

for polyamide filament yarn 29 tex, medium twist *Kr*=100 twists/meter (variant 2):

$$P_2 = 112.35 - 2.13P_0 - 19.77R - 0.63\varphi - 0.88P_0R + \\ +0.02P_0\varphi - 0.21R\varphi + 0.05P_0^2 + 24.67R^2 + 0.003\varphi^2, \quad (9)$$

for polyamide filament yarn 29 tex, medium twist *Kr*=400 twists/meter (variant 3):

$$P_3 = 101.06 - 1.83P_0 - 15.98R - 0.59\varphi - 0.85P_0R + \\ +0.02P_0\varphi - 0.19R\varphi + 0.05P_0^2 + 22.33R^2 + 0.003\varphi^2, \quad (10)$$

for polyamide filament yarn 29 tex, hard twist *Kr*=800 twists/meter (variant 4):

$$P_4 = 91.14 - 1.62P_0 - 10.12R - 0.57\varphi - 0.80P_0R + \\ +0.02P_0\varphi - 0.18R\varphi + 0.04P_0^2 + 19.0R^2 + 0.003\varphi^2. \quad (11)$$

For the nominal value of the angle in the middle of the experiment φ_P=135°, with the change in the yarn tension before the cylindrical guide *27.6 cN* ≤ *P_0* ≤ *32.4 cN*:, the equations (8-11) are converted as follows:

for polyamide monofilament yarn 36.3 tex (variant 1):

$$P_1 = 1.94P_0 + 12.75R - 0.02P_0^2 - 6.44R^2 + 0.53P_0R - 24.65 \quad (12)$$

for polyamide filament yarn 29 tex, flat twist *Kr*=100 twists/meter (variant 2):

$$P_2 = 79.67 + 0.23P_0 - 48.12R - 0.88P_0R + 0.05P_0^2 + 24.67R^2 \quad (13)$$

for polyamide filament yarn 29 tex, medium twist *Kr*=400 twists/meter (variant 3):

$$P_3 = 70.62 + 0.47P_0 - 42.44R - 0.85P_0R + 0.05P_0^2 + 22.33R^2 \quad (14)$$

for polyamide filament yarn 29 tex, hard twist *Kr*=800 twists/meter (variant 4):

$$P_4 = 59.48 + 0.68P_0 - 33.96R - 0.80P_0R + 0.04P_0^2 + 19.0R^2 \quad (15)$$

Table 3 Results of the first series of the experimental research to determine the joint effect of the yarn tension prior it goes to the cylindrical guide *P_0*, the radius of the cylindrical guide *R* and the nominal value of the angle φ_P on the yarn tension behind the cylindrical guide *P* (variants 1-4)

№	Factors			P_2 [cN]	P_3 [cN]	P_4 [cN]	P_1 [cN]
	Input tension x_1	Radius of the guide curve x_2	Braid angle x_3				
1	+1	+1	+1	88.53	87.10	85.13	50.35
2	-1	+1	+1	77.51	76.18	74.33	42.94
3	+1	-1	+1	107.17	104.11	99.81	38.26
4	-1	-1	+1	93.85	90.98	86.94	32.21
5	+1	+1	-1	78.57	77.31	75.55	45.47
6	-1	+1	-1	68.79	67.61	65.96	38.83
7	+1	-1	-1	54.48	91.77	87.97	35.41
8	-1	-1	-1	82.73	80.19	76.69	29.99
9	-1.215	0	0	76.80	75.09	72.72	36.06
10	+1.215	0	0	90.09	88.24	85.67	43.95
11	0	-1.215	0	101.21	97.77	92.92	31.65
12	0	+1.215	0	77.03	75.84	74.18	45.47
13	0	0	-1.215	77.57	75.91	73.61	37.79
14	0	0	+1.215	89.76	87.86	85.19	42.31
15	0	0	0	83.45	81.67	79.19	39.98

Table 4 Results of the second series of the experimental research to determine the joint effect of the yarn tension prior it goes to the cylindrical guide P_0, the radius of the cylindrical guide R and the nominal value of the angle φ_P on the yarn tension behind the cylindrical guide P (variants 2-4)

№	Factors			P_2 [cN]	P_3 [cN]	P_4 [cN]
	Input tension x_1	Radius of the guide curve x_2	Braid angle x_3			
1	+1	+1	+1	33.93	33.03	31.78
2	-1	+1	+1	21.56	20.86	19.89
3	+1	-1	+1	48.44	46.11	42.86
4	-1	-1	+1	28.58	26.91	24.56
5	+1	+1	-1	30.07	29.28	28.16
6	-1	+1	-1	19.15	18.53	17.67
7	+1	-1	-1	42.38	40.32	37.43
8	-1	-1	-1	25.11	23.64	21.57
9	-1.215	0	0	20.91	20.02	18.77
10	+1.215	0	0	37.15	35.89	34.14
11	0	-1.215	0	40.64	38.17	34.72
12	0	+1.215	0	25.46	24.77	23.82
13	0	0	-1.215	26.71	25.71	24.31
14	0	0	+1.215	30.98	29.83	28.20
15	0	0	0	28.77	27.69	26.19

Figure 12 shows the response surfaces for the first series of experiments for variants 1-4. The relevance of the regression relationships obtained was checked with the SPSS program for statistical processing of experimental data [5].

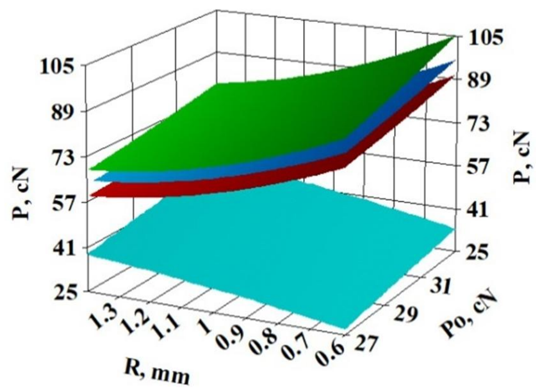


Figure 12 Response surfaces for the first series of experiments for variants 1-4:
■ - for polyamide filament yarn 29 tex, flat twist;
■ - for polyamide filament yarn 29 tex, medium twist;
■ - for polyamide filament yarn 29 tex, hard twist;
■ - for polyamide monofilament yarn 36.3 tex

For the nominal value of the angle in the middle of the experiment φ_P=135°, with the change in the yarn tension before the cylindrical guide P_0=30 cN, the equations (12-15) are converted as follows:

for polyamide monofilament yarn 36.3 tex (variant 1):

$$P_1 = 15.55 + 28.65R - 6.44R^2 \quad (16)$$

for polyamide filament yarn 29 tex, flat twist (variant 2):

$$P_2 = 133.89 - 74.52R + 24.67R^2 \quad (17)$$

for polyamide filament yarn 29 tex, medium twist (variant 3):

$$P_3 = 127.47 - 67.94R + 22.33R^2 \quad (18)$$

for polyamide filament yarn 29 tex, hard twist (variant 4):

$$P_4 = 118.13 - 57.96R + 19.0R^2 \quad (19)$$

Figure 13 shows graphic relationships of the change in the yarn tension after the cylindrical guide (the first series of experiments), which were obtained using the equations (16-19).

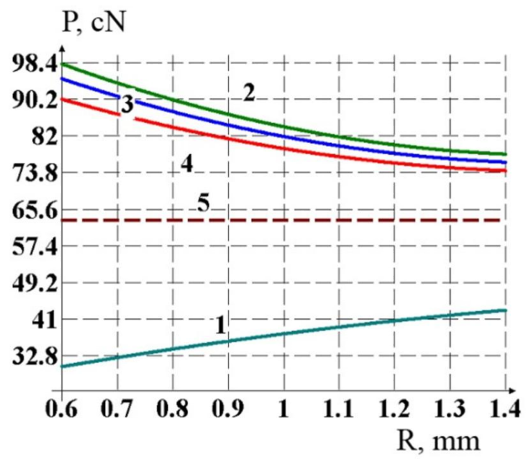


Figure 13 Graphic relationships between the change in the yarn tension after the cylindrical guide (the first series of experiments):
1 - for polyamide filament yarn 36.3 tex;
2 - for polyamide filament yarn 29 tex, flat twist;
3 - for polyamide filament yarn 29 tex, medium twist;
4 - for polyamide filament yarn 29 tex, hard twist;
5 - the relationship for polyamide yarn *D>>d, D=2R, d=2r*

For variants 2-4, for polyamide filament yarns, the tension P decreases when the radius R of the cylindrical guide is increased. This is explained by the fact that the yarn surface deformation is decreased in the contact area and, therefore, the value of the braid angle for the cylindrical guide also decreases. For variant 1, for monofilament yarns, the tension P increases as the radius R of the cylindrical guide increases, which is explained by an increase in the braid angle. The line 5 is an asymptote for relationships 2-6, which corresponds to the case when D>>d, equation (2).

The second series for *7.6 cN* ≤ P_0 ≤ *12.4 cN*:

for polyamide filament yarn 29 tex, flat twist *Kr*=100 twists/meter (variant 2):

$$P_2 = 38.96 + 1.3P_0 - 6.21R - 0.49\varphi - 2.88P_0R + \\ +0.03P_0\varphi - 0.14R\varphi + 0.07P_0^2 + 18.77R^2 + 0.002\varphi^2, \quad (20)$$

for polyamide filament yarn 29 tex, medium twist *Kr*=400 twists/meter (variant 3):

$$P_3 = 35.41 + 1.27P_0 - 3.56R - 0.47\varphi - 2.7P_0R + \\ +0.02P_0\varphi - 0.12R\varphi + 0.06P_0^2 + 16.55R^2 + 0.002\varphi^2, \quad (21)$$

for polyamide filament yarn 29 tex, hard twist *Kr*=800 twists/meter (variant 4):

$$P_4 = 29.07 + 1.08P_0 + 0.03R - 0.41\varphi - 2.45P_0R + \\ +0.02P_0\varphi - 0.11R\varphi + 0.06P_0^2 + 13.66R^2 + 0.002\varphi^2. \quad (22)$$

For the nominal value of the angle in the middle of the experiment φ_P=135°, with the change in the yarn tension before the cylindrical guide *7.6 cN* ≤ P_0 ≤ *12.4 cN*, the equations (20-22) are converted as follows:

$$P_2 = 9.22 + 4.74P_0 - 24.65R + 0.07P_0^2 + 18.77R^2 - 2.88P_0R \quad (23)$$

$$P_3 = 6.23 + 4.58P_0 - 20.21R + 0.06P_0^2 + 16.55R^2 - 2.7P_0R \quad (24)$$

$$P_4 = -2.48 + 4.32P_0 - 14.28R + 0.06P_0^2 + 13.66R^2 - 2.45P_0R \quad (25)$$

Figure 14 shows the response surfaces for the second series of experiments for variants 2-4. Relationships between the yarn tension after the cylindrical guide and the tension P_0 and the radius of the cylinder R were established at the fixed value of nominal angle for the cylinder φ. This value corresponded to the focus point of the experiment (Table 2). The relevance of the regression relationships obtained was checked with the SPSS program for statistical processing of experimental data [5].

For the nominal value of the angle in the middle of the experiment φ_P=135°, with the change in the yarn tension before the cylindrical guide P_0=10 cN, the equations (23-25) are converted as follows:

for polyamide filament yarn 29 tex, flat twist (variant 2):

$$P_2 = 63.62 - 53.45R + 18.77R^2 \quad (26)$$

for polyamide filament yarn 29 tex, medium twist (variant 3):

$$P_3 = 58.03 - 47.21R + 16.55R^2 \quad (27)$$

for polyamide filament yarn 29 tex, hard twist (variant 4):

$$P_4 = 46.72 - 38.78R + 13.66R^2 \quad (28)$$

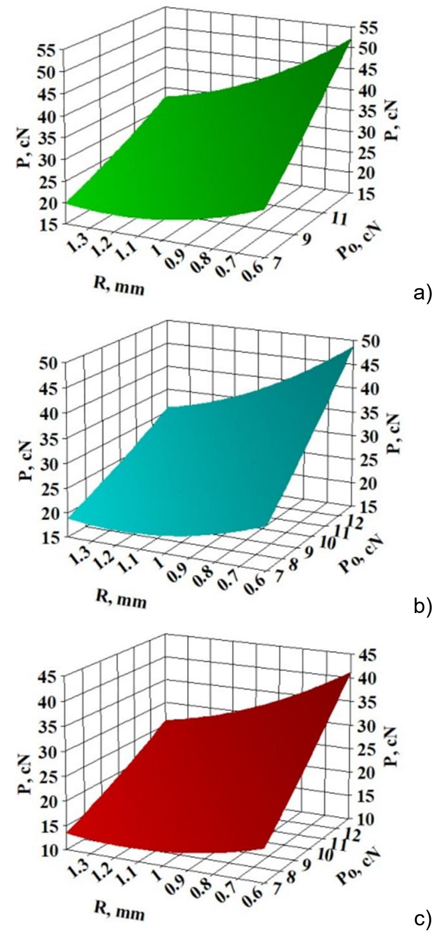


Figure 14 Response surfaces for the second series of experiments for variants 2-4:

a) for polyamide filament yarn 29 tex, flat twist *Kr*=100 twists/meter (variant 2);
b) for polyamide filament yarn 29 tex, middle twist *Kr*=400 twists/meter (variant 3);
c) for polyamide filament yarn 29 tex, hard twist *Kr*=800 twists/meter (variant 4)

Figure 15 shows graphic relationships of the change in the yarn tension after the cylindrical guide (the second series of experiments), which were obtained using the equations (26-28). For variants 2-4, for polyamide filament yarns, the tension P decreases when the radius R of the cylindrical guide is increased.

This is explained by the fact that the yarn surface deformation is decreased in the contact area and, therefore, the value of the braid angle for the cylindrical guide also decreases.

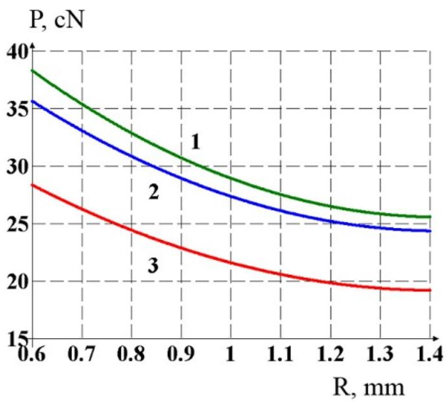


Figure 15 Graphic relationship of the change in the yarn tension after the cylindrical guide (the second series of experiments, variants 2-4)

The results obtained can be used to optimize the technological process of manufacturing filter fabrics from polyamide filament yarns and monofilament yarns, when it is possible, at the initial stage, to determine the intensity of the fabric formation process.

3 CONCLUSIONS

As a result of the comprehensive experimental research to determine the effect of the yarn structure on the tension degree when interacting with high-curved guides, regression relationships were obtained for polyamide monofilament yarns and filament yarns that made it possible to determine the effect of their structure, tension before the guide surface, radius of the high-curved cylindrical guide and the nominal angle for the guide on the tension degree after the guide.

In view of the above, two series of experimental research were implemented: for the change in the yarn tension P_0 before the cylindrical guide in the range from $27.6\ cN \leq P_0 \leq 32.4\ cN$ (the first series); for the change in the yarn tension P_0 before the cylindrical guide in the range from $7.6\ cN \leq P_0 \leq 12.4\ cN$ (the second series).

In the first series, for four types of polyamide yarns (variant 1 - polyamide monofilament yarn 36.3 tex, variant 2 - polyamide filament yarn 29 tex of flat twist, variant 3 - polyamide filament yarn 29 tex of medium twist, variant 4 - polyamide filament yarn 29 tex of hard twist) patterns in the change of the output tension were determined depending on the radius of the cylindrical guide way curve. In the second series, for variants 2-4, regression relationships were obtained to determine the joint effect of the yarn tension before the cylindrical guide P_0, the radius of the cylindrical guide R and the nominal value of the angle φ_P on the yarn tension behind the cylindrical guide P.

The results obtained enable optimization of yarn processing using production equipment, to reduce yarn breakage and to improve performance.

The results obtained can be used to improve technological processes in the textile and knitwear production.

Acknowledgement: *We are really grateful to Private Joint Stock Company "Technical Textiles Factory "TEKHNOFILTR" for the raw materials and equipment provided for carrying out the experiments and for the opportunity to try out the results of the research in a production environment.*

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ETHNIC DESIGNER COMPONENT OF CLOTHES' DECORATION TECHNIQUES USING EMBROIDERY

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Abstract: *The problem of incorporating the embroidery of ethno designer's clothing into the technology of decorating clothes is investigated. The technique of adaptation of the sign system of ornaments to the technological support of machine embroidery is developed taking into account the concept of regional differences in the national costume of Podillya. The mechanism of scaling the size of the report of the cross-member element in accordance with the characteristics of the canvas groups is investigated. A project-design of ribbon ornament compositions on the details of Podillya shirts and modern women's costume using the "Inkscape" program has been developed. It was established that the construction of a geometric ornament according to the laws of symmetry provides technical conditions for the creation and testing of the quality of the embroidery ornament in accordance with the contours of parts of garments in graphic editor of Draw Ltd.*

Keywords: *embroidery technology, ethno design, canvas, ornament report, cruciform element, scaling, embroidery machine, mosaic graph, program editor.*

1 INTRODUCTION

The Ukrainian national costume is a phenomenal thing both for beauty and for bright colors, according to the harmony of forms, regional variety and variety of embroidery ornaments.

The use of the principle of "well forgotten old" as a retro-fashion, national costume does not justify the innovation expectations in the way of design. This is due to the lack of reliability of group preferences of consumers for anthropological reasons, the lack of substantiation of segmentation of the embroidery decoration with the shape of the product, the use of archaic approaches to the time-styling of elements of the national costume to popularize the cultural heritage.

The harmony of the national costume is based on the canonical conception of the ethnic image of a person, which was selected by different generations to create a unique thing. The concept of ethno design requires radical changes in engineering design of modern clothes on the basis of spirituality of the Ukrainian people. Taking this into account, the integration of the heritage of the national costume in the development of the ethno design component by adapting the sign system of ornaments to the morphological structure of embroidery according to the gender-age function in the clothes design is becoming a crucial issue.

2 DISCUSSINS IDEAS

The key information about the rules of behavior of the ethnic group contains not only the conditions and scheme of movements, but also the description of the sign system of the chain of associations of aesthetic quality of the national costume. In particular, it is a form, a line, a color and an ornament [1]. Embroidery in clothing has become a powerful means of self-identification of the people and an integral part of their spiritual life.

The formation and development of the ethnic function of the garment as a piece of clothing and ritual in the evolution of the national costume contains the concept of regional differences in cut, color, decoration, methods of combining and wearing individual elements of clothing [2, 3].

The effectiveness of decorating with embroidery determines the technological support for making the ornaments. An analysis of the technique for embroidery has shown that there is a sufficient variety of perfect embroidery equipment that can be used in the manufacture of sewing products created in folk traditions. Changing of consumer needs and techniques for decoration requires continuous improvement of software. Modern software for decorating clothes with embroidery are developing in parallel with the change of technology. There are many programs for embroidery: Wilcom, Embird, XStitch, Craft Grid, Cross Magic, Pana Vue Image Assembler, PC Stitch, PM Stitch Creator, WIN-Stitch [4, 5]. However, most of them are highly specialized.

None of the modern programs contains a catalog of Ukrainian national ornaments.

The main areas of software development are the creation of programs for managing the embroidery machine (PCMM), which can be divided into: internal, which are intended for the organization of the equipment and its components; external, which control the process of embroidery decoration. The development of internal PCMs (firmware) is carried out by enterprises manufacturing embroidery machines [6].

Modern software editors for automated filling of arbitrary sections of cross-shaped elements (CSE) lead to the formation of uneven hegemony, which have several unnecessary stitches formed as a result of the transition from one stitch to another. Such CSE impair the quality of embroidery. In connection with this, there is a need for research on filling the embroidery ornament with only even cross-shaped elements.

3 METHODS

The ethno-design component is based on the synthesis of ethnic, archaic, authentic material and modern academic and non-academic forms of culture. It is an effective means of surviving national culture in modern conditions and a basis for a dialogue of modern cultures [7]. The level structure of the authenticity of the sign system of composite means, based on the example of the national costume of Podillya (Figure 1), forms four main components in the first level, among which the component 4M is chosen for researches, and two additional, in particular, technological aspects are considered in 2A.

