INNOVATIVE TECHNOLOGIES AND SUSTAINABILITY IN TEXTILES AND APPAREL

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CONTENT

PREFACE

It is an undeniable fact that textile products are an integral part of people's everyday life. In the process of exploitation of textile products, the human body directly contacts with textile materials throughout life, so the issue of their safety is especially important in the production of textiles and clothing.

Thus, studies that widely contribute to the development of the market of chemical products reduce the material consumption of technology and the cost of production and increase the ecological safety of the process are in high demand nowadays.

The awareness of sustainability is increasing in diverse industries, including fashion industry. In order to reduce the harmfulness to the world, fashion industry is seeking appropriate ways to be more sustainable.

Approximately two-thirds of clothing materials are sent to landfills, making it the fastest growing component of waste in the household waste stream. Within the last five years, textiles disposed of in landfill sites have raised from 7% to 30%.

With environmental issues being more prominent and fashion pollution noted, people learn how to be environmental friendly and second-hand/pre-owned stores have become very fashionable and respectable in Europe and the US.

Sustainable fashion concerns more than addressing fashion textiles or products. It comprises addressing the whole system of fashion. This means dealing with interdependent social, cultural, ecological and financial systems. It also means considering fashion from the perspective of many stakeholders

– users and producers, all living species, contemporary and future dwellers on earth. Sustainable fashion therefore belongs to, and is the responsibility of citizens, public sector and private sector.

In modern times, with a prominent trend towards sustainability and being ‘green’, sustainable clothing has expanded towards reducing the amount of clothing discarded to landfills, and decreasing the environmental impact of agro-chemicals in producing conventional fiber crops.

The clothing industry is quickly becoming a high-tech industry due to rapid advances in technology. Rapid change in the production usually means huge changes in design and style of the garments, which are under development, as well as in their fashion fabrics and sewing techniques, which must be applied almost instantaneously.

The issue of solving the above-mentioned tasks bring together researchers, information professionals, employers, media specialists, educators, policy makers and all other related parties from around the world to exchange knowledge and experience and discuss recent developments and current challenges in both theory and practice.

Increasing the quality of professional training of students, supporting their enterprising activity, development of the initiative manufacturer of cutting age technologies are the tasks those must be carried out by scientific society of modern era.

In order to teach students that will become highly qualified professionals in their area it is necessary to prepare systematic knowledge on pattern design systems, bio and photometric explorations of human body, 3D-design of clothing, modern sewing equipment, and other technical support systems. Implementation of the new technologies into the manufacturing process of the sewing enterprises is impossible without diligent research on the subjects of innovative techniques of textile processing and apparel design as well as fashion and fabric manufacturing industries.

The authors of the monograph combines many years of cooperation in various fields of science related to clothing design one way or the other.

Many of them have already been approved topical theoretical and applied research on innovative technologies and sustainability in textiles and apparel.

The monograph is intended for teachers and students at all levels from foundation up to postgraduate degree levels on clothing design and manufacturing courses. It might be very useful for practicing designers and pattern makers in the clothing industry as well.

We express our general gratitude for the help in preparing the monograph to the Rector of Khmelnitsky National University Mykola Skyba, the Mayor of Khmelnytskyi Oleksandr Symshyshyn, the head of the Centre for Laser Technologies of Metals Prof. dr. hab. Ing. Bogdan Antoszewski, and head of the company F.H. BARWA Jaroslaw Czajkowski for their support and cooperation in preparing for publication of monographs, as well as the entire editorial board and respected reviewers.

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CHAPTER 1.

PROGRESSIVE CHEMICAL TECHNOLOGIES AND TEXTILE INNOVATIONS

1.1 ANALYSIS AND CHOICE OF THE UNIVERSAL WORKING ENVIRONMENT FOR FORMATION OF TEXTILE MATERIALS

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Introduction

Economic revival of Ukraine is impossible without the creation of appropriate conditions that will ensure high quality of goods and increase their competitiveness in the domestic and world markets. One of the most important tasks that faced today in the light industry and trading companies is to provide the population with products that meet the requirements of consumers. Therefore, the aggravation of problems in improving the quality and efficiency of production of goods in domestic textile production in recent years dictates the urgent need to find alternative and fundamentally new technologies for the production of textile products.

There is also an application in the garment industry of innovative production technologies. Modern clothes are made mostly of flat materials, special attention must be paid to the methods of forming bulk parts of flat materials. Headwear is a significant place among the garments, as they are distinguished by their originality and the complexity of the formation of volumetric spatial forms. Recently, the improvement of the process of wet-heat treatment (WHT) is carried out in different directions: the development of new methods of formation, equipment, the search for new working environments.

Methods

An important role in changing the deformation properties of tissues is performed by moisture, which interacts with the structure of the polymer and acts in the system of "polymer-moisture" as a plasticizer and a carrier.

Studies [7, 8, 17, 18] showed that when moisture tissue up to 10% its deformation is achieved four times faster than in air-dry condition.

It is known [2, 13, 15] that the change in the state of the polymer is associated with changes in the ratio of intermolecular forces and thermal motion, which occurs under the influence of a number of external factors: - as a result of an increase in temperature, which leads to an increase in thermal motion, -

polymer sorption of various substances, which replace the part of intermolecular bonds and, thus, weaken the interaction between them.

In [3, 4], considerable attention was paid to the problem of lowering temperature regimes, the use of normalized working media and steam produced in various ways, and so on. It is known [1, 5-7, 9-12, 19] that the increase in the moisture content in the textile material significantly reduces the transition temperature from the glassy to the highly elastic state, improves the deformation properties, as well as the relaxation processes.

Fabrics are very complex in structure and properties of the system, the basis of which are fibers formed in yarn. In turn, the yarn has a certain degree of twist, so that the fibers can be in the middle or on the surface of the yarn. In addition, fabrics are exposed to various types of aperies and dyes that interact with fiber-forming polymers [14, 16], which significantly affects the process of access and interaction of the environment with the complex structure of the material (fibers, yarn, threads).

As a plasticizer today it is advisable to use moisture in the state of a liquid because structural plasticization occurs without the destruction of the molecular structure. As a result, the energy of the interaction of moisture with the polymer is slightly less intermolecular interaction. In this case, there is a partial solution (swelling) of the polymer, which leads to a change in the diameter of the fibers [10].

One of the main factors that determine one or another ability of textile materials to absorb water is the raw material composition, characterized by the presence in the structure of the fiber of the active polar groups.

In the process of humidifying the tissues with water, the moisture content of the latter significantly increases and reaches 60-120%, whereas when the tissue is found in a saturated vapor medium (Tp = 105^{o}C), the moisture content is reduced to (20-25%) [20]. The penetration of water into the fiber, reduces the forces of internal interaction between the chains; In addition, the attraction to each other of oppositely charged centers of salt bonds is weakened, which is the cause of the formation of intramolecular foldability and macroscopicity of macromolecules. In this connection, the mechanical properties of the fibers of the wool vary, in particular, their resistance to stretching decreases, which causes improvement of the molding ability of the fiber.

A number of papers [1, 5-7, 9-12, 19] confirm that improving the deformation properties of tissues occurs when they interact with active media in the process of formation. Active working environment for sewing materials is the aqueous medium, water vapor, surface-active substances, saturated air of various parameters, etc.

Thus, the alternative is the use of water, liquid-active working media (LAWM) in the process of formation, which will allow the maximum use of deformation properties of materials.

The aim of the work is to find a universal working environment for the formation and shaping of textile materials.

To achieve this goal you need:

- identify the main formulation characteristics for conducting research
- to perform a comparative analysis of components of complete deformation in different working environments for fabrics of a suit-coat group in order to choose the optimal.

Experimental

The paper presents the results of research on two tissues: coat art.45206 and costume «Topazio» art. 4511206. For example, fabrics of suit and coat assortment are used, which, due to their fiber content and structural characteristics, may have low indicators of molding ability.

That is, for fabrics with better molding properties, due to the fiber content and their structural characteristics, the patterns of distribution of components of complete deformation in the best quality will be manifested in a particular working environment. At the first stage of research, the values of the components of complete deformation when forming in vapor and water were determined. In addition, an intermediate environment with a temperature of 18 ° C and a humidity of 60% was taken. As a result of the results (Table 1), it was concluded that one of the main factors which can maximally change the deformation properties of the raw materials, that is, their moisture content.

And the possibility of maximum control of moisture content in the material in our opinion may in this case only water. It should be noted that, in contrast to the classical technology of the WHT, in the proposed environment it is possible to stabilize the temperature at the ambient temperature of 20°C.

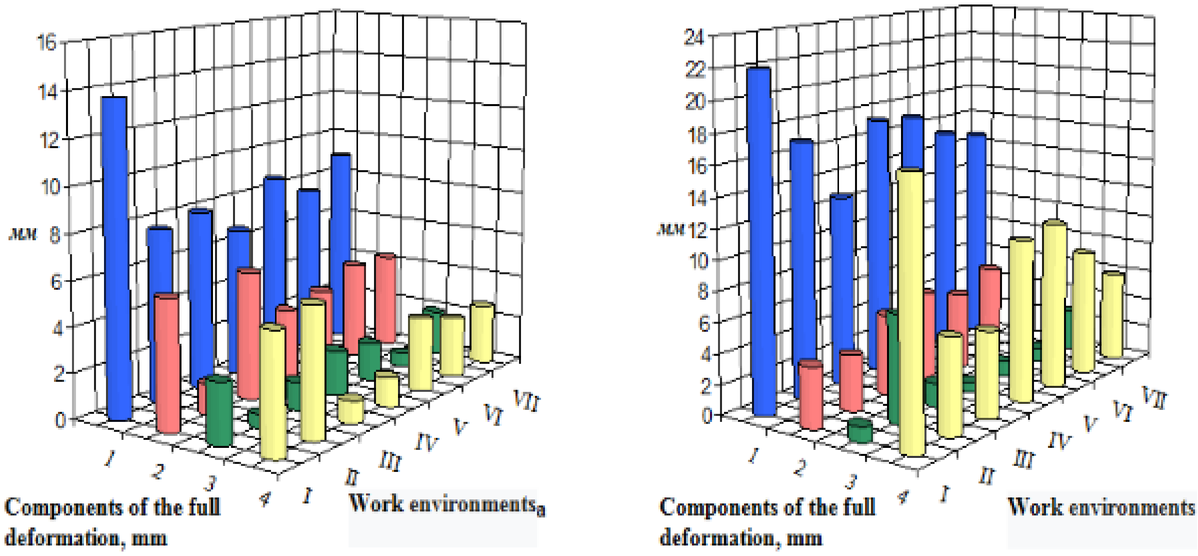
Table 1 Components of complete deformation in different working environments with static loading

Material		Environment	Complete deformation, ε, mm	Components of the full deformation, mm		
				conditionally elastic ε_{ce} $(\Delta\varepsilon_{ce})$	*elastic* ε_{el} $(\Delta\varepsilon_{el})$	*plastic* ε_{pl} $(\Delta\varepsilon_{pl})$
Coat fabric (art. 45206)	base thread	Water	17.0	4.5	1.6	11.3
		Environmental relative humidity 98% (saturated vapor)	10.8	5.0	1.2	4.6
		Normal conditions (temperature – 18 °C, humidity – 60%)	16.3	4.6	1.6	11.3
	weft thread	Water	20.6	5	3.3	12.3
		Environmental relative humidity 98% (saturated vapor)	11.17	4.0	1.2	5.8
		Normal conditions (temperature – 18 °C, humidity – 60%)	19.0	4.0	1.6	13.3
Suit fabric “Topazio” (art. 451187)	base thread	Water	12.0	4.6	2	5.3
		Environmental relative humidity 98% (saturated vapor)	0.45	0.15	0.12	0.18
		Normal conditions (temperature – 18 °C, humidity – 60%)	8.6	4.6	2.6	1.3
	weft thread	Water	20.65	3.6	1	16
		Environmental relative humidity 98% (saturated vapor)	0.7	0.23	0.2	0.27
		Normal conditions (temperature – 18 °C, humidity – 60%)	14.6	4.3	6.0	4.3

Sample tissues immersed in water have higher deformation properties compared with the environment relative humidity of the environment 98% (saturated vapors) and natural humidity of the environment. This is due to a decrease in friction between mutually perpendicular filament systems, since water, in addition to the plasticizer and the heat-carrier, is also a "lubricant" in the places where the threads are contacted [18].

Subsequent studies to improve the molding ability of textile materials were carried out in different waters: catholytic, anolytic, silicon and shungite waters, soft and copper. It should be noted that these waters differ in the content of chemical elements as indicated by their IR spectra.

According to the data, diagrams of complete deformation and its components (Fig. 1-2), which show the influence of different working media on the deformation properties of tissues, are constructed. It should be noted that the standard for comparing the influence of working media on the materials was taken from ordinary water.



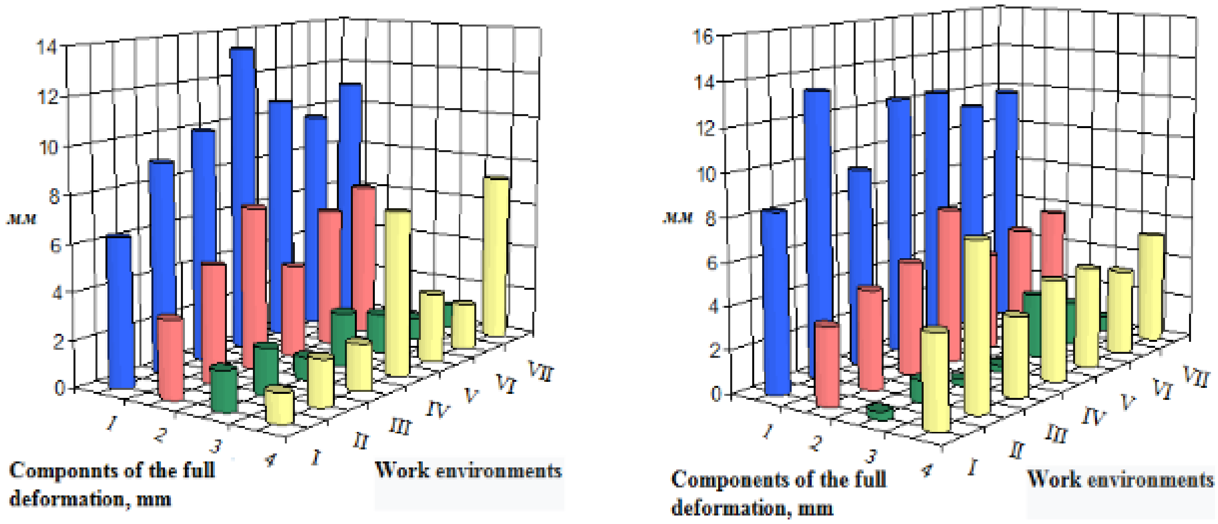
a b

1 - complete deformation, 2 - conditionally elastic deformation; 3- elastic deformation 4 - plastic deformation, I - catholyte, II - anolyte, III - silicon water, IV - shungit water, V - soft water, VI - copper water; VII - ordinary water; a - base; b - weft

Fig. 1. Full deformation and its components at static loading of coat fabric art. 45206

From the diagrams it is evident that in the coat fabric there is a significant increase in the elastic deformation of the filament base in the catholyte and silicon water by 13,2%; At the same time, there is no observed deformation along the yarn thread. Elastic deformation increases in catholyte – based on 13,5%, decreases in anolyte and copper waters by 3%; there is no observed increase in growth. However, for forming operations, it is important to increase the plastic component of the deformation. In this case, the proportion of plastic deformation increases on the base filaments in the catholyte by 19.6%, anolytic by 21,1%, and soft water by 12,2%. In the threads of the droplet, the growth of plastic deformation in the catholyte is 28,3%, in anolyte 10,5% and in soft water by 18,3%.

In the costume fabric there is a significant increase in the elastic deformation of the filament base in silicon water by 25,9%. On the threads of the duct elastic deformation increases in shungit water by 12,8%. The smallest of its values in the threads of the base and the droplet are observed in the Catholic. Elastic deformation increases in shungit water - based on 2,3%, decreases in the catholyte by 6,3%. Growth of elastic deformation is observed in soft water by 4.3%, and decrease in silicon and shungite waters. The plastic component of the deformation along the filaments of the base increases in shungite water by 7%, and decreases in the catholyte. In the ducts, the increase in plastic deformation is observed in anolyte by 14,5%, and the decrease in silicon water by 2,2%.



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1 - complete deformation, 2 - conditionally elastic deformation; 3- elastic deformation 4 - plastic deformation, I - catholyte, II - anolyte, III - silicon water, IV - shungit water, V - soft water, VI - copper water; VII - ordinary water; a - base; b - weft

Fig. 2. Full deformation and its components at the static load of the costume fabric art. 451187

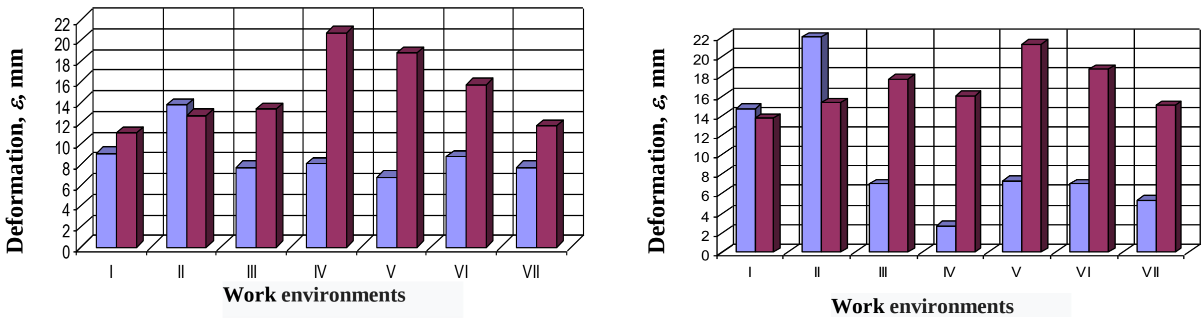
The analysis of the results obtained under the action of static load showed that for selected fabrics as a working medium it is expedient to use catholyte, anolyte, shungit and silicon water. However, at the current stage of development of the WHT for the formation and determination of deformation properties of materials, it is proposed to use dynamic loads. Therefore, the further stage of research is the study of the forming properties of tissues under dynamic loads in the proposed working environments. The research was conducted according to the developed method [19] and with the use of the patented device [20] (Table 2).

Table 2 Full deformation and its components at dynamic loads in the investigated environments of fabrics of a coat-costume assortment

Material		**Work environments**	**Complete deformation, ε, mm**	**Components of the full deformation, mm (%)**		
				conditionally elastic ε_{ce} ($\Delta\varepsilon_{ce}$)	*elastic* ε_{el} ($\Delta\varepsilon_{el}$)	*plastic* ε_{pl} ($\Delta\varepsilon_{pl}$)
1	2	3	4	5	6	7
Coat fabric (art. 45206)	base thread	catholyte	12.67	2.33 (18.4)	3.67 (28.9)	6.67 (52.6)
		anolyte	13.33	2.33 (17.7)	3.33 (24.9)	7.67 (57.5)
		silicon water	20.67	5.0 (24.2)	2.67 (12.9)	13.0 (62.9)
		shungit water	18.67	3.67 (19.7)	2.33 (12.5)	12.67 (67.9)
		soft water	15.67	3.0 (19.1)	2.33 (14.9)	10.33 (65.9)
		copper water	11.67	3.33 (28.5)	4.33 (37.1)	4.0 (34.3)
		ordinary water	11.0	5.67 (51.5)	4.33 (39.4)	1.0 (9.1)
	weft thread	catholyte	15.33	2.67 (17.4)	2.67 (17.4)	10.0 (65.2)
		anolyte	17.67	3.0 (16.9)	4.67 (26.4)	10.0 (56.6)
		silicon water	16.0	8.67 (54.2)	3.0 (18.8)	10.33 (64.6)
		shungit water	21.33	2.67 (12.5)	3.67 (17.2)	15.0 (70.3)
		soft water	18.67	5.33 (28.5)	4.33 (23.2)	9.0 (48.2)
		copper water	15.0	6.67 (44.5)	3.33 (22.2)	5.0 (33.3)
		ordinary water	13.67	5.0 (36.6)	4.67 (34.2)	4.0 (29.3)
Suit fabric “Topazio” (art. 451187)	base thread	catholyte	15.33	4.67 (30.5)	5.33 (34.8)	5.33 (34.8)
		anolyte	18.67	3.67 (19.7)	4.67 (25.0)	10.33 (55.3)
		silicon water	22.33	7.33 (32.9)	6.33 (28.3)	8.67 (38.8)
		shungit water	19.0	4.33 (22.8)	2.67 (14.1)	12.0 (63.2)
		soft water	24.67	4.33 (17.6)	3.0 (12.2)	17.33 (70.2)
		copper water	21.33	6.67 (31.3)	3.67 (17.2)	10.33 (48.4)
		ordinary water	12.0	1.67 (13.9)	2.67 (22.3)	7.67 (63.9)
	weft thread	catholyte	19.67	5.33 (27.1)	6.67 (33.9)	7.67 (38.9)
		anolyte	23.67	9.33 (39.4)	8.0 (33.8)	6.33 (26.7)
		silicon water	25.0	10.0 (40.0)	7.33 (29.3)	7.67 (30.7)
		shungit water	26.33	13.33 (50.6)	2.33 (8.8)	10.67 (40.5)
		soft water	28.67	5.67 (19.8)	5.67 (19.8)	17.33 (60.4)
		copper water	24.0	6.67 (27.8)	8.33 (34.7)	9.0 (37.5)
		ordinary water	16.67	7.0 (41.9)	4.0 (2.9)	4.67 (28.0)

Results

Studies on the formation properties of tissues in different working environments have shown that the use of structured water allows to improve the deformation of tissues with different fibrous composition under static and dynamic loading. In particular, under the action of static load, it is clearly observed an increase in total deformation in all working media. At dynamic load, there is a decrease in the proportion of elastic deformation, indicating a change in the orientation of fibers in threads and threads in the fabric with the complex action of the additional load and water.



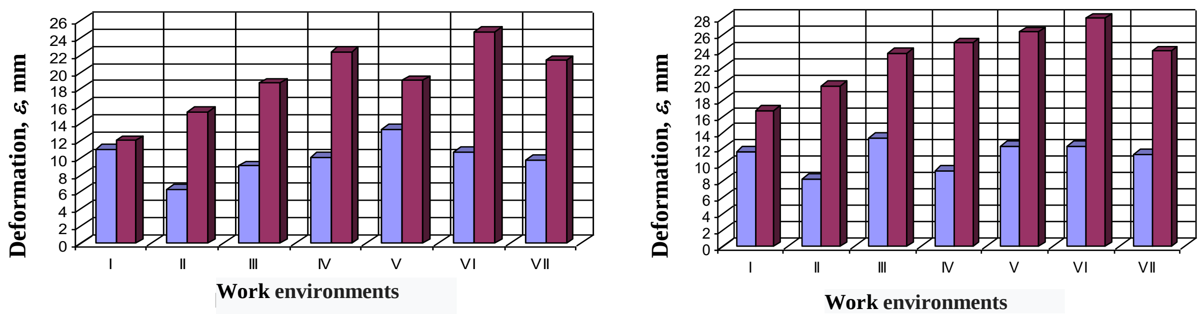
a b

I – catholyte, II – anolyte, III – silicon water,
IV – shungit water, V – soft water,
VI – copper water; VII – ordinary water;
a – basis; b – ducks

– static load;

– dynamic load

Fig. 3 Changing the complete deformation with the static and dynamic load of coat fabric art.45206



a b

I – catholyte, II – anolyte, III – silicon water,
IV – shungit water, V – soft water,
VI – copper water; VII – ordinary water;
a – basis; b – ducks

- static load;

- dynamic load

Fig. 4 Changing the complete deformation with the static and dynamic load of the costume fabric art.45118

At the same time there is a significant increase in the plastic component of deformation, which indicates the expediency of using structured water to improve the deformation properties of tissues. Changes in the total deformation of the fabric by the filaments of the base and the dip are presented in Fig. 3 – 4.

Data analysis shows that when dynamic load deformation increases by an average of 35%. Replacing ordinary water with a structured can increase the total deformation by 25% and the fraction of plastic by 50%. Thus, as a result of the research and comparison of the results, it was found that the best working environments for the formation of hat details are catholyte, anolyte, silicon and shungite waters.

Conclusions

In determining the molding abilities, the deformation-relaxation characteristics were taken as the basis: complete deformation and its components. At the first stage of research on these characteristics, the working environment of the classical technology of the WHT - saturated steam and water was compared, and it was concluded that water significantly improves the deformation ability of selected tissues. This is explained by the fact that in water the moisture content of tissues increases significantly, which is the main reason for such differences. The received positive changes in terms of deformations in water became the basis for the use of different waters for chemical content. These were structured waters that differ in their chemical composition and environment: sour, alkaline.

In addition, the research used a different strength field: static and dynamic. These two characteristics also made a significant positive. As a conclusion of these studies, it is possible to state that the replacement of steam with technical water and in turn technical water to various structured water, depending on the fiber content of the fabric, as well as methods of activating the "coarse" structure of the material: static or dynamic load gives the opportunity to significantly increase the moisture content fabrics and thus their molding ability.

It has been established that the use of structured water can increase the total deformation by 25%, and the use of dynamic loads by 35%.

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1.2 STUDY OF THE EFFECT OF ACRYLIC AND URETHANE POLYMER COATINGS ON THE FUNCTIONAL PROPERTIES OF COTTON FABRIC

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Introduction

Today, increasing competition in the textile market leads to the need to give household textiles additional improved properties, such as protection from exposure to water, oil, fire, bacteria and microorganisms, dirt [1–7]. Coatings are also known that give a textile material a complex of properties [3, 8, 9].

Traditionally, special types of finishing of textile materials are carried out by impregnating them in solutions of chemical reagents, which impart appropriate properties to the fibrous material, as well as by fixing the active substances on the surface of the fabric with the help of a polymeric binder. Synthetic acrylates and polyurethanes are widely used as binders. Acrylic polymers form a film, which is characterized by good adhesion, light resistance, resistance to high temperatures, washing and dry cleaning, but at the same time low resistance to dry and wet friction [10–12]. Coatings with increased resistance to physical and mechanical stress can form polyurethanes [10, 13, 14].