The choice of composition of clothing ornamentation depends on the technique of decoration and the material type. The network is used as a way of connecting parts with each other. The "bottom" technique provides the product with saturation, so the composition of such products is always easier. Using the "cross" technique, the ornament became more complex and versatile compared to the "bottom", and the technique "flattening" - is the summit of any composite solutions. That is, the composition of the garment is an entire system that combines all the structural and decorative elements of the product. As the technique of "cross" is most often used in Podillia [8, 9], it is chosen for further study of the concept of sign symbols in the design of a modern wardrobe.

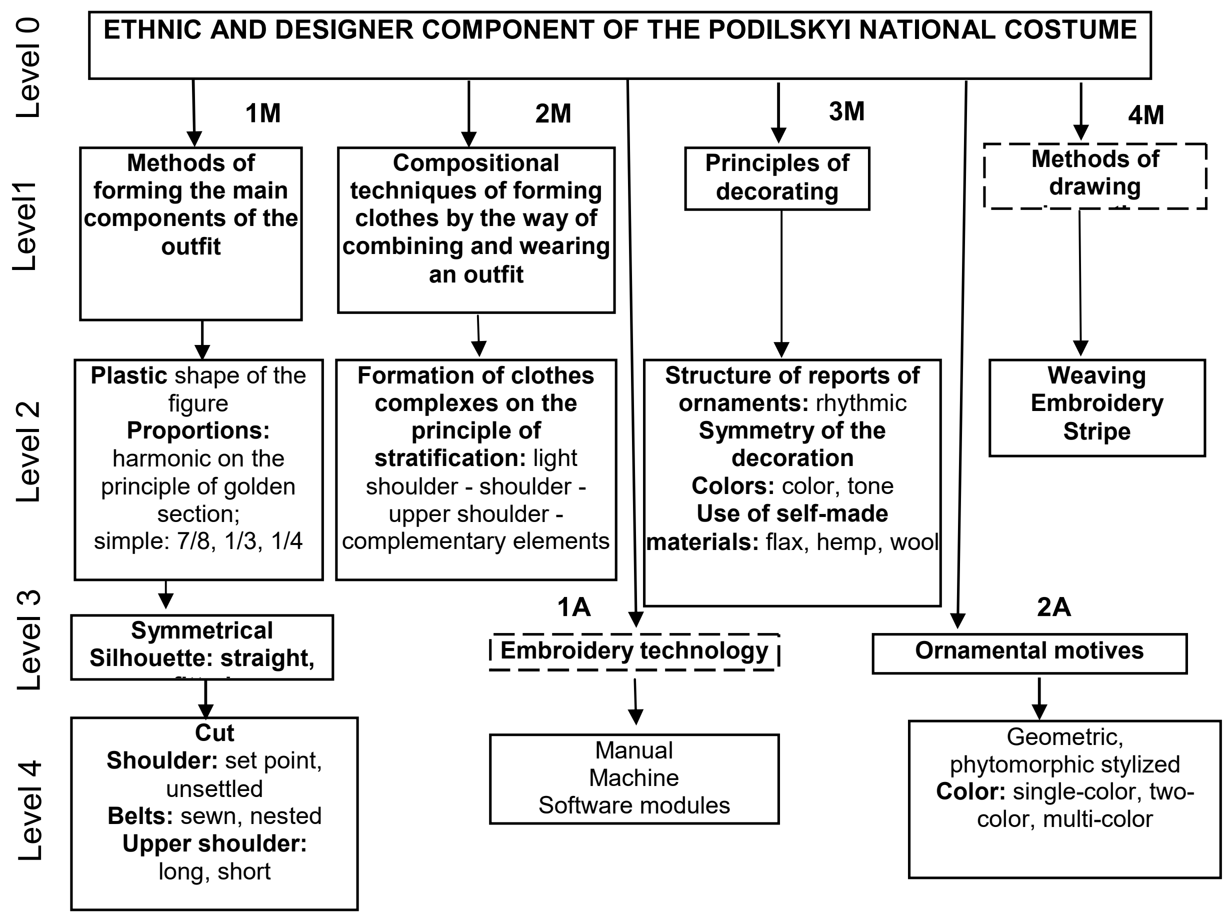


Figure 1 Scheme of ethnic and design component of the national costume of Podillya: M - the main components; A - additional components

According to the purpose, materials for embroidery are divided into two types: 1) the basis on which embroidery is performed - a fabric or a canvas; 2) the embroidered material - threads, ribbons, cords, beads, etc. [9]. The modern textile industry produces fabrics specially designed for cross-stitch embroidery. The criteria by which fabrics are classified into one or another group are the composition of the material, the method by which the fabric is woven, as well as its use [10]. As the main fabrics for making clothes with embroidery, the ones made of fibers of natural origin are usually chosen. These are hemp, linen, silk and woollen fabrics. Especially technologically qualitative materials are considered to be natural fabrics of factory production: cotton, percale, colophon, batiste, china, muslin and silk. Do not overlook the home-made fabric (Table 1).

Those of these fabrics, which have a clearly defined fabric of linen weave, are used as a basis for embroidery. On fabrics with a very small weave structure or poorly traced, the embroidery is performed on a temporary canvas or on a water-soluble net. Or they perform the embroidery on a permanent canvas with a clearly distinguished weave of the required density, which then tune in to parts of the details. Threads take the dominant place among the embroidered materials. They come in color, quality and thickness. Threads that have different composition and structure are used for embroidery on fabric and on canvas. As for composition, they are divided into three groups: 1) natural - linen, silk, wool, cotton, hemp; 2) artificial - staple, viscose; 3) synthetic - fervor, linen fabric, metal, gold and silver [11].

By structure all threads are divided into 2 groups – divisible and indivisible. Divisible threads can be separated into several threads and can be used as one at a time or in a combination with other threads to make them thinner or thicker. Indivisible are those which are not divided by structure. To increase the bulk you can use several folded threads of the different length (Table 2).

The most popular manufacturers of embroidery threads are DMC (France), Anchor and Madeira (Germany), Ariadna (Poland), Belka (China) and Gamma (Russia).

Manufacturers of threads for embroidery develop a variety of palettes, which have more than 1000 shades of colors. Each color has its name and its shades are indicated by the corresponding numbers (Table 3).

Table 1 Classification of fabrics used for the manufacture of embroidered products

№	Raw material composition	Names of fabrics
		Natural fabrics
1	flaxseed	Marquisist, Batista, Homespun, Plain-Dyed
2	Hemp	Homespun harsh, acid, semi-white, and plain-colored
3	Cotton	Chittish, beard, madapolam, various types of canvas, velvet, lamuth, percale, batiste, reps, satin, marquis, mittal, muslin
4	Silk	Atlas, Repts, Crepesatin, Toal, Crepesine, Georgette
		Artificial, synthetic and mixed fabrics
5	Artificial	Staple, acetate fiber, krepedeshin, krepsatin, lizeta
6	Synthetic	Twist, lavsan (terlene, dactron, tergale, tetheron), nitron, kapron, casmillon, silon
7	Mixed	Flax with lavsan, wool with lavsan

Table 2 Characteristics of threads for embroidery

№	Raw material composition	Characteristics of the main features
1	Cotton	In the rush or twisted, muline, crunchy, iris, flask
2	Cotton and paper	Muline, bleached and non-bleached threads of different thicknesses
3	Silk	Aartificial silk, natural twisted or in a single thread of the most diverse colors from bright to light - pastel shades, as well as silk muline
4	Linen	non-bleached, thin and rough torsion or in the ridge
5	Stained	Embroidery threads in big coats or on bobbins of different shades
6	Viscose	Embroidery viscose of different thickness, twisted in coils or on bobbins
7	Woolen	Volatile, gas, twisted wool, wool in one thread or in a band
8	Mixed and synthetic fibers	Acrylic, semi-cotton, braid, soutiques, lurex, metallized
9	metallic	Spools, tinsel plated, golden and silver cord, spruce, spiced

Table 3 The numbering of the main colors used for the manufacture of nationally-designed clothing

Color's name	The company-producer of threads			
	Gamma	DMC	Anchor	Madeira
	Numbers of color shades			
black	0420	310	403	black
red	0012	600-606	31-46	206-210
yellow	3192, 0042	307	289-298	103-114
green	0209, 0210, 0319	702-703	226-238	1306, 1307
orange	3195, 3196	721-740	303-316	201, 202
blue	0082, 0308	791-798	131-178	904-912
sky-blue	3121, 0023, 0304	996	130, 1090	1103, 0907
burgundy	0062, 0708, 3211	347-356	1014-1025	401-407
dark brown	0217-0219	300-304	351-359	2602, 2005
light brown	0054	437	360-364	2011, 2012
dark green	3158, 0212, 0213	518	923	2704
orange-red	0044	946	332	207
grey	3179, 0917	611-613	831, 898	1902, 1903

The development of engineering and technology makes it possible for the sewing industry to use a high-speed personal computer, which greatly enhances the possibility of mass production of clothing with embroidery. In most cases, the bearers of information are CDs or DVDs distributed by embroidery machines manufacturers that contain patterns with embroidery patterns [12]. The main characteristics of industrial embroidery machines include: the rate of execution of decorating with embroidery; number of heads; number of needles (heads); size of the working area or maximum size of the shoulder; the memory of the machine and the information carrier (Table 4).

Table 4 The main characteristics of industrial embroidery machines

The name of the characteristics of industrial embroidery machines		Range of variation
The speed of embroidery making [st/min]		1200-1400
Number of working heads [unit]		1-24
Hoop	flat [mm]	Hoop
	cylindrical [mm]	
Number of needles [unit]		1-12
Information carrier [kilobite]		256-800

In existing software editors, there are two ways to create CE (Figure 2).

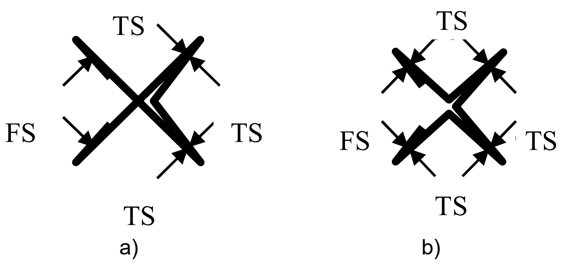


Figure 2 Schemes of existing methods of machine embroidery of CE, stitches: a) of different lengths; b) of the same length

In the first method of embroidery, fastening stitches (FS), which length is twice the size of the transition stitches (TS), and in the second - the length of the FSs and the TSs is the same FS=TS. However, it is evident that in both ways there is TS for another FS, which cannot be avoided, even in simple patterns of embroidery ornamentation. That is, regardless of the methods of formation, existing cruciform element (CEs) are uneven. Especially it is visible on the diagonal with CEs, formed by stitches of different lengths (Figure 3).

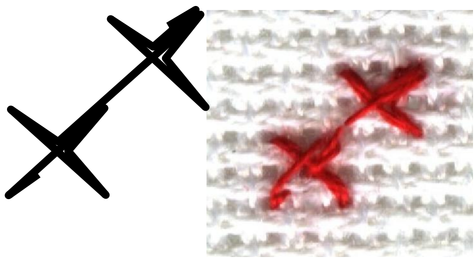


Figure 3 Scheme of existing CEs, arranged diagonally and formed by stitches of different lengths

This leads to deterioration in the appearance of the embroidery. The number of TSs depends on the complexity of the shape of the element of the ornament, the place of the beginning and the end of the embroidery. Existing software modules for editors for embroidery machines use an algorithm for forming FSs that leads to a chaotic formation of the TSs during the embroidery process. A new way to fill the embroidery ornaments with double cruciform elements (DCEs) allows embroidering any form of ornaments without the formation of TSs, since the transition and consolidation are carried out at the expense of the stitches included in the DCEs (Figure 4) [13].

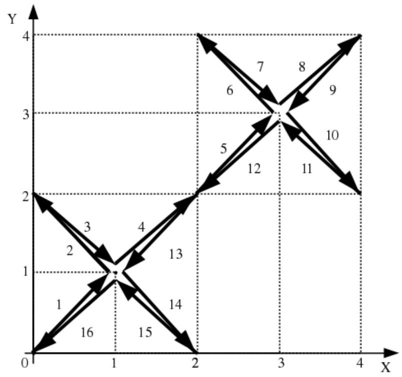


Figure 4 Diagram of DCEs arranged diagonally

Each of the stitches is marked with a serial number, which increases with the performance of several DCEs. The beginning and the end of the system of two DCEs coincide.

4 EXPERIMENTAL

The technology of manual embroidery takes into account the selection of rational parameters of the ornament according to the parameters of density. The mechanism of using a grid in machine embroidery is based on the principle of scaling the dimensions of CE canvas.

The development of a method for selecting rational parameters of the canvas density relative to the parameters of the ornament consists of selecting such density, which allows getting a multiple number of repetitions of a report on a given area of decoration. For this purpose, the size of the design part to be decorated is compared with the size of the ornament that is applied to it. The parameters of the ornament are calculated based on the amount of CEs, which are contained in the given decorating area with the selected canvas type and the size of the CEs, which are planned to be embroidered.

The 15 samples (Table 5) were selected for research on modern types of canvas, for each of them the density (number of CEs per 10 cm of canvas) was determined according to the base and the abb (Table 6). For each sample of the canvas, *lx* is calculated, which is the value of the base (minimum) of CE, which takes one cell on a warp and one cell in a weft. Accordingly, the number of basic CEs in 10 cm canvas corresponds to its density. The range of variation of this indicator is divided into three groups:

small (30-35 CEs per 10 cm) with l_x = 0.10-0.19 cm;

medium (40-60 CEs) with l_x = 0.20-0.29 cm;

high (60-100 CE) with l_x = 0.30-0.35 cm.

Table 5 Photographical pictures of modern types of canvas

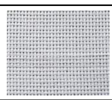
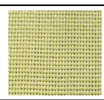
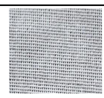
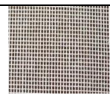
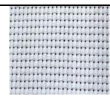
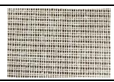
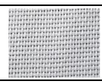
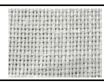
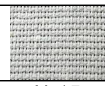
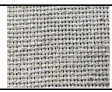
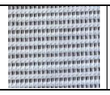
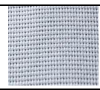
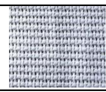
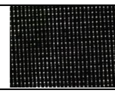
№ of a canvas	№1	№2	№3	№4	№5
general look					
№ of a canvas	№6	№7	№8	№9	№10
general look					
№ of a canvas	№11	№12	№13	№14	№15
general look					

Table 6 Characteristics of groups of canvas according to linear density of basic CEs

№ of canvas sample	**name of canvas**	**density of canvas**	**The number of basic CEs per 10 cm canvas**		**measurement of a basic CE *lx* [cm]**	
			on the base	**on the abb**	**on the base**	**on the abb**
3	Hardanger	high	90	87	0.11	0.10
13	Davosa 18		61	65	0.17	0.14
4	Davosa 22		70	68	0.15	0.15
6	Stramin		85	40	0.15	0.23
2, 11	Aida 16		61	60	0.17	0.17
1, 15	Aida 14	medium	53	54	0.20	0.2
7	Floba 14		56	52	0.21	0.2
10, 14	Aida 11		52	43	0.20	0.24
5, 8	Hardanger	small	46	46	0.25	0.25
9	Aida 8		35	36	0.32	0.32
12	Vienna		40	38	0.33	0.32

The basic dimensions of CEs are output (minimum) for a certain type of canvas and can be increased both in warp and in the weft, but no more than to a size of 0.30 cm, as recommended for embroidery [14, 15]. The magnitude of the increase in CEs in relation to its basic sizes is characterized by the scaling factor - n. Accordingly, their number in 10 cm will be reduced by the value of n. In the range of clothing, this indicator varies within n = 1-3 (Figure 5). The higher the canvas density, the higher the n factor = it can be 2-3, for the low-density canvas we recommend using n = 1-2.

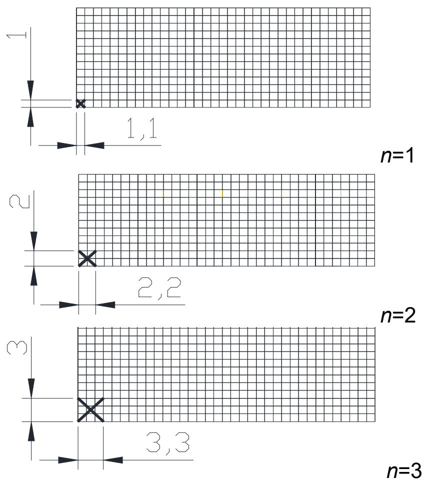


Figure 5 Variants of parameters of CEs at different values of the scaling factor

The amount of CEs in the decoration area is calculated taking into account the basic sizes for each type of canvas and the sizes of the decorating areas of the clothes designs (Equation1):

$$k = \frac{l_d}{l_x \cdot n}, \tag{1}$$

where, k is the number of CEs in the decoration area; l_d are the sizes of the decoration area; l_x are basic dimensions of CEs; n is a coefficient of scaling of CEs.

Taking into account the inter-dimensional range of variation of decorating zones [16] (at the bottom of the product - 2.0 cm; in the length of the collar - 1.0 cm; in the length of the cuff - 0.5 cm) and the basic sizes of CEs for each canvas one can determine the permissible deviation of their number, within which the length of the ornament can be adjusted throughout the part of the detail. The allowed quantity of CEs, which may enter the boundary of the interval spacing, is calculated (Equation 2):

$$\Delta k = \frac{\Delta}{l_x \cdot n}, \tag{2}$$

where, Δk is the quantity of CEs in the segment of inter-dimensional interval; Δ is the value of the inter-dimensional interval.

To determine the scaling factor of a CE, it is necessary to compare the height of the ornament, calculated for a particular type of canvas, with the parameters of the decoration area. In the sleeve, cuffs and riser collars, the height of the ornament is compared with the width of these details. The height of the ornament is calculated using the following equation (Equation 3):

$$l_r^b = k \cdot l_x, \tag{3}$$

where, l_r^b is the height of the pattern within one report; k is the number of CEs in the report in height; l_x are basic sizes of CEs [mm].

If, as a result of the test, it is established that the height of the ornament exceeds the height of the decoration area, then a choice of canvas of lower density is performed for it and a re-check the conformity of the height of the ornament to the dimensions of the part is conducted. If the height of the ornament is half that of the details, then they take n factor = 2, if they are three times, then take n which is equal to 3.

With different densities of the canvas and with different values of CEs, the size of the ornament within a single report will be different (Figure 6). According to the selected scaling factor, their magnitude is calculated on the warp and on the weft (Equation 4):

$$l_r = l_r^b \cdot n, \tag{4}$$

where, n is the factor of scaling CEs.

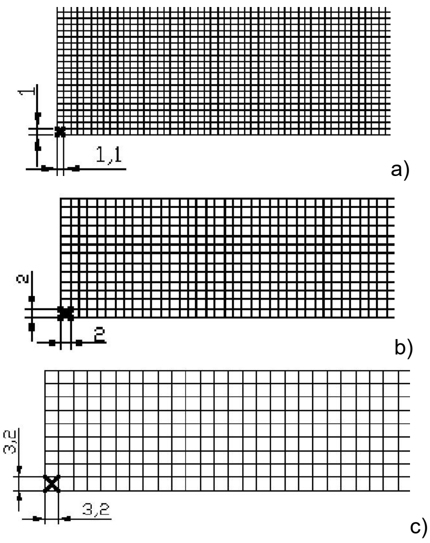


Figure 6 Parameters of CEs on different types of canvas: a) canvas № 3; b) canvas №1; c) canvas №9

To determine the multiplicity of the repeat of the report on the entire part of the detail, one should determine the natural size of the ornament within a single report (Equation 5):

$$l_r = k_r \cdot (l_x \cdot n), \tag{5}$$

where, l_r is the length of the ornament within a single report [cm]; k_r is the number of CEs in the report [units]; l_x are basic sizes of CEs [cm].

Multiplicity of a repeat of a report on a decorating area is calculated (Equation 6):

$$k_{r.r} = \frac{l_d}{l_r}, \tag{6}$$

where, $k_{r.r}$ is a coefficient of multiplicity of the repeat report; l_d is the size of the detail area [cm]; l_r is a report size [cm].

To ensure a clear coincidence of the beginning and the end of the ornament with the outside of the decoration area, the multiplicity of the repeat of the report should be equal to the whole number. Taking into account the number of CEs that are within the reporting range and the multiplicity of its repetition, the number of CEs in the ornament is counted (Equation 7):

$$k_0 = k_n \cdot k_r, \tag{7}$$

where, k_o is the number of CEs in the ornament [the unit]; k_n is the number of CEs in the report [units].

Then we determine the difference between the amount of CES contained in the decoration area of the part and those contained on the ornament area (k-k_o). The obtained figure is compared with the permissible deviation of the number of heights lying within the inter-dimensional interval. If it does not exceed the permissible limit $k\text{-}k_o \leq \Delta k$, then the selected report is considered rational. Otherwise, we should choose a new canvas and re-perform calculations.

One of the important characteristics of the ornament is the size measurement, which should be compared with the size of the details. The size of the report depends on the size of the cross and the number of crosses k on the warp and on the weft that are within the report. This parameter is chosen as the main one for characterizing the size of the ornament. In each group of typical reporting chart schemes (Figure 7), the range indicators of crosses on the warp and on the weft were investigated. Since the decorations of the insert (chemisette) and the collar (cuffs) use different patterns in the pattern of the ornament, their sizes have been determined separately.

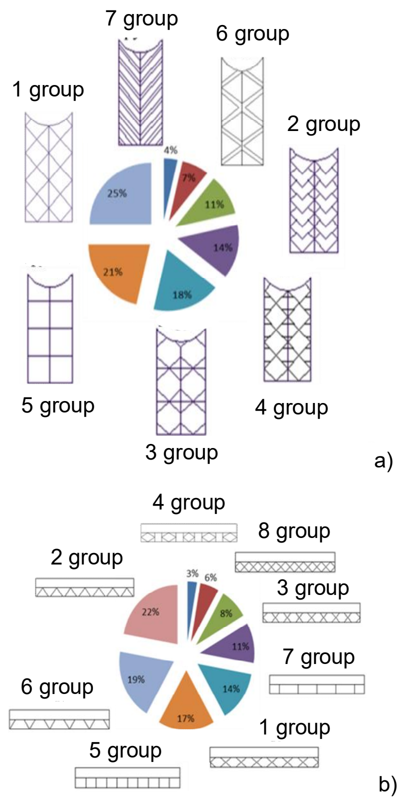


Figure7 Typical reporting frameworks: a) legacies; b) collar and cuffs

The analysis of the size of the report indicates that there is a similarity between the different groups of the typical schemes of insertion (chemisette) and collar (cuff), despite the fact that the range itself is quite large. In this case, the schemes considered within one group of ornaments, are characterized by a different filling area, which is clearly and visually observed (Figure 8). Characteristics of the size of the report are given on the example of chemisette and collar (Table 7). Variants of sizes of ornaments indicate the visual difference of the area of filling the report, (Figure 9), so when choosing an ornament, you must take into account the size of the parts and the size of the product itself.

Table 7 The number of crosses in the report

№ of report group	Number of crosses in the report [pcs]					
	Report Size Groups, chemisette			Report size groups, collar and cuff		
	small	medium	large	small	medium	large
1	16 - 25	26 - 35	36 - 44	5 - 9	10 - 14	15 - 18
2	16 - 26	27 - 38	39 - 49	6 - 9	10 - 12	12 - 15
3	16 - 30	31 - 44	45 - 59	5 - 12	13 - 20	21 - 28
4	16 - 30	31 - 46	47 - 62	5 - 10	11 - 16	17 - 21
5	16 - 32	33 - 49	50 - 64	9 - 12	12 - 15	15 - 19
6	30 - 39	40 - 49	50 - 60	9 - 13	14 - 18	19 - 23
7	38 - 44	45 - 51	52 - 58	10 - 14	15 - 18	19 - 22

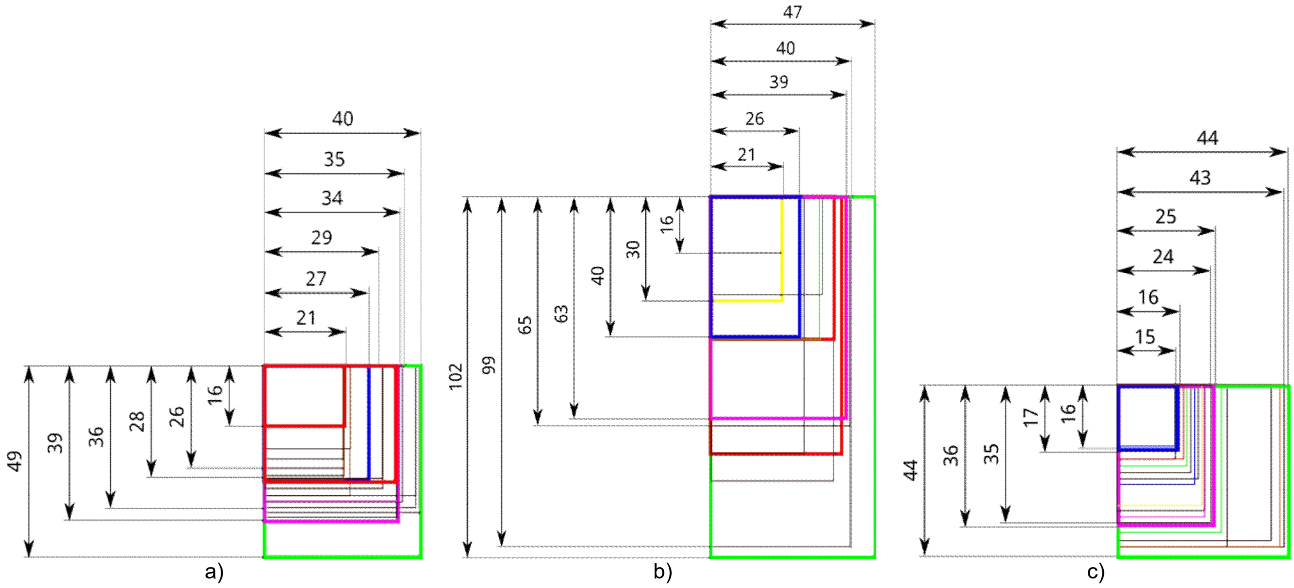


Figure 8 Graphic diagrams of reporting boundaries: a) group 1; b) group 3; c) group 5

To determine the proportionality of ornament parameters with details of clothing, the size of the report must be determined in units similar to the size of the design. For this, it is necessary to take into account the basic size of the cross for each canvas (Table 8) and the number of crosses in the report. According to these indicators, for each type of canvas, the basic reporting sizes (Equation 8) were calculated:

$$l_r^b = k \cdot l_x \cdot \tag{8}$$

where, l_r^b – the basic size of the report; k – number of CE in the report; l_x – basic dimensions of CEs [mm].

The results of calculating the baseline reports based on the warp and on the weft allow you to quickly navigate in determining the natural parameters of an arbitrary report on a given type of canvas.

Analyzing the existing assortment of canvas kinds [17, 18], it has been determined that for large reports it is expedient to use a canvas with a density of 100-70 cells per 10 cm that allows to obtain a CE size of 0.1-0.14 cm, for medium-sized reports - canopy density 65-50 cells per 10 cm with the size of CE 0.15-0.19 cm, for reports of small size - a canopy with a density of 30-50 cells per 10 cm with a size of CE 0.2-0.32 cm. So, the larger the number CEs in the report, the more dense canvas has to be selected for embroidery. This allows you to balance the natural sizes of various ornaments in a constant range of values, which is important for the range of clothing of a certain size-group and age-group.

Taking into account the above recommendations, the ranges of the ornament for the garment details, which are most often to be decorated (chemisette, collars and cuffs) (Table 8), are calculated.

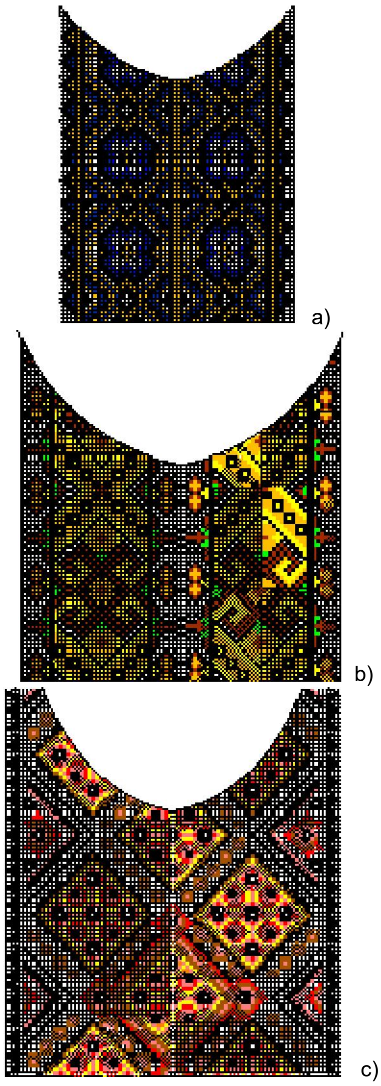


Figure 9 Variants of report sizes: a) small; b) medium; c) large

Table 8 Characteristics of the size of the report and the ornament

Report and Pattern Indicators	Number of CEs in the report [pcs]					
	chemisette			collar and cuff		
	Report Size Groups			Report Size Groups		
	small	medium	large	small	medium	large
Report size, quantity of CEs	15-25	25-35	35-45	10-15	15-25	25-30
Size of a CE [cm]	0.32-0.2	0.2-0.14	0.14-0.11	0.32-0.2	0.2-0.14	0.14-0.12
Ornament size [cm]	4.8-5.0	5.0-4.9	4.9-5.0	3.2-3.0	3.0-3.5	3.5-3.6

The basis of the formation of the configuration of the embroidery ornament is the affine transformations on the area [19]. Some of them are such transformations as displacement, tension-compression, turning. Affine transformations of an object on an area are described by a pair (Equation 9) provided that (10):

$$\begin{cases} X = A_x + B_y + C, \\ Y = D_x + E_y + F, \end{cases} \quad (9) \qquad \begin{bmatrix} A & B \\ C & D \end{bmatrix} \quad (10)$$

where *A*, *B*, ... *F* are constants; *x*, *y* are the coordinates of the transformation; *X*, *Y* are the new coordinates of points of objects.

The affine transformation called the direct shift (Figure 10) is described by the following equation (Equation 11).

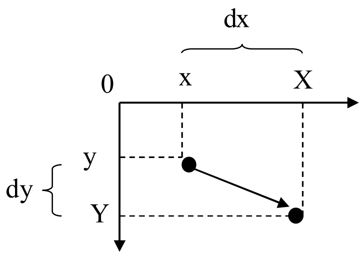


Figure 10 Affine transformation, shift

The inverse transformation allows you to calculate the previous coordinates of the points of objects by known new coordinates (Equation 12):

$$\begin{cases} X = x + dx, \\ Y = y + dy. \end{cases} \quad (11) \qquad \begin{cases} x = X - dx, \\ y = Y - dy. \end{cases} \quad (12)$$

In the matrix form, direct transformation (Equation 13), inverse (Equation 14):

$$\begin{bmatrix} 1 & 0 & dx \\ 0 & 1 & dy \\ 0 & 0 & 1 \end{bmatrix} \quad (13) \qquad \begin{bmatrix} 1 & 0 & -d\mathrm{x} \\ 0 & 1 & -dy \\ 0 & 0 & 1 \end{bmatrix} \quad (14)$$

Stretching - compression (Figure 11). This transformation can be called scaling.

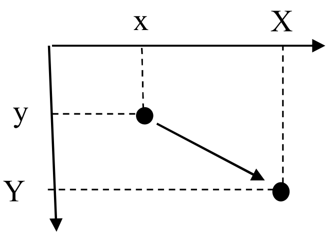


Figure 11 Affine transformation, tension – compression

Straight transformation (Equation 15), inverse (Equation 16):

$$\begin{cases} X = k_x x, \\ Y = k_y y. \end{cases} \quad (15) \qquad \begin{cases} x = X/k_x, \\ y = Y/k_y. \end{cases} \quad (16)$$

In the matrix form, straight transformation (Equation 17), reverse (Equation 18):

$$\begin{bmatrix} k_x & 0 & 0 \\ 0 & k_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (17) \qquad \begin{bmatrix} 1/k_x & 0 & 0 \\ 0 & 1/\mathrm{k_y} & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (18)$$

The rotation around the center of the coordinates (0.0) can be straight (Figure 12a) or inverse (Figure 12b).

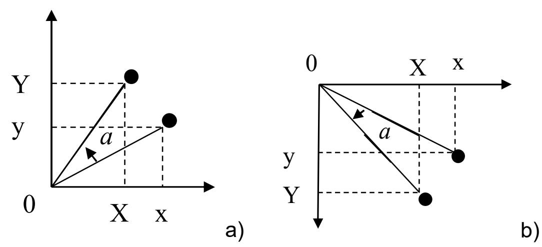


Figure 12 Affine transformation, turn of the object: a) straight; b) inverse

Formulas for the inverse transformation can be obtained if you imagine the rotation of the point with coordinates (*X*, *Y*) at the angle (-*a*).

Straight transformation (Equation 19), inverse (Equation 20). *I_n* a matrix form, a straight turn (Equation 21), an inverse (Equation 22).

$$\begin{cases} X = x\cos\alpha + y\sin\alpha, \\ Y = x\sin\alpha + y\cos\alpha. \end{cases} \tag{19}$$

$$\begin{cases} x = X\cos\alpha + Y\sin\alpha, \\ y = X\sin\alpha + Y\cos\alpha. \end{cases} \tag{20}$$

$$\begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{21}$$

$$\begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{22}$$

The considered variants of principles of creating embroidery ornaments allow to develop graphic schemes of their construction and to structure the composition of the ornament from its largest to the smallest parts and elements. The highest rank of the division is the composition of the ornament - the methods of arranging elements and modules (motives) on the area. Strapped rectilinear, curvilinear, carpet and other ornament compositions can be seen. The line composition has three variants: horizontal, vertical, and oblique (Figure 13) [20].

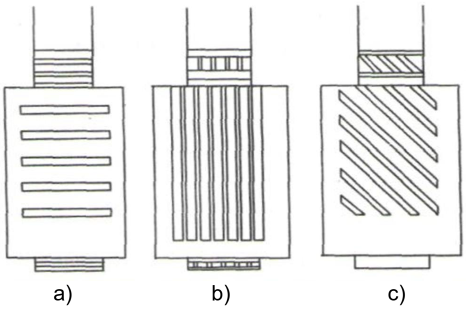


Figure 13 Line composition of the ornament on the sleeves of women's shirts: a) horizontal; b) vertical; c) oblique

In addition to line ornaments there are ornaments that fill the entire area, for example, a lattice ornament. It is placed on a conditional lattice with different forms of cells. In Ukrainian national clothes, lattice ornaments were used with certain restrictions. This is due to the structure of the fabric or canvas, which could not be located at an angle to the base and abb (Figure 14).

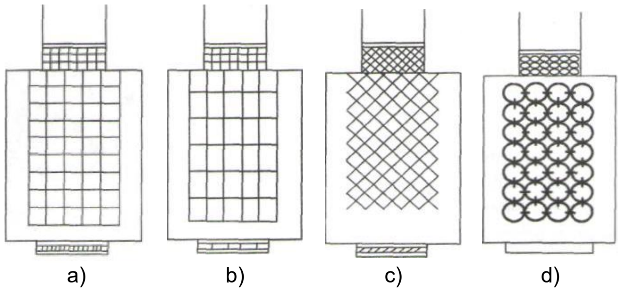


Figure 14 Systems of nodes of simple ornamental lattices on the sleeves of women's shirts in Podillya region: a) square; b) rectangular; c) rhombic; d) hexagonal

Simple lattices of ornament differ in the system of knots [21]. Accordingly, the patterns with the lattice structure of the composition can be grouped into types (Figure 15).

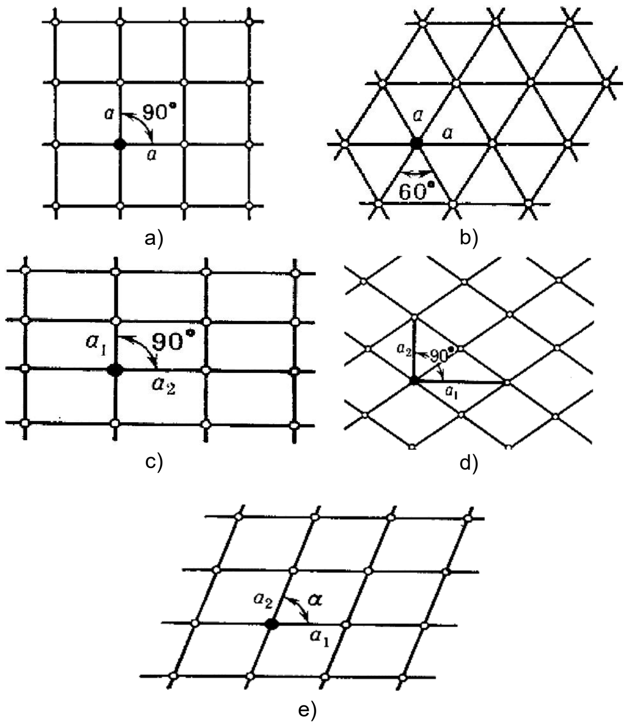


Figure 15 Types of two-dimensional lattices (grids) Brave: a) square; b) hexagonal; c) rectangular; d) rhombic; e) an oblique parallelogram

Different types of symmetry are used when creating line and lattice ornaments. In total there are 7 types of symmetry [22]. To create them we can use the following transformations: parallel transfer; mirror symmetry with vertical axis; mirror symmetry with horizontal axis and rotational (central symmetry) (Figure 16).

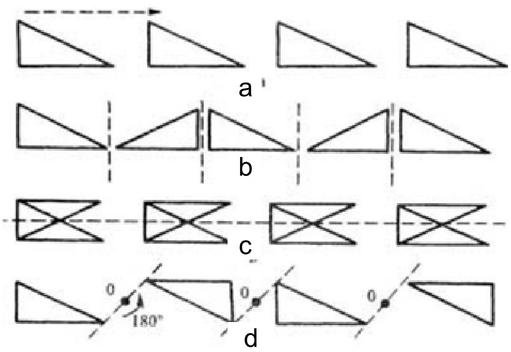


Figure 16 Conversion diagrams for creating line ornaments: a) parallel transfer; b) mirror symmetry with a vertical axis; c) mirror symmetry with a horizontal axis; d) rotating (central symmetry)

Of the 17 groups of symmetry of lattice ornaments [22], only 12 groups (Table 9) are used in Ukrainian national clothes.

5 RESULTS

Analysis of the internal filling of the typical basis of the pattern of the embroidery ornament indicates that within the base there is a repetition of the shape of the outer contour in smaller shapes that fill the foundation. On the basis of the similarity of the combination of the external and internal contours of the ornament, seven groups of typical patterns of decoration of the chemisette (Figure 17a) and 8 groups - the typical schemes of decoration of collar and cuffs (Figure 17b) are allocated.

The use of the method for selecting the dimensions of the CEs to the size of the parts, taking into account the size of the report, ensures a clear positioning of the beginning and the end of the ornament on the decoration area (Figure 18).