Formed polymer coatings should not impair the hygienic and mechanical properties of the textile material, as well as be stable throughout the life of the products. Under the action of sunlight, high temperature, water, and air oxygen, decomposition processes quickly start to flow in polymers and decomposition products accumulate. Therefore, polymers and polymer compositions, which are used to create coatings on textile materials, must meet a number of requirements to the physicochemical properties. These properties primarily include the tensile strength, elongation at break, resistance to hydrolysis and soap-soda treatment, which are depend on the parameters of the spatial network of the polymer [15].

The goal of the work was to study the physicochemical characteristics of the individual polymer films of acrylic and urethane nature, as well as the effect of the formed polymer coatings on the mechanical and hygienic properties of textile material.

Materials and Methods

A cotton fabric with a surface density of 230 g/m^2 was selected for the study.

The following aqueous dispersions of acrylic and urethane nature were used as film-forming substances:

Tubifast AS 4010 — aqueous dispersion of styrene-acrylic copolymer (dry residue is 45%, pH = 7–9, viscosity at 20°C is <700 mPa·s);

Akratam AS 02.1 — water dispersion of styrene, butyl acrylate and acrylic acid copolymer (dry residue is 50%, pH = 7.5–8.5, particle size ≈ 0.06–0.08 μm, viscosity at 23°C is 700 mPa·s);

Lacritex 640 — acrylic copolymer, modified by the addition of an adhesion promoter (dry residue is 55–57%, pH = 2–3, particle size ≈ 0.2 μm, viscosity at 25°C is not less than 5000 mPa·s);

Aquapol 12 — aliphatic polyurethane (dry residue is 30.3%, pH = 7.81, particle size < 0.1 μm, viscosity at 25°C is 17.4 mPa·s);

Aquapol 14 — aliphatic polyurethane (dry residue is 35%, pH = 7.36, particle size ≈ 0.1 μm, viscosity at 25°C is 20.1 mPa·s).

Polymer films were formed on glass substrates, followed by drying at 80°C for 60 min and heat treatment at 150°C for 3 min.

The determination of the relative elongation at break was carried out using a RT-250M machine.

The test of film resistance to hydrolytic degradation and soap-soda treatment was carried out at a temperature of 60°C for 60 min. The stability of polymer films to hydrolysis and soap-soda treatment was determined by the gravimetric method.

The polymers were applied to the fabric from a solution with different concentration by impregnation with double immersion and pressing to a residual moisture content of 80%. Then the treated textile material was dried and subjected to a heat setting at 150°C for 3 min.

The influence of the formed polymer coatings on the mechanical properties of the fabric was estimated by the rigidity index in accordance with GOST 10550-

93 using the console method. Rigidity of the samples was measured separately for warp and weft directions.

Hygienic properties of the fabric samples with a polymer coatings were determined by indicators of air permeability (GOST 12088-77) and hygroscopicity (DSTU GOST 3816:2009).

Results and Discussion

The physicochemical properties of individual polymer films of acrylic and urethane nature were investigated at the first stage. The test results of the formed polymer films are presented in Table 1.

Table 1 Physico-chemical characteristics of polymer films

Polymer dispersion	Characteristics of films			
	Appearance	*Relative elongation at break,%*	*Hydrolytic stability,%*	*Stability to soap and soda treatment,%*
Tubifast AS 4010	transparent, tacky	>1000	90	88
Akratam AS 02.1	transparent, non-tacky	596	92	90
Lacritex 640	transparent, tacky	550	85	60
Aquapol 12	transparent, non-tacky	480	93	91
Aquapol 14	transparent, non-tacky	76	95	93

All investigated polymer dispersions form a transparent film that will ensure the absence of the negative influence of the selected preparations on the coloristic properties of the fabric in the process of finishing.

An analysis of the relative elongation at break of the polymer films under study (Table 1) shows that the films based on acrylic dispersions Tubifast AS 4010, Akratam AS 02.1 and Lacritex 640 have the most elasticity. The reason for this is the presence in acrylic polymers of long flexible sections of molecules separated by functional groups, which promote the interaction between the chains with the formation of cross-linked structures [16]. Polymers of this type easily relax and quickly distribute the stresses that arise during the deformation of films.

The physicomechanical properties of polyurethane films depend on the nature of the functional groups and their location. A hard fragment of the polymer chain, giving the polymer its hardness, strength, and reduced elasticity, is formed by isocyanates, and the flexible sections, which determine its softness and elasticity, are formed by compounds of polyethers and polyesters [17]. In accordance with the data obtained (Table 1), the Aquapol 14 film is characterized by the least elasticity, which indicates a high degree of cross-linking of the polymer.

The tendency of polymer films to hydrolysis is determined by the nature of the functional groups and bonds that make up the polymer. During the hydrolysis of the side functional groups, the chemical composition of the polymer changes. Hydrolysis of the bonds that make up the main molecular chain leads to a decrease in the molecular weight of the polymer. During washing of textile materials, the influence of standard detergents and mechanical action are added to the hydrolysis at elevated temperature, which contributes to the destruction of polymers. Thus, it is important to study the stability of polymer films to soap-soda treatment.

The results of determining the stability of polymer films to water treatments (Table 1) show that the samples under study are subjected to various degrees of hydrolytic degradation. The highest hydrolytic stability has a polyurethane film Aquapol 14. Acrylic film Lacritex 640 is characterized by the lowest indicator of hydrolytic stability. The data obtained correlate with the indicators of the films resistance to soap and soda treatment and confirm the high crosslinking degree of the polyurethanes under study.

In the process of textile materials finishing it is necessary to control the rigidity of the fabric, since this parameter significantly affects the appearance of products and determines their use and aesthetic properties. Therefore, the influence of the formed polymer coatings on the rigidity of cotton fabric was studied at the next stage of the work. The obtained indicators of the fabric samples rigidity after treatment in solutions with different concentrations of the studied polymer dispersions are presented in Table 2.

Table 2 Effect of polymer coatings on the fabric rigidity

Treatment	**Concentration, g/l**	**Bending rigidity, E_I, μN·cm^2**	
		warp direction	***weft direction***
without treatment	0	10200	2562
Tubifast AS 4010	50	10578	2751
	100	20623	5586

Treatment	**Concentration, g/l**	**Bending rigidity, E_I, μN·cm^2**	
		warp direction	***weft direction***
Akratam AS 02.1	50	16636	8138
	100	37105	13666
Lacritex 640	50	27040	13571
	100	45954	14943
Aquapol 12	50	32833	11258
	100	51972	19476
Aquapol 14	50	38872	10209
	100	52019	19913

In the process of fabric finishing, fine polymers penetrate deeply into the interfiber space. After the processes of drying and heat treatment, which are accompanied by the formation of spatial cross-linked structures, the elastic properties of the obtained polymer–fiber composite are enhanced and the rigidity of the textile material increases.

In order to compare the change in rigidity of the fabric after finishing with the rigidity of the unfinished material in Fig. 1, 2 shows the relative increase in the studied indicator in the warp and weft direction, respectively.

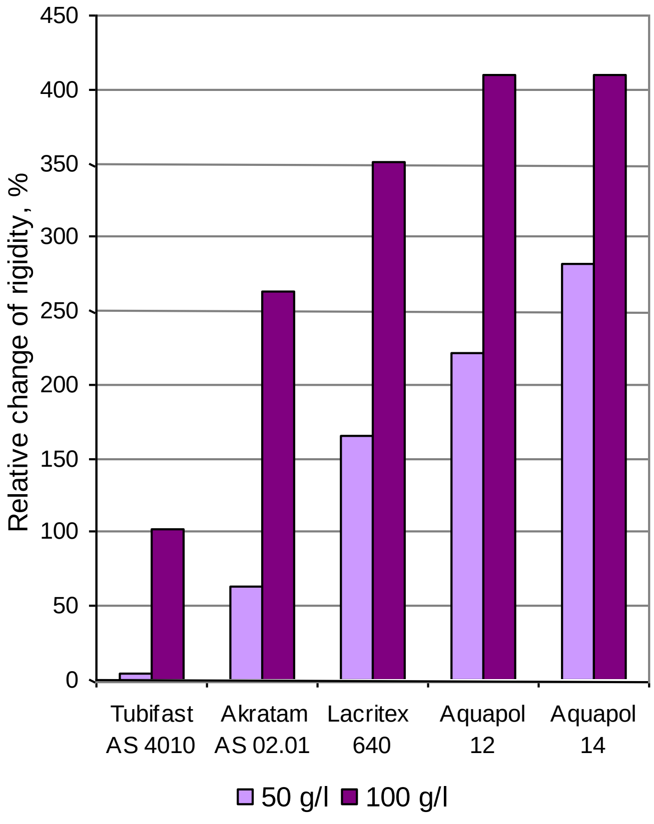

Fig. 1. Relative change in the rigidity of the fabric in the warp direction

Data analysis in Fig. 1 shows that the use of Tubifast AS 4010 styrene-acrylic dispersion at a concentration of 50 g/l slightly increases the rigidity of the fabric in the warp direction by 3.7%, and the rigidity of the fabric increases by 120.2% at a concentration of 100 g/l. In the case of the use of the dispersion Akratam AS 02.1, a rigidity increase in the warp direction is observed by 63.1% with a polymer concentration of 50 g/l and by 263.8% at 100 g/l. The use of acrylic dispersion Lacritex 640 leads to an increase in the studied parameter in the warp direction by 165.1% and 450.5% at 50 g/l and 100 g/l, respectively.

When determining the rigidity of the fabric in the weft direction (Fig. 2) for the studied samples with acrylic coatings, similar dependencies are observed.

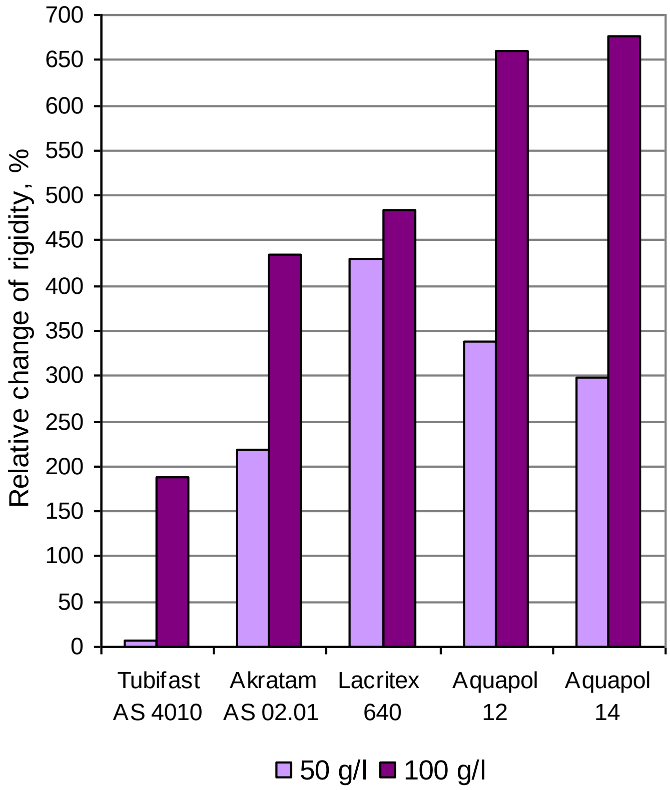

Fig. 2. Relative change in the rigidity of the fabric in the weft direction

Thus, the results of the study of the rigidity of fabric samples with acrylic coatings in the warp and weft directions (Fig. 1, 2) indicate the advantages of using the styrene-acrylic dispersion Tubifast AS 4010 at two concentrations tested.

The different influence of the studied acrylic copolymers on the rigidity of cotton fabric due to differences in the chemical structure of the binders. The determining factor in the reactions of acrylic copolymer macromolecules with macromolecules of the fiber-forming polymer is the interaction of its functional groups with the reactive groups of the fiber polymer. As a result of the reaction of a large number of carboxyl groups in the structure of Lacritex 640 macromolecules with hydroxyl groups of cellulose, a cross-linked structure is formed, which leads to a decrease in the flexibility of the fibers and a change in the elastic properties of the material. The presence of monomers such as butyl acrylate and acrylic acid esters in the polymer structure causes the production of soft and elastic textile materials, which is observed in the case of Tubifast AS 4010 and Akratam AS 02.1.

When using polyurethane dispersions Aquapol 12 and Aquapol 14 (Fig. 1, 2) at a concentration of 50 g/l, the fabric samples rigidity in the warp direction increases by 221.9% and 281.1%, respectively, and the rigidity in the weft direction increases by 339.4% and 298.5%. Increasing the concentration of the studied polyurethanes to 100 g/l leads to an increase in rigidity in the warp direction by 409.5% for Aquapol 12 and by 410% for Aquapol 14, and in the weft direction by 660.2% and 677.2%, respectively.

The obtained experimental data prove that the main factor influencing the rigidity of the finished fabric is the chemical structure of the used polymer binder.

At the next stage of work, the influence of polymer coatings on the hygienic properties of textile material was studied. The results of determining the air permeability and hygroscopicity of the fabric samples are presented in Table 3.

Table 3 Effect of polymer coatings on the hygienic properties of the fabric

Treatment	**Concentration, g/l**	**Air permeability, $dm^3/m^2 \cdot s$**	**Hygroscopicity, %**
without treatment	0	238	8.33
Tubifast AS 4010	50	229	6.84
	100	201	6.81
Akratam AS 02.1	50	218	6.97
	100	205	6.7
Lacritex 640	50	236	6.76
	100	222	6.63
Aquapol 12	50	229	6.75
	100	213	6.68
Aquapol 14	50	233	6.65
	100	222	6.57

Analysis of the data obtained (Table 3) shows that the use of these acrylic dispersions at a concentration of 50 g/l leads to a decrease in fabric hygroscopicity by 16.3–18.8%. Increasing the content of acrylic polymers in the impregnating bath to 100 g/l reduces this indicator by 18.2–20.4%.

When using the studied polyurethane dispersions, the hygroscopicity of the treated fabric is reduced by 18.7–20.2% at a polymer concentration of 50 g/l and by 19.8–21.1% at a concentration of 100 g/l.

The air permeability of fabric samples with acrylic coatings decreases by 0.8–8.4% and by 6.7–15.5% at polymer concentrations of 50 g/l and 100 g/l, respectively. The highest indicator of air permeability is characterized for the sample with Lacritex 640 coating at both concentrations.

The use of polyurethane dispersions Aquapol 12 and Aquapol 14 at concentrations of 50 g/l leads to a decrease in the air permeability of the fabric by 4% and 2%, respectively. Increasing the concentration of polyurethanes in the impregnating bath to 100 g/l leads to a decrease in the studied parameter by 10% for Aquapol 12 and by 7% for Aquapol 14, respectively.

The decrease in the hygroscopicity of the textile material after processing is explained by the fact that the formed polymer coating creates an obstacle for water vapor absorption by the macro- and micropores of the cellulose fiber. The decrease in the air permeability of fabric samples after the application of the polymer coating is due to the change in the parameters of the handle.

Conclusion

The study of the physicochemical characteristics of polymer films based on styrene-acrylic and urethane polymers was conducted, and the effect of these coatings on the rigidity and hygienic properties of cotton fabric was determined.

According to the results of determining the relative elongation at break, resistance to hydrolysis and soap-soda treatment, the best indicators are characterized by films based on polyurethane dispersions Aquapol 12, Aquapol 14 and styrene-acrylic dispersion Tubifast AS 4010. However, when studying the effect of the studied polymers on the rigidity of cotton fabric, it was found that the use of dispersions Aquapol 12 and Aquapol 14 leads to a deterioration of the elastic properties of textile material due to the formation of a more rigid spatial structure of the polyurethane film. In addition, the use of these polyurethane dispersions to a greater extent reduces the hygroscopicity of the treated textile material.

Considering the results of a comprehensive analysis of the effect of polymer coatings on the mechanical and hygienic properties of fabric, the dispersion based on styrene-acrylic copolymer Tubifast AS 4010 can be recommended as a binder for immobilizing functional additives on the surface of cotton textile material for clothing assortment.

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1.3 STUDY OF THE EFFECT OF PROCESSING QUALITY, SURFACE AND SUPRAMOLECULAR STRUCTURE OF COTTON KNITTED FABRIC WITH VARIOUS PREPARATION METHODS ON THE LIGHTFASTNESS OF COLOURS

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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].

The process of cotton knitwear preparation is the most technologically complex, energy-consuming and labor-intensive stage of finishing works. Therefore, technologically and scientifically-based exclusion of some operations is relevant when producing high quality cotton knitted fabrics with low cost.

It is known [14, 15] that the preparation includes a set of processes that ensure the removal of natural impurities (mainly waxy substances) and substances deposited on the fabric during their manufacture (oiling agents) from grey knitted fabric in order to give high capillarity and whiteness. In the course of preparation, the following aggressive factors influence on textile materials:

1) alkaline boiling solution at high temperature, which is the cause of the destruction of cellulosic material under the influence of atmospheric oxygen;

2) peroxide compounds used in bleaching and leading to a decrease in the strength and degree of polymerization of cellulose.

The milder conditions will be during the preparation of textile materials, the more will be preserved strength and natural properties of cellulose, and clothing will have a higher quality [16–18].

Light fastness of colour is an important indicator of quality for textile materials intended for sportswear, T-shirts, clothes for children. Since the range of fabrics for summer clothing is widely represented by cotton knitwear, the study of the effect of its preparation on the light fastness of colors is an actual task. There is no direct relationship between high indices of light fastness and other indicators of the resistance of colors to physical and chemical effects (washing, dry and wet crocking). However, it can be argued that, in general, the quality of color depends on the rate of diffusion and sorption of the dye, which are determined by the physicochemical properties of the fiber [19].

It is known [17, 18] that on a fabric that has been maximally cleared of natural and technological contaminations, it is possible to get pure and bright colors that are resistant to washing, dry and wet crocking. But it should be noted that the effect of the degree of preparation on surface and supramolecular structure of cotton fiber cellulose, its resistance of obtained colours to the action of light was not investigated on cotton knitted fabric with different degrees of.

Method

Study was carried out on grey cotton rib knitted fabric 1×1 with surface weight 150 g/sm2. Preparation of knitted fabric was carried out under the conditions given in Table 1.

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 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 combined preparation principle of knitted fabric and composition of surfactants were developed in previous works [20, 21]. 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.

The capillarity of fabric was determined by the height of potassium dichromate solution (5 g/l) on a 30 cm long strip of fabric after 30 and 60 min.

Whiteness was evaluated using a PCE-TCR 200 colorimeter.

The degree of wax removal was measured using a gravimetric method by determining the samples mass before and after extraction of knitted fabric with petroleum ether for 6 h.

The breaking strength was determined using the tearing machine RT-250K by breaking small strips.

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 CuKα-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 $(1/2\beta)\times 2$ 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.

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

where K is a constant that is associated with the form of crystallites (with an unknown form of crystallites K=0.89);

β is the angular half-width (width at half height) of the clearest singlet diffraction maxima.

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

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

where Qcr is the area of diffraction maxima, which characterize the crystal structure;

(Qcr+Qam) is the area of the entire X-ray diffractogram in the 2θ interval, in which the amorphous-crystalline structure of the samples is observed.

Dyeing cotton knitted fabric was carried out using reactive bifunctional dyes Bezaktiv Cosmos S-C: Rot, Blue and Gold («Bezema») by exhaust dyeing method with the 1/50 solution rate. The dye solution contained 1% dye and dyeing auxiliaries (30 g/l NaCl + 15 g/l Na2CO3). The dyeing was done for 60 min in 60°C, and afterwards overflow cold, hot washing, boiling soaping and cold rinsing procedures are applied.

The light fastness of samples was evaluated after exposure of Light Fastness Tester (Mercury-Tungsten Lamp) RF 1201 BS («REFOND») with a PCE-TCR 200 colorimeter.

Colour measurements were averaged for each sample. Total colour difference (dE) was measured on the dyed cotton knitted fabrics samples after light exposure. Colour difference was calculated according to CIE 1976 L*a*b* equation (3):

$$dE = [(dL)^2 + (da)^2 + (db)^2]^{1/2} \tag{3}$$

where dL – difference in lightness-darkness,

da – difference in redness-greeness, and db – difference in yellowness-blueness.

Results and discussion

The degree of preparation was evaluated by the value of capillarity (Fig.1), whiteness (Fig. 2), degree of waxes removal (Fig. 3) and strength (Fig. 4) of the prepared textile material.

Grey cotton knitted fabric has no capillarity. The minimum capillarity that a textile material must have after preparation is 100 mm; well-prepared fabrics are characterized by capillarity in the range of 150-170 mm. The results of determining the effect of preparation method on capillarity are shown in Fig. 1.

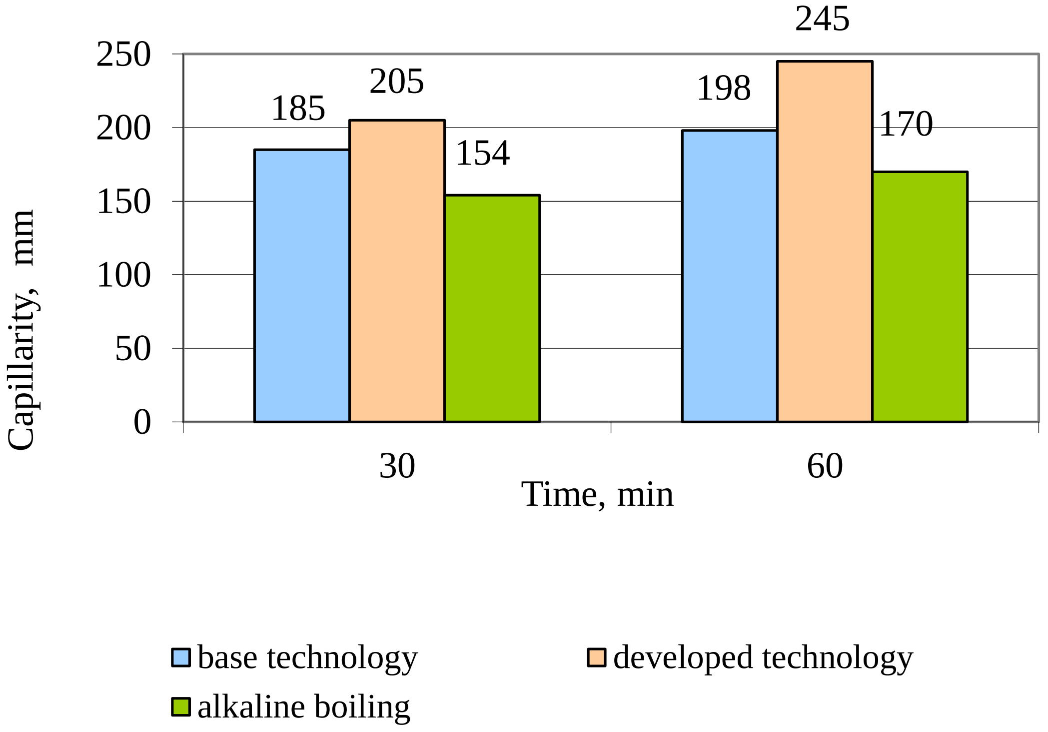

Fig. 1. The influence of preparation method of cotton knitted fabric on the capillarity index value

The results show that the studied preparation methods provide indexes of the capillarity of cotton knitted fabric at the level of 154–205 mm in 30 min, and 170–245 mm in 60 min. It should be noted that the lowest capillarity is characteristic of the sample after bleaching, and the highest capillarity is characteristic of the sample prepared according to the developed principle.

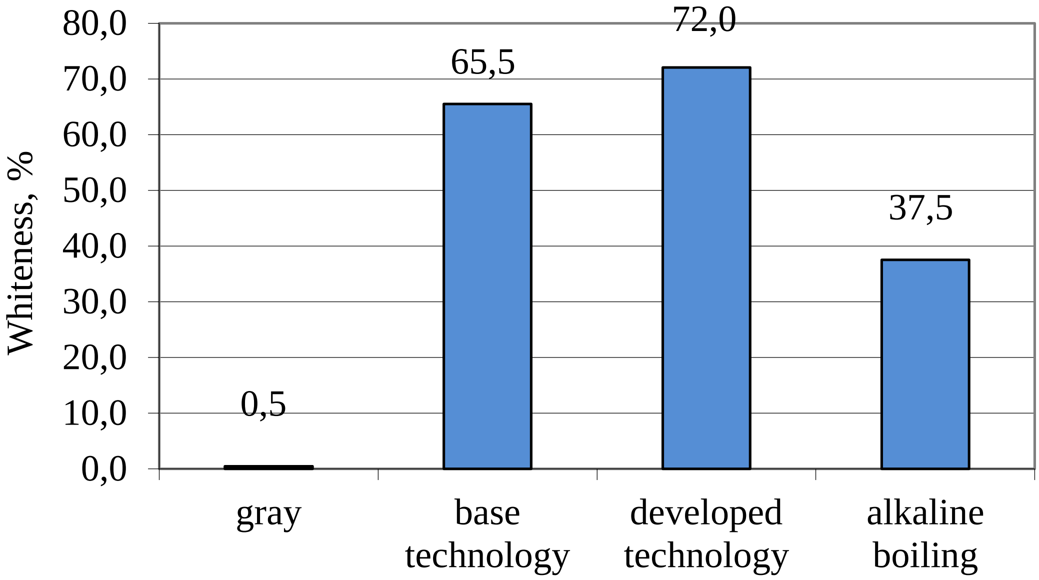

Fig. 2. The influence of the preparation method of cotton knitted fabric on the value of whiteness index

The obtained results (Fig. 2) showed that individually alkaline boiling and bleaching provide a slight increase in whiteness compared with the preparation by combined methods according to the base and developed principles.

The diagram in Fig. 3 illustrates the obtained data on the degree of wax removal from knit samples depending on the preparation method. The data indicate that a grey sample contains most waxes. After preparation according to the studied methods, the content of wax-like substances decreases. Moreover, when preparing according to the base principle, there is less wax on the knitted fabric than after alkaline boiling. The least amount of waxes contains a sample prepared according to the developed principle.

The data presented in Fig. 3 correlate with the results of the determination of capillarity and show that no more than ≈58% of initial waxes are removed during knitted fabric preparation according to individual principles and to the combined base principle. This fact explains the low indexes of knitted fabric capillarity according to these methods of preparation.