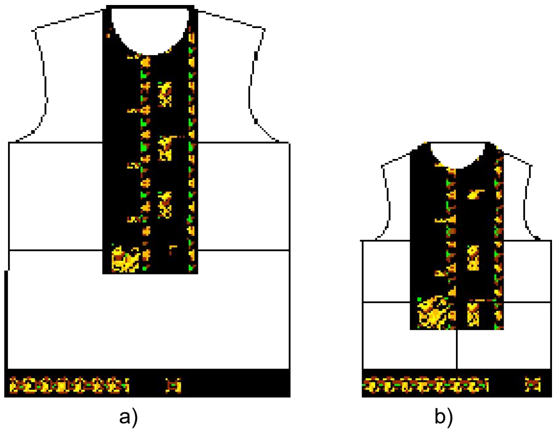


Figure 18 Positioning of the ornament on shirts-embroidered shirts: a) male; b) children's

Table 9 Symmetry groups of embroidery ornamentation taking into account Ukrainian national traditions

Code	Symmetry group	Code	Symmetry group
p1	Simple displacement	p2	Rotating to 1800
pm	Reflection	pg	Reflection with a shift
cm	Reflection + reflection and shift	pmm2	Reflection + reflection
pmg2	Reflection + rotating to1800	pgg2	Reflection with a shift + rotating to 1800
cmm2	Reflection + reflection+ rotating to 1800	p4	Rotating to 900
p4mm	Rotating to 900+ reflection to the angle of 450	p4gm	Rotating to 900+ reflection to the angle of 900

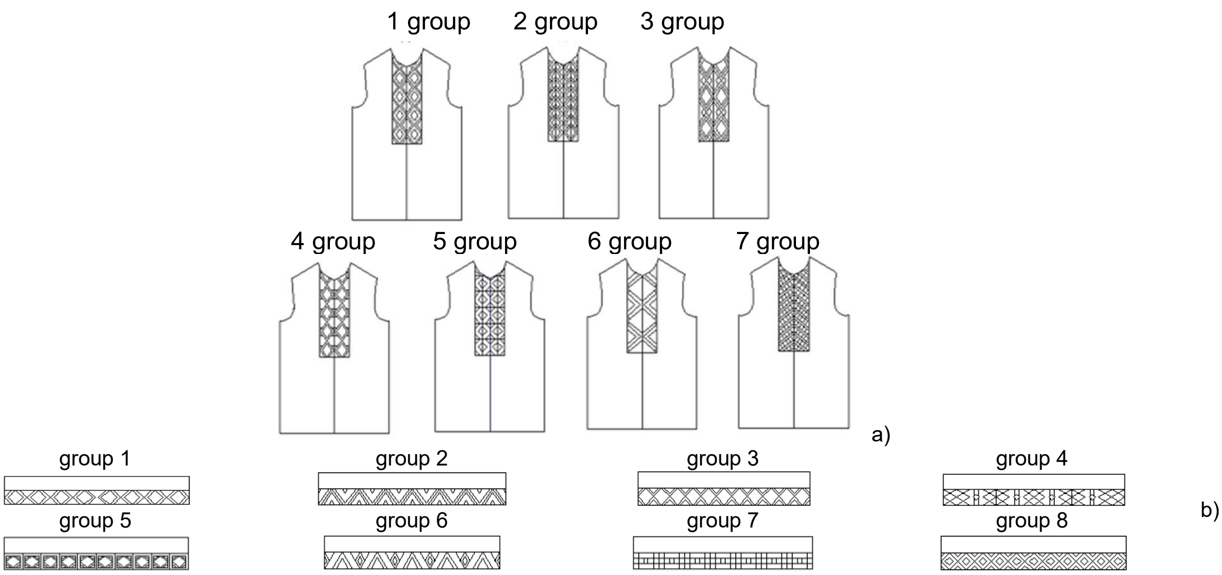


Figure 17 Typical structure of the base of the geometric ornaments of a man's shirt: a) chemisette; b) collar and cuffs

To fill the 3×2 ornament area (Figure 19), a graph *G* has been developed that contains n(*G*)=49 vertices and m(*G*)=48 edges. Figure 19 shows that (as in the case of one or two DCEs) the degree of all vertices (except the vertices of the beginning (*S*) and the end (*E*)) of the graph *G* is equal to two, since adjacent to each of them there are two vertices (located on the edges incident with it). This applies to all the graphs *G*, which can be formed, regardless of the number of DCEs and their relative position on the ornamental site [13].

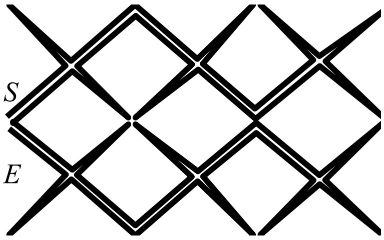


Figure 19 Scheme of rectangular area filling 3×2 DCEs

Proceeding from the definitions of Euler [23], if the graph has only two odd knots (the degree of vertices of the beginning graph (*S*) and the end (*E*) is equal to one), it can be traversed along a route that begins at one of these knots and ends in another (a route that starts in a paired knot cannot cover all knots). That is, it is theoretically possible to fill the arbitrary area of the DCE, (Figure 19). The roundabout can be done in one of two directions (depending on the location of the start of the roundabout). However, the beginning (end) of the bypass can be located in any of the corners of the square, which is described around an arbitrary DCE. If each of the centers of a DCE is denoted by one point and connected by ribs, the received subgraph *P* of graph *G* will be the graph of the machine (Figure 20). This graph allows to simplify the filling of the DCE of any part of the embroidery ornament.

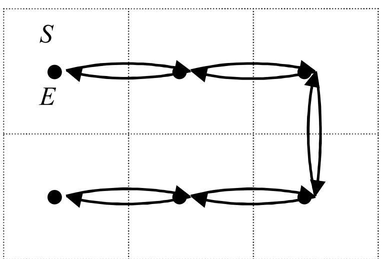


Figure 20 The graph of the machine for filling the rectangular area 3×2

Let us consider the Euclidean space, which is a two-dimensional Cartesian coordinate system and an integer-lattice Z^2 in it. Elements (*x, y*) of the Z^2 set are marked with *v*. We will call the number $\rho(v, v')=|x-x'|+|y-y'|$ - the distance between $v=(x, y)$ and $v'=(x', y')$. We call the elements *v* and *v'* adjacent if the distance between them corresponds to the inequality $1\geq\rho(v, v')<2$. Let $B=\{e, k, l, m, n, r, s, w\}$ be the alphabet of the arc marks (Figure 21).

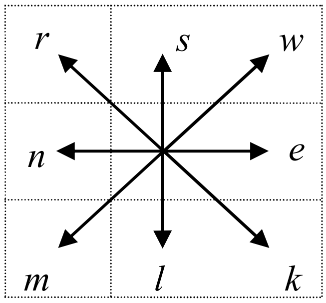


Figure 21 Marking the arcs of a mosaic graph in accordance with their direction

The graph $L=(V, E, a, b)$ (Figure 21) is called a planar non-oriented finite bound graph in which the set of vertices *V* is a subset of Z^2, *E* is the set of arcs, $a{:}v\in V\rightarrow a\in A$ - vertex markup function, $b{:}(v, v')\in E\rightarrow b\in B$ - arc markup function. Through $|L|$ the number of vertices of the graph *L*. is denoted. For any vertex *v*, $E(v)$ denotes the set of all arcs output from it. A circle with a center at the vertex *v* is called the set $K1(v)=\{v'|v'\in Z^2,\ 1\geq\rho(v,v')<2\}$. The domain $O(v)$ of the vertex $v\in V$ is called the set of vertices adjoining it with $K_1(v)$. The arcs (*v, v'*) and (*v', v*) of the marked graph are called opposite.

The graph *L* is mosaic, its arcs can be parallel or at an angle of 45° to the coordinate axes. Only neighboring peaks can be connected by arcs, the vertices of the top contain marks of all arcs coming out of it (Figure 22).

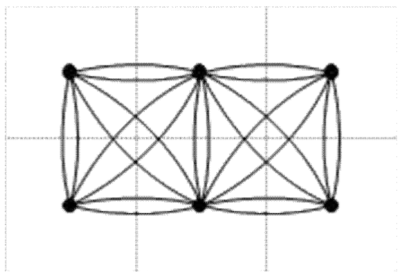


Figure 22 A mosaic graph for a fully filled area of 3×2

The symbol *b* from the mark of vertex *v* of the mosaic graph *L* indicates *v'* to the vertex *v* from the set Z^2 if the vertices *v* and *v'* can be connected by an arc with the direction *b*.

The mosaic graph $L=(V, E, a, b)$, in which the vertex is a plurality of marks of all the arcs coming out of it, is called a graph of a labyrinth or labyrinth.

In searching for route *p*, numerical coding is adopted. Then, *B*={1, 2, 3, 4, 5, 6, 7, 8} is an alphabet of arc marks, and the route *p* corresponding to the graph of the automaton *P* (Figure 19) can be written *p*=5, 5, 3, 1, 1, 5, 5, 7, 1, 1.

For the development of programme module (PM) and automation of the process of decorating with ornaments of embroidery, a mathematical model with the use of graph theory has been developed.

The creation of ornamental stripes was done using the Inkscape program. Each symmetry group is associated with its visual perception, which is illustrated in the example, the application of a single elementary figure according to Table 9 (Figure 23).

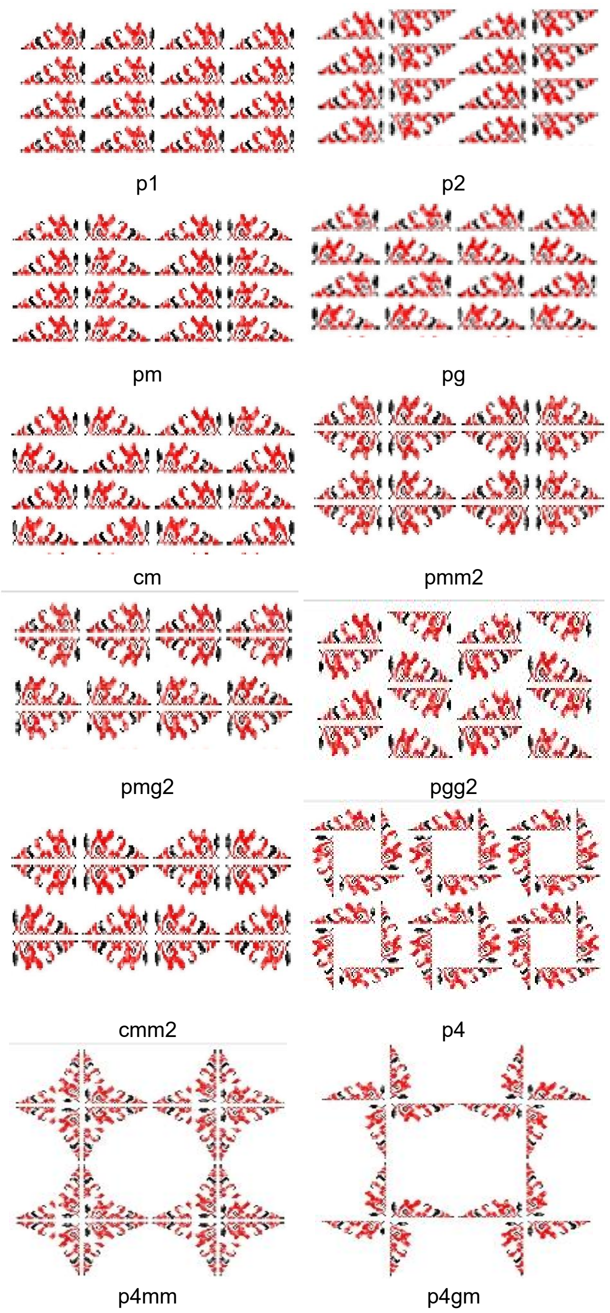


Figure 23 Types of lattice ornaments created with the help of PM "Inkscape" taking into account Ukrainian national traditions

Photographic images of embroidery ornaments are shown on Figure 24.

Figure 24 Photographic images of embroidery ornaments made DCEs

6 CONCLUSIONS

In determining the effectiveness of the methodology for calculating the parameters of the ornament (a group of reports, decoration areas, symmetry laws, the route of a mosaic graph), which flows from the levels of the ethno design component (Figure 1), it is logical to use software engineers in the machine embroidery that use the algorithm for filling ornamentation of DCEs without stitching transition. It should be noted that this method does not explain the mechanism of selecting rational parameters of the density of the report in repetitions in the area of decorating. In this sense, it is advisable to employ a method for selecting rational parameters of the canvas density relative to the parameters of the ornament. To prove this assertion, a method for scaling the CEs according to the characteristics of the canvas groups is proposed (Table 6). The description of the segmentation of the size of the ornament by the reports groups in the channel of the canvas density gives the possibility of affine transformations of the ornament on separate parts of the product on the principle of a triptych. This does not diverge from the practical data known from the works [14, 16, 24], which correspond to the transformation schemes in the symmetry groups. The optimal compositions of ornaments (Figures 13 and 14), in contrast to the results of studies published in [25-27], allow the following to be stated:

- the main regulator of choosing the parameters of the ornament for decoration of parts is not so much the complexity of the composition, as the density of the canvas, as a prototype of the grid;
- for a large group of reports, it is expedient to use canvas № 25-32, for medium-sized reports - canvas № 16-22, for reports of small size - canvas № 8-14. This allows you to balance the natural sizes of various ornaments in a constant range of values, which is important for the range of clothing of a certain size-age purpose.

The structuring of the outer contour through the internal contour of the report on the principle of parallel transport for the formation of a lattice kind of ornament has a substantial influence on the internal filling of the typical basis of the embroidery ornament.

In some types of ornament, the construction of its basis is performed by parallel displacement of the same report along the transfer axis; in other ones a parallel transfer with a stretch of report along the transfer axis is used.

Such conclusions can be considered expedient from a practical point of view, as they allow to reasonably approach to the choice of graphic editor of the software module of embroidery.

Graphic editor of Draw Ltd. allows you to create and check the quality of the location of embroidery ornaments, contours of which correspond to contours of parts of garments.

From a theoretical point of view, using a mosaic graph of filling an ornamentation area [23], which depends on the location of the DCEs, their number and location of the beginning (end) of the roundabout of the graph of the graph is difficult to accomplish without automation since it is necessary to perform certain actions clearly: to determine the size and forms of arbitrary sections filled with one color; formation of DCEs clockwise; the transition between isolated DCEs (which do not bind to each other at one point) and others.

The proposed technique of the technological aspect of embroidery involves the possibility of obtaining the parameters of the ornament with the prediction of their conformity to the parameters of the parts or separate areas of decorating directly before the process of embroidery. This greatly reduces the time spent on the production of original patterns of clothing and increases its aesthetic quality in general.

However, it is impossible not to claim that the principle of the triptych in the information function of the emblem symbolism depends on the sex-age characteristics of the product and indicates the ambiguous effect of the scaling of the report. Such uncertainty imposes certain limitations on the use of software modules, which can be interpreted as a lack of this study. Potentially interesting direction of further research can be focused on the capsular approach to the design of assortment complex in the wardrobe of an ethnically oriented group of consumers.

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DESIGNING OF SPECIAL CLOTHING BASED ON EXPERIMENTAL RESEARCHES OF MATERIAL PROPERTIES

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Abstract: *The article presents the results of experimental researches on determination of thermal and physical characteristics of thermal insulating materials using the principle of spatial three-dimensional presentation of the study object with distributed parameters. The proposed method of research and obtained experimental results provide an opportunity to determine thermal and physical properties of materials with high accuracy, which creates the conditions for improvement of the quality of special clothes designing.*

Key words: *high temperature environment, thermal insulating materials, temperature conductivity coefficient.*

1 INTRODUCTION

The performance of works in unfavorable conditions always requires the use of special clothes. Integrated design approach consists in the development of special clothes with increased operational, hygienic and aesthetic indicators, as well as in the development of design and technological solution that would provide the highest possible level of worker`s protection and at the same time meet the ergonomic requirements for this product.

Scientific developments in the field of special clothes designing, and the growing consumers` demands on the quality of products and their appearance, all the above set more and more complicated tasks for the designers of the clothes. Development and creation of new sets of specials clothes require integrated design and technological solution for its components, taking into account protective properties, ergonomic and aesthetic indicators [1].

Materials used in the manufacturing of heat-protective clothing protect against radiation and convection heat, as well as against open flame impact [2]. Generalized classification of materials is provided in Figure 1: for the intended purpose they are divided into thermal flame proof materials (for outer layers), thermal insulating materials (for inner layers) and lining materials.

It is known [2-6] that thermal insulating layer (non-woven textile material) plays a significant role in increase of the protective properties of the products aimed to protect against the influence of high temperature environment. Non-woven textile material is a textile fabric, obtained from one or several layers of textile materials, as well as their combination with non-textile materials, fastened together in different ways. The following materials can serve as the basis for non-woven textile materials, namely: fibrous covering, system of threads, fabrics, knitted fabrics, tapes and other framework structures. Threads, fibers and various adhesive components can be used as base fasteners.

By the way of production, non-woven materials can be divided into covering-stitched, thread-stitched, framework-stitched, needle-punched, glued and composite materials. Formation of covering is made in different ways: using the sew-knitted and needle-punched technologies. The sew-knitted technology is used in the production of non-woven fabrics, made by knitting with threads (yarn) or fibers of the most fibrous covering (covering-stitched), threads (thread-stitched), textile fabrics, tapes, nets, etc. (framework-stitched), with the formation of loops of threads or fibers (needle-punched). Therefore, covering-stitched, thread-stitched and framework-stitched methods of production are distinguished.

Needle-punched non-woven fabrics are made by piercing the fibrous covering with special needles, entangling and sealing of fibers on needle-punched machines [2].

Considering raw material composition, non-woven materials are subdivided depending on the type of fibers, from which they are made. A wide range of non-woven thermal insulating materials includes half-wool, cotton, synthetic wadding pads of heat-resistant fibers, knitted half-wool wadding pads, needle-punched half-wool and synthetic fabrics.

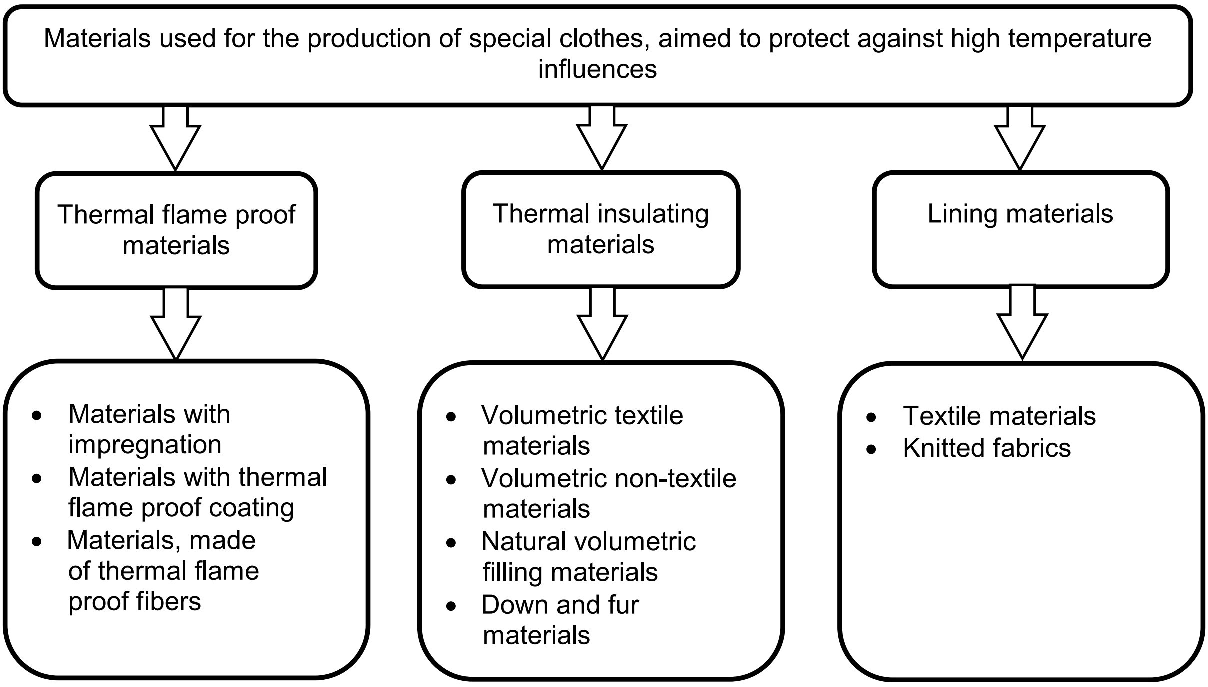


Figure 1 General classification of materials used for production of means of hands protection against high temperature influences

When designing special clothes, in order to get the predicted properties, it is necessary to know basic thermal and physical indicators of the materials, from which the package of the clothes is made. Therefore, the object of the research is thermal insulating materials, used in the production of special protective clothes, with unknown thermal and physical characteristics. Selection of appropriate materials in the process of designing new types of special clothes necessitates experimental researches on their thermal and physical properties using the methods and devices that provide high accuracy of measurements. The research method is proposed, based on the simulation of dynamic processes in the objects with distributed parameters. Thermal insulating materials, namely volumetric non-woven materials, are selected for the further research. The main criterion in the selection of thermal insulating materials for special clothes against high temperature influences is the determination of materials thermal characteristics because only the knowledge of these properties provides an opportunity to design the means with the maximum degree of protection. However, when designing and developing special clothes, physical and mechanical characteristics of thermal insulating material cannot be neglected. Thus, the material with shallow thickness and density and with a small coefficient of thermal conductivity can be considered as the best thermal insulating material [3-7].

2 EXPERIMENT PLANNING

The velocity of propagation of heat transfer in the process of heating of the fabric, and the gradients of fixed temperature of the layers of clothes, designed to work in high temperature conditions, both are completely determined by temperature conductivity of the fabrics. The development of the method of experimental determination of temperature conductivity of various materials, which provides the opportunity to make grounded decisions during the special clothes designing and to predict its properties, is an important task at the design of special clothes.

The aim is achieved by the fact that the package of materials with unknown thermal and physical characteristics is researched as a three-dimensional object with distributed parameters. In spatial objects with distributed parameters, the coordinates of the state gradually change over time along certain spatial coordinates. The modeling of technological objects with such parameters is possible considering the directions of change of the state coordinates. Mathematical modeling of objects with distributed parameters is related to certain spatial systems of coordinates, in which the object of modeling is located in accordance with the directions of key parameter changes [7-9].

In different layers of the package of fabrics, the temperature is a function of not only time, but also geometric coordinates of the considered layer. In this regard, it should be taken into account that the boundary conditions are the necessary elements of the models of objects with spatial distribution of influencing parameters.

The mathematical model of such an object in dynamics is a differential equation in partial derivatives. Material mathematical modeling of this category of objects with the use of electronic computing machines is associated with significant programming complexities [7-10]. That is why an approximate replacement of objects with distributed parameters by a certain set of objects with lumped parameters, which can be described using the scheme of ordinary differential equations, is widely used.

The velocity of propagation of heat transfer in a three-dimensional environment, the temperature conductivity coefficient of which is *a*, in time *t* in coordinates *X, Y, Z,* is described by the Fourier equation, which in the three-dimensional environment is as follows:

$$\frac{\partial T(t,X,Y,Z)}{\partial t} = \alpha\left(\frac{\partial^2 T(t,X,Y,Z)}{\partial X^2} + \frac{\partial^2 T(t,X,Y,Z)}{\partial Y^2} + \frac{\partial^2 T(t,X,Y,Z)}{\partial Z^2}\right) \tag{1}$$

For the experimental studies of thermal and physical properties of fabrics, the samples of fabrics are used, the length and width of which are considerably larger than their thickness, because the transfer of the heat in real conditions takes place through the thickness of the package. As a result, we can consider:

$$Z = \infty;\ X = \infty \tag{2}$$

If we study the temperature change in the separate layers of the package of fabrics, then the Y_i coordinate may take the value $Y_i = ih$, that is:

$$Y_1 = h;\ Y_2 = 2h;\ Y_3 = 3h;\ \text{etc.} \tag{3}$$

If the *Y* spatial coordinate is fixed, then the Fourier equation for each layer of the package of fabrics has the form of ordinary derivatives:

$$\frac{dT_i(t)}{dt} = \alpha\frac{d^2T_i(t)}{dY^2},\ i = 1 \ldots N-1 \tag{4}$$

where, *i* - serial number of the package layer; *N* - number of layers of the investigated fabric; $T_i(t)$ - change of the temperature of *i* layer of the package in time.

Distribution of temperature in separate layers of fabric causes the transformation of mathematical description of temperature field as a continuous function into a lattice function, the value of which exists only for fixed values of *Y* coordinate. This causes the need to replace ordinary derivatives by finite differences.

During the experiments, when forming the required volume (array) of data, determination of the results of experiment is possible only for fixed moments of time, so the nature of temperature change as a continuous time function should be replaced by the function of discrete time t_n with a constant step of quantization τ_κ:

$$\tau_\kappa = t_n - t_{n-1}. \tag{5}$$

where, n = 0; 1; 2…; τ_κ - step of quantization of time; t_n and t_{n-1} - the values of t_n and t_{n-1} discrete moments of time.

The left side of the Fourier equation can be replaced by finite differences:

$$\frac{dT_i(t)}{dt} \approx \frac{1}{\tau_K}\left(T_i(t_{n+1}) - T_i(t_n)\right) \tag{6}$$

An analogue of the second derivative, on the right side of the Fourier equation, can be obtained by replacing the differential of the continuous function and its argument with the corresponding increment.

Direct difference of the first order, as an analogue of the temperature differential along the *Y* coordinate, is a temperature difference between *i* and *(i+1)* layers of the fabric:

$$\begin{aligned}\Delta T_i(t) &= T_{i+1}(t) - T_i(t) \approx dT_i(t)\\ \Delta T_{i-1}(t) &= T_i(t) - T_{i-1} \approx dT_{i-1}(t)\end{aligned} \tag{7}$$

Direct difference of the second order of the temperature in *n* moment of time along the *Y* coordinate can be considered as the difference between the finite differences of the first order:

$$\begin{aligned}\Delta^2 T_i(t_n) &= \Delta T_i(t_n) - \Delta T_{i-1}(t_n) = T_{i+1}(t_n) - \\ &- T_i(t_n) - T_i(t_n) + T_{i+1}(t_n) = \\ &= T_{i+1}(t_n) - 2T_i(t_n) + T_{i+1}(t_n) \approx d^2T_i(t_n)\end{aligned} \tag{8}$$

Second-order differential

$$dY^2 = h^2 \tag{9}$$

Taking into account the necessity of formation of data array as a set of values of variables, when conducting experimental researches, the second derivative, which is on the right side of the Fourier equation, should be replaced by the finite difference of the second order.

Taking into account (6, 8) and (9), the equation (4) takes the form:

$$\frac{1}{\tau_K}\left(T_i(t_{n+1}) - T_i(t_n)\right) = \frac{\alpha}{h^2}\left(T_{i-1}(t_n) - 2T_i(t_n) + T_{i+1}(t_n)\right) \tag{10}$$

where, $T_i(t_n)$ - the temperature in *i* layer of fabric in *n* moment of time; $T_i(t_{n+1})$ - the temperature in *i* layer of fabric in *(n+1)* moment of time; $T_{i-1}(t_n)$ - the temperature in *(i-1)* layer of fabric in *n* moment of time; $T_{i+1}(t_n)$ - the temperature in *(i+1)* layer of fabric in *n* moment of time.

Whereof:

$$\mu = \frac{\left(T_i(t_{n+1}) - T_i(t_n)\right)}{\tau_K\left(T_{i-1}(t_n) - 2T_i(t_n) + T_{i+1}(t_n)\right)} \tag{11}$$

As a result of transformation (10, 11), we obtain the formula for calculating the temperature conductivity coefficient of α fabric:

$$\alpha = \frac{h^2\left(T_i(t_{n+1}) - T_i(t_n)\right)}{\tau_K\left(T_{i-1}(t_n) - 2T_i(t_n) + T_{i+1}(t_n)\right)} \tag{12}$$

Thus, the determination of the temperature conductivity coefficient comes down to its calculation, using the formula (12), inserting the instantaneous values of the temperatures in three adjacent layers of the packages of clothes with predicted thickness of the package *h* (T_{i-1}, T_i, T_{i+1}) at the previous moment (t_n) and at the moment after the interval τ_K (t_{n+1}).

The proposed method of studying thermal and physical properties of fabrics has a lot of significant advantages, which lie in the fact that the determination of thermal and physical values takes place in dynamic process of distribution of heat transfer in the layers of the package of materials; the received formula eliminates the possibility of significant additive and multiplicative measurement errors. It can be stated that the proposed method of research allows determining different thermal and physical properties of the fabrics with high accuracy when using modern means of microprocessor and computer technologies, thus creating the conditions for improving the quality of special clothes designing.

3 RESULTS AND DISCUSSION

The conducted analysis of modern thermal insulating materials used for production of means of hands protection against high temperature influences has proven that the following packages of materials should be used in the research: (TEX-1) – covering-stitched woolen wadding pads (Ukraine), thickness of the layer of material *h* = 6 mm; (TEX-2) – thread-stitched woolen-phenylene wadding pads (Ukraine), thickness of the layer of material *h* = 5 mm; (TEX-3) – needle-punched sheet, made from oxalone fibers (Russia), thickness of the layer of material *h* = 2.75 mm; (TEX-4) – needle-punched sheet, made from Nomex meta-aramid fibers (DuPont, Switzerland), thickness of the layer of material *h* = 3 mm; (TEX-5) – non-woven sheet, made from phenylene fibers (Russia), thickness of the layer of material *h* = 3 mm.

Temperature conductivity coefficient of the materials has been determined in the training laboratory of Kyiv National University of Technologies and Design on the results of unsteady distribution of the temperatures in separate layers of the package in the process of heating and cooling of the package [11].

Therefore, the results of determination of temperature conductivity coefficient as an object parameter due to the algorithm, based on formula (12), do not depend on the initial and boundary conditions of the experiments. However, in order to confirm such a hypothesis, the evaluation of repetition of experiment results, as well as the determination of the most reliable value and confidence range of the values of temperature conductivity coefficient of the selected samples of materials were repeatedly carried out in two different modes in selectable initial and boundary conditions. The first mode consisted of heating of pre-cooled package, the second mode, vice versa, consisted of cooling of pre-heated package.

Figures with even numbering (Figures 2 - 20) present the curves of unsteady distribution of the temperature field in the layers of the investigated packages of materials in two modes (heating and cooling). Each curve shows each column of a five-dimensional array of a corresponding table, which is considered as a data series. Series 1, 2, 3, 4 correspond to the temperatures, measured by the channels of the module under the ordinal numbers 0, 1, 2, 3, which coincides with the number of the layer in the package.

Figures with uneven numbering (Figures 3 - 21) present the results of calculation of temperature conductivity coefficients of the packages of corresponding materials, using (12). The calculations are performed, taking *i* = 2, since the temperature, measured by the channel 2 of the module, is the temperature of the flatness, equally-spaced from two surfaces of heat-exchange capacities.

During the analysis of the curves of heating of the package layers, provided in Figure 2, stochastic oscillations, imposed on the growing curves, have been revealed, which cause more significant fluctuations in the values of temperature conductivity coefficient, calculated by the formula (12) and represented as a dotted line in the Figures 3 and 4 and require approximation of the obtained dependencies. The result of approximation of the function of dependence of the temperature conductivity coefficient on the relative time, the polynomial of the second order, demonstrates that there is a certain transition process, after the end of which the fixed value of the desired indicator $a_m = 5.1 \times 10^{-7}$ m^2/s is set.

The graph of cooling of the same package (Figure 4), as in the case of heating, shows the characteristic non-matching of the curves of heat changes in the inner layers, symmetrically relative to the middle layer, which is caused by the presence of convectional method of heat transfer over the thickness of the package during the experiment. The function of the change of temperature conductivity coefficient in the relative time, calculated and approximated by the corresponding polynomial (12), gives a fixed value $a_m = 5.05 \times 10^{7}$ m^2/s and indicates a high degree of repeatability of the experiment results, performed in different modes.

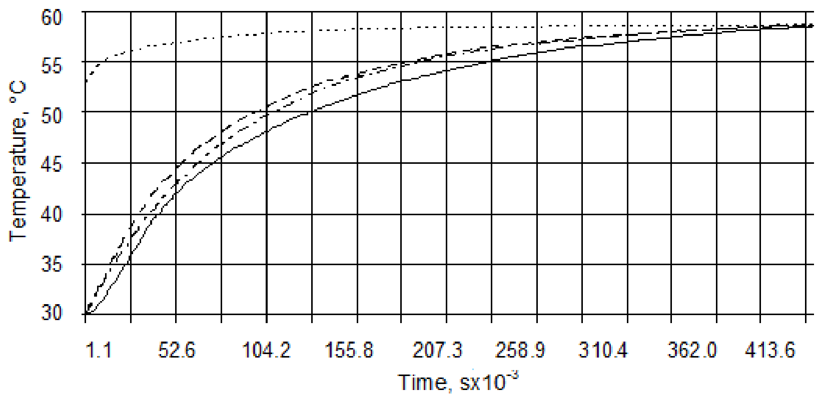


Figure 2 Curves of distribution of the temperature field in the TEX-1 package (heating mode)

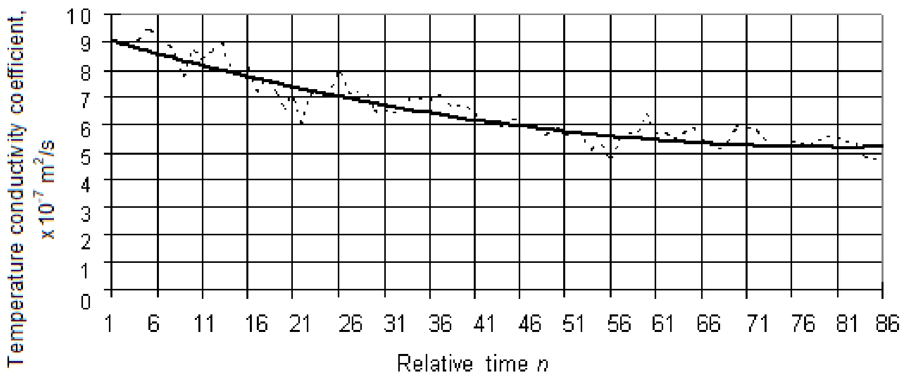


Figure 3 Approximated dependence at determining the temperature conductivity coefficient in the TEX-1 package

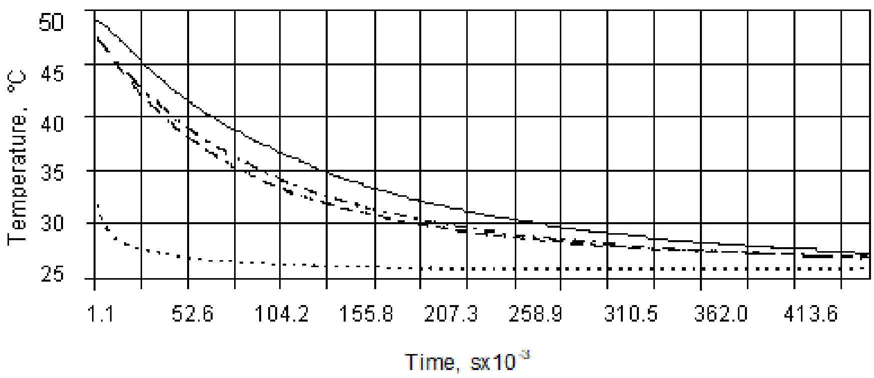


Figure 4 Curves of distribution of the temperature field in the TEX-1 package (cooling mode)

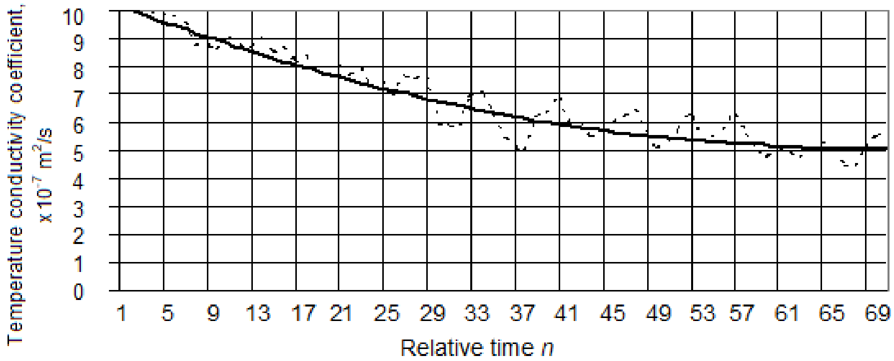


Figure 5 Approximated dependence at determining the temperature conductivity coefficient in the TEX-1 package

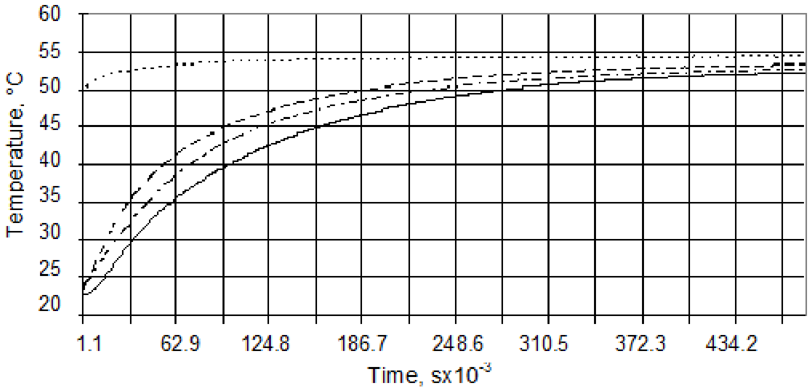


Figure 6 Curves of distribution of the temperature field in the TEX-2 package (heating mode)

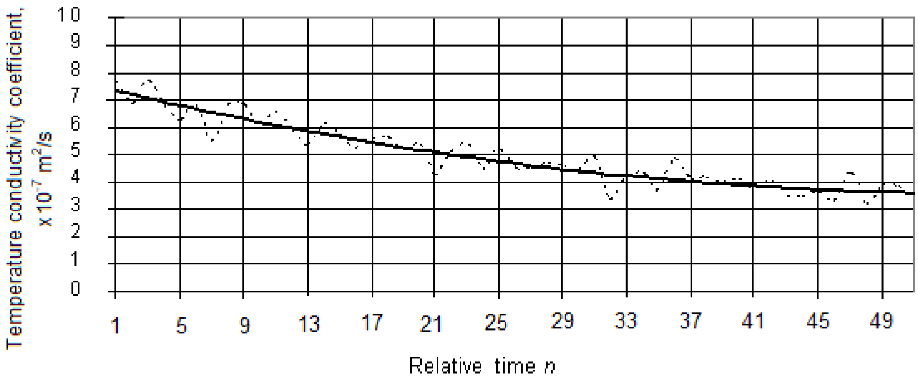


Figure 7 Approximated dependence at determining the temperature conductivity coefficient in the TEX-2 package

Analyzing the curves of total time of heating to the fixed value (TEX-2 and TEX-1 packages, Figures 6 and 2), its small difference can be noted. But considering the smaller thickness of the layers of TEX-2 package in comparison to TEX-1 package, there is a general assumption that the TEX-2 package temperature conductivity coefficient is smaller than the TEX-2 package temperature conductivity coefficient. The graph, provided in Figure 7, completely confirms this assumption, according to which the fixed value is $a_m = 3.7\times10^{7}$ m^2/s. Approximated superficial analysis of the curves of cooling of TEX-2 and TEX-1 packages, as provided in Figures 8 and 4, causes analogous assumptions, as in the case of heating of the packages, that the temperature conductivity coefficient in the TEX-2 package should be smaller than in the TEX-1 package. Figure 9, which illustrates the results of determination of specified thermal and physical parameter of the material, indicates that the fixed value of the temperature conductivity coefficient is 3.6×10^{-7} m^2/s and is slightly differ from the result, obtained during the heating of the package.

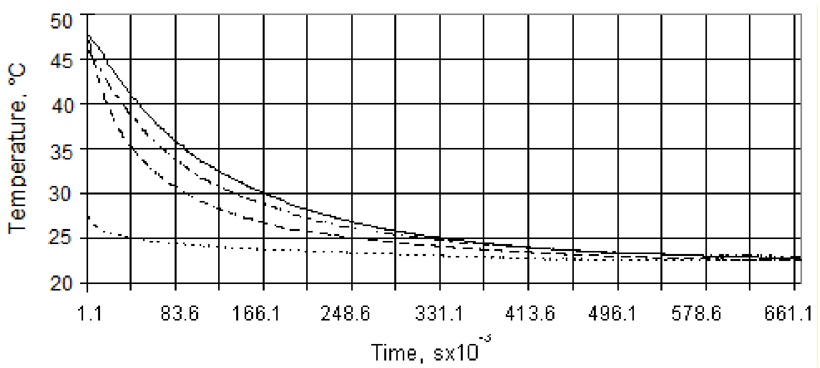


Figure 8 Curves of distribution of the temperature field in the TEX-2 package (cooling mode)

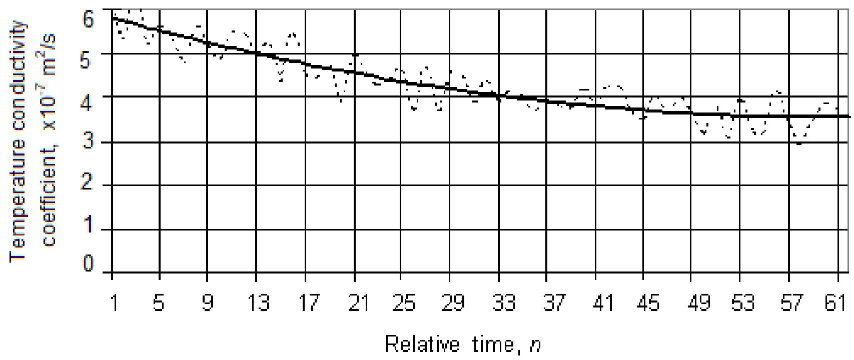


Figure 9 Approximated dependence at determining the temperature conductivity coefficient in the TEX-2 package

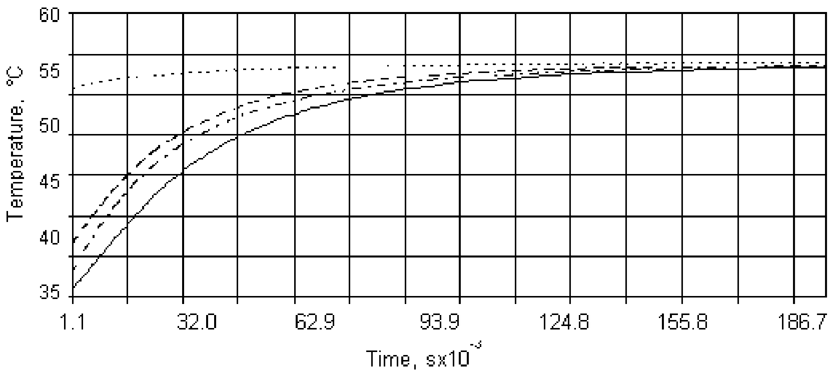


Figure 10 Curves of distribution of the temperature field in the TEX-3 package (heating mode)

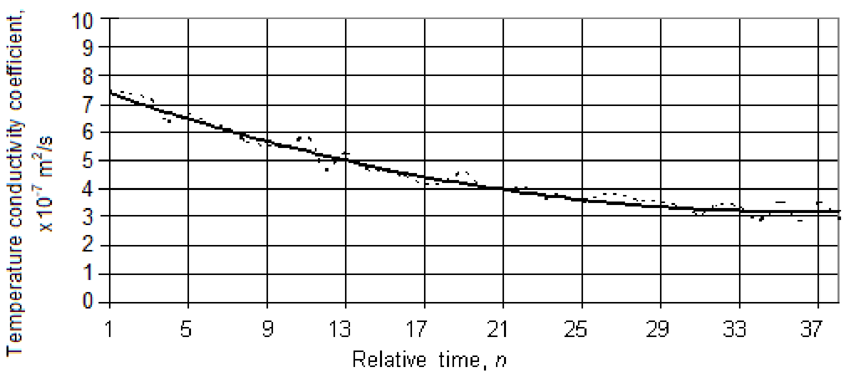


Figure 11 Approximated dependence at determining the temperature conductivity coefficient in the TEX-3 package

Since the thickness of the TEX-3 package is almost twice less than the thickness of the TEX-1 and TEX-2 packages, the comparative analysis of the curves of heating, provided in Figures 10, 6 and 2, do not provide an opportunity to make previous assumptions regarding the values of temperature conductivity coefficients. Analyzing the diagram of changes of this parameter (Figure 11), we can conclude that the material in the TEX-3 package has a fixed value of the temperature conductivity coefficient, equal to 3.2×10^{-7} m^2/s, that is 1.6 times smaller than in the TEX-1 package and 1.2 times smaller than in the TEX-2 package.