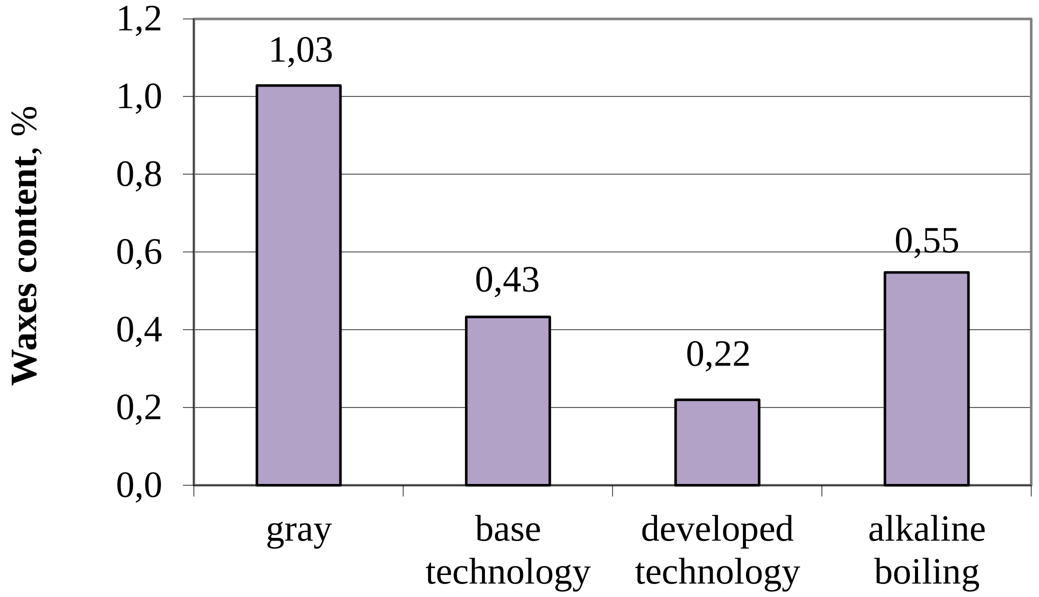

Fig. 3. The influence of the preparation method of cotton knitted fabric on the waxes content

It is established (Fig. 4) that the bleached sample and the sample prepared according to the base principle have the lowest strength. The knitted fabric prepared according to the developed principle is the least damaged.

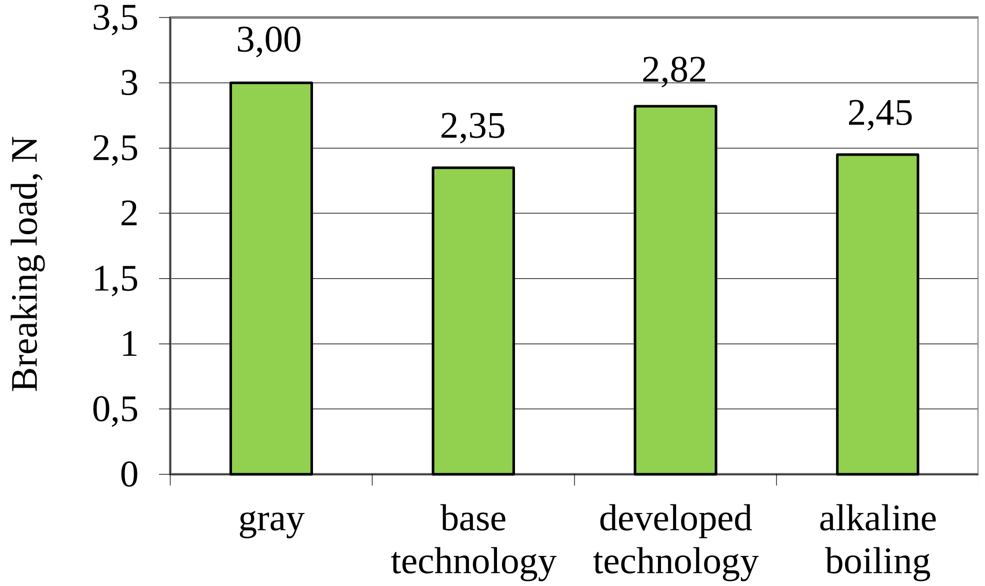

Fig. 4. The influence of the preparation method of cotton knitted fabric on the index of breaking load

Grey cotton knitted fabric does not have capillarity due to the presence of natural fatty and waxy substances and knitting oil. Available waxy substances are arranged on the fiber in such a way that their hydrophobic groups are directed away from the surface of the fiber, as a result of which textile materials are not wetted with water, becoming hydrophobic.

Removal of cotton waxes and oils applied to the threads prior to the knitting process and some amount of water-soluble cellulose impurities during the boiling process increases the capillarity of the knitted material. However, during the boiling, cotton colouring matters are not removed, which leads to a slight increase in the whiteness of the knitted material and, as a result, to obtain less bright colors.

The bleaching solution is not able to penetrate deep into the fibers during bleaching due to the presence of hydrophobic substances on the surface of the textile material. The conditions of the bleaching process (pH of the medium, temperature) are such that in the first stage waxes and oils are removed. At this time, hydrogen peroxide, intended for the oxidation of coloured cotton impurities, decomposes unproductively. Thus, neither high capillarity nor whiteness can be achieved during whitening. In addition, the high temperature of the bleaching process at 98°C and the presence of hydrogen peroxide cause significant damage to the textile material.

The combined preparation method by the base principle includes sequential operations of boiling and bleaching, as a result of which the knitted fabric acquires high indexes of capillarity and whiteness. However, the preparation by the base principle occurs at elevated temperatures, which leads to a decrease in the strength of the textile material.

The developed preparation principle of cotton knitted fabric through the use of highly effective surfactant composition allows combining operations of boiling and bleaching as well as carry out the process at a reduced temperature of 80°C [20, 21]. The result is a textile material with a high degree of removal of waxy substances, high indexes of capillarity, whiteness and a low loss of strength. In addition, this technology of preparation due to the use of low temperatures is energy saving, more economical and environmentally friendly.

Next, we studied the effect of the preparation method on the degree of fixation of reactive dyes on the knitted fabric (Fig. 5).

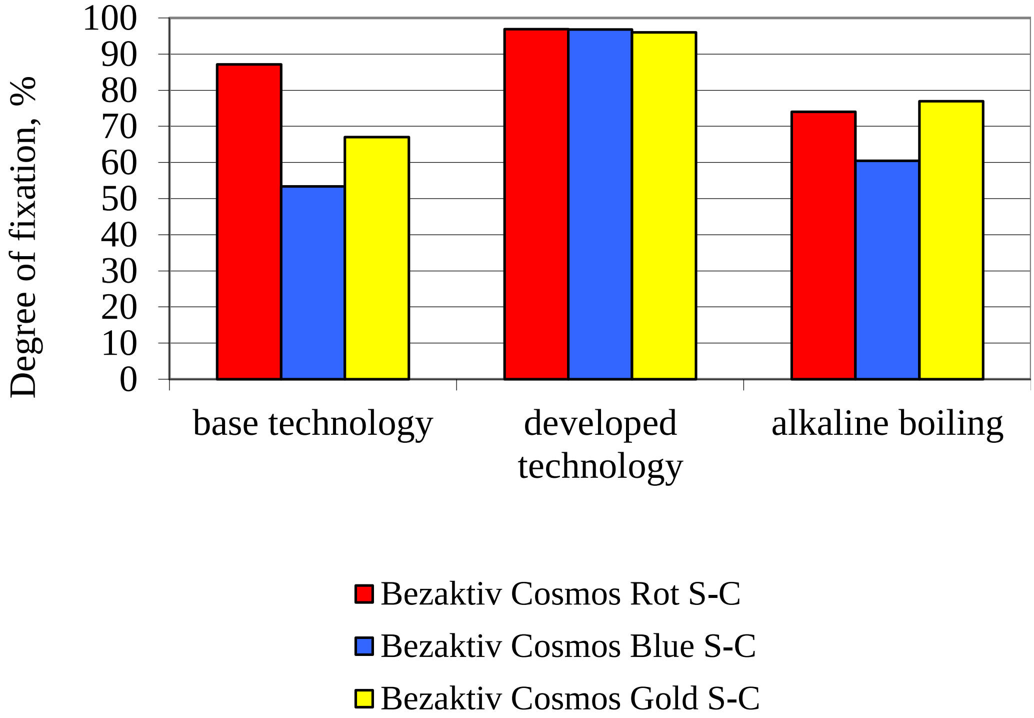

Fig. 5. The influence of the preparation method of cotton knitted fabric on the degree of fixation of reactive dyes

The results (Fig. 5) show that among the studied preparation methods, only the developed principle provides high fixation indexes of reactive dyes. Obviously, this is due to a more complete removal of wax-like substances and oil from knitted fabric during its preparation, and, therefore, high capillarity and high sorption properties of the textile material. The sorption surface of the fiber is determined by systems of submicroscopic pores and capillaries, as well as existing cavities and cracks. In the process of preparation, the structure of the fibrous material changes, the surface is freed from impurities, pores open, microcracks appear. The internal stress decreases, causing unevenness of properties, ensuring the penetration of chemical reagents into the fiber. As a result, the dyes penetrate deeper into the fiber, and the degree of fixation of the reactive dyes on cotton knitted fabric is increased.

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 (Fig. 6) 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 (Fig. 6b, c, d) does not undergo changes as compared with the surface of the original grey fiber (Fig. 6a).

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 Fig. 7.

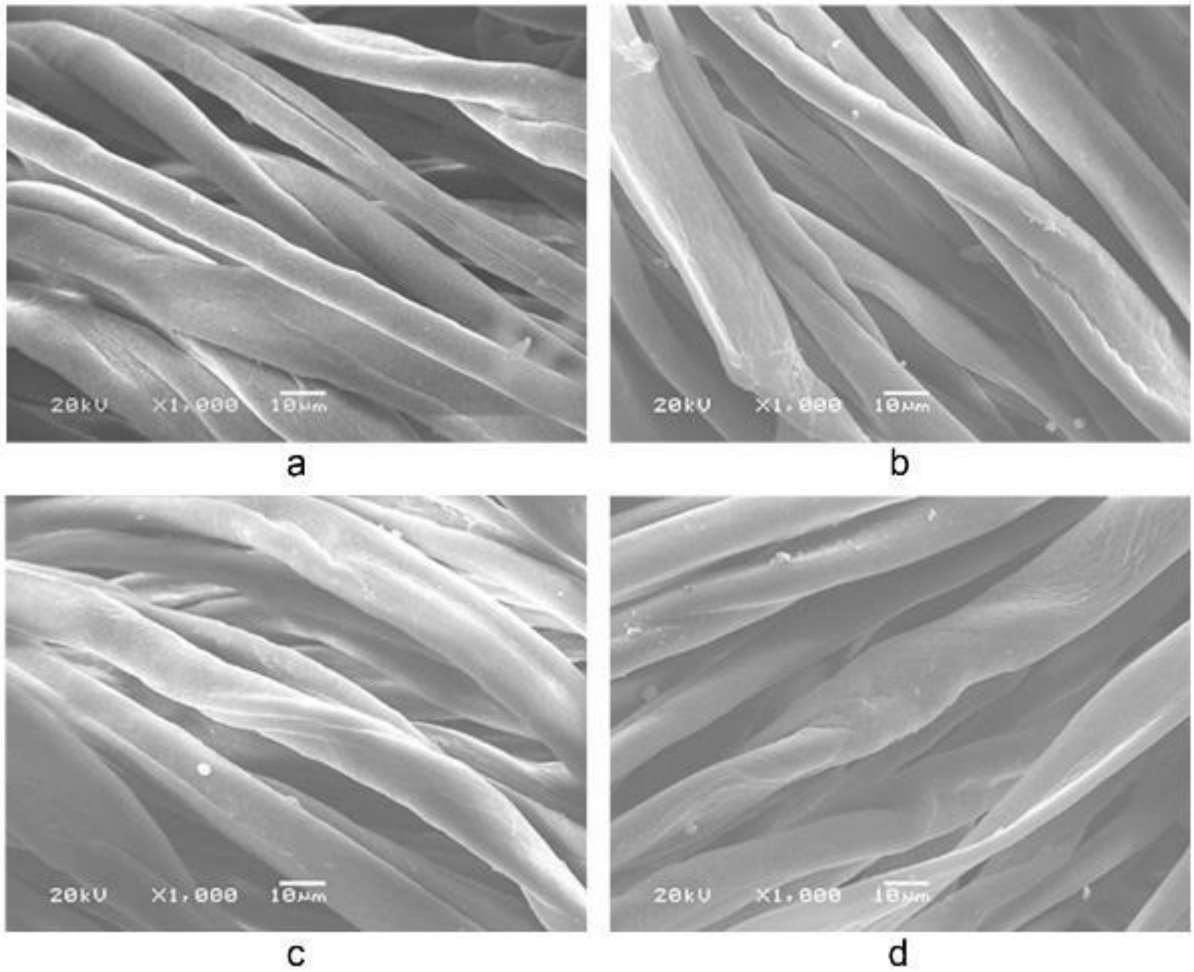

Fig. 6. Example Micrographs of cotton fiber samples: a – gray; b – base technology; c – developed technology; d – alkaline boiling.

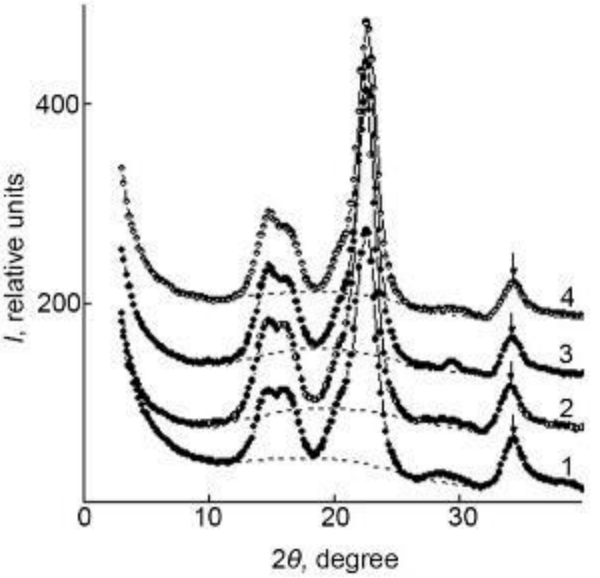

Fig. 7. Wide-angle X-ray diffractograms of cotton knitted fabric samples: 1 – gray; 2 – base technology; 3 – developed technology; 4 – alkaline boiling

When analyzing X-ray diffractograms of knitted fabric (Fig. 7), 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 Fig. 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 L14.8°, L26.6° 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 2θm=14.8°, L14.8°, nm***	***Crystallite size at 2θm=22.6°, L26.6°, 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 Xcr of the cotton knitted fabric samples under study are presented in Fig. 8.

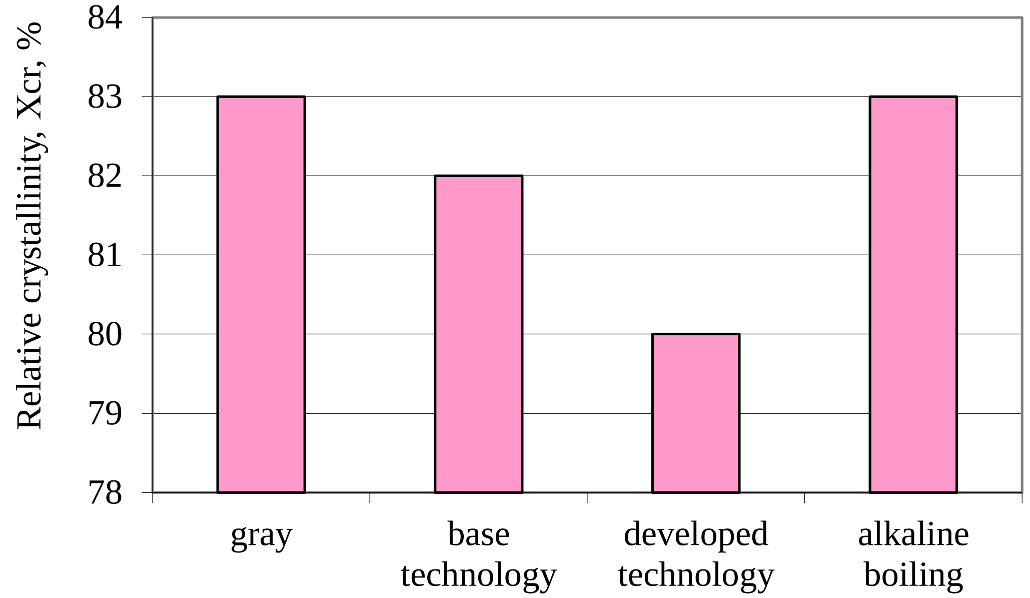

Fig. 8. The relative level of crystallinity of cotton knitted fabric samples: 1 – gray; 2 – base technology; 3 – developed technology; 4 – alkaline boiling

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 Xcr of the studied samples is about 80% regardless of the preparation method (Table 2). The smallest crystallinity level Xcr=80% has a sample prepared according to the developed technology, and the highest crystallinity level Xcr=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 2θm=29.4° for sample 3, prepared by the developed technology.

Next, we studied the effect of the preparation method on the degree of fixation of reactive dyes on the fading kinetics of colours on cotton knitted fabric (Fig. 9) and the light fastness of the colours obtained (Table 3).

Table 3 The influence of the preparation method of cotton knitted fabric on the light fastness of colours of reactive dyes

Dye	**Samples**		
	base technology	***developed technology***	***alkaline boiling***
Bezaktiv Cosmos Rot S-C	3	4-5	2
Bezaktiv Cosmos Blue S-C	4	5-6	2-3
Bezaktiv Cosmos Gold S-C	4	5	2

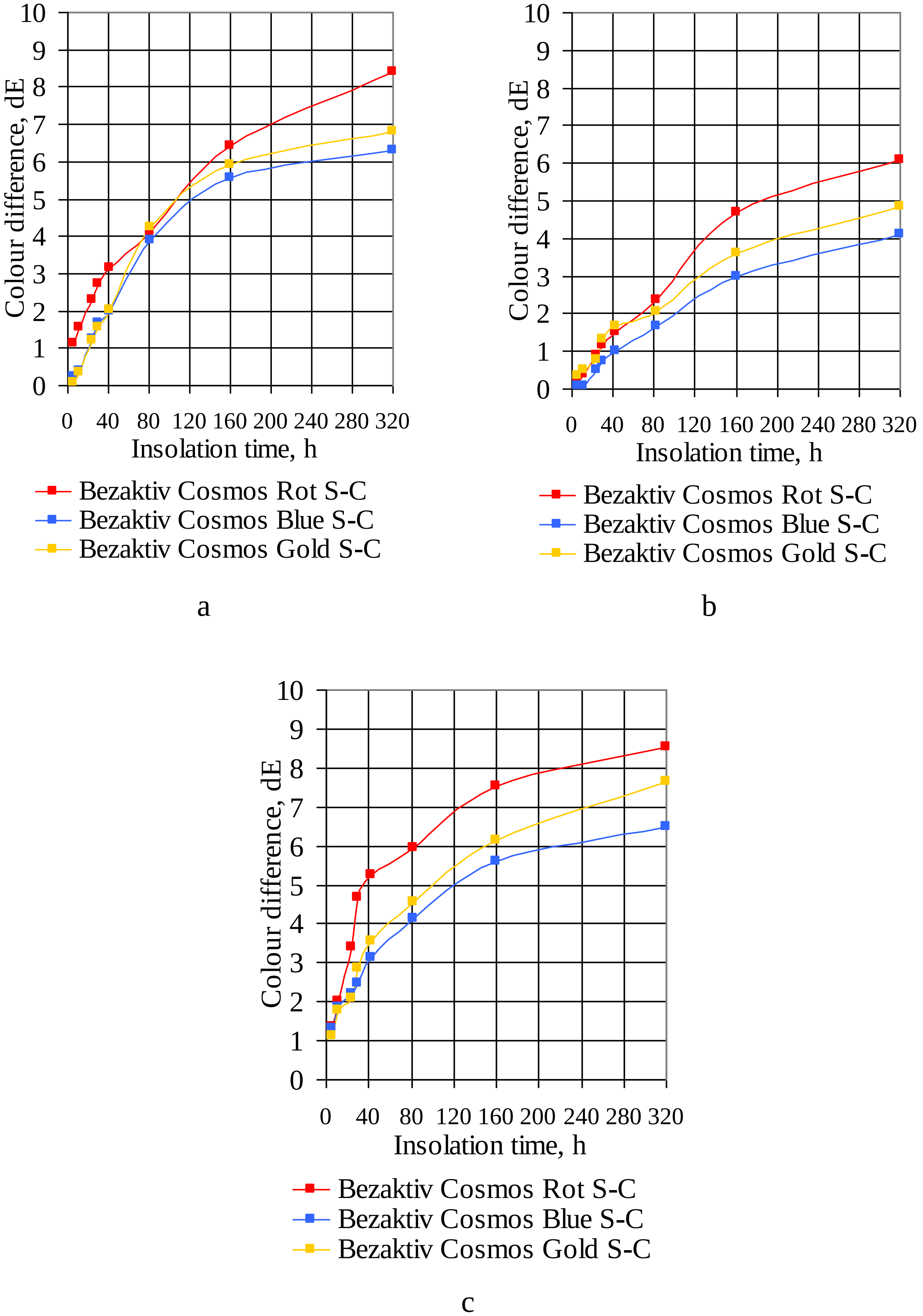

Fig. 9. The influence of the preparation method of cotton knitted fabric on the fading kinetics of colours of reactive dyes: a) – base technology; b) – developed technology; c) – alkaline boiling

The obtained data testify to low indices of light resistance of the colors of the samples prepared by the methods of boiling and bleaching and according to the base principle. The light fastness of the colors of knitted fabric, prepared according to the base mode, is somewhat higher than that of samples subjected to alkaline boiling and bleaching. The reason for this may be the incomplete removal of waxes and, as a result, low capillarity indexes, which leads to non-dyeing of the textile material and a decrease in the resistance indexes of the obtained colours to the action of light. The colours of knitted fabric, prepared according to the developed principle, are characterized by high index of light fastness.

Conclusion

It has been established that the developed preparation principle of cotton knitted fabric contributes to the maximum removal of wax-like and colouring matters from a textile material, and as a result, increased capillarity and whiteness. In this case, the strength of knitted fabric is reduced slightly. This is facilitated by the application of the previously developed highly effective surfactant 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.

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.

As a result of preparation according to the developed principle, the knitted fabric obtains high sorption properties in relation to reactive dyes, and the resulting colours are characterized by high resistance to the action of light.

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1.4 INVESTIGATION OF THE PROCESSES OF INTERMOLECULAR INTERACTION IN SOLUTIONS OF BIOLOGICAL SURFACE-ACTIVE SUBSTANCES

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Introduction

The concept of integrated study of colloid-chemical, physical indicators of efficiency of biological surface-active substances (biosurfactants) and application of a systematic approach to the analysis of chemical and technological processes of aqua-cleaning of finished products is developed. The molecular composition of the micelles X_1^m and the interaction parameter in mixed micelles β^m are determined. The regularities of the process of intermolecular interaction in solutions of ecosystems are established on the basis of the theory of regular solutions and the model of pseudo-phase separation. Binary compositions based on biosurfactants with synergistic effect in micelles formation, which may be influenced by a steric factor associated with the advantageous nature of packaging of biochemical molecules in mixed micelles, as well as the possibility of micelle formation of optimal composition are proposed. The mechanism of adsorption of compositions of biosurfactants on fibers and the structure of adsorption layers on the basis of analysis of the chemical structure and spatial structure of biosurfactants. The chemical structure of the surface of the fibers and their properties in aqueous solutions are described.

Method

The adsorption of compositions of biosurfactants on the surface of textile materials in a solvent environment depends on many factors, the main of which are the properties of the surface of the fibers and the qualitative and quantitative characteristics of the components of the compositions [1].

The most important characteristics of the surface of the fiber that affect the adsorption processes of are:

- its chemical structure, which determines the hydrophilicity or hydrophobicity of the surface, the presence of polar groups, the electrokinetic potential of the surface in the solution, the ability to swell, etc;
- surface morphology characterized by smoothness or roughness, pore size and capillaries, presence of defects on the surface, thickness of the fiber, etc.

Compositions are characterized by the chemical nature of components, sizes and ratios of hydrophilic and hydrophobic parts in each biosurfactant the quantitative ratio of components in the mixture, the concentration of the mixture of biosurfactants in solution.

For this evaluation and analysis of the process of intermolecular interaction in solutions of biosurfactant the theory of regular solutions and a model of pseudophase separation were used [2], according to which the molecular composition of the micelle X_1^m was determined (the mole fraction of component 1 – LAS-80 in the mixture with the second component – non-ionic biosurfactant (Omero-16) and the interaction parameter in mixed micelles β^m). A numerical method of calculations using the Maple 14 program was used.

In this research, samples of cotton and polyester fabrics and their mixtures were treated with aqueous solutions of compositions of biosurfactant [3, 4] with different ratios of components and with different concentrations of solutions. To study the properties of the tissues in the process of wet-cleaning with compositions of the biosurfactant, a composition with a mass fraction of 67 % Omero-16 and 33 % LAS-80, corresponding to the molar ratio of LAS-80 to Omero-16, as 7 : 1.

Experimental

Structural formulas of the main components of used non-ionic organic pollutants are presented in Fig. 1.

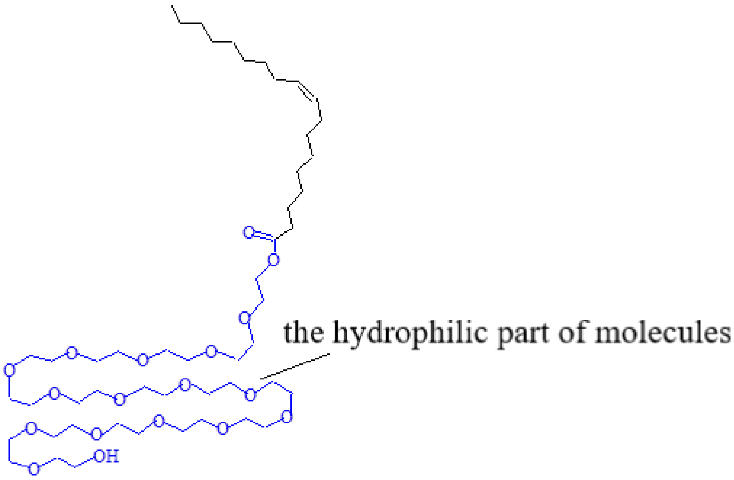

Fig. 1. Structural formulas for non-ionic surfactant Omero-16 and its conditional symbols

These non-ionic biosurfactant have a high degree of oxyethylation, i.e. the polyoxyethylene part is larger than the hydrophobic carbon chain, therefore we are asked to conditionally denote the hydrophilic part of such molecules with two balls ( in our schemes of blue colour).