In the cooling mode (Figure 12), as well as in the heating mode, it is impossible to make previous assumptions regarding the value of temperature conductivity coefficient for the TEX-3 package due to the above motives. It can be noted that the value of temperature conductivity coefficient in the cooling mode (Figure 13) $a_m = 3.1 \times 10^{-7}$ m^2/s, slightly deviates from the coefficient value, obtained in the heating mode.

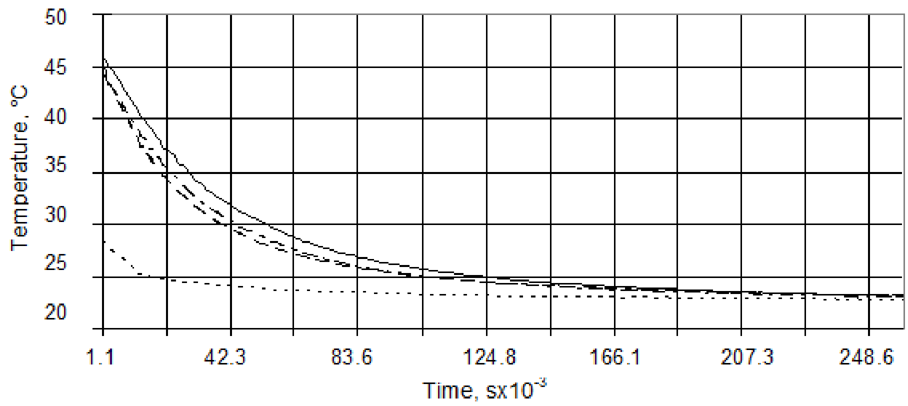


Figure 12 Curves of distribution of the temperature field in the TEX-3 package (cooling mode)

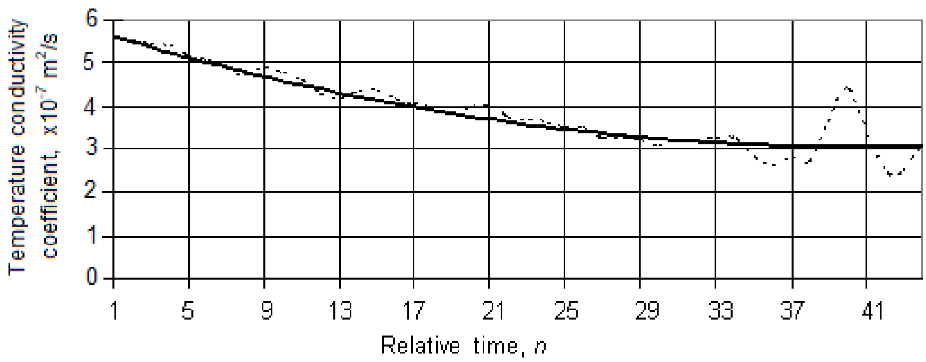


Figure 13 Approximated dependence at determining the temperature conductivity coefficient in the TEX-3 package

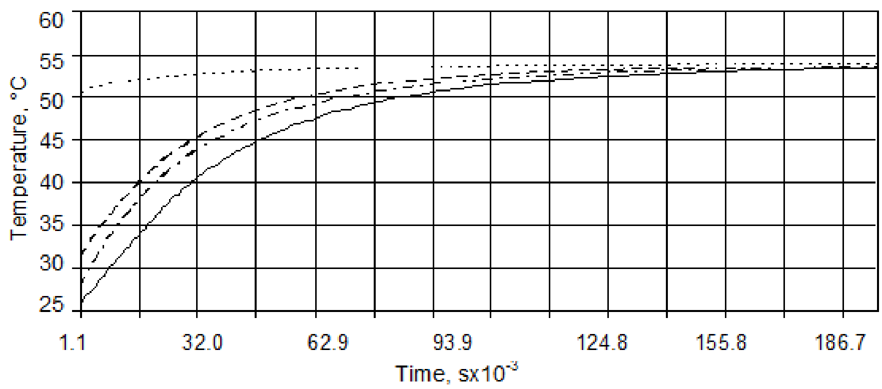


Figure 14 Curves of distribution of the temperature field in the TEX-4 package (heating mode)

Comparing the curves of the temperature change during the heating of the TEX-4 package (Figure 14) with the corresponding graph for the TEX-3 package, it is possible to note almost the same time of completion of the transition process. Considering that the thickness of each layer of the TEX-4 package is bigger than of the TEX-3 package, it can be presumably assumed that the TEX-4 package temperature conductivity coefficient should be greater. This assumption is confirmed by a graph (Figure 15), according to which the fixed value of the temperature conductivity coefficient is 3.7×10^{-7} m^2/s.

Comparative analysis of the curves of cooling of the TEX-4 (Figure 16) and the TEX-3 packages (Figure 12), taking into account the thickness of the packages, makes it possible to draw a preliminary conclusion that the value of temperature conductivity coefficient of the TEX-4 package is bigger. The result of the determination according to the curve (Figure 17) confirms the preliminary conclusion, since the temperature conductivity coefficient equals to 3.6×10^{-7} m^2/s.

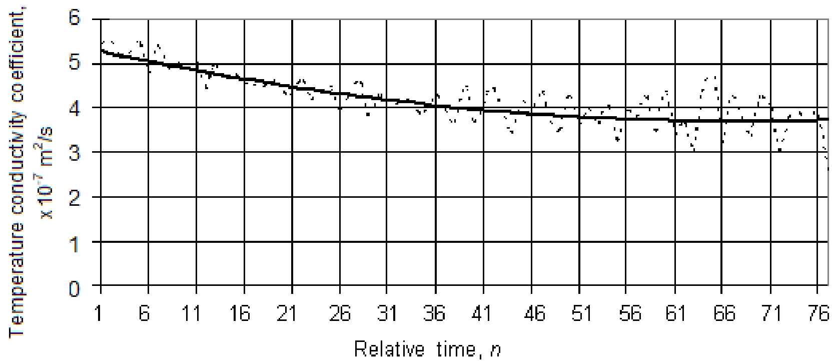


Figure 15 Approximated dependence at determining the temperature conductivity coefficient in the TEX-4 package

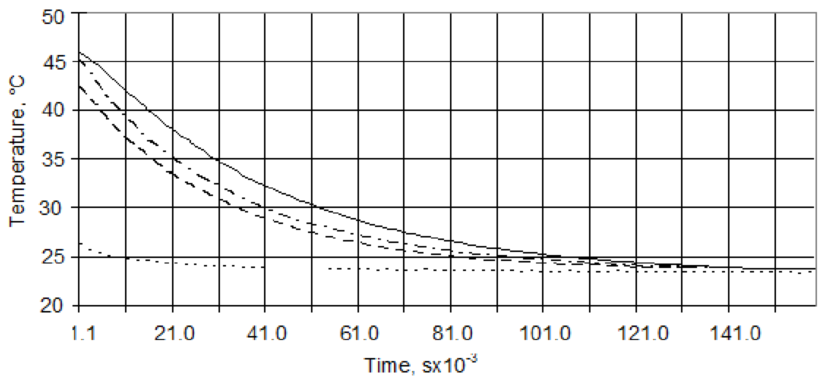


Figure 16 Curves of distribution of the temperature field in the TEX-4 package (cooling mode)

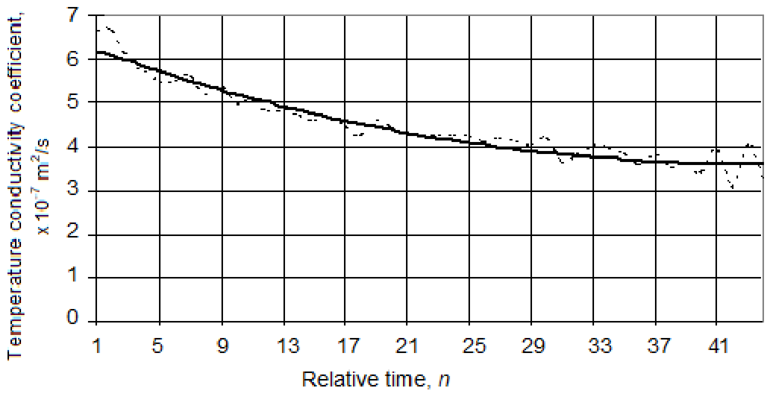


Figure 17 Approximated dependence at determining the temperature conductivity coefficient in the TEX-4 package

Superficial comparative analysis of thermal and physical properties of the materials in the TEX-4 and the TEX-5 packages is simplified by the fact that the layers of the packages have the same thickness. In such a case temperature conductivity coefficient is greater for the material, the package of which warms up to the established mode faster. In accordance with Figures 14 and 18, the material of the TEX-5 package is such material. The value of coefficient, as provided in Figure 19, is 4.6×10^{-7} m^2/s.

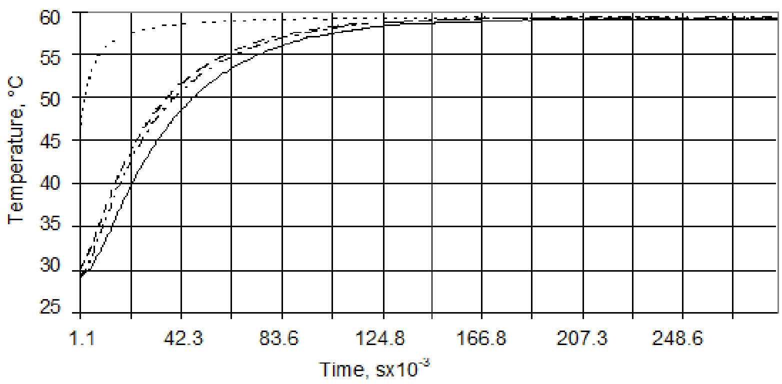


Figure 18 Curves of distribution of the temperature field in the TEX-5 package (heating mode)

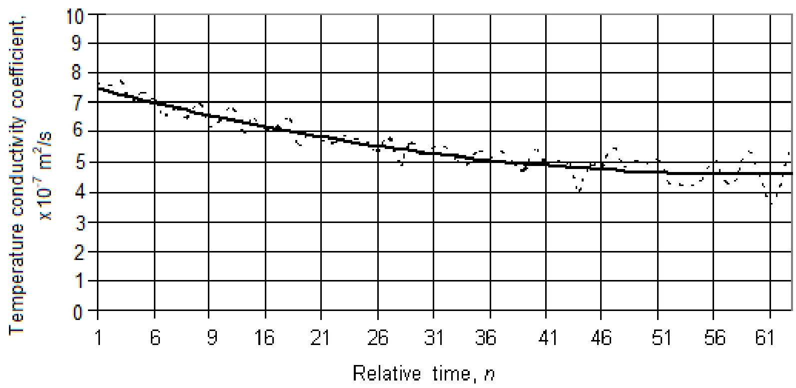
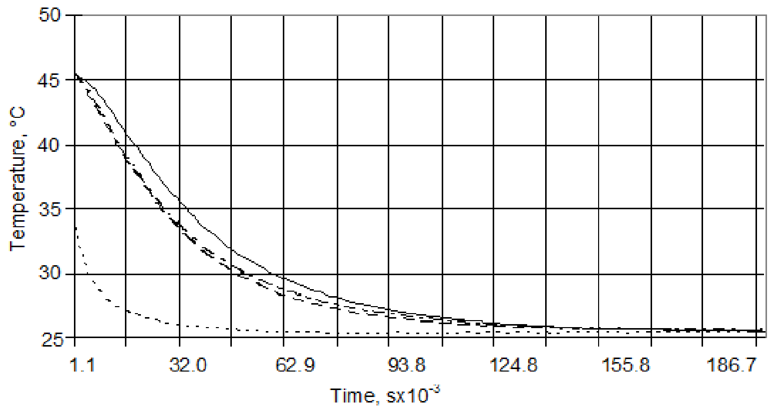


Figure 19 Approximated dependence at determining the temperature conductivity coefficient in the TEX-5 package



Figurer 20 Curves of distribution of the temperature field in the TEX-5 package (cooling mode)

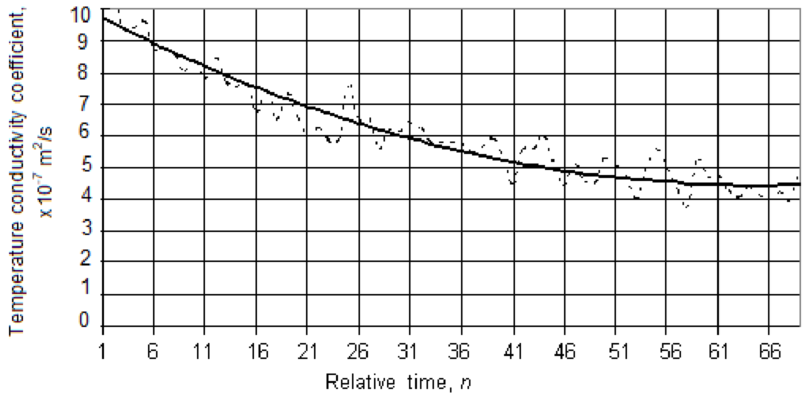


Figure 21 Approximated dependence at determining the temperature conductivity coefficient in the TEX-5 package

Comparing the curves of cooling of the TEX-5 and the TEX-4 packages (Figures 20 and 16), it is undeniable that the TEX-5 package cools to the constant temperature faster than the TEX-4 package. With equal thickness of the package layers, it means that temperature conductivity coefficient for the TEX-5 package should be greater. The constant value of temperature conductivity coefficient in the cooling mode, as determined in Figure 21, is 4.5×10^{-7} m^2/s.

Analysis of transient characteristics, provided in the figures with even numbering (Figures 2-20), shows that the curves of warming and cooling of the first and third layers do not coincide in some way, although both are at the same distance from the surface of heat-exchange capacities with the same temperature.

Figures with uneven numbering (Figures 3-21) show changes in temperature conductivity coefficient over time. The curves clearly show the decrease of the coefficient to the full set value both during the heating and the cooling of the package. This fact can be explained due to the nonlinear properties of the materials, the essence of which is that the temperature conductivity coefficient depends on the temperature gradient between the adjoining layers of the materials. At the beginning of heating or cooling these gradients are bigger than when approaching the steady-state mode. That is why at the beginning of transition process the temperature conductivity coefficient is maximal, then, when approaching the static condition, it decreases and acquires the steady-state value.

Determination of temperature conductivity coefficient should be attributed to the indirect measurements, during which the search value is calculated using the appropriate formula (12), which considers the value of temperature, measured by direct measurements. The processing of the experiment results is as follows: determination of the most reliable value and confidence range at the value of the confidence coefficient of 0.95 is carried out in accordance with the method [12, 13].

The results of experimental determination of temperature conductivity coefficients of the packages are provided in Table 1.

Table 1 Determination of temperature conductivity coefficient in the process of heating and cooling the package of the materials

Package code (raw material composition)	Package thickness h [m]	Material density ρ [kg/m^3]	Temperature conductivity coefficient a_m [x10^{-7} m^2/s]	
			Heating	Cooling
TEX-1 (covering-stitched woolen wadding pads)	0.024±0.001	69	5.10±0.18	5.05±0.15
TEX-2 (thread-stitched woolen-phenylene wadding pads)	0.020±0.001	65	3.70±0.14	3.60±0.12
TEX-3 (needle-punched sheet, made from oxalone fibers)	0.011±0.0005	49	3.20±0.11	3.10±0.1
TEX-4 (needle-punched sheet, made from Nomex meta-aramid fibers)	0.012±0.0006	42	3.70±0.16	3.60±0.14
TEX-5 (non-woven sheet, made from phenylene fibers)	0.012±0.0006	52	4.60±0.17	4.50±0.15

Analyzing the data obtained in the experimental study, it should be noted that the value of temperature conductivity coefficient has a good repeatability, which indicates the stability of processes that take place in opposite directions (heating – cooling). Some difference in the values of the given thermal and physical parameter of the material for different modes can be explained by the impact of the abovementioned nonlinear properties of the materials. Therefore, during the forced heating of the package, the temperature conductivity coefficient is slightly greater than during the free cooling (the difference does not exceed 2%).

4 CONCLUSIONS

To conclude, analyzing thermal and physical parameters of the researched materials, presented in Table 1, it may be deduced that despite the fact that the TEX-1 package and the TEX-2 package have almost the same density of the material, the temperature conductivity coefficient of the material with phenylene fibers additions is almost 1.5 times smaller than of the material, made from natural raw materials. The material, made from meta-aramid fibers (TEX-4 package), having low density and thickness in comparison with other researched materials, has a small value of temperature conductivity coefficient, which indicates its advantage. From an ergonomic point of view, it is more appropriate to use it in special clothes as it has average thermal and physical parameters at a small thickness. Comparing the results of the obtained data on determination of temperature conductivity coefficient using different methods, it should be noted that such results differ in the range of not more than 3%, which is the permissible error in measurements of thermal and physical characteristics of the materials.

The proposed method of studying thermal and physical properties of fabrics has a lot of significant advantages, which primarily lie in the fact that the determination of thermal and physical values takes place in dynamic process of distribution of heat transfer in the layers of the package of materials; the received formula eliminates the possibility of significant additive and multiplicative measurement errors. It can be stated that the proposed method of research allows determining different thermal and physical properties of the fabrics with high accuracy when using modern means of microprocessor and computer technologies, thus creating the conditions for improving the quality of special clothes designing.

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IDENTIFYING THE VALUES OF WHITENESS INDEX, STRENGTH AND WEIGHT OF COTTON SPANDEX WOVEN FABRIC IN PEROXIDE BLEACHING OF DIFFERENT CONCENTRATION

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Abstract: *The purpose of this research is to identify the values of whiteness index, strength and weight (g/m^2) of cotton spandex woven fabric in hydrogen peroxide (H_2O_2) bleaching of different concentration. Different concentration of H_2O_2 chemical during bleaching exhibits different values of the above stated properties. H_2O_2 in aqueous alkaline medium produced per hydroxyl ion that helped H_2O_2 to undergo homolytic fission to two hydroxyl radicals ($OH^{\bullet}$), which formed oxycellulose that attacked the cellulose of fibers, yarns or fabrics. Oxycellulose injured the mechanical properties like tear, tensile and weight values of the fabrics containing cellulose. Besides, H_2O_2 with NaOH solution established good bleaching action that improved the optical properties like whiteness values of fabric. The operation was conducted at 100°C to 110°C temperature with the machine speed of 40 meter per minute where the pH was observed from 10.5 to 11.5. Powerful oxidizer like H_2O_2 was used in this research for bleaching the specimen in ″Benninger Ben Bleach″ machine at different concentrated H_2O_2 solution like 15%, 25% and 35% with different gram per liter ratio. Whiteness index, weight, tear strength and tensile strength of the specimen were carried out in accordance with the test method mentioned in this paper. This research is practice based, and the outcomes are advantageous to the personnel involved in textile industries, who are in charge of conducting the bleaching operations of cotton spandex woven fabrics and to controlling of their above mechanical and optical properties.*

Keywords: *Concentration, oxidizer, oxycellulose, whiteness index, mechanical properties, optical properties.*

1 INTRODUCTION

There is a great importance of this research in the textile wet processing zone since the task of controlling strength properties of the bleached samples were always challenging. Cotton fabrics were always wounded while bleaching in higher concentrated bleaching solution with the presence of strong alkali. Different scholars worked related to this experiment at different times where literature review exposed different results, some of which were similar and some were widely dissimilar. Due to the range of variables involved, if any parameters were changed while experiment, then another properties of the specimen were also changed.

Haque et al reported that chlorine bleaching is a powerful process with poisonous vapors those may tint on wood floorings and on matting. They proposed to work in a well-ventilated area where air circulation is more. Wearing rubber gloves with an apron is must to conduct these processes of bleaching. Direct contact to skin with bleaching substitute can cause chemical burning [1]. Kalantzi et al recommended to use dilute bleaching substitutes since strong bleaching substitutes can injury cloths and also ruining the next wash cycles. After washing treatment is very important as harmful chemicals substituents are removed by the process of after wash treatment [2]. Benefiel et al also reported that after dyeing is done, it is required to stop the chemical process of the chlorine by rinsing the fabric with clean water. It can be used bleaching stoppers to stop the process of bleaching. It suggested to not use vinegar or ammonia to neutralize bleaching reactions since mixture of these chemicals substituents with bleach can create poisonous gas [3]. Peng et al reported that bleaching substituents work best on cotton, linen, rayon and etc. Bleaching is also done at the blends of cotton with synthetics like polyester or other manmade fibers. Bleaching actions is good at higher temperatures. Less temperature bleaching is much less effective [4].

Yu et al also reported that concentration of different bleaching substituents is used based on the fiber compositor, weight and thickness of the cloths. If the thickness and weight of the cloths are more, higher bleaching substituents are applied [5].

Liu et al also reported that thin fabrics are cold bleach with lesser concentration as higher temperature bleach with higher concentration does severe damage to the cloths [6]. Luo et al also reported that for increasing the optical whiteness effect on the cloths, bleaching is done. For conducting the whitening treatment on cloths heavy bleach is mandatory. The more the bleaching is, the better the whiteness is and vice versa [7]. Xu et al also reported that small amount of bleaching substituents will lead the wool fibers and silk fibers to degrade. These fibers are natural but they are obtained from animals. These fibers are also hampered against bleaching reactions [8].

Halim et al reported that bleaching is the common name of any chemical substituents those are applied technologically and internally to whiten fabrics, to lighten hair color and to eliminate stains. It habitually states, specially, to a weak solution of sodium hypochlorite [9]. Ke et al reported that bleaching agents have wide range of bactericidal possessions, which make them useful to sanitize and disinfect and are applied in the sanitation of stagnant water to control bacterial attack, viruses movement and algae growth in many areas where disinfected conditions are needed [10]. Liu et al reported that bleaching agents are also used in many industrial places, notably in the bleaching of wood pulp and other natural animal fibers. Bleaching substituents also have other negligible applications in removing fungus, killing unwanted plant, and swelling the permanence of cut flowers [11]. Wang et al reported that bleaches work by responding with other dyed natural materials like organic dyes, and revolving them into colorless substituents. Majority of the bleaching agents are oxidizing agents which can eliminate electrons from other particles. Some of the bleaching agents are like reducing agents which can provide electrons in the solution [12]. Hossain et al reported that reducing agents are uses like as in sulphur dioxide for bleaching wool, either as gas or as liquid solutions with sodium dithionite. Bleaching basically acts with many other natural materials as well the proposed dyed pigments, so they may deteriorate or impairment the natural substituents like as fibers, yarns, fabrics, etc., and deliberately applied dyes like as the indigo on denim fabrics. At the same times, digestion of the goods, inhalation of the smokes, or interaction with skin or eyes may reason for health injury [13].

Edwards et al reported that initial procedure of bleaching comprises of spreading fabrics in a bleaching bath to whiten by the accomplishment of the sun and water. In the 15th century, there was a substantial fabric bleaching production unit was in Europe countries specially in the western Europe, by the use of irregular nonacidic baths and acidic baths like lactic acid from sour milk and later diluted sulfuric acid [14]. Eren et al reported that chlorine built bleaching agents those are shortened the process of bleaching from months to hours, were created in Europe in the 16th century [15]. Chattopadhyay et al discovered that sodium hypochlorite bleaching those were the first profitable bleach was available in Paris and they were spread out all through the country later on [16]. Bigambo et al reported that the sterilizing and refreshing capability of hypochlorite bleaching agents were significantly enhanced in medical applications, public health and also in sanitations at school, college, universities and in hospitals [17]. Han et al reported that the first manufactured hydrogen peroxide was in the year of 1816 by responding barium peroxide with nitric acid. Hydrogen peroxide was first applied for bleaching in 1864, but was not commercially vital till the year of 1932 [18]. Zhou et al reported that hydrogen peroxide was used as a washing bleach substituents in Europe as the initial 20th century, was not famous in the North America till the year of 1970 [19].

Altay et al reported that an oxidizing bleaching agent acts by contravention the chemical bonds that break up the chromophore. The changing of the molecule levels into a dissimilar material, which does not comprise any chromophore, or does not comprises a chromophore which does not engross visible light sources are based on chlorine but are of oxygen anions those respond through the early nucleophile attack [20]. Oliveira et al reported that broad spectrum efficiency of most bleach is because of their general chemical reactivity in contradiction of natural organic compounds. The discriminating toxic actions of antibiotics destroy many proteins, which makes them tremendously handy antiseptics. Nevertheless, hypochlorite bleaches of lesser concentration were seen to attack the bacteriological by interfering with heat tremor proteins on their walls [21].

Hareem et al reported that most industrial and household bleaching substituents are belonged to three broad classes like chlorine based bleaches, peroxide-based bleaches and sulphur dioxide based bleaches. Chlorine based bleaches, where energetic chemical constituent is chlorine, typically from the decay of several chlorine substituents such as hypochlorite or chloramine [22]. Hassan et al also reported that in peroxide based bleaching compounds; the active agent is oxygen, practically from the decomposition of a peroxide constituent like hydrogen peroxide [23]. Haque et al reported that sulphur dioxide based bleaching compounds, where active compound is sulphur dioxide, perhaps from the decay of several oxo sulphur anion [24].

Indi et al reported that sodium dithionite is recognized as sodium hydrosulphite that is a significant reductive bleaching compound. Sodium dithionite is a white crystal like powder with a feeble sulphurous scent. It is got by the reaction of sodium bisulphite with zinc [25]. Mojsov et al reported that this is usually used in industrial applications like dyeing, color fixation or other processing operations to remove surplus dye particles, remaining oxide and unintentional pigments. The reaction of sodium dithionite with formaldehyde creates rongalite that is applied in bleaching reactions [26].

Smriti et al conducted a risk assessment program that was completed by the European Union declared that the hypochlorite substances are not safe to the environment and they are daily destroying the ecological balance. Evaporation of hypochlorite is almost instant in the natural water background that reaches in a short time concentration [27]. Mojsov et al reported that the unstable chlorine compounds were pertinent in some indoor setups; which have insignificant influence in exposed environmental circumstances. Supplementary, the role of hypochlorite contamination in environment is expected as negligible in soils. Besides, breathing risk from chlorine and highly poisonous chlorinated spinoffs still exists [28]. Hannan et al reported that the sodium hypochlorite solution like 3% to 4% is characteristically weak for harmless use when sterilizing exteriors and when used as drinking water. A feeble solution like 2% bleach in heated water is distinctive for disinfecting plane surfaces previous to steeping of beer or wine. They conducted hypochlorite bleaching with the mechanism of disinfectant action for achieving good and harmless bleaching consequences [29].

Gedik et al reported that the color safe bleach is a chemical treatment that uses hydrogen peroxide as the active element for the purpose of removing stains from the cloths. They denied using hydrogen peroxide rather they used sodium hypochlorite or chlorine bleach because of smooth and harmless processing operations and consequences [30].

Tavares et al also reported that hydrogen peroxide bleaching has chemical constituents those can help to brighten colors. Whitening treatment can be done on cotton based compounds to get a good and even dyeing effect [31]. Udhayamarthandan et al reported that hydrogen peroxide is also applied for cleansing purposes and water purifications, but its antiseptic possibilities may be imperfect due to the concentration in the color safe bleach solution as associated with other applications [32]. Wang et al reported that the safety of bleaching substituents is dependent on the compounds present in the solution and also on their respective concentration percentages. The higher the concentration of peroxide bleaching solution is, the more the harmful activity is [33]. Kar et al reported that it is most often recommended to dilute the solution so that good bleaching action and even dyeing shade may be possible to obtain [34].

Xia et al also reported that if bleaching substituents are connected to the skin or to the eyes, it can cause severe annoyance problem, desiccating and even burns. Breathing of the bleach fumes can cause serious injuries to the interior parts of the body especially the lungs [35]. Wen et al reported that protective equipment such as hand gloves, masks, helmets and gown should always be used when using bleach substituents and chemical reactions [36]. Zhao et al also reported that bleaching chemicals should not be mixed with vinegar or such products those may contain ammonia. This incident can generate high poisonous chlorine gas which is very dangerous to the human body and mind. Chlorine gas is dangerous and can cause severe burns in the side and on the outside. In rare cases, bleaching substituents can be an addictive substance for definite individuals [37]. Hossain et al reported that sodium hypochlorite along with organic compound can act to produce chlorinated impulsive organic substances. Chlorinated substances are released while clear out function, few of them are poisonous and possible creature carcinogens [13].

Luo et al showed that interior air concentration considerably rise 10 to 50 periods for chloroform and 1 to 1200 times for carbon tetrachloride, correspondingly, over baseline amount in the household while using bleached substances [7]. It was explained that the raise of chlorinated unstable natural complex was low for plain bleach and high for heavy bleach. They also reported that use of such products may drastically raise cancer risk. The application of sodium hypochlorite reacting with natural compound is safer that all other bleaching process. Wang et al also reported that unstable chlorine substances can be applicable in interior setting since it has minor hamper on natural surroundings including air, water and soil. Industrial bleaching is rapidly destroying the situation of water so that plants and fish cannot grow in water. They do not get healthy environment [12].

Madhu et al experimented that the application of chlorine dioxide while bleaching has condensed the toxic compound production. This process may reduce the risk of respiration both for human and animals. Sodium hypochlorite (NaClO) named as liquid bleach is used in most of the household activities to clean the cloths. This process is easier to whiten that fabric quickly [38]. Islam et al also reported that the use of NaClO is safer to take care of the water for drinking and also to maintain swimming pond free from all contagious diseases. Chlorinated compound like calcium hypochlorite (CaClO), calcium hydroxide (CaOH) and calcium chloride (CaCl) are available at market; those people are daily using to whitening the cloths. These products are easily available as white powder or as white tablets [39].

Islam et al reported that previously bleaching agents were only used to whiten the fabrics at household. But from 19th century bleaching was industrially started in Western Europe applying alkaline baths and acid baths. The elastic performances of cotton spandex woven fabric were controlled with proper heat setting temperature in stenter machine [40].

Islam et al experimented that optimum strength of the cotton spandex woven fabric was achieved with suitable heat setting temperature. A shrinkage property of cotton spandex woven fabric was controlled with appropriate heat setting temperature [41].

Korlu et al reported that fabrics containing cellulose fibers such as cotton are pretty sensitive to the alkaline or oxidative compounds and these fabrics are mostly destroyed while bleaching process. Metal ions like chromium, iron, manganese, copper, nickel, their oxides and salts affect the fabrics while H_2O_2 bleaching. Catalytic metal decomposition of H_2O_2 damaged the fabrics while bleaching [42].

The present research is conducted on cotton spandex stretched woven fabrics to study the impact of bleaching operation on the mechanical and optical properties of stretched fabrics.

2 EXPERIMENTAL PART

2.1 Materials used

Fabrics of different fiber content with different concentrated H_2O_2 solution were used in this research to do the required experiments. Fabric part and chemical part both are shown in Table 1 and Table 2 separately.

97% cotton and 3% spandex woven fabric was used in this research as mentioned in Table 1. The width and weight of the sample was 53" and 323 g/m^2. The weave of the fabric was 3/1 left hand twill.

In Table 1, for the given construction in serial no. A, 20x(10+70D)/125x58 shows a construction of a cotton spandex woven fabric. Cotton percentage is 97%. Along with this 3% spandex is inserted in weft way to provide elasticity. Here, warp yarn count is 20 Ne which is a non-stretched yarn made up of cotton fibers, but weft yarn count is (10+70D) that means, spandex of 70 denier is used with the core of 10 Ne yarn in weft way to make it stretched. Thread density in ends per inch is 125 and picks per inch is 58. The weight of the fabric is 323 g/m^2 and width is 53".

Table 1 Cotton poly spandex woven fabrics of different composition

S.N	A
Construction	20×(10+70D)/125×58
Composition	97% cotton / 3% spandex
Weave	3/1 left hand twill
Width	53
Weight (g/m^2)	323

Various chemical compounds as mentioned in Table 2 were used in this research while bleaching the specimen. pH medium and ration of the chemicals compounds were also mentioned in Table 2. Trade names along with chemical formula were mentioned in this table.

Table 2 Chemicals and auxiliaries used in this research

S.N	Trade/Chemical name	Chemical formula	Medium	Ratio [g/l]
1	Sodium metasilicate	Na_2SiO_3	Alkaline	5-7
2	Sodium hydroxide	NaOH	Alkaline	5-6
3	Hydrogen peroxide	H_2O_2	Acidic	4-7
4	Wetting agent	$C_{20}H_{37}NaO_7S$	Alkaline	2-3
5	Sequestering agent	$C_{14}H_{23}N_3O_{10}$	Acidic	1-2

2.2 Methods used

Different ASTM and AATCC test methods were used to identify the different parameters of fabrics as stated below.

Whiteness index of the specimen was measured in agreement with the test method AATCC 183. Weight of the specimen was measured in the unit of g/m^2 in accordance with ASTM test method D3776. Tear strength of the specimen was measured in agreement with ASTM test method D2261. Tensile strength of the specimen was measured in accordance with the ASTM test method D5034.

Spectrophotometer was used to measure the whiteness index of the specimen. Strength tester was used to measure the strength of the specimen. GSM cutter and electric balance were used to measure the weight of the specimen.

Testex spectrophotometer TF131 was used in this research for measuring the whiteness index of the specimen. This instrument was invented in China in the year of 2002. Double beam is used to measure the whiteness index of the specimen with an integrated sphere. The specimen is scanned over the section of the spectrum and emitted rays are competently gathered by the detector within the incorporated range. Color difference values and whiteness index can be measured with this instrument.

Tensile strength of the specimen was conducted with Titan 10 Universal Strength Tester of James Heal of UK in accordance with the ASTM D5034 standard. This equipment is computer connected to a data analyzing system software to process and displays the results in the required standard. This machine is equipped with a high quality load cell system that can ensure the maximum accuracy to the limit.

Tearing strength of the specimen was conducted with Titan 10 Universal Strength Tester of James Heal of UK in agreement with ASTM D2261 Standard.

Testex circular sample cutter TF513A/C/D was used to cut the specimen to measure the weight of fabric.

Testex electric balance TF120 was used to measure the weight of the specimen in g/m^2 unit.

Counting glass was used to measure the (EPI) ends per inch and (PPI) pick per inch of the fabric. Herovo counting glass was used in this research to count the EPI and PPI of a fabric.

Fiber composition was tested with TESTEX Fiber Content Analysis Tester TB300 in accordance with AATCC20 standard in an independent laboratory to confirm the composition as mentioned in Table 1.

Projection microscope Projectina DMM 2000 was used to check the length section of the yarn before and after bleaching. The Digital Measuring Microscope DMM-2000 with Macro and Micro optics option has an enhanced technique with outstanding image quality to check the yarn surface. It impresses especially by its modular and compact design and by its very easy handling. This instrument use PIA-7000 software for ımage processing, comparison and measuring in combination with digital cameras.

Benninger bleaching machine Ben Bleach was used in this research. The working width of the machine was 220 cm. It had water tank, boiler, padder, vapor box, etc, for conducting the operations. The entire length of the machine was 32 meter. The speed of the machine was kept 40 meter per minute at 100°C to 110°C with the bath pH of 12 while bleaching the specimen [43].

2.3 Bleaching

Bleaching is a process by which the natural colors of the textile materials are removed to obtain an optimum level of whiteness values. It is an oxidation process by which the natural colors of the fabrics are damaged. With a view to applying the optical brightening agent, optical whitening agent or optical fluorescent agent good bleaching is the prerequisite. For achieving the dull shade bleaching process may not be necessarily required but for achieving brilliant shade bleaching processing is mandatory. Usually, bleaching chemicals generate some adverse influence on the cellulosic part of the cotton fabrics that’s why the bleaching process should be continued cautiously. In general, 2% to 3% weight loss is occurred from the cotton fabrics due to the destruction of the cellulosic part of the fabrics. When the cellulosic parts are destroyed, the strength like tear and tensile are also reduced. Due to the attack on the cellulosic part of the cotton fabrics, the fibers, the yarns and the fabrics become weak which have direct influence on the strength properties on fabrics.

Bleaching reaction in different concentrated H_2O_2 solution

For removing the natural color and for increasing the whitening effect of cotton fabric bleaching was done with the chemical mentioned in Table 3. Different concentration like 15, 25 and 35% of H_2O_2 solution were used to bleach the cotton blended fabrics as mentioned in Table 3. Ratio of H_2O_2 was 4.5, 5.5 and 6.5 gram per liter in each concentration. Bleaching treatment was carried out in ″Benninger Ben Bleach″ machine that was a continuous bleaching process for woven fabrics. Temperature of the bleaching was 100°C to 110°C at the machine speed of 40 meter per minute with the pH of 10.8 on the scale of 0 to 14.

Table 3 Concentration and ratio of H_2O_2 in bleaching treatment

S.N	H_2O_2 concentration [%]	Amount of H_2O_2 [g/l]		
1	15	5	6	6.5
2	25	5	6	6.5
3	35	5	6	6.5

H_2O_2 was a stable chemical compound at acidic medium therefore it was required to add alkali for reaction. pH above 10, H_2O_2 was absolutely unstable when it disintegrated by water and oxygen. The free oxygen has no bleaching action and the catalysts were the reason of decline of bleaching power. H_2O_2 released hydrogen ion and per hydroxyl ion in the below way as mentioned in equation 1:

$$H_2O_2 \rightarrow H^+ + HO_2^-$$

H_2O_2 released per hydroxyl ion (HO^2-) in aqueous medium and chemically acted as a feeble dibasic acid. HO^2- ion was extremely unstable in the existence of oxidizable ingredient. It was disintegrated therefore bleaching action happened. NaOH triggered H_2O_2 since H+ ion was counter balanced with alkali that was advantageous for the discharge of O_2. Equation 2 shows the disintegration of per hydroxyl ions (HO^2-):

$$HO^{2-} \rightarrow HO^- + [O]$$

For happening bleaching action, the stabilized H_2O_2 required to be activated with alkalis. In alkaline medium H_2O_2 decomposed as like as the succeeding reaction. Equation 3 shows the decomposition of H_2O_2 solution:

$$H_2O_2 + OH^- \rightarrow OOH^- + H_2O$$

Conversely, at higher pH (exceeding 10.7) the discharge of per hydroxyl (HO^{2-}) ion was so speedy that it became unstable with the creation of oxygen gas which had no bleaching action. If the degree of decomposition was high, the unutilized HO^{2-} injured the fabrics. A harmless pH for the cotton fabric bleaching was between 10.5 - 10.8. Here the rate of evolution of per hydroxyl (HO^{2-}) ion was equal to the rate of the consumption for bleaching. At higher pH, H_2O_2 was not stable and therefore a stabilizer was often added in the bleaching action.

Sodium metasilicate (Na_2SiO_3) was a stabilizer that was used in H_2O_2 bleaching to help stabilization by formation of a complex with per hydroxyl ions

(HO^{2-}) which became free gradually at higher temperature. The silicate provided buffering action and its solution was colloidal in nature.