The real spatial conformation of the molecules due to the thermal motion of the molecules varies over time due to the possibility of rotation of groups of atoms around single ligaments.

The carbon chain may be partly shaken into the globule, which reduces the contact area of the hydrophobic part of the surfactant with a polar solvent. The hydrophilic polyoxyethylene chain is stabilized by apparently oriented water molecules and becomes swirling or meandroform [5] (Fig. 2).

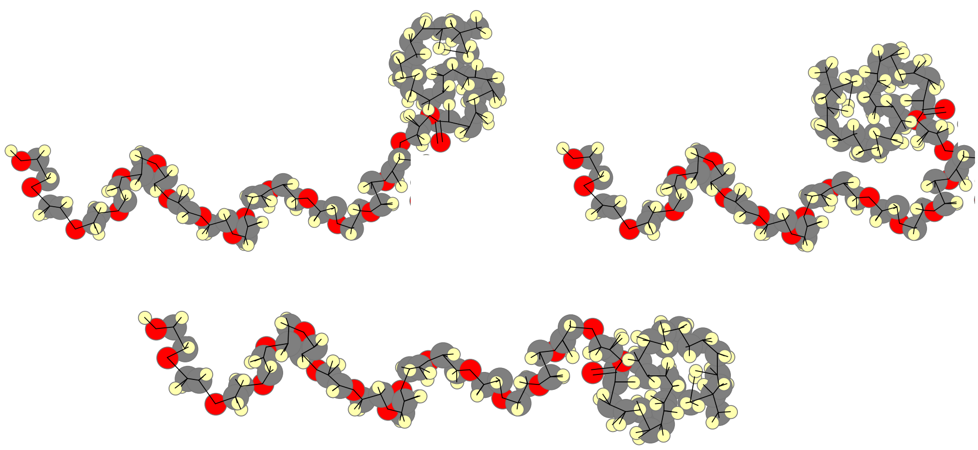

Fig. 2. Examples of possible spatial conformations of the Omero-16

The structural formula of one of the main components of the LAS-80 mixture is shown in Fig. 3.

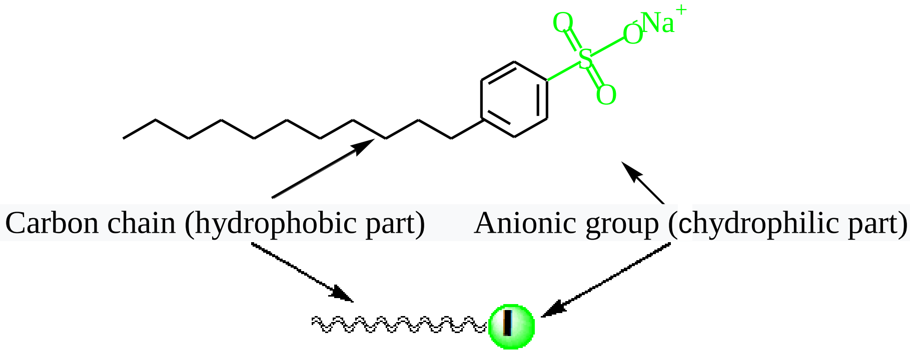

Fig. 3. Structural formula and conditional symbol of LAS-80

For this mixture, shall we consider the processes and mechanism of adsorption of surfactant on cotton and polyester fibers from an aqueous solution at concentration of biosurfactant compositions close to the values of critical micelle concentration.

Cotton fibers are capable of swelling in biosurfactant water solutions. At the same time, the specific surface of the fiber increases, the capillary-porous structure changes and the description of adsorption processes becomes complicated [6]. But the processes of adsorption and desorption of large molecules of nonionic surfactants in capillaries occur much more slowly than on the surface [2, 7], therefore we confine to describing the probable mechanisms on the surface of cotton fibers.

In aqueous solutions, the surface of cotton fabric has a negative value of the electrokinetic potential, which is due to the presence of hydroscopic groups of cellulose fibers.

Calculation of parameters of interaction and composition of mixed micelles of binary compositions of biosurfactant in aqueous solutions are given in Table 1.

Table 1 Calculation of parameters of interaction and composition of mixed micelles of binary compositions of biosurfactant in aqueous solutions

α	**0.2**	**0.333**	**0.5**	**0.667**	**0.8**
20^0C					
C, M	0.00021	0.00022	0.00023	0.00024	0.00026
X_1^m	0.157	0.261	0.408	0.563	0.707
$β^m$	-0.159	-0.118	-0.176	-0.281	-236
C`, M	0.000214	0.000225	0.00024	0.000257	0.000273
25^0C					
C, M	0.00017	0.00018	0.00021	0.00024	0.00026
X_1^m	0.139	0.224	0.317	0.454	0.586
$β^m$	-0.664	-0.669	-0.402	-0.426	-0.701
C`, M	0.000182	0.0002	0.000229	0.000267	0.000308
30^0C					
C, M	0.00013	0.00015	0.00018	0.00024	0.00029
X_1^m	0.118	0.151	0.224	0.312	0.457
$β^m$	-1.284	-0.823	-0.669	-0.329	-0.562
C`, M	0.000143	0.000164	0.0002	0.000257	0.000333

The calculation of the composition of the micelle and the interaction parameters, showed that the micelles anionic – non-ionic enriched with a stronger biosurfactant – non-ionic (Omero-16) already in the molar fraction anionic surfactant W = 20 % and more. The negative value of the interaction parameter indicates the existence of excessive attraction between the components of the mixture in the micelle. At the same time, there is a synergistic effect in the micelle formation, which can be influenced by the steric factor associated with the advantageous packaging of the molecules biosurfactant in mixed micelles. Thus, the synergy in the mixtures of biosurfactant is influenced by the small difference between the critical micelle concentration of individual surfactants, as well as the possibility of forming an optimal micelle composition. With an increase in the lactic content of LAS-80 in mixed micelles from 20% to 80%, there is a significant change in the composition of the micelle.

Results

It has been previously determined that the developed composition of biosurfactant is not subject to the rule of additiveness, but reveals the properties of synergism, which is manifested in decreasing the critical micelle concentration and the surface tension of the solution in comparison with the corresponding values of individual biosurfactant [7]. The phenomenon of synergism also occurs when adsorbed on the surface of fibers. The mechanism of adsorption and formation of adsorption layers is determined by a more superficially active substance, which in this mixture is a non-ionic biosurfactant – Omero-16.

Because of the large size of the molecules and the long oxytylated chain, the molecules of Omero-16 have a great affinity for the hydrophilic surface of the cotton fiber, therefore, they win in competition with the active surface centers in relation to the anionic biosurfactant LAS-80 which has the same charge with the surface and electrostatically repels from the surface. Thus, the Omero-16 molecules adsorbed on the surface of the fiber, shielding the negative charge of the surface, which promotes adsorption of anionic biosurfactant (quantitatively 6-7 times more than Omero-16), but mostly for the surface of the adsorbed non-ionic biosurfactant. These processes occur practically simultaneously, a bimolecular layer is formed at the same time from both biosurfactants (Fig. 4).

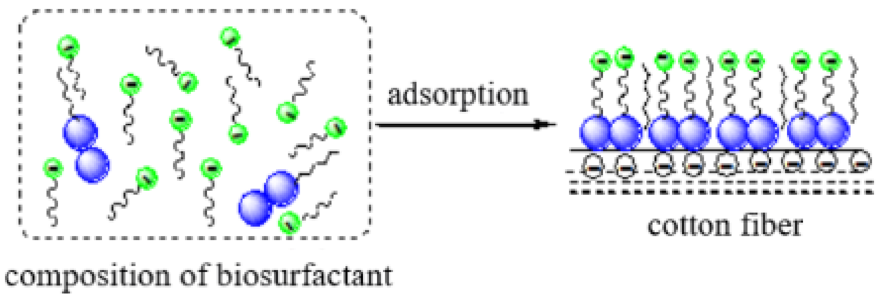

Fig. 4. The scheme of adsorption of the mixture of Omero-16 and LAS-80 on cotton fiber

The adsorption of non-ionic biosurfactant on the surface of the fiber is due to the Van der Waals interaction (dispersion, dipole-dipole) of the parts of the ecologically active particles and the surface fragments of the fibers and the formation of hydrogen bonds between the hydrophilic part of the biosurfactant and the polar groups of the fiber [1, 5].

Taking into account the length of the polyoxyethylene chain, its landing area and the quantitative advantage of LAS-80 molecules in the solution it can be assumed that the bimolecular layer is formed not only due to Van der Waals interaction of the hydrophobic carbon chains of the non-ionic and anionic biosurfactant but also due to the intermolecular interaction of the final 2-3 groups of hydrophobic chain LAS-80 with methylene portions of the polyoxyethylene chain of Omero-16 (Fig. 5).

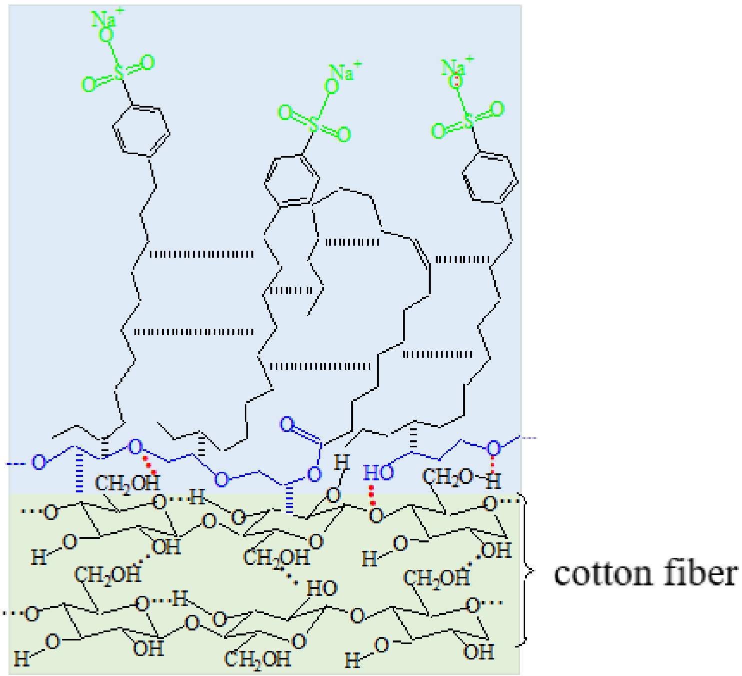

Fig. 5. Scheme of molecular interactions and the formation of hydrogen bonds during adsorption of Omero-16 (on the scheme of the molecular fragment) and LAS-80 on the surface of the cotton: IIIII – Van der Waals interaction between the carbon chains, IIIII – Van der Waals interaction between the polyoxyethylene chain and the surface of cotton fiber, … – hydrogen bonds between the biosurfactant and the surface of cotton fiber

Polyester fibers are synthetic fibers with a smooth hydrophobic surface that has a negative charge (the electrokinetic potential of polyester fibers is – 125 to – 65 mV). Due to the rather high polarity of the polyester surface, molecules of non-ionic biosurfactant can be adsorbed not only due to the interaction of the hydrophobic part of the biosurfactant with hydrophobic polyester regions, but also due to the Van der Waals interaction of polyoxyethylene chains with polar surface groups [7, 8].

Thus, on the surface of the polyester, a layer of the biosurfactant molecules is formed, which is arranged parallel to the surface. In case of adsorption of the composition of Omero-16 and LAS-80, a bimolecular layer is formed simultaneously. The first layer of the Omero-16 molecules parallel to the surface of the polyester that shields the negative charge of the surface facilitates the adsorption of the anionic biosurfactant LAS-80, which forms the second adsorption layer. The end-groups of the carbon chain LAS-80 powered by Van der Waals forces are contained on the hydrophobic part of the Omero-16 and on the methylene arias of the polyoxyethylene chain (Fig. 6, Fig. 7).

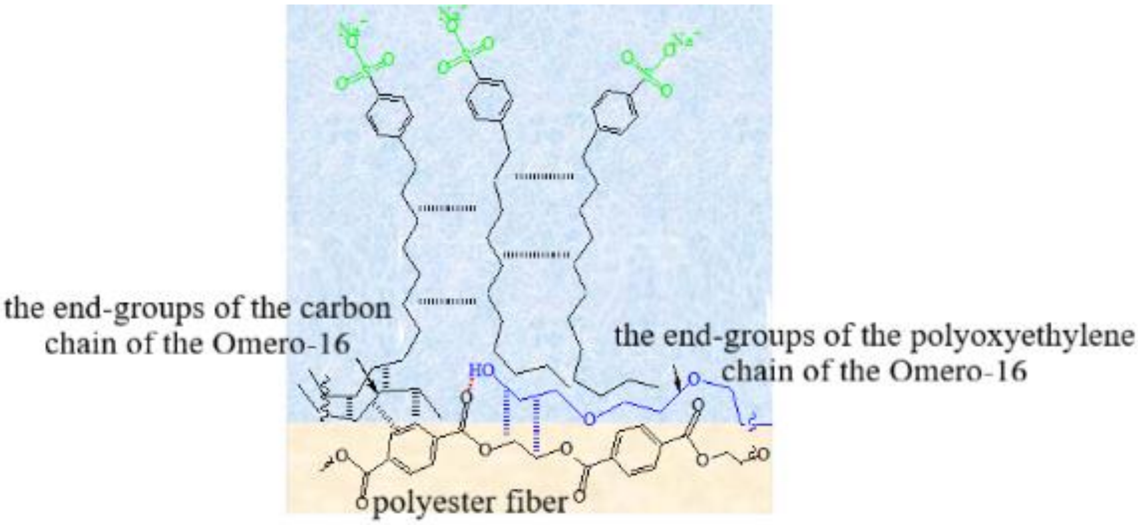

Fig. 6. Scheme of possible interactions during adsorption of Omero-16 (on the scheme fragments of adjacent molecules) and LAS-80 on the surface of polyester fiber

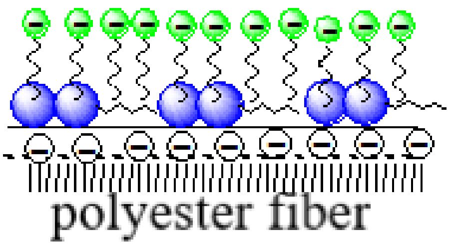

Fig. 7. Scheme of the structure of the bimolecular layer of Omero-16 and LAS-80 on the surface of polyester fiber

Investigation of the proposed mechanisms of adsorption of the composition of biosurfactant on fibers and the structure of adsorption layers is based on the analysis of the chemical structure and spatial structure of the biosurfactant, the chemical structure of the surface of the fibers and its properties in aqueous solutions, literary sources in which the mechanisms of adsorption of surfactant on various textile fibers are considered and substantiated, as well as on the analysis of isotherms of adsorption [1, 5, 7].

In order to establish the patterns of adsorption of the studied compositions in the tissues, the adsorption isotherms in adsorbed isotopes in the coordinates of the mass of the adsorbed biosurfactant G (mg/g of fiber) is the concentration of the mixture of biosurfactant in the initial C solution (g/l) (Fig. 8).

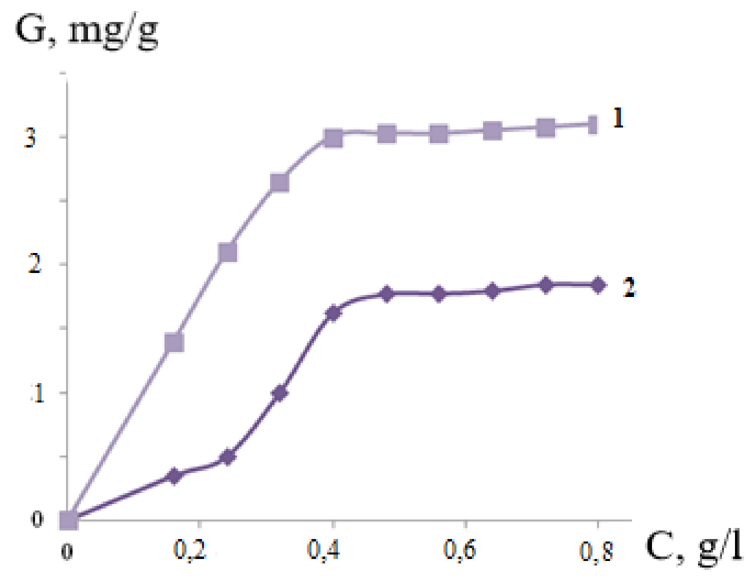

Fig. 8. Isotherms of adsorption of the mixture of Omero-16 and LAS-80:
1 – on cotton fiber; 2 – on polyester fiber

The amount of adsorption (G, mg/g of fiber) is determined by the difference in the concentrations of the composition of the biosurfactant in the solution before and after equilibrium determination. The concentration of the solution of the composition of biosurfactant was determined by the surface tension isotherm (Wilhelm's method).

According to the C. H. Giles classification of the isotherm of adsorption, the composition of biosurfactant on cotton fibers can be attributed to isoterms of the type L-2, which are characterized by saturation of the adsorption layer at a certain concentration, above which adsorption reaches the limit [1, 5]. In the formation of bimolecular adsorption layers at the adsorption isotherm of one biosurfactant there is the formation of two plateaus (isotherm type L-4 by C. H. Giles). In our case, when adsorbing the mixture of two biosurfactants, the formation of a single plateau (within the studied concentrations of compositions of biosurfactant) is observed, which is evident in favor of the model of simultaneous formation of the bimolecular layer, in which the process of formation of the first layer of non-ionic biosurfactant promotes the adsorption of the anionic biosurfactant (second layer). With the increase in the concentration of the composition of biosurfactant in the solution, the following layers are not formed, since the large-sized Omero-16 molecules have a greater affinity for the aqueous medium than to a negatively charged, non-dense surface of the hydrophilic heads (sulpho groups) and can not be retained on the surface of the second layer.

The isotherm of adsorption of the composition of biosurfactant on polyester belongs to the class S-2. This type of isotherm has a characteristic concavity of the initial region relative to the axis of concentration, which is characteristic for the weak interaction of the adsorbate with the adsorbent. The formation of a single plateau within the concentrations studied, as in the previous case, indicates the simultaneous formation of a bimolecular layer from two biosurfactants.

Conclusion

Consequently, studies and calculations based on the model of pseudophase separation have shown the synergistic effect of the mixture of biosurfactants in the molar LAS-80 fraction of more than 20 % and above, which is manifested in lowering the critical micelle concentration and surface tension of the solution in comparison with the corresponding values of the individual biosurfactant. The behavior of the biosurfactant mixture is determined by the behavior of a stronger biosurfactants environment, which displaces the less surface-active component of the mixture (LAS-80) from micelles and adsorption layers.

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1.5 PAINTING OF ELASTIC MATERIALS OCCURRING IN ARMAMENT AND MILITARY EQUIPMENT

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Introduction

Military equipment currently used by Army consists of many types of materials, its outer elements subject to masking painting are increasingly made of different types of light metal alloys and plastic composites. There are also different parts of the plating made of elastic materials such as canvas covers, protective covers, mud flaps and others. In addition to typical military equipment, there are mock -ups of the equipment that must look like real equipment.

All materials of alloy, composites, elastic materials require appropriate surface preparation to apply masking paint, which allows for proper masking of the equipment [1-7].

Coating properties

Many types of elastic materials are used in the armaments industry, including rubber components such as seals, reinforced rubber components such as mud flaps, covers and canvas covers made of plastics or various types of textile materials (textiles). The next group are the elements from "hard" plastics e.g. bumpers, slats, mirror housings, composite armour. In Addition, in the case of pneumatic deception device beyond above described there are others with special properties (e.g. pumping capability, flame retardability).

Each of these groups should be approached separately by considering the 3 basic parameters that must be fulfilled:

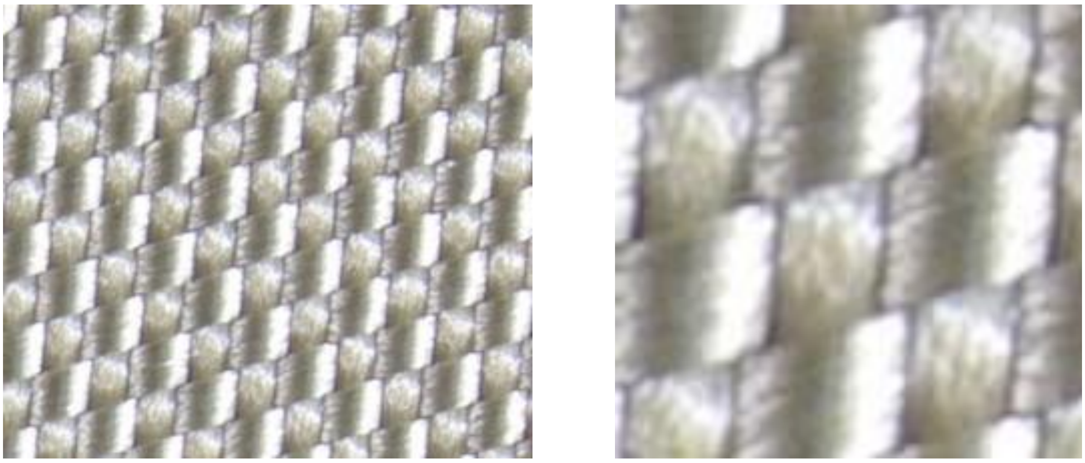
a. adhesion of paint to the substrate,
b. suitable flexibility,
c. proper electromagnetic waves reemission (masking).

Adhesion

Adhesion can be determined as the adhesion forces between the surfaces of different materials. To make the coating properly adhered to the ground, it must be properly prepared. Basic preparation is the removal of contaminants such as: loose particles e.g. dirt, dust, grease, oil, wax and others.

Another important procedure is the so-called expanded surface, which increases the paint contact surface with the substrate. One way is to grind the surface with sandpaper or matting fleece for example Scotch Brite. Such preparation is not always advisable, some materials contain in their structure fibres, which after grinding could extend beyond the coating (e.g. laminates).

In the case of textile materials (Fig. 1), it is not possible or necessary to expanded surface by grinding. The surface of textile materials is expanded by the occurrence of fibres and their weaves. In this case, the applied paint should obtain its adhesion by penetrating inside the fibre structure and between the fabric weaves and mechanically to "anchor".



a b

Fig. 1. Fabric no: a) 5499; b) 5499

In the industry, there are also plastics, which require special measures to increase the interlayer adhesion of the so-called adhesion promotors. Such products are designed for selected plastics and are usually applied in a very thin layer of about 5-15 µm to form a bridge between the ground and the coating.

There are also plastics that are practically not suitable for applying paint products to them. These are materials whose surface energy is equal to or less than the surface tension of the paint. Such plastics are better to dyed at the stage of their production.

Obtaining proper adhesion between the substrate and the paint coating, the lack of chips, the coating delaminating is an important criterion for ensuring proper masking of military equipment and components made of elastic materials.

Flexibility

In the previous paragraph, it was presented how to ensure proper adhesion to the substrate. From this point we can move to another important property what is the flexibility. Flexibility is a mechanical property of material that describes the ability of the material to return to its basic shape after deducting the forces that acting on it.

In the case of paint, always take into account the flexibility of the entire coating, which sometimes consists of many layers of varying elasticity.

The flexibility depends largely on the fibre material used in the paint and so better elastic properties have paints on the basis of vinyl or acrylic resins, while worse properties have paints based on alkyd, polyurethane or epoxy resin.

To increase the flexibility of the paint, special additives called plasticizers are used to reduce intermolecular impacts and increase the mobility of polymer chains in the paint (Fig. 2).

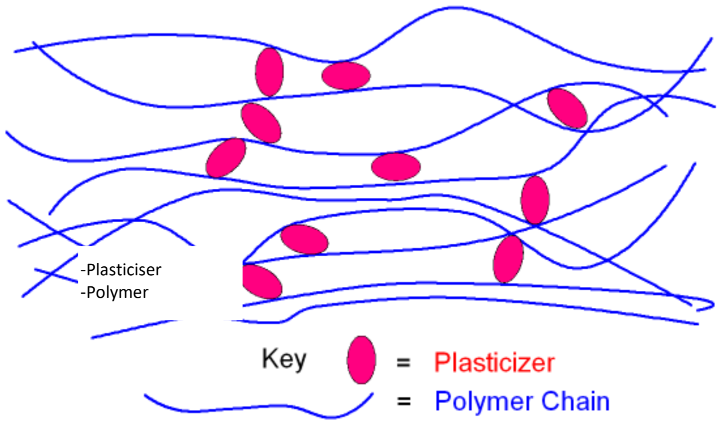
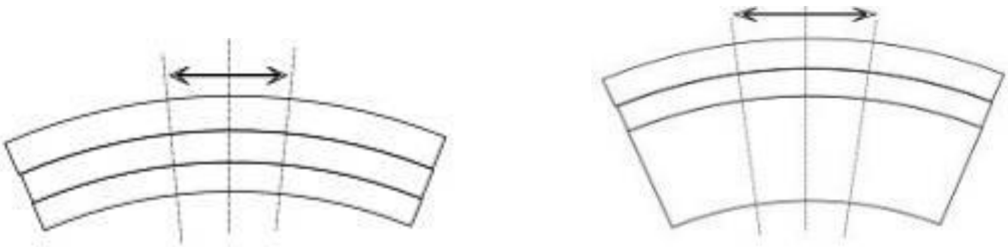


Fig. 2. Plasticizer arrangement for polymer

The elastic behaviour of the coatings is influenced among others by the type and elasticity of the substrate. Coating is completely differently loaded for example, reinforced rubber, and otherwise on the canvas cover. The required displacement of the paint, so the shear and tensile forces are different (Fig. 3).

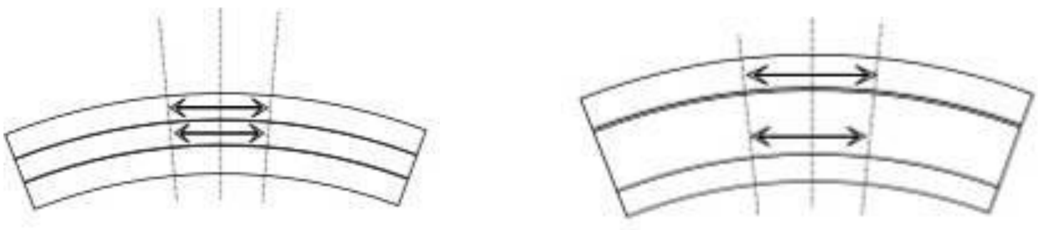


a b

Fig. 3. Displacement of the coating consisting of a layer of primer and a layer of topcoat: a) on the canvas cover, b) on the reinforced rubber

The flexible properties of the coating are also affected by the type and direction of the acting forces. For example, the canvas cover of a transport vehicle is subjected to cyclic deformation and a bend with an angle of 90^0. On the other hand, the mud-guard or side-cover of an armoured vehicle made of reinforced rubber is otherwise deformed, but other deformation is subject to pneumatic deception devices of vehicles or folding water tanks.

The thickness of the coating also has an influence on the proper behaviour of the coating on the elastic material. We should use as thinnest coatings as possible, because the greater the thickness of the coating, the greater the displacement of the coating and the greater deformation of it (Fig. 4). For flexibility, the applied paint should meet the above-mentioned ones.



a b

Fig. 4. Coating displacement: a) thin two-layer coating, b) thick two layer coating

Masking

If we have selected a coating that is characterized by proper adhesion to the substrate, and the appropriate flexibility taking into account the nature of the work and loads, then the next thing is to provide masking, so to get the relevant element of electromagnetic waves in the ultraviolet, visible and near infrared range, in accordance with the applicable defence standards. It should be remembered that the coating is penetrated by electromagnetic waves and in the case of near infrared, proper reemission is affected by such properties as:

- reemission of camouflage coating,
- film thickness of camouflage coating.

They may also be affected by:

- reemission of primer coating,
- film thickness of the primer coating,
- substrate.

These factors should be taken into account in the proper selection of the paint coating.

Coating application on elastic materials

In the manufacturing of new military equipment and in its exploitation, the predominant ways of applications of liquid paints are two methods: pneumatic and hydrodynamic.

Pneumatic method

The pneumatic method is carried out using pneumatic paint guns, where the paint is atomized and transported to the item using compressed air in the range of 2-4 bars. The paint pressure is in the range of 0.7-3 bars.

This method has a disadvantage: the conveying air produces an air cushion on the ground and the paint inadequately penetrates the material.

Using this method (Fig. 5) in painting elastic materials that have the ability to absorb paint, use the first layer of lower viscosity. This is to penetrate the paint in the material structure and create a better adhesion of the next layer.

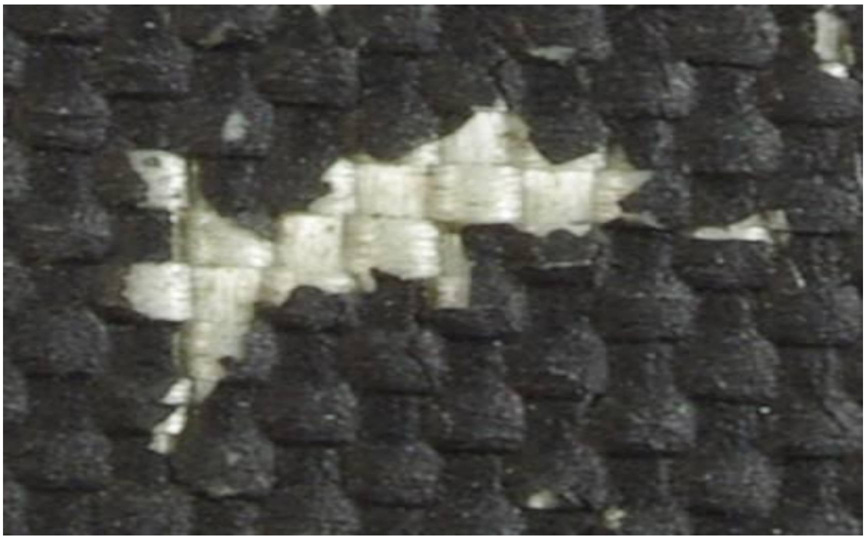


Fig. 5. Wetting the fabric with a standard air gun application

Hydrodynamic method

The hydrodynamic method uses hydrodynamic pumps to increase the paint pressure. The atomization and transport of the paint is carried out using the energy that releases the paint at the exit of the gun nozzle from the pressure of 80-540 bars to atmospheric pressure.

This method (Fig. 6) gives better results in the application of elastic materials, such as fabrics, than the pneumatic method as a result of better penetration of the substrate.

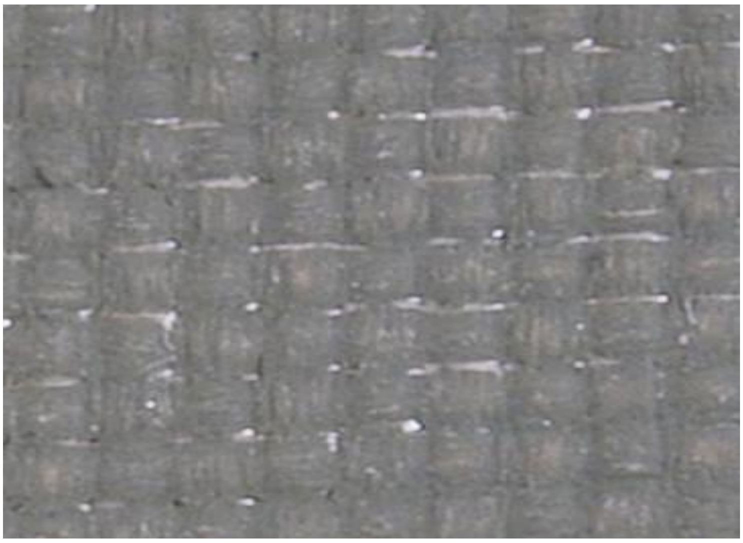


Fig. 6. Wetting the fabric with the application by hydrodynamic method

Coating method

This method is not used for applications of coatings for military equipment, while it is used in the textile industry. With proper adaptation of the paint and technological parameters of the coating lines, it is necessary to obtain a satisfactory end result on elastic materials such as fabrics. The method involves the coating of the fabric using a knife and a shaft (Fig. 7).

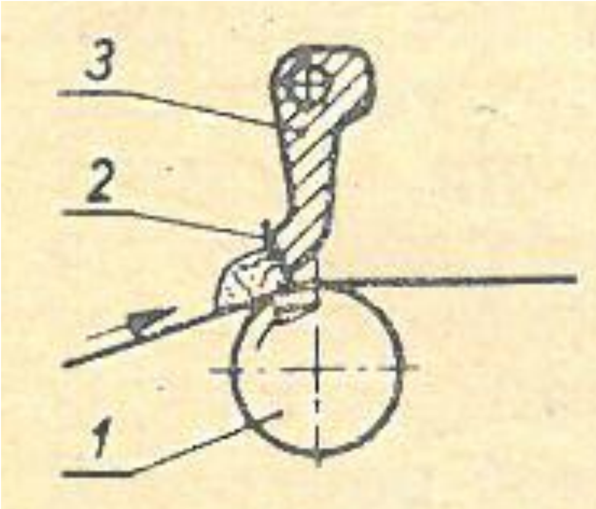


Fig. 7. Method of coating fabrics: 1 – roll, 2 – knife edge, 3 – knife [3]

In this method, the paint is scraped and pressed into the fabric, permeating it partly, thus creating a good base for the application of the next layer (Fig. 8).

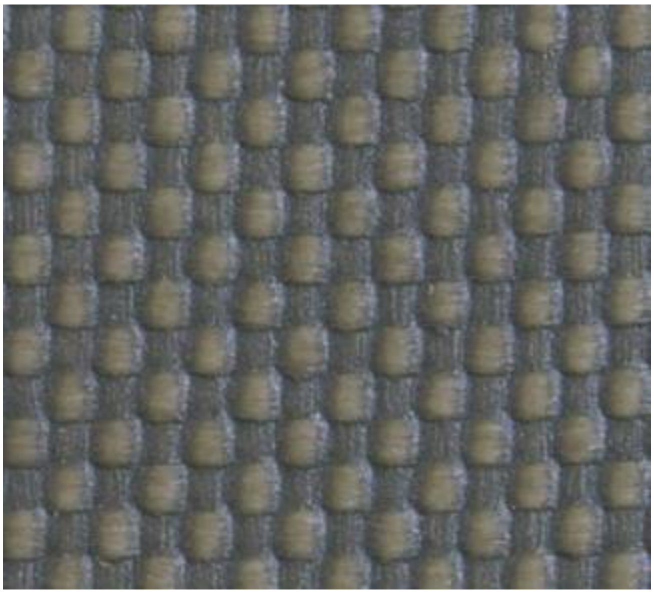


Fig. 8. Fabric imposed on the pounder

Coating of elastic materials and The Standard

Military Standard NO-80A200:2011 on special paints for masking paint develops and determines exactly the masking properties of the coating, but also specifies the other parameters, which go beyond the scope of masking and relate to the mechanical properties of the coating. These parameters mean that it is necessary to specify on the certification stage the type of primer coating, which in the vast majority of cases is not a problem, while a few percent are just cases using different types of other substrates such as: aluminium, anodized aluminium, aluminium alloys, various types of stainless steel, composites, rubbers, laminates, fabrics and other specific materials that require the use of special paints dedicated to the relevant type of substrate. This problem makes it necessary to choose between the use of a certified set of standard-compliant paints, but an unsuitable for the type of substrate and working conditions and a set of paints with undocumented partial conformance to the military standard, but which give proper masking of the object.

Conclusion

Masking of elastic materials is a fairly difficult action and creates many problems. Thanks to the knowledge and experience, it is possible to obtain proper masking of the equipment without the occurrence of coating problems such as delaminating, cracking, exfoliation. Please note that when writing about masking equipment, we require the equipment to be unrecognized at a distance of 1km with an unarmed eye, a night vision instrument with 250m. Slight damage to the coating or paint defects will therefore not affect the recognition of the equipment from such a distance.

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CHAPTER 2.

CLOTHING TECHNOLOGY AND DESIGN

2.1 THE INCREASE OF THE EFFICIENCY OF SEWING ENTERPRISES WORK WHICH USE THE "CROSS" METHOD OF EMBROIDERY

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Introduction

The garment enterprises of Ukraine in the process of work face a number of problems, among which are the following:

– high competitiveness, overflow of the local ukrainian market with imported goods and "second-hand clothing";

– lack of favorable conditions for the purchase of high quality equipment that is not manufactured in Ukraine;

– low level of investment from foreign investors and from the state;

– rapid change in consumer needs;

– lack of a system for analyzing the activity of enterprises [1].

That is why research to improve enterprise performance is relevant. To do this, it is necessary to solve the number of tasks:

– to study the condition of the garment enterprises on the basis of studying and generalization of statistics;

– to outline the main problems that hinder the development of the enterprise;

– to find ways to solve identified problems;

– to form prospects for development.

Methods

The analysis of the directions of production intensification at the garment enterprises that use cross-stitch embroidery is better done using a systematic approach. It is possible to use SWOT analysis to analyze the production processes of such enterprises. The sense of it lies in the analysis of internal and external factors of the enterprise, risk assessment and competitiveness of products in the industry, as a result ways to formulate and select a further strategy of the enterprise can be selected [2]. This is done by dividing everything related to their improvement into four categories: Strengths (S), Weak (W), Opportunities (O), Threats (T), which is the abbreviation (SWOT).

SWOT analysis is a tool that does not contain the final information to make management decisions, but allows you to streamline the process of considering all the available information (using your own opinions and estimates). SWOT analysis allows you to formulate a comprehensive list of enterprise strategies, taking into account their characteristics - adaptation to the environment or formation of action on technological processes.

The use of SWOT analysis is explained by the fact that strategic enterprise management involves a large amount of information that must be collected, processed, analyzed, used, and therefore there is a need to find, develop and apply methods of organizing such work.

Many local and foreign scientists, such as Westwood J., Dibb S., Doyle P., Kudenko N.V., Zavgorodnya G.V., Tereshchenko V.M., Balabanov L.V. investigated the problems of SWOT analysis usage. In the writings of these scientists, it is noted that SWOT analysis provides a basis for evaluating the effective aspects of the activity and the ability to correct its weaknesses, that is, defines both external and internal factors [3].

Therefore, according to the proposed SWOT analysis, the general characterization of the state of engineering training at garment enterprises should begin with the formation of four categories of areas of production intensification.

Experimental

The entry of Ukrainian enterprises into the international market requires manufacturers of garments to manufacture high-quality, competitive products in the world market of consumer industry technologies. This requires not only the use of modern advanced equipment in the design and manufacture of clothing but also to develop the latest technologies and new models that will have world-class novelty [4]. Therefore, over the last decade, more and more Ukrainian and international designers have been widely using various types of apparel decoration: appliqués, embroidery, stones, cords and more. The most used type of decoration is definitely embroidery. It is used on different types of clothing:

outerwear, lightweight, uniform, in linen and so on. Embroidery is even used to decorate leather goods, handbags and shoes.

To study the efficiency of work and conduct a SWOT analysis, sewing enterprises of Khmelnitsky were selected, which specialize on manufacture of garments decorated with embroidery.

In the first stage of the SWOT analysis is the first category of strengths (S) identified the advantages that Khmelnitsky enterprises have. These include:

– specialization of production (production of clothing with embroidery);

– good geographical location (Khmelnytskyi, availability of wholesale and retail commodity market);

– high reputation among consumers (diplomas, awards, participation in All-Ukrainian and International competitions);

– uniqueness of products (use of ornaments of traditional and stylized embroidery of different regions of Ukraine);

– the use of the latest specialized equipment (re-equipment of production, installation of multi-needle embroidery complexes);

– high level of working conditions (adherence to the basic rules of safety and sanitary standards at the production).

The following category (W) contains the disadvantages inherent in the enterprises of the studied region:

- obsolete equipment (use of outdated equipment and technology, imperfect form of production organization);

– financial instability (exchange rate dependency);

– weak marketing strategy (lack of advertising, analysis of enterprise performance, consumer needs statistics).

In the third stage (O), opportunities are created that can improve the efficiency of enterprises:

– entering new markets (opening of online shops, participation in international exhibitions, competitions, fashion shows, etc.);

– expansion of the range (search for new sources of creativity);

– acceleration of market growth (exit from the comfort zone, updating of collections of clothes every 14 days, change of furnishings at constant assortment);

In the last, fourth stage (T), we form the category of the most unfavorable factors that are a threat to most enterprises.

– change of needs and tastes of buyers (influence of world fashion trends, dependence on the season);

– competition (increasing influence of suppliers of resources and materials, entry of international brands into the country's market, as well as second-hand and stock goods);

– worsening working conditions (shortage of labor, low-skilled personnel, unstable economic situation in the country). These directions may destroy the enterprise or make it unable to perform the production process.

The results of the analysis are shown in Table 1.

Table 1 SWOT analysis of garment enterprises, Khmelnitsky

1 Strong (S) or advantages	**2 Weak (W) or disadvantages**
1.1 Production specialization 1.2 Good geographical location of enterprises 1.3 High reputation among customers 1.4 Competitive advantages 1.5 Implementation of the latest equipment 1.6 High level of working conditions	2.1 Internal production problem: - outdated equipment; - imperfect methods of processing units of products; - imperfect form of production organization. 2.2 Financial instability 2.3 Poor marketing strategy
3 Opportunities (O)	**4 Threats (T)**
3.1 Entering new markets 3.2 Expansion of the product range 3.3 Accelerating market growth	4.1 Changing customer needs and tastes 4.2 The growing influence of suppliers 4.3 Deterioration of working conditions

Having analyzed the weaknesses and strengths, a strategic alternative to the development of garment enterprises can be offered, according to SWOT analysis. Due to regular growth of technical equipment, improvement of organization of works and intensification of production, it is possible to withstand external competitive pressure.

Therefore, one of the main steps in improving the efficiency of enterprises is to increase the competitiveness of production. In this case, the decoration of the product plays a very important role. By changing the trim you can achieve a virtually unlimited variety of appearance of products, leaving a constant assortment. An example of this approach is the production of embroidered products. It is enough to change the decoration, the design of which remains unchanged, and the product again becomes competitive. The use of sustainable assortment allows production to reduce the cost of design and technological training. Only the stages of preparation and direct finishing of the products remain expendable. That is why, at these stages, it is necessary to carry out studies that will improve production efficiency and lead to a reduction in labor costs.

Results

One of the strengths (S) of SWOT analysis is sub-points 1.3 high reputation among the customers and 1.4 competitiveness. To improve these indicators, the authors propose to embroider garments with double cross-shaped elements (DCE) [5]. Modern software editors for the automated production of ornaments fill it with non-uniform cross-shaped elements (CE), which have several extra stitches formed as a result of the transition from one stitch to another [6]. Such CEs impair the quality of the embroidery. In connection with this, there is a need to create a way of filling the embroidery ornament with only uniform CE.

Improving the quality of decoration with DCE embroidery was confirmed by expert assessment. The quality of the ornaments of the embroidery with the cruciform elements and the DCE was evaluated according to the method of Polyshko S.P., Kozlova A.L. [7]. This technique compares the individual quality indicators of the products to be evaluated with those of the basic sample. Expert evaluation was carried out on the generalized quality index [8]. For this purpose, 10 experts were involved who completed the expert assessment of the developed questionnaire (the number of criteria of the i-th index n=10). Each of the experts used the scale of evaluation of the quality of the criteria of embroidery ornaments, developed according to DSTU 1066-96 [9], DSTU 1157-91 [10] (Table 2).

Table 2 Quality Score for Criteria

The quality of criteria	Score in points
Completely absent	5
Appears weakly	4
Appears	3
Appears greatly	2
Completely appears	1

A total of 10 criteria for assessing the quality of embroidery ornaments, which means *m*=10 (number of criteria of the *j*-th index). To assess the quality of each expert, Table 3 was completed.

Table 3 Evaluation of the quality of embroidery patterns

Criteria for evaluating the quality of embroidery patterns	cruciform element	DCE
1 The stitches do not fit snugly to the fabric		
2 The embroidery looks loose		
3 There is a lower thread on the front surface of the embroidery		
4 Not fixed stitches		
5 The weave of threads is not formed in the fabric		
6 On the inside surface there are loops and knots from the top thread		
7 Bottom thread tightened		
8 The ornament is not neat on the front or inside surfaces		
9 The stitches of the transition between the ornament elements of the same color are not removed		
10 Uneven density of thread tension within the ornament		

The result of each expert's work is the scoreboards for each of the ten criteria for the quality of embroidery ornaments made by existing (ornament made by cruciform elements) and proposed by the author (ornament made by DCE) methods.

Generalized Quality Score *Y* is calculated by the formula 1 [7]:

$$Y = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} K_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{m} R_{ij}}, \qquad (1)$$

where *n* – the number of experts of the *i*-th index;

m – the number of criteria of the *j*-th index;

K_{ij} – evaluation of the quality of the embroidery patterns of DCE;

R_{ij} – expert evaluation of the quality of ornaments of cross stitching.

The processing of the data obtained from the experts is carried out using Tables 4 and 5.

Table 4 Expert evaluation of the quality of embroidery ornaments made of cross-shaped elements

Criteria for evaluating the quality of embroidery patterns	**Experts**										$\sum_{i=1}^{10} R_{ij}$	$\frac{1}{10}\sum_{i=1}^{10} R_{ij}$
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
1 The stitches do not fit snugly to the fabric	4	4	5	4	5	4	3	5	4	5	43	4,3
2 The embroidery looks loose	4	3	4	3	3	3	4	4	4	5	37	3,7
3 There is a lower thread on the front surface of the embroidery	5	4	4	5	4	4	5	5	5	5	46	4,6
4 Not fixed stitches	4	3	4	3	4	4	4	3	4	3	36	3,6
5 The weave of threads is not formed in the fabric	5	5	5	5	5	5	5	5	5	5	50	5
6 On the inside surface there are loops and knots from the top thread	5	4	5	4	3	5	4	3	4	5	42	4,2
7 Bottom thread tightened	5	4	5	5	5	5	4	5	5	5	48	4,8
8 The ornament is not neat on the front or inside surfaces	4	3	3	4	3	3	4	3	3	3	33	3,3
9 The stitches of the transition between the ornament elements of the same color are not removed	4	4	4	4	5	4	4	4	4	4	41	4,1
10 Uneven density of thread tension within the ornament	4	3	4	3	4	3	4	3	4	4	36	3,6
$\sum_{j=1}^{10} R_{ij}$	44	37	43	40	41	40	41	40	42	44	$\sum_{i=1}^{10}\sum_{j=1}^{10} R_{ij} = 4{,}12$	
$\frac{1}{10}\sum_{j=1}^{10} R_{ij}$	4.4	3.7	4.3	4	4.1	4	4.1	4	4.2	4.4		

Table 5 Expert evaluation of the quality of embroidery ornaments made by DCE

Criteria for evaluating the quality of embroidery patterns	**Experts**										$\sum_{i=1}^{10} K_{ij}$	$\frac{1}{10}\sum_{i=1}^{10} K_{ij}$
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
1 The stitches do not fit snugly to the fabric	5	5	5	5	5	4	5	5	5	5	49	4,9
2 The embroidery looks loose	5	4	4	5	4	4	5	5	5	5	46	4,6
3 There is a lower thread on the front surface of the embroidery	5	5	5	5	4	4	5	5	5	5	48	4,8
4 Not fixed stitches	5	4	5	5	4	5	5	4	5	4	46	4,6
5 The weave of threads is not formed in the fabric	5	5	5	5	5	5	5	5	5	5	50	5
6 On the inside surface there are loops and knots from the top thread	5	4	5	4	5	5	4	5	4	5	46	4,6
7 Bottom thread tightened	5	5	5	5	5	5	5	5	5	5	50	5
8 The ornament is not neat on the front or inside surfaces	4	5	4	4	5	5	5	4	5	4	45	4,5
9 The stitches of the transition between the ornament elements of the same color are not removed	5	5	5	5	5	5	5	5	5	5	50	5
10 Uneven density of thread tension within the ornament	5	4	5	4	5	4	5	4	5	4	45	4,5
$\sum_{j=1}^{10} K_{ij}$	49	46	48	47	47	46	49	47	49	47	$\sum_{i=1}^{10}\sum_{j=1}^{10} K_{ij} = 4{,}75$	
$\frac{1}{10}\sum_{j=1}^{10} K_{ij}$	4.9	4.6	4.8	4.7	4.7	4.6	4.9	4.7	4.9	4.7		

Determined by formula (1), the generalized quality index Y is equal to 1.153, which corresponds to a 15.3% improvement in the quality of the embroidery pattern of the DCE compared to the existing cruciform elements.

When comparing individual Quality Scores, we found that:

– the index 5 remained unchanged, since it characterizes the correct execution of the stitches of embroidery and depends on the setting of the embroidery machine;

– less than 12% increased indicators 1, 3, 7, they depend on the amount of movement of the platform of the embroidery machine (in the embroidery patterns formed by the DCE the movement is smaller);

– all other indicators have changed by more than 12%, due to differences in PCEM, which allows to embroider the ornament of DCE;

– more than the others – by 26,6% the indicator 8 changed (the ornament is not trimmed on the face or inside surfaces), this is due to the fact that in the proposed method DCE do not have stitches of transition.

Therefore, it was experimentally proven that the quality of the embroidery ornamentation made by the DCE using the proposed PCEM increased by 15.3% (Fig. 1).

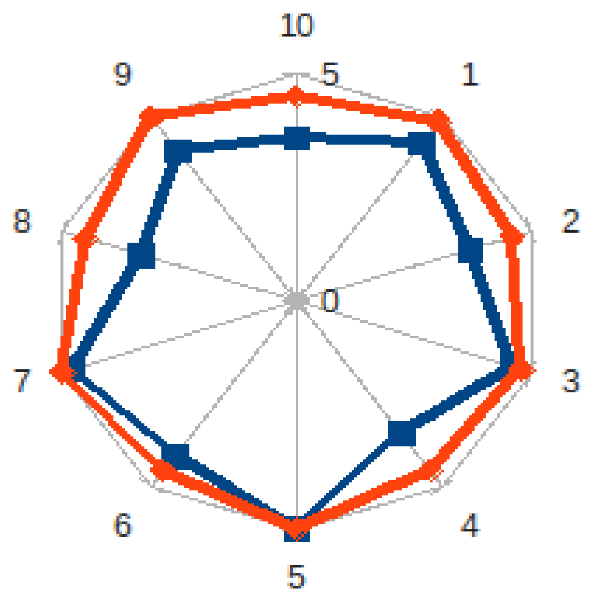

Fig.1. Diagram of quality comparison of embroidery patterns, where - cruciform elements; - DCE

Industrial testing of decoration of embroidery ornaments, made by DCE at Khmelnitsky enterprises was carried out.

Conclusions

Improvement of the efficiency of the sewing enterprises in Khmelnytskyi, which use cross-stitch embroidery, is proposed to be carried out by means of SWOT analysis. It is determined that the basis for intensifying the work of such enterprises is its capabilities: 1.3 high reputation among customers and 1.4 competitiveness. Using these indicators, you can achieve an unlimited variety of appearances of products, leaving a constant assortment. The quality of the embroidered products is enhanced by the DCE decoration, which is confirmed by the expert evaluation. The social effect of the implementation of research results is to improve the quality of decoration of embroidery ornaments made by DCE by 15.3%.

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2.2 GENERAL CHARACTERISTICS OF METHODS OF CONSTRUCTION OF 2D-NETS OF CLOTHING DETAILS

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Introduction

The market economy has always paid great attention to the quality of products, so quality issues are not overlooked today. Consumers choose clothes they need or according to the fashion tendencies, manufacturers – try to anticipate, create, offer and sell, responding to the requirements and market conditions.