The presence of alkalis in H_2O_2 solution formed perhydroxyl ion. The presence of UV light helped H_2O_2 to undergo homolytic fission to two hydroxyl radicals ($OH^{\bullet}$). The metal actions had a catalytic consequence on the decomposition of H_2O_2. The decomposition rate was higher, it formed oxycellulose and attacked the cellulose. The produced oxycellulose hampered the strength and other mechanical properties of fibers or fabrics containing cellulose because of severe localized action. For reducing harmful effect of metal action, sequestering agent like di-ethylene tri-amine penta acetic acid was used in the research that was shown in Figure 1.

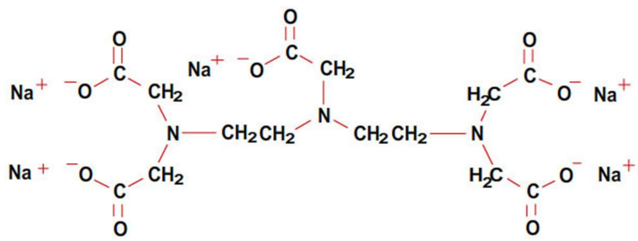

Figure 1 Di-ethylene tri-amine penta acetic acid (DTPA)

Di-ethylene tri-amine penta acetic acid stops the metal ions from catalytically disintegrating peroxide solutions by chelating them. This complex shaped a 3D structure as shown in Figure 2, which comprises of water of salvation molecules and this was composed by sequestering agent molecules.

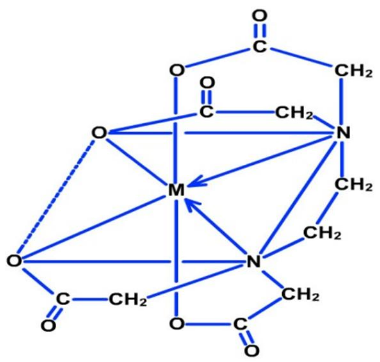

Figure 2 3D representation of Di-ethylene tri-amine penta acetic acid metal complex

Experiment for whiteness index, strength and weight of the samples were carried out after getting the bleached fabric in accordance with the standard provided by ASTM and AATCC standard.

2.4 Whiteness index test

Whiteness index of the bleached samples were measured by the Testex spectrophotometer TF131 in agreement with the test method provided by AATCC 183. Sample of size 4×4 cm was cut and prepared for the measurement of whiteness index. This instrument ejected double beam to measure the whiteness index of the specimen. Light rays are expelled through the samples and spectrums reading are collected by the sensor within the integrated assortment. Whiteness index of the samples were measured with the facilities of this instrument after bleaching the samples as mentioned in Table 3 and results were shown in Figure 3.

2.5 Tear strength test

Tearing strength of the bleached sample was measured by the Titan 10 Universal Strength Tester in agreement with the standard provided by ASTM D2261 test method. Sample size like 75×200 mm was cut from the bleached fabrics and placed in the Titan 10 Universal Strength Tester to measure the tear strength of the fabrics in both warp and weft way. Tear strength was measured for the treated fabrics with different concentrated H_2O_2 solution of different amount and shown the consequences in Figures 4 and 5.

2.6 Tensile strength test

Tensile strength of the bleached sample was measured by the Titan 10 Universal Strength Tester in agreement with the standard provided by ASTM D5034 Standard. Sample of size 100×150 mm in both warp and weft way were cut and placed in Titan 10 Universal Strength Tester to measure the tensile strength of the fabric from each type. Tensile strength was measured for the treated fabrics with different concentrated H_2O_2 solution of different amount and shown the consequences in Figures 6 and 7.

2.7 Weight test

Circular sample cutter Testex TF513A/C/D was used to cut the fabric and Testex Electric Balance TF120 was used to measure the weight of the samples in g/m^2 unit in accordance with ASTM test method D3776. Fabric should be conditioned in room temperature for 4 hours before taking the weight. Weight values can be taken by cutting 10×10 cm square area of the fabrics or 11.28 cm round cutting by the circular sample cutter. Weight was measured for the treated fabrics with different concentrated H_2O_2 solution of different amount and shown in Figure 8.

2.8 *Microscopic test*

Bleached fabrics were collected and yarns were unplugged from fabric to place in Projection Microscope Projectina DMM 2000 with glycerine for assessment. Yarns of before bleaching and after bleaching was taken from fabric and microscopic evaluation were taken to assess the performance as shown in Figures 9 and 10.

3 RESULTS AND DISCUSSION

3.1 Results of whiteness index

Bleached samples were placed in the spectrophotometer instrument and light beams were ejected through the samples to get the desired whiteness index values. In acidic medium H_2O_2 was stable, therefore few bleaching action occurred. But in strong alkaline medium with the presence of NaOH solution, good bleaching action occurred that had a direct impact on the whiteness values of fabric. Result of whiteness index are shown in the Figure 3. It was seen that lower whiteness values were obtained for the fabrics of lower concentrated hydrogen peroxide solution and vice versa. It was also seen that lower whiteness values were obtained for the fabrics of lower amount of hydrogen peroxide solution and vice versa.

3.2 Results of tear strength

Bleached samples were placed in the Titan 10 Universal Strength Tester to get the desired tear strength values. Presence of NaOH in H_2O_2 solution creates per hydroxyl ion that helped H_2O_2 to undergo homolytic fission to two hydroxyl radicals ($OH^{\bullet}$), which formed oxycellulose and it attacked the cellulose of fibers, yarns or fabrics. Oxycellulose injured the strength properties of fabrics containing cellulose. Result of warp tear strength and weft tear strength was shown in the Figures 4 and 5. It was seen that higher strength values were obtained for the fabrics of lower concentrated hydrogen peroxide solution and vice versa. It was also seen that lower strength values were obtained for the fabrics of higher amount of hydrogen peroxide solution and vice versa.

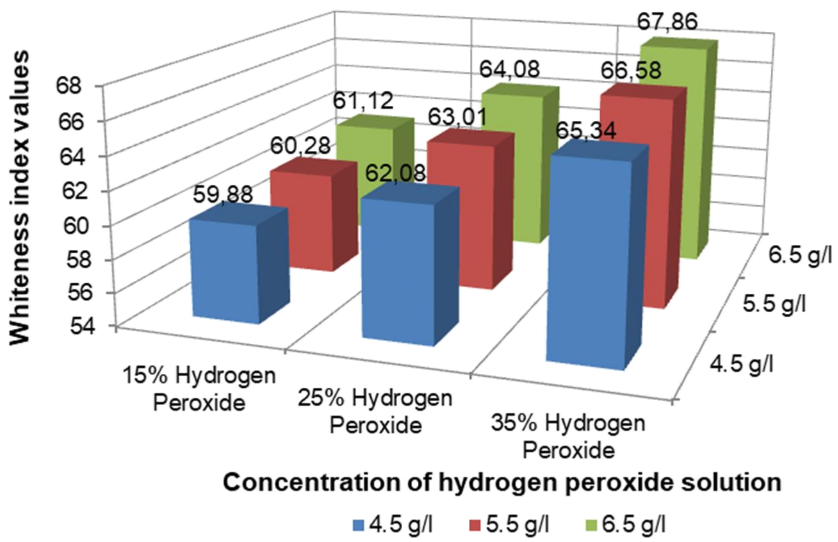

Figure 3 Whiteness index values of different concentrated hydrogen peroxide solution of different amount

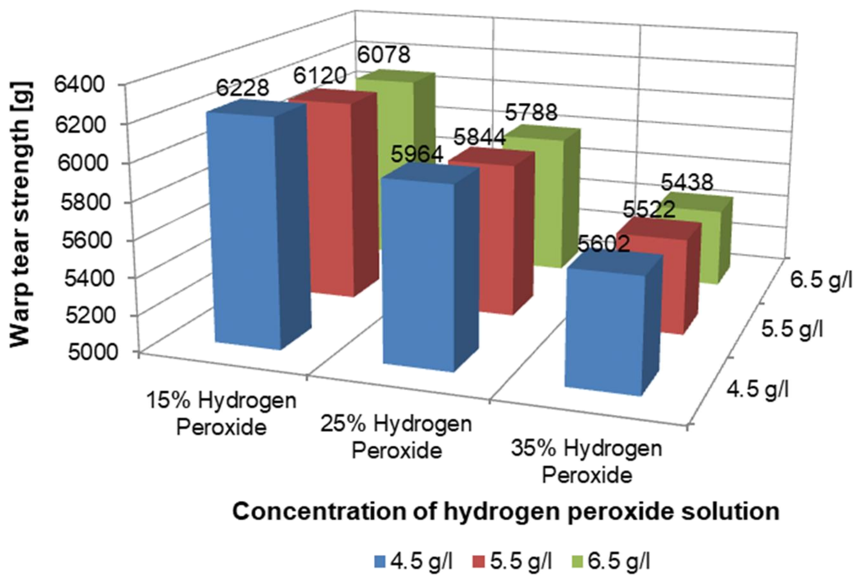

Figure 4 Warp tear strength of different concentrated hydrogen peroxide solution of different amount

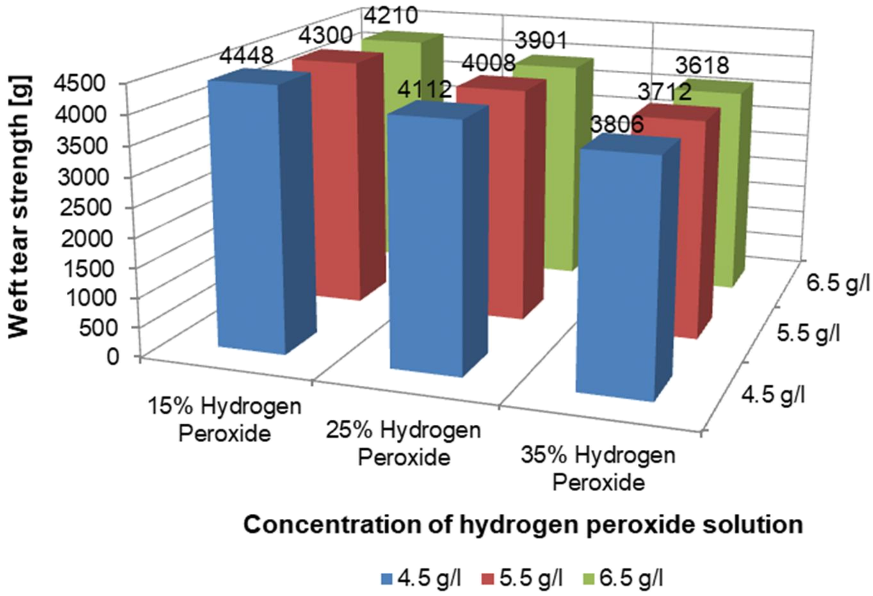

Figure 5 Weft tear strength of different concentrated hydrogen peroxide solution of different amount

3.3 Results of tensile strength

Bleached samples were placed in the Titan 10 Universal Strength Tester to get the desired tensile strength values. As from the previous experimentation it was clear that bleaching action produces oxycellulose that injured the cellulose of fabrics and reduced the tensile strength. Result of warp tensile strength and weft tensile strength was shown in the Figures 6 and 7. It was seen that higher strength values were obtained for the fabrics of lower concentrated hydrogen peroxide solution and vice versa. It was also seen that lower strength values were obtained for the fabrics of higher amount of hydrogen peroxide solution and vice versa.

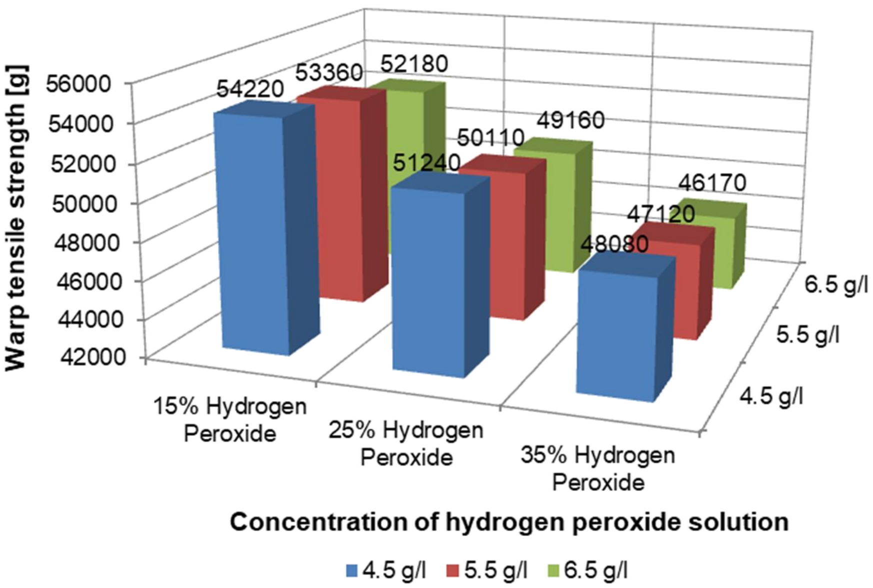

Figure 6 Warp tensile strength of different concentrated hydrogen peroxide solution of different amount

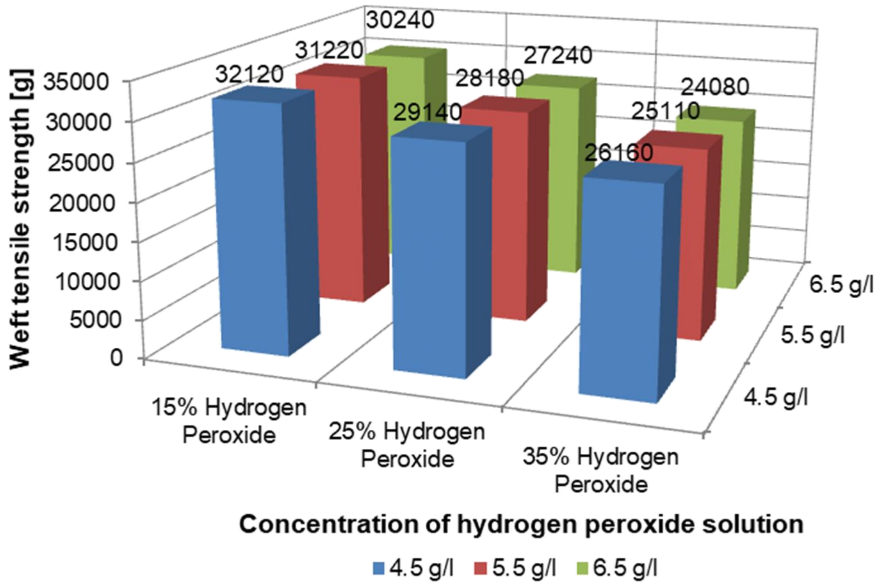

Figure 7 Weft tensile strength of different concentrated hydrogen peroxide solution of different amount

3.4 Results of weight

Bleached samples were conditioned and prepared for getting the weight values. While bleaching the cellulose of fabrics were injured and it helped to lose some fibers from yarns, which reduced the weight of the fabrics. Weight values were shown in the Figure 8. It was seen that higher weight values were obtained for the fabrics of lower concentrated hydrogen peroxide solution and vice versa. It was also seen that lower weight values were obtained for the fabrics of higher amount of hydrogen peroxide solution and vice versa.

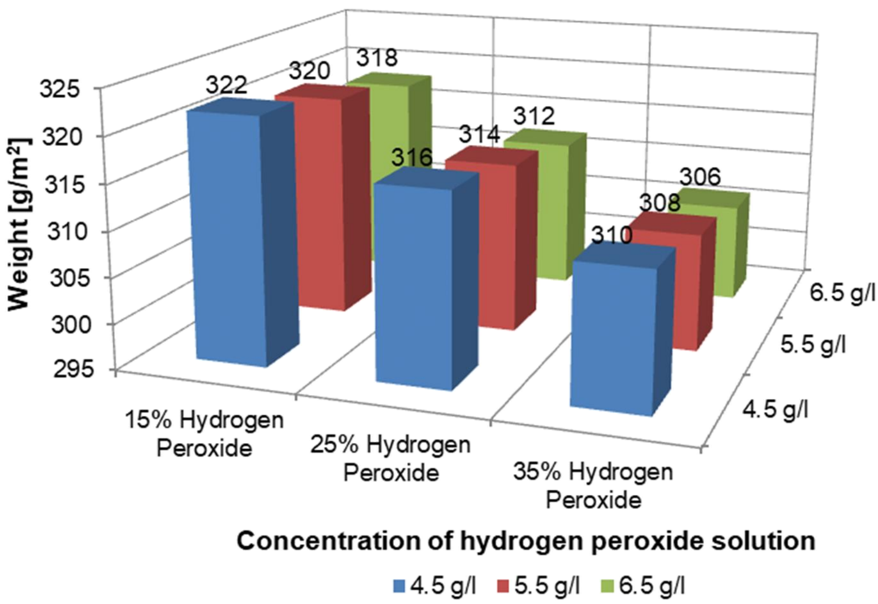

Figure 8 Sample weight of different concentrated hydrogen peroxide solution of different amount

3.5 *Microscopic observation*

Before bleaching the yarns have more hairiness, but after bleaching the yarns have less hairiness. H_2O_2 bleaching made the fiber loss of the yarns, which had direct consequences with the strength and weight loss of the yarns. More concentrated H_2O_2 solution removed more fibers from yarns, hence the strength loss and weight loss was more. Figure 9 shows the yarn of before bleaching and Figure 10 shows the yarn of after bleaching.

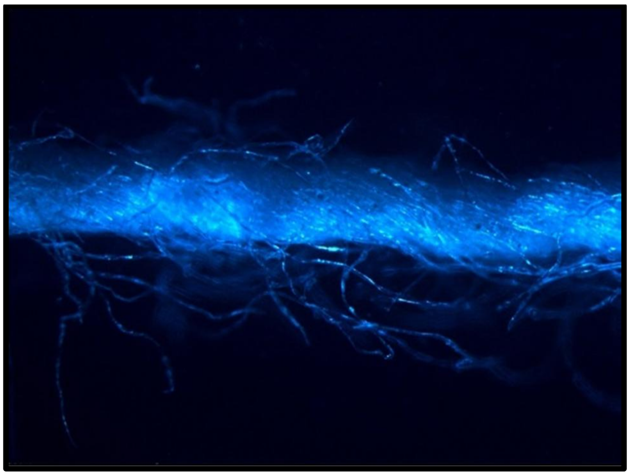

Figure 9 Microscopic view of a yarn of before bleaching

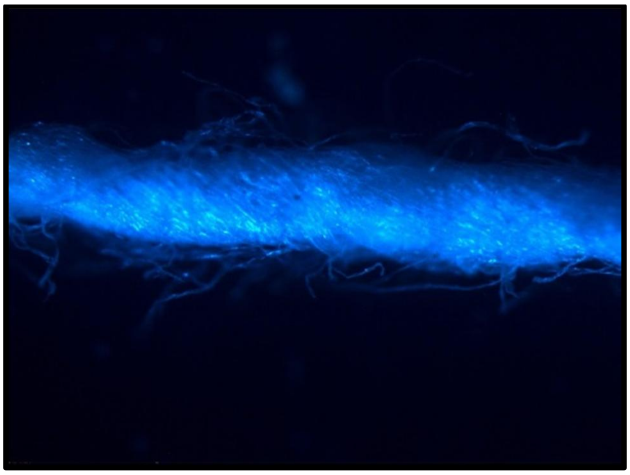

Figure 10 Microscopic view of a yarn of after bleaching

4 CONCLUSION

It was seen throughout the research that bleaching with higher concentrated H_2O_2 gave higher values for whiteness index, lower values of weight, tear and tensile strength of fabrics. Bleaching operation wounded the mechanical and optical properties of fabrics. Higher concentrated H_2O_2 damaged more cellulosic fibers of the fabric as a result less values of strength was achieved. Besides, more cotton fibers were lost while bleaching with higher concentrated H_2O_2 therefore, less values of weight was obtained. Different concentrated H_2O_2 with different volume exhibited different values of pH of the bath. Bleaching played a vital role in the textile wet processing zone to control the important physical properties of the fabrics. So, expertise knowledge of processing operation is essential to be successful at every batch by batch operation in industries. This research is beneficial to the personnel involved in textile industries who are responsible for bleaching operations of woven fabrics and it exposed potential ways for the scholars to further study in this field.

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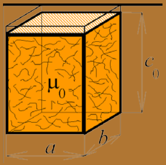

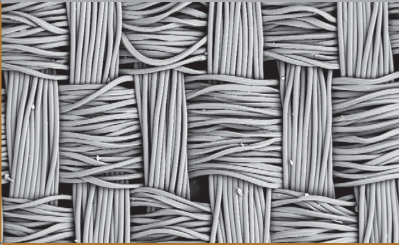

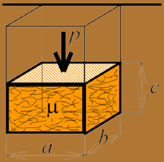

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