As the garment is approaching a certain geometric figure only by its silhouette, getting a precise 2D-net of the primary model given by the sketch is a difficult task. Accuracy is determined by the experience and qualification of the specialists, so the methods of obtaining a 2D-net of clothing details are approximate. The 2D-nets of the parts obtained from the finished product sample are more accurate because the final dimensions of the garment surface are used in their construction.

Methods

The purpose of the work is to consider the problems of construction in the aspect in which they affect the quality of clothing, as well as to analyze existing methods of construction clothes in terms of their history of development, principles of construction structural bases and the state of the information base.

Experimental

The history of development of the form and construction of clothing can be divided into directions: the first one – the evolutionary formation together with the development of people and the society itself, and the second direction – the development of the form and construction of clothing under the influence of fashion.

There are dozens of methods of construction techniques known in the history of the garment industry. Such diversity takes place because of the lack of uniform principles for their creation. They are a reflection of the practical experience of the authors in the form of recommendations on techniques for the construction of patterns and the application of the observed relationships in the placement of individual points and lines in the drawing. Without revealing the content of construction and calculations, the authors of the methods offered ready-made solutions for making patterns of specific clothes [1, 2].

The main task of construction clothes is to design drawings of details for an individual or a typical figure. In the vast majority each technique includes information about the figure of a person or a finished garment, methods of processing the information obtained in the form of calculations, using which the size of the structural sections and knots of details of clothing, and methods of geometric construction are determined. When constructing the features of the structure, cuts and methods of technological treatment are taken into account [3].

Existing design methods are divided into: approximate and engineering. Approximate construction methods include: model, design, graphic and geometric methods.

Approximate methods for constructing a net of clothing details

The waxwork method appeared many centuries ago but has not lost its relevance. Creating a model of clothing and obtaining a 2D-net of its details is carried out by modeling the product on a human figure or on a dummy.

The experimental way of construction the garment allows you to accurately take into account the peculiarities of the human figure and the natural property of the fabric to form. However, this is a rather "painstaking" method, since it is necessary to work with a large piece of fabric, constantly cutting off all unnecessary, and it takes a lot of time to try on.

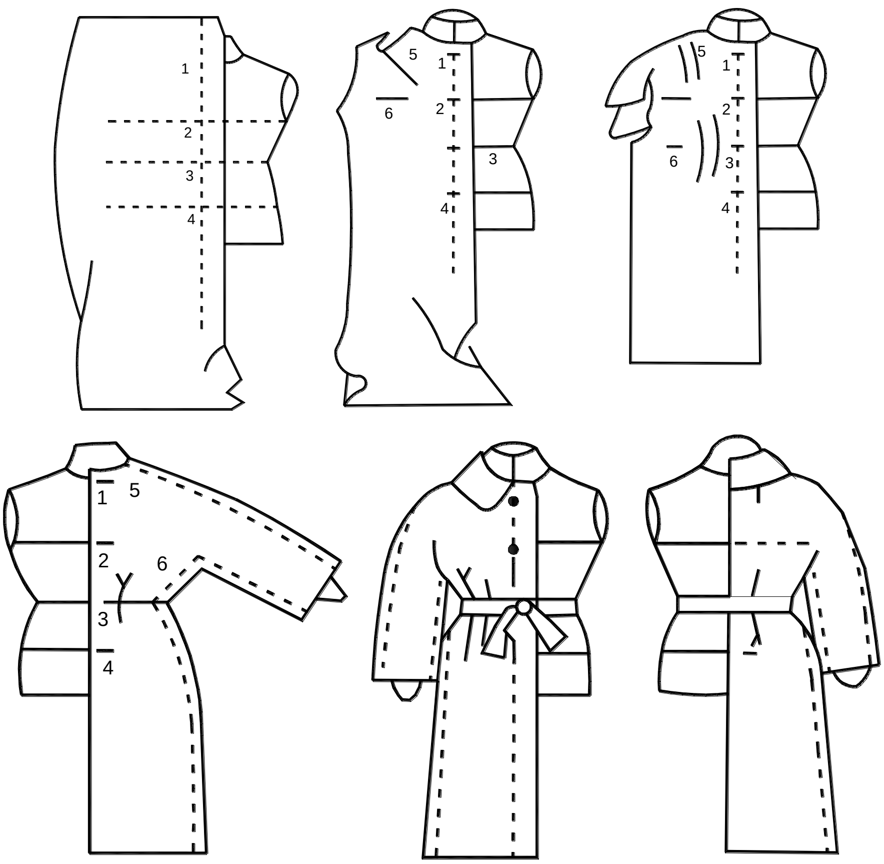

Fig. 1. A waxwork method

The deceptive simplicity and accessibility of the waxwork method requires a specialist of advanced artistic taste and professional skill. Even with the high qualification, the accuracy of obtaining the 2D-net of the garment parts by the waxwork method is not high enough, so numerous subsequent adjustments are inevitable. The final refinement of the primary parts of the 2D-net is performed during the try on. In its pure form and in its entirety, the waxwork method is rarely used today. However, the long and sufficiently successful use of the waxwork method makes it possible to consider it not only as a universal way of creative search in the field of modeling, but also a method of solving a number of practical problems in the field of construction clothes for individual and mass production. Waxwork method of clothes construction is one of the varieties of method of draping directly on the stand [6].

Calculation and graphical methods

The formation of calculation and graphical methods of construction clothing began in the late eighteenth - early nineteenth century. Highly skilled experienced cutters began to apply simple empirical calculations and graphical constructions for the preliminary development of cut drawings. Today, several dozens varieties of calculation and graphical methods are known.

In 1800, the London-based cutter Michel developed a cut system called Drittel. The author divided half of the bust level girth into three equal parts (1/3 each for the width of the back, armhole and front) and in each rectangle with the side 1/3 bust level girth were made graphical constructions of the approximate 2D-net of the garment details. This method allowed to create uniformity of cut of clothes for different sizes.

On the basis of this method, a new system of cutting – cellular, is subsequently created. In this system, the rectangle was further broken down into 6 more parts and separated by 18 small cells at the top and 2 large cells at the bottom. This made it possible to capture in more detail the shape of the cut details when scaled by size. The idea is simple: dividing the original drawing into cells with the same side can be enlarged or reduced proportionally to your liking.

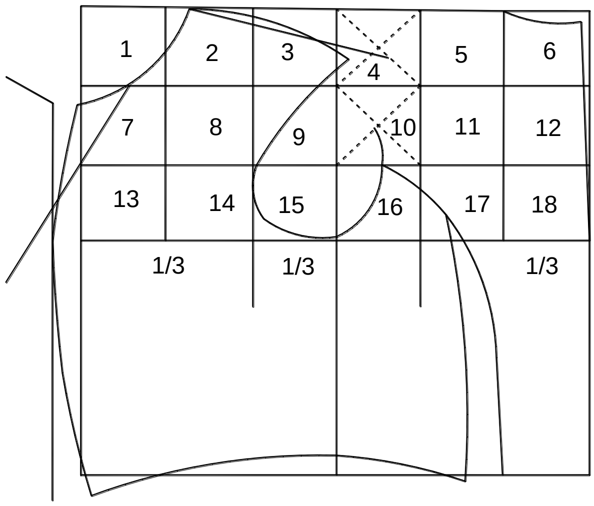

Fig. 2. Cellular method

For the construction of the drawings, a Cartesian coordinate system with cell highlight was used, which facilitated the systematization of the drawings and the design of the member lines of the garment details.

When the metric system was brought to France, the human figure was measured with a centimeter tape. This period refers to the measure cut system with was developed by Kompein. Taking the 48th size as the main one, it proportionally increased or decreased the measurement results of all other figures. The drawings of the structure were constructed with the help of a scale tape with a price of division 1/48 from half of the bust girth of a specific figure. However, this system did not take into account the size of other sections of the figure, such as waist length, armhole depth, etc.

Different variants of the large-scale method of cutting have existed long enough, developed and improved by different authors. Despite all attempts to improve them, they gave more or less susceptible results only for proportional figures, and for figures with deviations in the manufacture of structures required numerous fits and alterations. It was necessary to find ways to measure and construct the drawings of the cut details in accordance with the real structure of the figure of a person.

In the 1840 G. A. Muller created a trigonometric cutting system (Fig. 3). According to this system, the principle of spherical trigonometry was applied to measure the figures, and the construction of the drawings was performed by means of arc notches along the sides of the triangle. Their vertices were the conditional points of the details of the structure, and the sides - the measurements of the figure of a person. A similar system was created simultaneously with Müller by Russel. Improving the trigonometric system, M. Lutu in 1886 developed a universal system based on the beginnings of analytical geometry, and in 1900 he began work on a new cut system, including measuring the position of the body of a human figure. This system was called in the west – Kompel, and in Russia – "Society of St. Petersburg cutters".

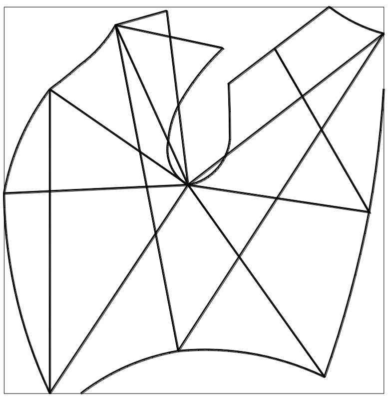

Fig. 3. Trigonometric cutting system

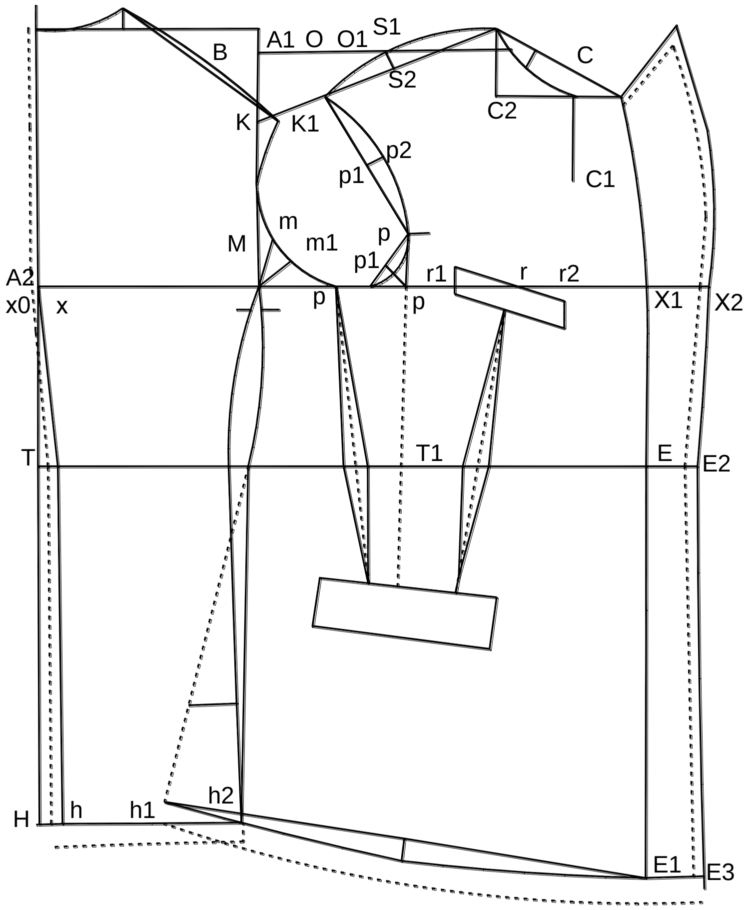

Fig. 4. The Langridge system

The so-called coordinate system of the Levitanus brothers and the Langridge system became the most famous in Russia. These systems did not require complicated calculations and involved the construction of drawings at individual points found by geometric construction in a rectangular coordinate system (Fig. 4). The simplicity of such systems distinguished them favorably from others. The Russian coordinate system was introduced into the practice of construction by M. F. Metuzal in 1900-1905. This cutting system is based on a detailed account of the structure of the human body.

Improving the mass production of clothing required new approaches to construction. Taking measurements from the customer became impossible. Measurements of a particular figure began to be replaced by calculations based on proportional dependencies on the leading dimensions - chest girth and full height. This led to the emergence and formation of varieties of coordinate system - settlement and mapping and proportional calculation.

The basis of these systems is the idea that figures of people of the same size and height without significant deviations of the body can be taken as conditionally normal and considered "the same". This allowed harmonizing the garment form, applying the principle of parallel gradation in size, height and more. For conditions of mass production, the most successful was the coordinate system of design of S. M. Korotkov, developed in 1934 (Fig. 5). Using a coordinate system, the author systematized it and summarized it in the book "construction Clothes", closely related to the technology of making clothes.

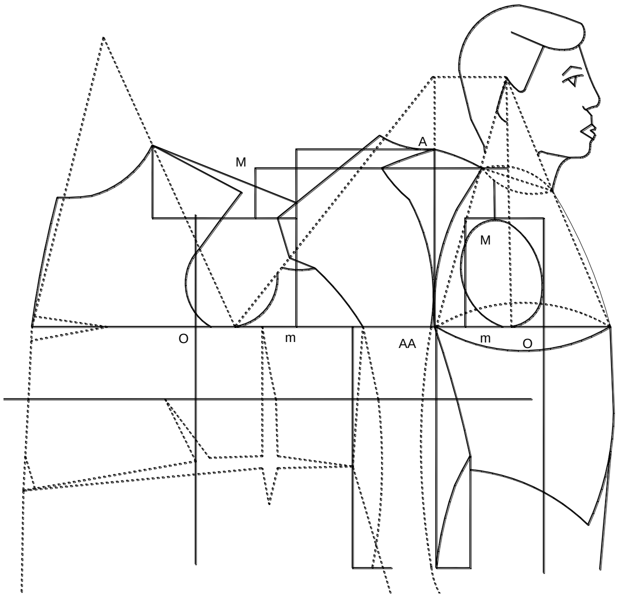

Fig. 5. Coordinate system of Korotkov

Later constructors M. V. Ruchkin, F. A. Postnikov, G. A. Samarov, A. I. Cheremnykh, M. I. Tsarev and others have contributed to the improvement of this method of construction clothing. It was used for many years until the accumulated material on mass anthropometric measurements proved that there were no proportions in human dimensions.

Since 1959, the CSIISP has been working on the creation of a unique method of construction men's, women's and children's clothing. Experience has shown that the methods and techniques for constructing drawings of garment designs are almost the same, only the object of design changes [5]. The calculation and analytical method was laid on the basis of the technique, according to which the drawings of the structure are constructed by geometrical 2D-nets of the smoothed outline of a figure of a person with allowances for free fitting and decorative design. The dimensional characteristics of the figure are based on the table of measurements obtained on the basis of anthropological measurements with adjustment to the thickness of the linen. The calculation formulas are based on the correlation between the dimensional features of the figure.

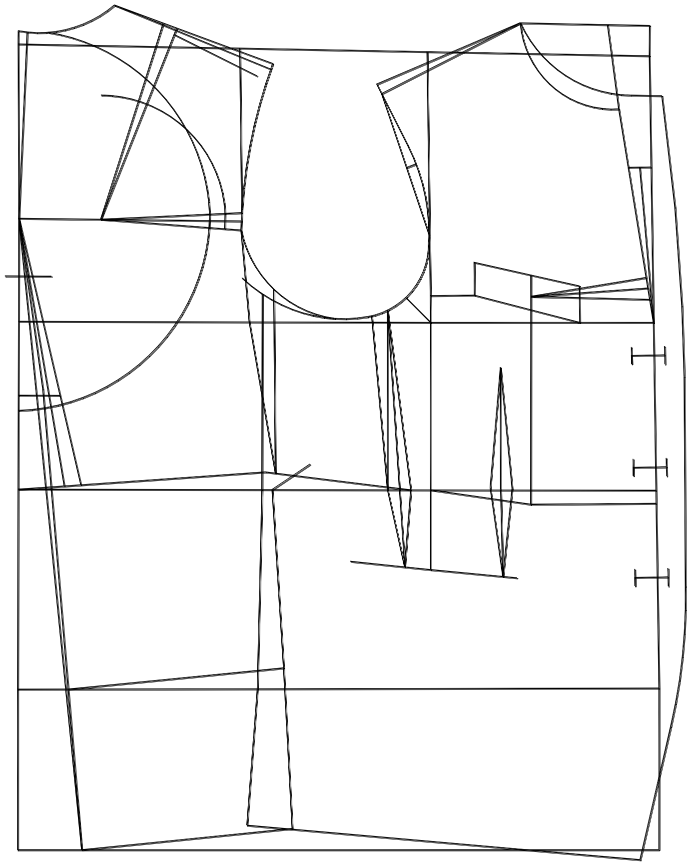

Fig. 6. The unique design method (CSIISP, men's jacket)

However, despite the cumbersome graphical constructions and calculation formulas, even with a successful at first glance choice of allowances, the method, nevertheless, does not provide the necessary accuracy of the construction of the base of the garment construction requires its refinement in the process of manufacturing prototypes. In the event that fittings and fits cannot be avoided, it would be more convenient to use a simplified method of constructing the original drawing or to refine already proven and proven structures.

Calculation and graphical methods have become widespread due to the elementality of empirical calculations and the simplicity of graphical constructions. These methods are a "recipe" for building the design of basic clothing details of the appropriate type of cut, and silhouette in relation to the appropriate direction of fashion and manufacturing technology.

Approximate clothing design techniques are required to develop primary patterns of new models. However, the high precision and manufacturability of building a part 2D-net is one computationally-graphical method that cannot be achieved due to the imperfect information on anthropological measurements and estimates. Changing the fashion and dimensional typology of the person is accompanied by the elucidation of significant changes empirical calculations and graphical construction drawings of new silhouettes of clothing, which leads to the aging of methods.

The method of EMCO REV. Summarizing the experience of construction member states for the Mutual Economic Assistance Council, the EMCO REV methodology was developed. Unification of calculations, detailing and classification of allowances, new methods of graphical construction of individual units have complicated the method of construction, but have not made it better and more reliable than previous ones. In construction practice, it is more of a common language for transmitting information than a tool of daily use. However, the use of pattern design systems partially eliminated this and such detailing became appropriate. This allows EMCO REV to create its own variants of the methods, supplementing and refining what was created earlier [3-4].

Geometric method. As a basis, a 2D-net of the surface of a figure or dummy with the subsequent constructive construction of the 2D-net of the basic details of clothing is used. To construct a surface 2D-net, the principle laid down in the triangulation method is used. In this case, the surface is broken into large enough triangles, conditionally taking them as unfolded. They construct surface 2D-nets on the plane and develop special templates, which are approximate 2D-nets of a given surface of a human (dummy) figure. In accordance with the sketch of the model, the contours of the templates are redecorated with patterns lines, taking into account the distribution of composite allowances, the position of the lines of the joints and decorative and structural elements. Typical patterns allow you to build the basic details of clothing models and provide the basis for typical clothing construction. The geometric method is less time consuming in comparison with the calculation-graphic methods, but it does not allow to take into account the dressing property of fabric and to design the necessary technological processing.

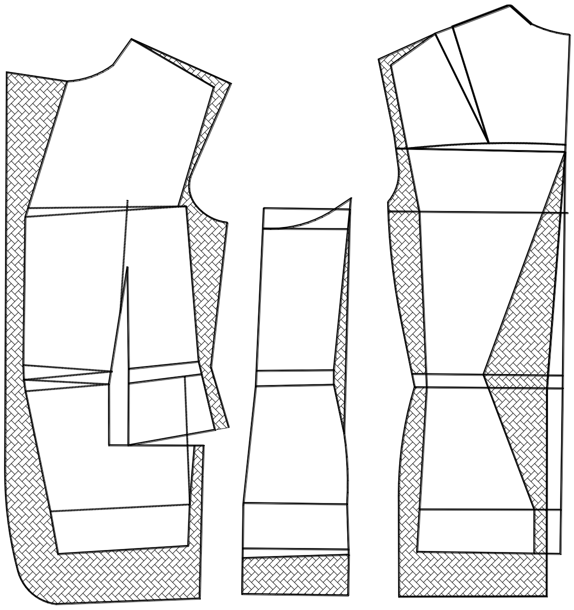

Fig. 7. Geometrical method

Engineering construction methods

The invention of scientific, fairly accurate and convenient methods of constructing the 2D-net of garment surface details has always been one of the urgent problems of developing a rational system for its design. The accuracy of the construction of the 2D-net of the surfaces depends on the consumption of material, the quality of landing and processing, the degree of complexity of processing the product in the manufacturing process, aesthetic and operational characteristics of the product. All surfaces are divided into folded and unfolded. Folded are called surfaces that can be aligned with the plane at all their points, so they can be stacked on a plane without tears and folds. A surface that cannot be reconciled with the laying plane is non-expandable. The 2D-nets of such surfaces are approximated.

The surface of a person's figure, mannequin, and clothing is not a geometric surface and can only be expanded with some approximation. The shape of a piece of clothing made of flat material is obtained either by constructively articulating it into parts using such elements as seams, darts, folds, or by way of forcibly changing the geometric dimensions of the cut pieces in separate sections, using stretching or pressing on the base and weft, as well as at angles (in the oblique direction). It is impossible to obtain body surface 2D-net by geometric methods.

In practice, a combined method is used: depending on the properties of the fabric itself, either structural elements or deformation of the fabric prevail. The choice of the method of obtaining the shape of the garment depends on the nature of the surface, its curvature, the ability of the fabric to create the desired shape due to its own deformation and construction methods.

There are a number of engineering methods for the design of 2D-nets: triangulation, slash planes, geodesic lines, auxiliary lines of deployment, calculation of 2D-nets of clothing parts by model samples, etc.

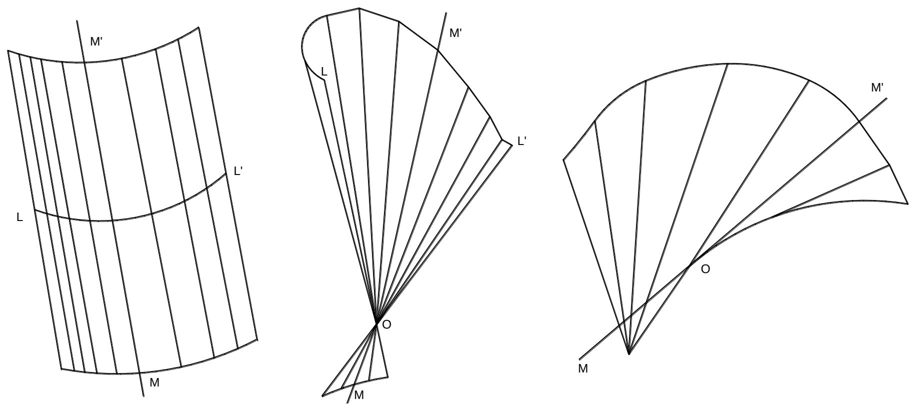

Fig. 8. Examples of expanded surfaces

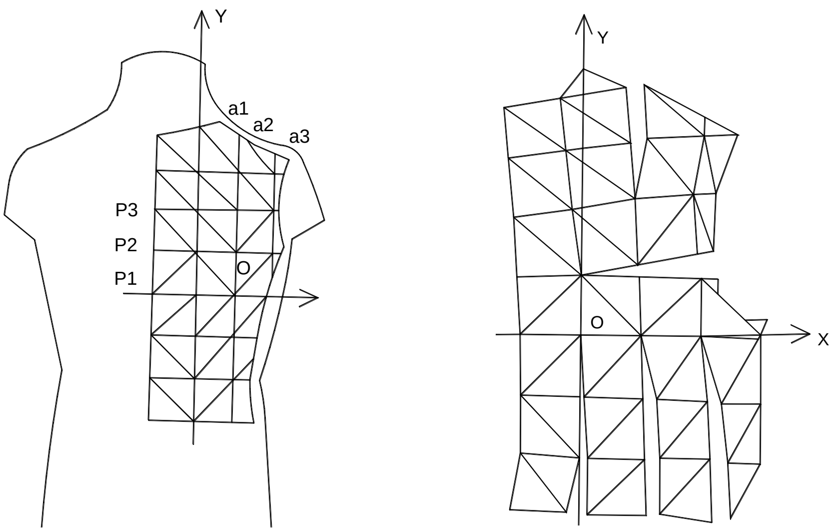

Fig. 9. Triangulation method

Triangulation method.

A common technique for constructing an approximate technical 2D-net is that the surface is broken into elements and replaced with elements of conditionally expandable surfaces, which are then expanded. The accuracy depends on the number of elements that break the surface.

The method of secant planes, proposed in 1954 by A. I. Ivanova, is one of the first attempts to obtain a 2D-net of clothing details by means of descriptive geometry. Each section of the selected figure is conditionally equated to the unfolded geometric surface of the figure and sequentially unfolded and laid on the plane. The complexity of the interconnections of the individual sections of the 2D-net do not allow using this method in practice.

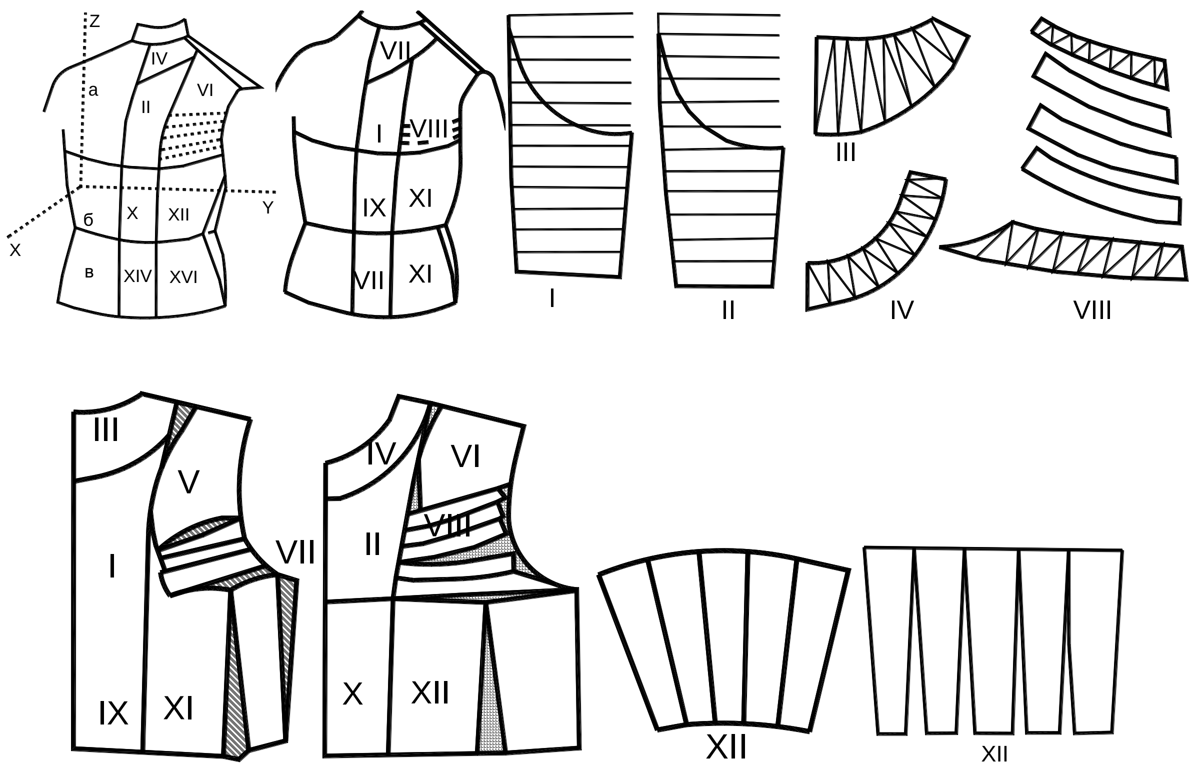

Fig. 10. The method of cutting planes

The essence of the method of geodetic lines lies in the modeling on the surface of a number of geodetic lines with a given step and sequential construction of the 2D-net of the selected areas of the surface bounded by the geodetic lines on the plane. The method allows obtaining a 2D-net of the surface of the workpiece, which can determine the amount of technological processing required, for example: the size of the tuck, the size of the fit or stretch of the fabric. This method has found its application in retrieving information about a human figure.

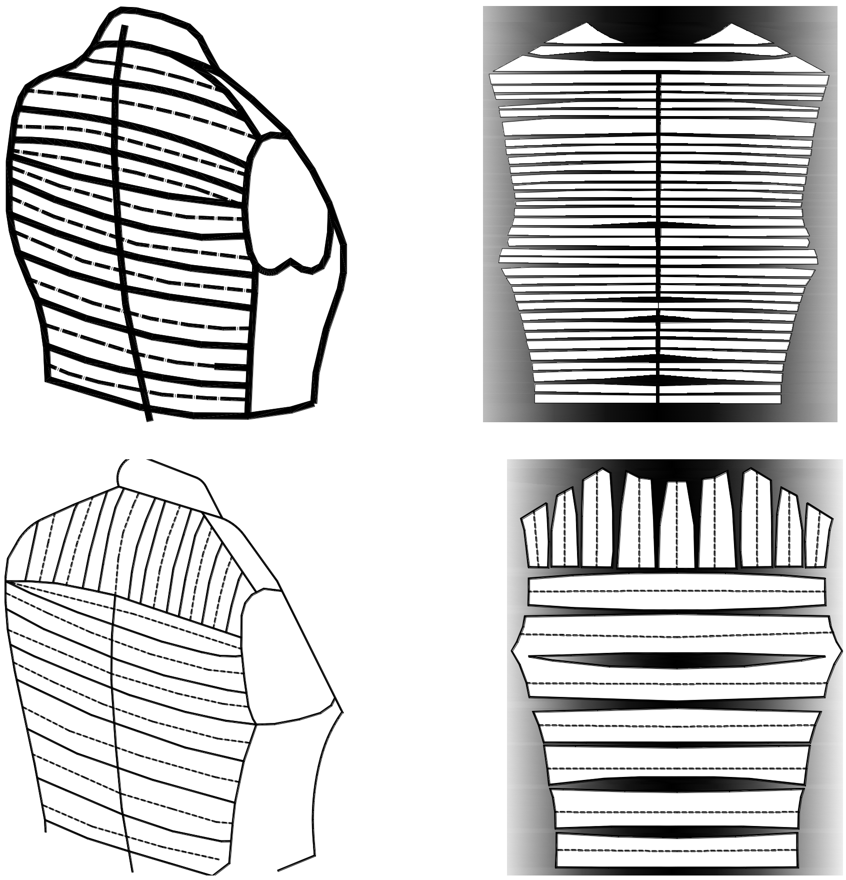

Fig. 11. Method of geodetic lines

The method of auxiliary lines of deployment allows obtaining a sufficiently accurate copy of the scan of the sample product, to determine the technological processing of the parts included in the sample. The basis of the method of auxiliary deployment lines developed by G. L. Trukhan, is taking into account the peculiarities of the fabric structure: namely, the weave of the warp and weft threads at an angle of 90°. Each "characteristic" point of scanning of a workpiece is found by directly measuring (on the finished product) the lengths of the corresponding segments of filaments (stitches), which are laid along the base and the weft in the product, and then these measurements are deposited on the plane and analyzed.

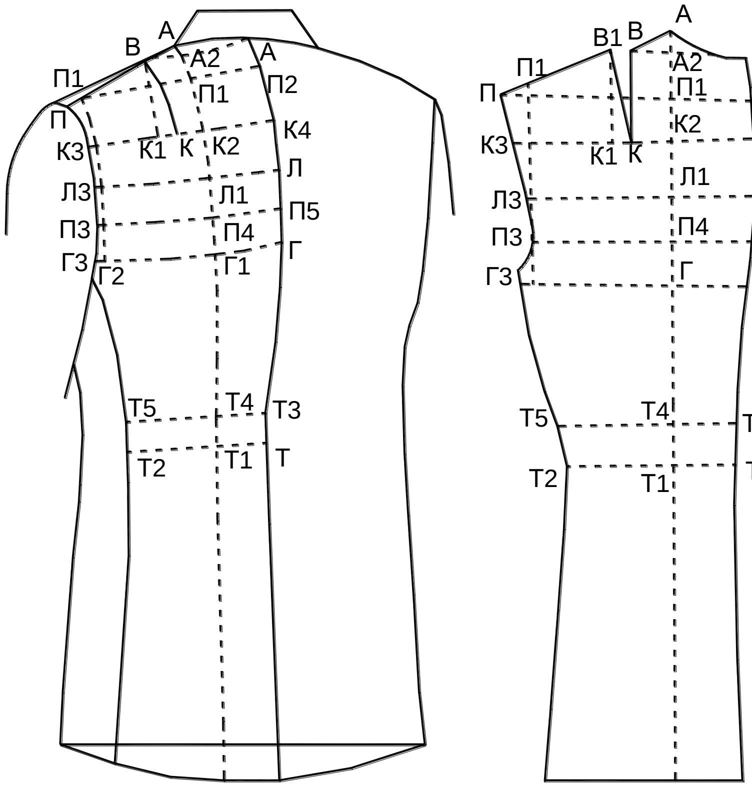

Fig. 12. Auxiliary Deployment Line Method

It is difficult to obtain an exact copy of the parts from the finished sample by this method, because it is impossible to restore all the technological processing that has undergone the details of the cut and the product as a whole. In the plane of the drawing without proper transformation, these details cannot be stacked. It is advisable to use this method in the studio, when it is necessary to specify the fit of the garment on a figure on balance, figure, silhouette, etc.

The method of calculating the parts pattern based on model samples is considered in a number of works performed under the guidance of O. V. Savostitsky. The bottom line is that two mutually perpendicular filaments of the warp and weave mesh are secured on the unfolded surface along the orthogonal geodetic axes adopted. When the mesh is completely combined with the surface, its filaments form a Chebyshev mesh. It can be stacked in rectangular axes on a plane and get a 2D-net. Using the mesh-canvas, the Chebyshev mesh is simulated directly on a given surface, subject to the theoretical conditions of its construction and simultaneous adjustment of the part on the same surface, taking into account technological requirements. Using this module to obtain an exact copy of the product model requires the creation of a primary specimen and an internal dummy, which significantly increases the design time and limits the possibilities of creative search.

Conclusion

So the conclusion can be drawn, as a result of the characteristics of methods of constructing the 2D-net of garment details, it is expedient and scientifically justified to create progressive and existing methods of constructing the 2D-net of garment details in order to improve the quality of garments, as well as to fully satisfy the various requirements for clothing of industrial and individual production, using the principles laid down in each method.

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2.3 DEVELOPMENT OF THE MULTIVARIATE CONSTRUCTION OF A BRIDAL DRESS WITH APPLICATION OF THE TRANSFORMATION PRINCIPLES

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Introduction

In the field of making bridal apparel, the conformity of the products to the modern fashion trends and the aesthetic perfection of the features of their appearance are of paramount importance. However, the full provision of these indicators does not guarantee the physiological comfort of the product, which depends primarily on the proportionality and convenience of the design.

Quite often consumers are faced with the problem of mismatch between the size of the corset and the size of the bra cups. By increasing the negative modeling effect that results from the mismatch between the size of the corset and its cups, the pressure of the cups on the breast of the consumer increases, causing psychological and physiological discomfort. In order to solve this problem, there is a need to develop a multivariate design of a wedding dress with the possibility of its transformation into adjacent sizes. This will improve its proportionality and comfort with respect to the consumer's morphological features. This approach allows us to provide the ergonomic comfort of a wider range of consumers and reduces the time required to produce products of the required size range by designing them through one or more sizes.

Today, buying clothing is moving from a physical domain to a virtual domain, expanding the geography of both consumers and product manufacturers. Individual versions of wedding dresses using the method of "mass customization" in the clothing industry is offered to transform into the appropriate body type of each woman [1]. Therefore, the development of wedding clothing with the possibility of its transformation into a specific figure may be appropriate for those who prefer buying clothes through a network of online stores.

To achieve this goal, the following tasks should be solved: 1) to perform morphological analysis of the structural elements of the basic design of a wedding dress; 2) to investigate the design parameters of the corset and the adjacent cup sizes to determine the boundaries of the multivariate contours of the parts; 3) to develop schemes of details' gradation of a corset and a bra; 4) to develop a universal design of a wedding dress with the possibility of its transformation into adjacent sizes.

Method

The analysis of literature and electronic resources [2-8] revealed that the existing variety of modern products-transformers and elements that provide the principles of transformation, makes it possible to apply them in wedding clothes for brides, which is relevant today.

Mostly the transformation of the elements of a wedding dress is used to change quickly its style to the taste of the bride, or to change the functional purpose of the product - from festive to cocktail, or from spring to summer.

However, the issue of transforming wedding dresses into different sizes is not solved by the manufacturers. Therefore, the issue of designing a wedding dress transformer, providing it with convenience and functionality, which will allow you to change quickly and adjust the size of the dress according to the individual features of the bride remains unresolved.

There are a number of different principles of transformation [3-5] that provide different functions of the product-transformer. However, the principle of "stretching - contracting" is the basic principle for resizing the product's parts. In wedding wear it is ensured by the use of elastic bands, elastic threads, elastic fabrics and lace, waist and chest internal elastic fastenings for corsets and bodices, elastic bands, laces and other materials with elastic properties in different parts of the product [3]. Accordingly, these elements are basic application materials that should be used in the design of a transformer product.

The main indicators of quality, mandatory for all types of garments, include: compliance with the basic functional purpose; possibility of dry cleaning, washing, ironing; static compliance; conformity of the product to the modern direction of fashion; level of processing and finishing of the product; the clarity and expressiveness of the performance of trademarks and labels [9]. However, for this type of clothing, all technological decisions made to ensure transformation to different sizes, should look aesthetically perfect, not spoil the appearance, but rather complete it, be comfortable to use and ensure the speed of transformation. Therefore, the main task of the structural component of the system "wedding dress-figure" - the implementation of all initial requirements in the dress, which provide three interdependent elements: "product design - materials - processing technology".

Experimental

The analysis of modern models of wedding dresses indicates the variety of their silhouette shapes and design features (Fig. 1). They are characterized by different levels of horizontal joints, which distinguish certain structural departments of the figure: chest, waist, pelvic thigh. However, among the models considered the most common design of a dress is X-shaped silhouette (Fig. 1), which consists of a corset and a skirt, so this one is advisable to be chosen as a base. Sometimes it can be complemented by a mesh bodice with elements of decor that is worn over a corset, although it does not carry the load in the formation of a silhouette.

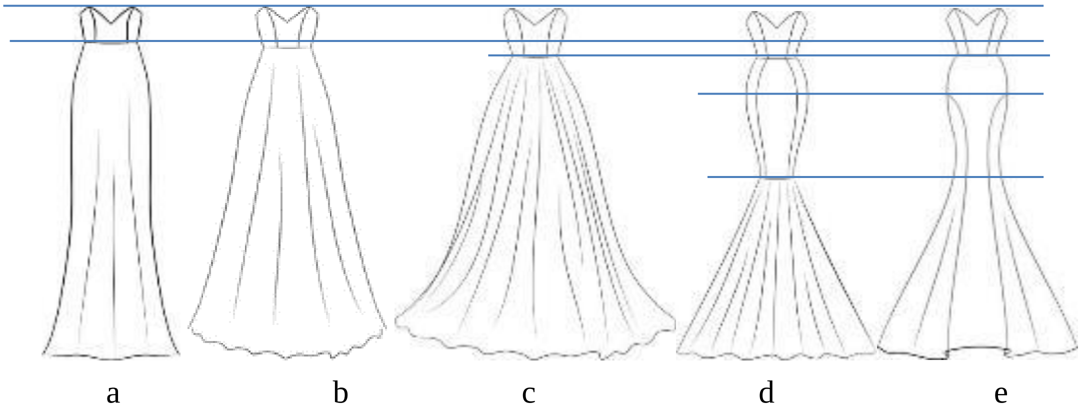
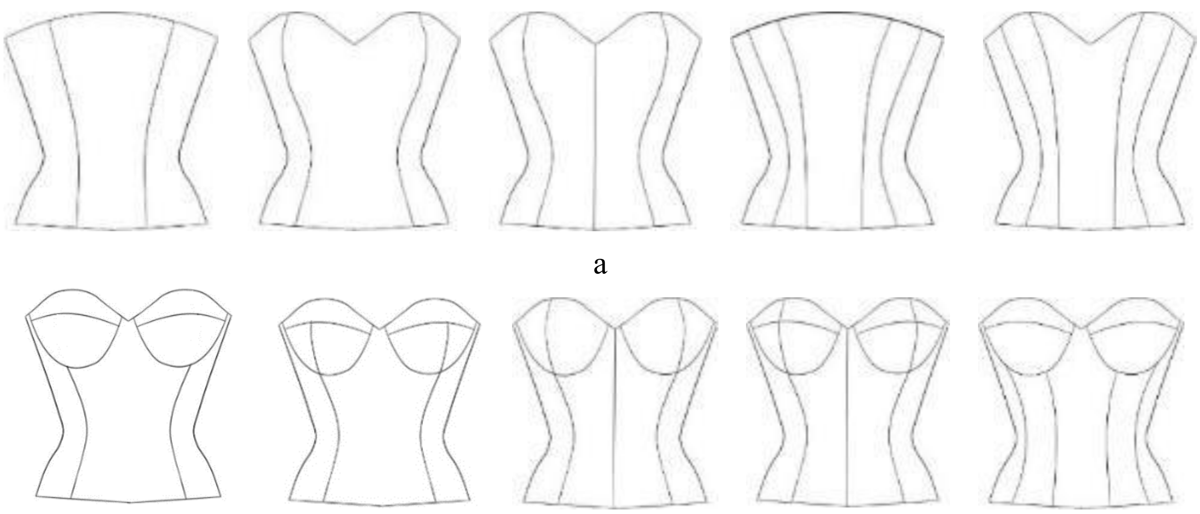


Fig. 1. Varieties of wedding dresses' silhouettes: a) A-shaped, b) straight; c) X-shaped; d, e) "fish"

To achieve the diversity of the appearance of wedding dresses within the same silhouette different types of structural members of the corset are used (Fig. 2): a six-seam, a seven-seam or a ten-seam one with a solid-tailored bodice cup or detachable one. The detachable cup can have 1 vertical or 1 horizontal seam, 1 horizontal and 1 vertical on the lower part, or 1 horizontal and 1 vertical on the upper and lower cup details.



a

b

Fig. 2. Varieties of corsets' designs of wedding dresses: a) with a solid cup; b) with a detachable cup

For the waist part of the corset a 9-seam design is optimal, with 2 lateral seams, allowing to adjust the bend of the trunk on the sides; with 2 relief seams on the front and back, which allow to correct the projection of the abdomen and the flexion of the trunk from the side of the back; and the middle seam in the front - to adjust the distance between the centers of the chest and the size of the projection of the abdomen. Using a full-cut cup in the design allows the transformation of the product only in the horizontal direction, which does not provide a vertical transformation in the breast, which is caused by the increase in the vertical diameter of the breasts in the transition to a larger size. Therefore, to ensure the best ergonomics of the product, it is advisable to use a design with a detachable cup containing 1 horizontal and 1 vertical seam on the top and bottom details of the cup.

To allow for transformation, each of the inner seams of the corset must contain elastic inserts. However, this complicates the transition of the elements of the transformer clasp from the relief seams in front of the corset in the vertical seams of the cup. Therefore, there is a need to design two separate modules - a bra or bustier and a corset belt. The corset belt will be worn over the waist of the bra (bustier) and over the skirt (Fig. 3), which is the third separate module of the dress. To adjust the waistline along the waist, it is advisable to design a belt with an elastic band and a lace and loop fastener in the middle seam.

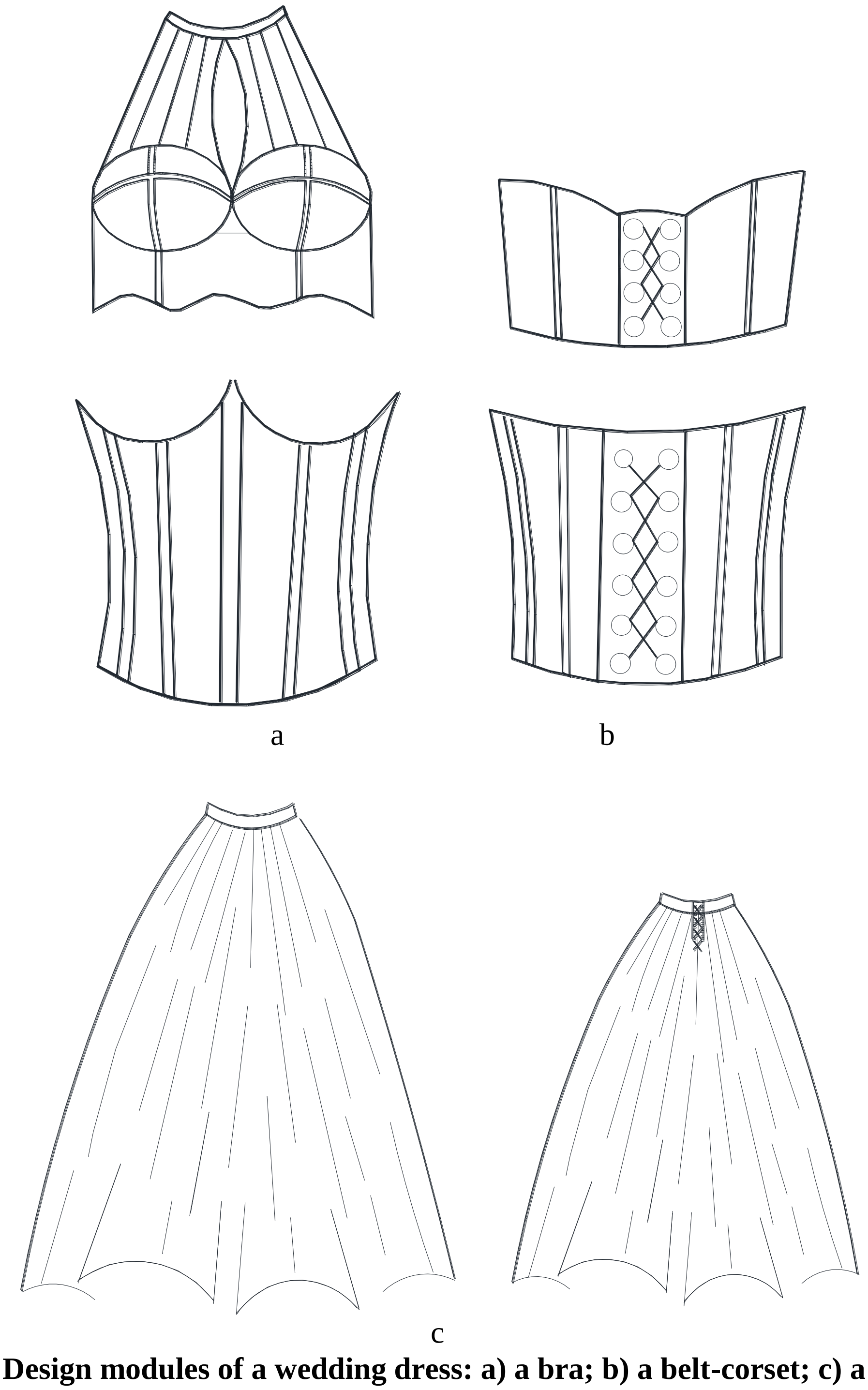


Fig. 3. Design modules of a wedding dress: a) a bra; b) a belt-corset; c) a skirt

The nature of the use of transforming elements in the design of the dress depends on the type of situation that is predicted during the product's sale. There are four kinds of such situations:

1) if the breast size is smaller than the cup size, molded foam inserts in the bra cup should be used to balance the gap between the breast and the cup;

2) if the size of the breast is larger than the size of the cup, it is necessary to design the cups with inserts in the vertical and horizontal seams of elastic materials with high coefficient of elongation to ensure the transformation of the volume of the bra on the breast section on the principle of stretching;

3) when the chest size is larger or smaller than projected, it is necessary to design a mobile lace fastener and loops or eyelets in the middle seam of the back to ensure transformation of the volume of the product at the level of the breast range IV and the waist range by the principle of pulling or stretching;

4) in case of disproportionate increase in the size of the individual parts of the torso, it is necessary to design elastic inserts in the seams of the joints of the parts of the corset to ensure a rapid transformation of the product's volume at the level of the breast range IV or the waist on the principle of stretching.

Since any of the listed design situations may be present in the same product, all of the listed items must be contained therein.

To secure the basic size of the corset belt and bra cups, the elastic inserts should be fastened with concealed zippers, overhanging elastic loops and buttons, or with decorative hooks and loops (Fig. 4), which allow the product to be quickly transformed into the desired areas of the structure. The use of these types of fasteners is advisable, since it allows connecting the parts of the butt and avoid material thickening at the joints, which is extremely important for corsetry products.

Variations in the arrangement of the transformer elements in the selected structure may contain individual types of fasteners. It is most appropriate to use no more than 2 varieties of transformative elements in one product to provide an aesthetic look (Fig. 5).

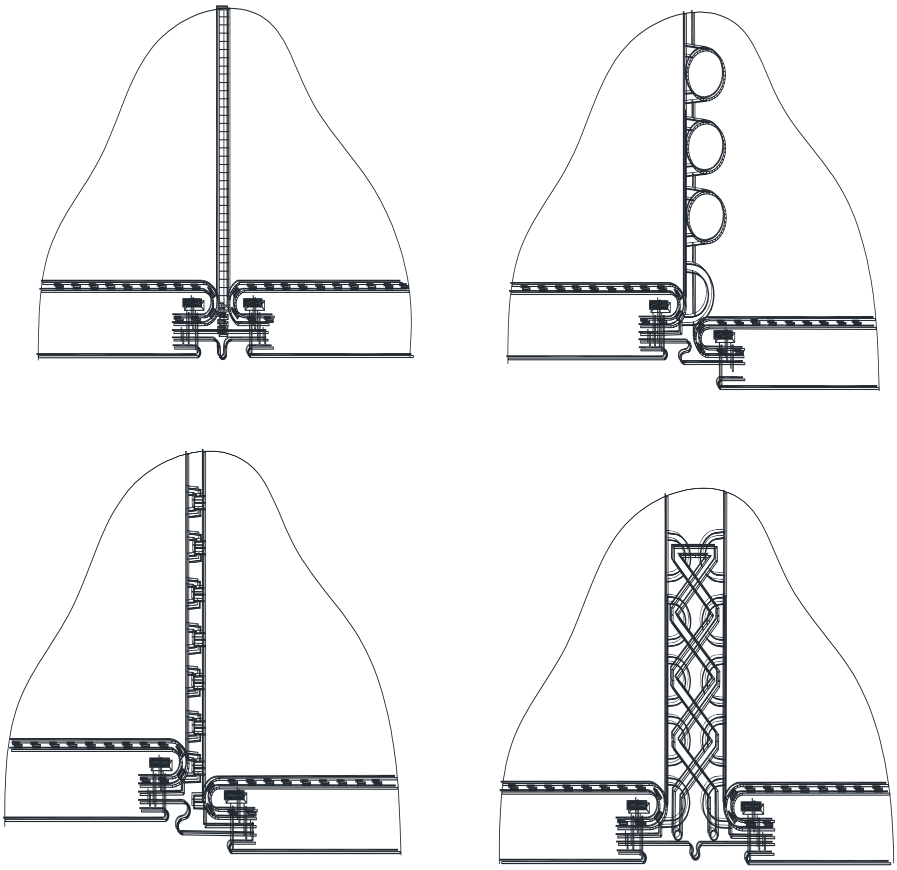


Fig. 4. Types of transforming buckles of a wedding dress

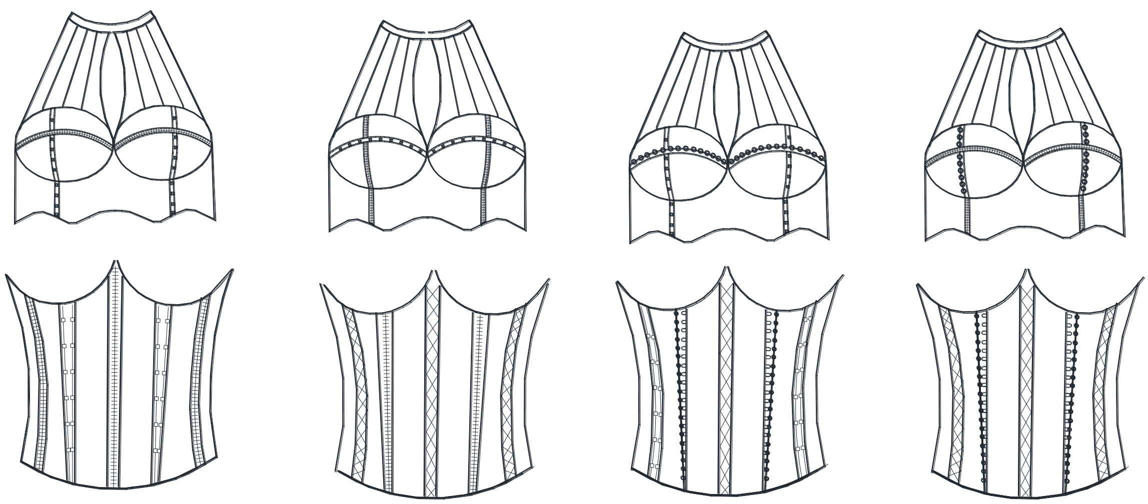


Fig. 5. Transformer fasteners in corset and bra models

Two basic corset designs with a detachable cup were constructed for the development of the multivariate design of the dress according to the method of Antipova A.I. [10] for the adjacent dimensions 170-92-100, 170-96-104 with the size of Brg (breast girth) IV = 80 cm, Brg (breast girth) IV = 84 cm (Fig. 6). The size of the Brg IV is an important feature of the bra group's corsetry. It selects the size of the bra and the corset belt and determines the size of the bra cup in a wedding dress. The division of the proposed structure provides an average modeling effect, which is regulated by elastic insertions at the seams.

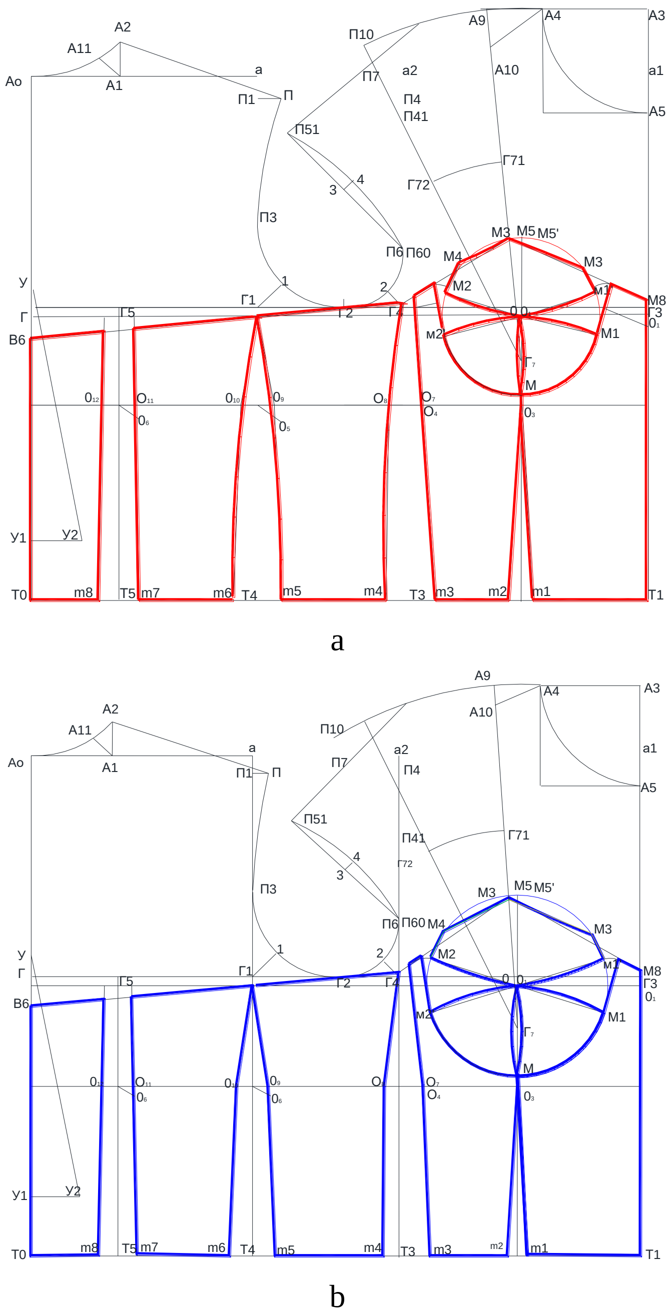


Fig. 6. Basic designs of corsets for the sizes: a) 170-92-100; b) 170-96-104

The method of grouping the details of the cup and corset belt determines the increments that increase the volume of the breast and the size of the waist area of the trunk to a larger size (Fig. 7). Transforming cup details here are the elastic inserts (for a larger size) and molded inserts (for a smaller breast size) that are attached according to the swimsuit principle. The design of the condition of the bra in the terms of increments corresponds to the increments of the design points of the upper contour of the corset bodice.

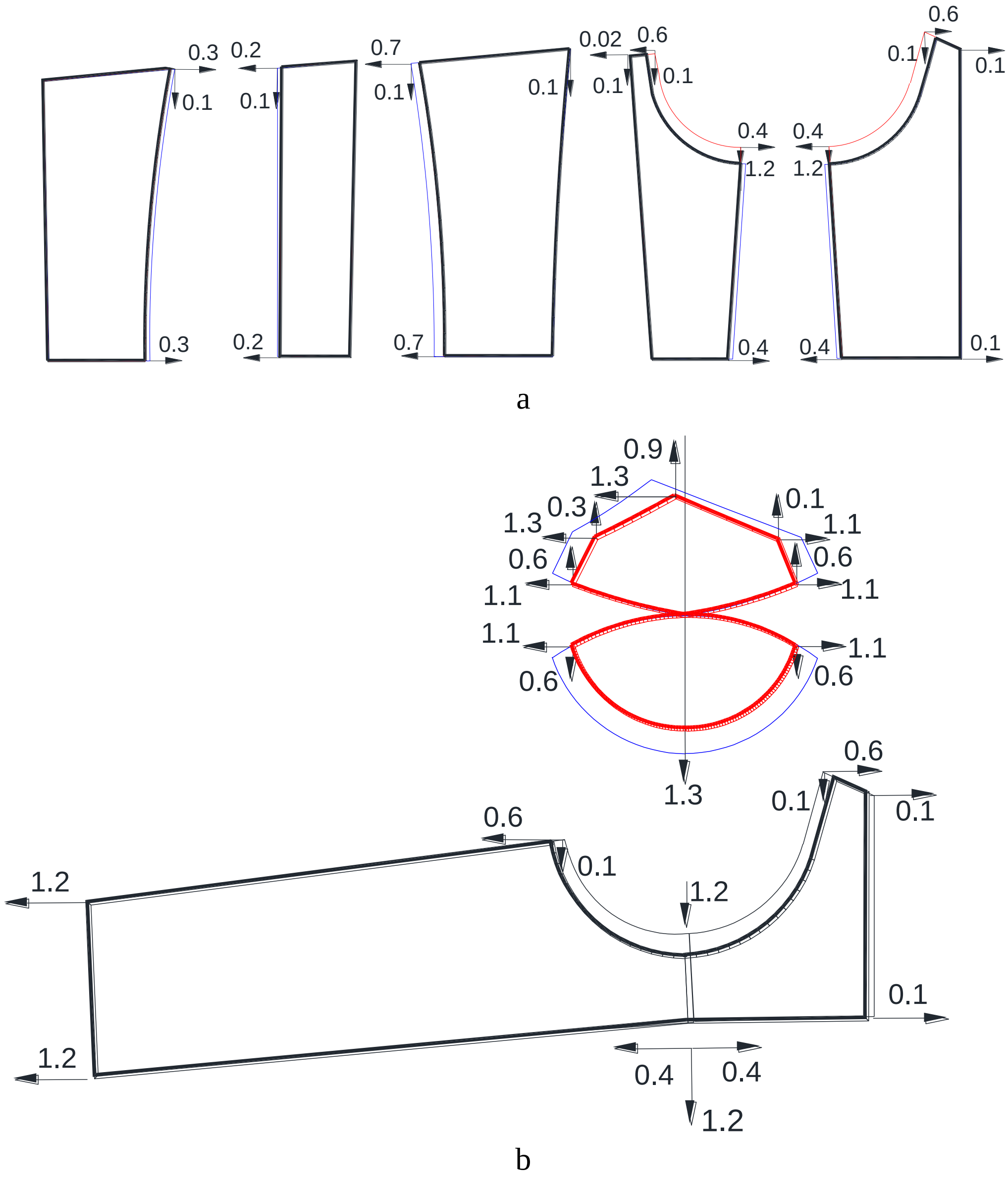


Fig. 7. Schemes of details' gradation: a) a corset belt; b) a bra

When combining structures of two adjacent sizes, the method of grouping determines the difference of parameters in the main structural points of the parts of the bra and the corset belt (Fig. 8). This difference is the basis for determining the size of the elastic inserts at the parts of the bra and the front of the corset belt. On the details of the back of the corset belt the width of the inserts corresponds to the magnitude of the increments indicated in the graduation scheme (Fig. 7). It was decided that the rectangular elastic inserts should be located in the relief seams of the front and back, in the side seam of the back of the corset belt, in the relief seam of the bra, between the lateral and central parts of the cup and the transverse wedge-shaped insert - between the upper and lower details of the cup (Fig. 9).

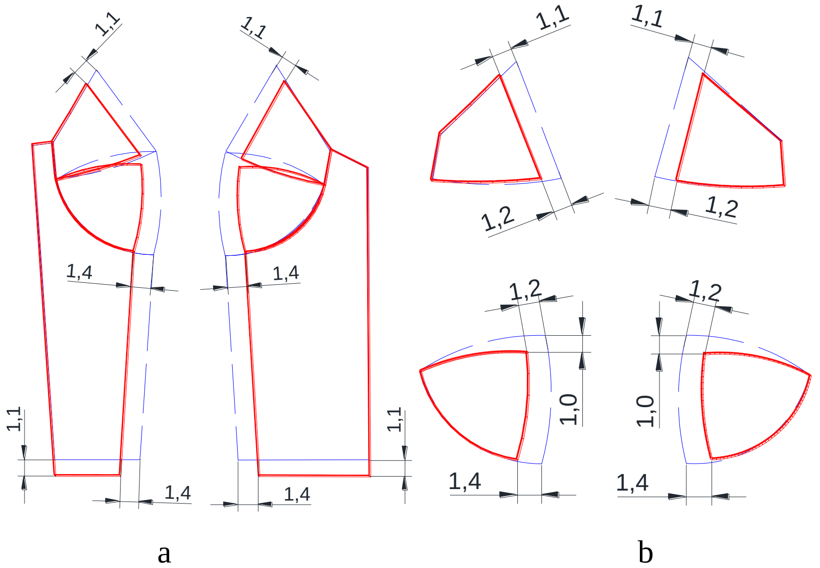


Fig. 8. Scheme of increments in the main structural points of the details: a) bra cups; b) the front of the corset belt

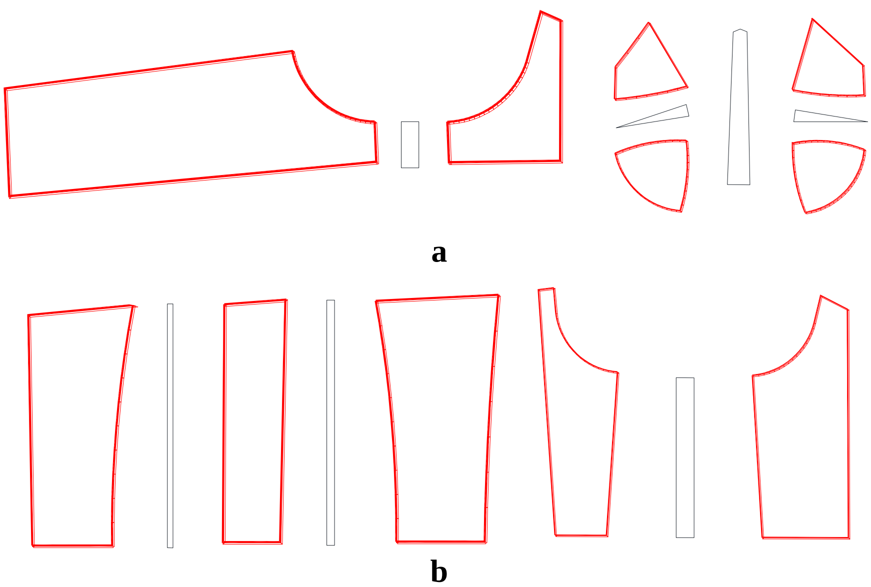


Fig. 9. Multivariate construction: a) a bra; b) a corset belt

Taking into account the defined parameters of the inserts, a universal multivariate design of a wedding dress has been developed for the basic size

170-92-100. It is based on the basic design of the corset for size 170-92-100, which is transformed to the size of 170-96-104 by means of unbuttoning the seams at the locations of elastic inserts. If you need to move to a smaller size, all the transforming elements are fastened at the seams of the connection of the bra parts and the corset belt and by pulling the corset belt along the middle seam of the back we can adjust the design to a smaller size. In a smaller size, additional foam inserts are inserted into the cup details on the inside of the cup (Fig. 10).

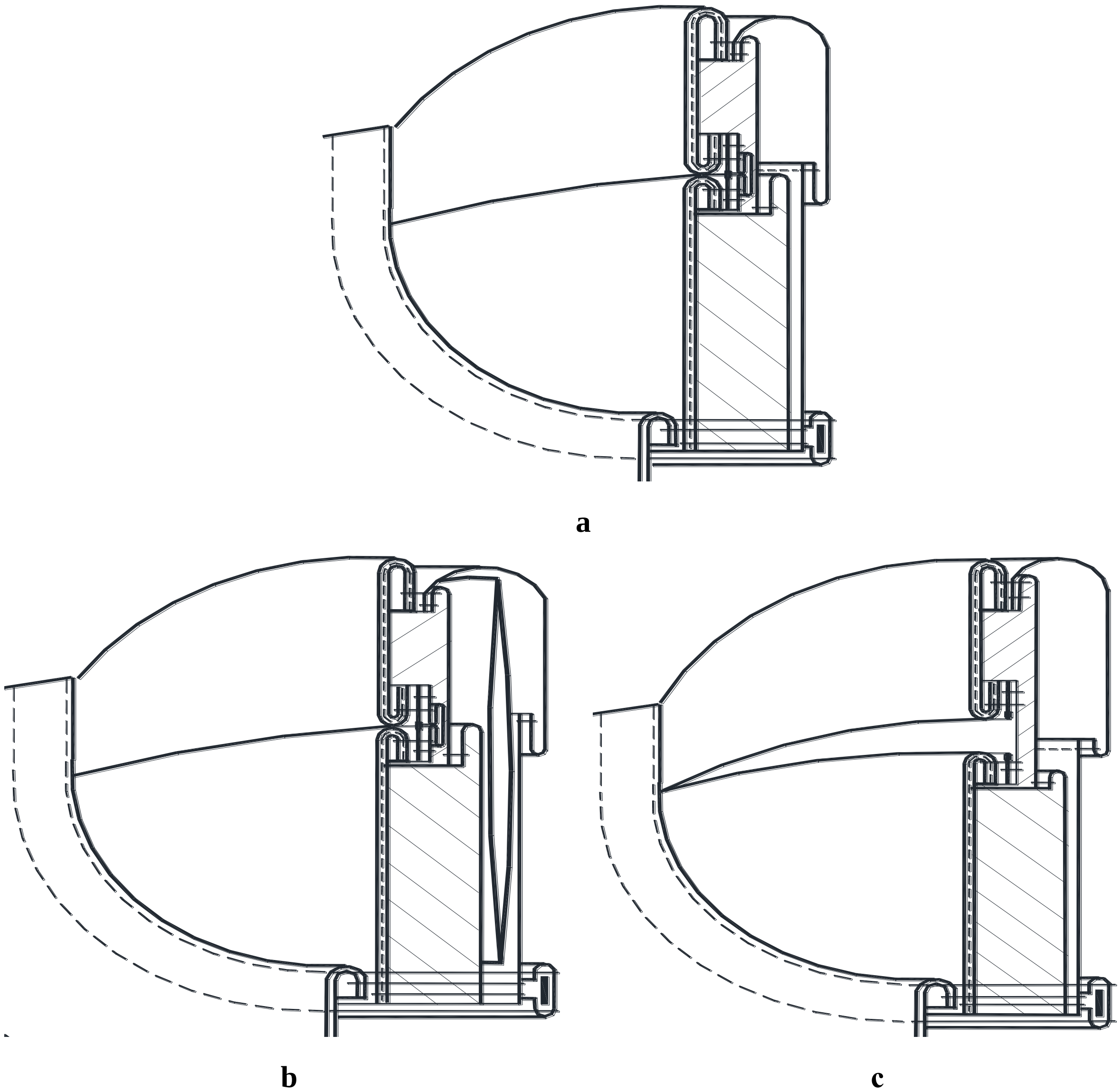


Fig. 10. The technological scheme of transformation of a bra cup:
a) the basic size; b) a smaller size; c) a larger size

The multivariate design of the corset meets the requirements of creating a wedding dress of ready-made elements with the possibility of transformation into adjacent sizes. Technologically, each module is handled separately. Plug-in connections, technological inserts transform the size of the product.

Results

The developed multivariate design of a wedding dress provides the expansion of its functional and ergonomic properties, due to the possibility of transformation into adjacent sizes and therefore prolongs the period of relevance of consumer demand for the product.

In industrial production, it is advisable to develop multivariate designs only for basic sizes in groups of small, medium and large sizes, which reduces the size range in their manufacture, but does not limit it while selling.

The designed construction is mobile because it consists of individual blocks that allow for more flexible coupling of its component blocks and is therefore more comfortable to use than the classic rigid corset design commonly used in classic wedding dresses.

The proposed transformative elements are characterized by a slight thickening of the seams at the joints of the parts and are therefore suitable for use in the group of corsetry, as a basic component of a wedding dress unit. Provided they are made of decorative materials – they serve as an additional decoration of the product, which is extremely important for the range of wedding dresses.

The developed design reduces the stages of design preparation and provides parametric, functional and dimensional compatibility with the individual figure of the consumer.

Conclusions

The novelty of the work is to develop a multivariate design, which consists of three blocks: a detachable corset belt, a bra and a detachable skirt which allow the transformation of product sizes at the level of the three main trunk belts - chest, waist and pelvic thigh.

To build the basic bra design and the corset belt, the 9-seam corset design with a detachable 2-seam cup has been chosen as the most rational one. It allows you to adjust the longitudinal and transverse dimensions of the cup, the transverse dimensions of the corset belt and the values of the bend of the torso along the waist at the front, back and sides, which is extremely important for each individual figure.

To determine the boundaries of many possible options, we have found differences in the parameters of the details of the base structures, constructed according to the method of A. Antipova for adjacent sizes 170-92-100 and 170-96-104. By grouping identical parts, the increment values at the main points of the bra and corset belt have been determined, which became the basis for the design of their grading schemes and allowed to determine the parameters of the elastic inserts, which should be located at the joints of the parts.

The parameters of details obtained as a result of gradation of structural parts, confirmed their compatibility and compliance with the normative values of dimensional features of consumers of typical size-height and high ergonomic design indicators on the basis of visual evaluation of the manufactured samples.

A combination type of transformer elements has been developed, which consists of combining elastic inserts with a clasp fastener on a secret "lightning" braid, metal hooks and hinges, hinged elastic loops and buttons, which are located at the joints of parts combining.

The proposed transformer elements are convenient to use by the location and technique of their fastening. Therefore, they allow you to adjust quickly the parameters of the product to the anatomical features of the individual figure.

Taking into account the mobility of this design, it can be used as model patterns to clarify the changes that must be made in the design while manufacturing wedding dresses by individual order in the sewing studio.

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2.4 FASHION SKETCH DESIGN BASED ON PARAMETERS OF FASHIONABLE FIGURES

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Introduction

A clothing designer usually emphasizes fashion proportions of clothes models when creates a sketch of new clothing item. Proportions of the clothing silhouette are perceived as fashionable if they are similar to the proportions of a fashionable figure. Moreover, it is an undeniable fact that nowadays any clothing designer while creating the sketch is assisted by a number of computer technologies of modern era those allow making its proportions as precise as it whenever might be.

There are a number of papers [1, 2, 3, 7] on the subject of automated clothing sketch creation. Development of parametric representation model of clothing silhouette for analysis and forecasting of form creation trends is presented in [2]. This article discusses the steps for creating parametric representation models of the costume frontal silhouettes. The model created is a part of the automated costume design information system.

Another paper [7] deals with the process of designing new models of women's clothing by automating sketch design in conditions of small sewing enterprises. There have been created templates of graphic images of different types of female figures, libraries of modern materials textures, which are most often used for women's clothing manufacture. Besides, the method of new model sketches creation of women's clothes with the use of figure templates and libraries of materials has been developed. Authors developed a methodical support for the use of the universal graphic editor Xara Designer Pro on the AWS of a designer of a small sewing enterprise [7].

The datasets of graphic images of clothing were developed, and subsequently representatives of several different science schools such as Ivanovo State Textile Academy [3, 4], Kharkiv State Academy of Design and Arts [4, 6], and Khmelnytskyi National University [9] analyzed them.

However, any scientist does not prove the nature of the interrelationships between parameters of fashionable figures sketches and parameters of creative sketches of fashionable clothing items yet.

One can assume that the characteristics of sketches of clothing models are correlated to parameters of fashionable figures in the same period.

Method

A dataset of graphic images of fashionable figures have been formed in previous published works [8, 9, 10]. Graphic image of each fashionable figure is considered as a set of measurements those lie in two orthogonal directions: 12 heights, 10 widths, and an angle (table 1, fig. 1).

Table 1 The list of fashionable figures parameters

Code	**Direction**	**Parameter**	**Source**	Calculation
H_0	Heights	Head	[12]	T_{73}
H_1		Neck	[11]	T_1-$T7_3$-T_4
H_2		Shoulder height	[11]	T_4-T_5
$H3$		Shoulder to over bust	[11]	T_5-T_{11}
H_4		Over bust to bust line	[11]	T_{11}-T_6
H_5		Bust line to waistline	[11]	T_6-T_7
H_6		Waistline to hipline	[11; 13]	T_7-T_{103}
H_7		Hipline to thigh midline	[13; 14]	T_{103}-T_{18}
H_8		Thigh midline to knee	[14; 11]	T_{18}-T_9
H_9		Knee to shin midline	[11; 14]	T_9-T_{21}
H_{10}		Lower leg	[14]	T_{21}-T_{24}
H_{11}		Foot height	[14]	T_{24}
H_{12}		Full height	[11]	T_1
W_1	Widths	Neck diameter	[11]	T_{54}
W_2		Shoulder diameter	[11]	T_{53}
W_3		Diameter at over bust line	[10]	T_{450}
W_4		Diameter at bust line	[12]	T_{99}
W_5		Waist diameter	[11]	T_{55}
W_6		Thigh diameter	[11]	T_{56}
W_7		Width at thigh midline	[10]	T_{180}
W_8		Width at knee girth line	[10]	T_{90}
W_9		Width at the level of shin girth	[10]	T_{210}
W_{10}		Width at ankle line	[10]	T_{240}
α	–	Shoulder angle	[11]	$arcsin(T_{72}/T_{31})$

Input data for the current research is a dataset of creative sketches of women’s dresses. It consists of 300 sketches, which form 10 retro rows. Each row refers to the certain decade from 1920 to 2010. A number of parameters differ for each row as it depends on geometrical forms of the dresses those belong to the given row.

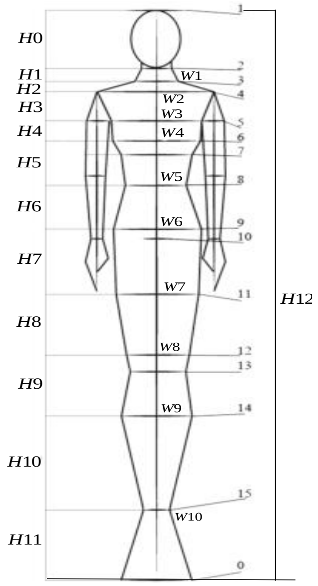
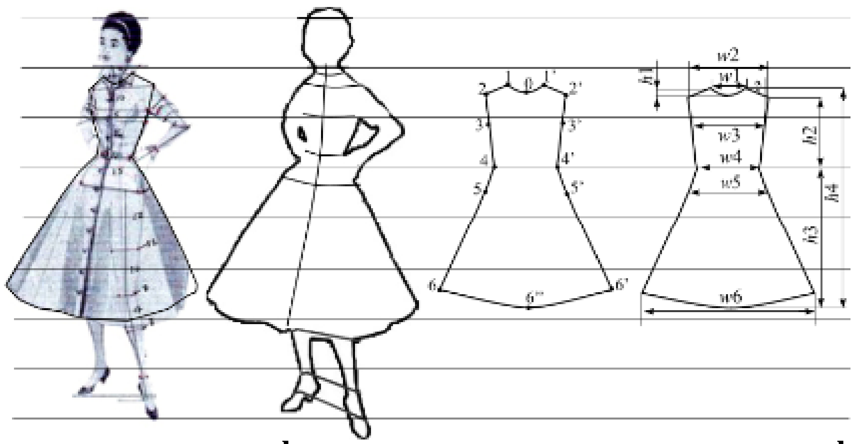


Fig. 1. Measurements of the image of a fashionable figure

Total amount of 11 basic parameters are selected to characterize the outer shape of a dress sketch. Such set of selected parameters was spotted in the each retro row of images. Thus, it forms a graphic image of a dress and is sufficient for its identification. Since the shape of a dress in the image is a flat silhouette, its characteristics are related to the points of maximum curvature of the silhouette, which denote places of extreme shape change.



a b c d

Fig. 2. Parameters (a, b, d) and informational points of the outer shape of the creative sketch of a dress (c)

Such points are the ones, through which lines of the outer contour and lines of constructive elements pass: neckline (0-1), shoulders (2), armscye depth (3), waistline (4), hipline (5), and hemline (6) (fig. 2). The parameters of a dress are measured between the pairs of basic information points, which are located to the right and left along the axis of symmetry (Table 2).

Table 2 Parameters of the creative sketch of a dress

No	Parameter	Code	Main points
1	Neckline depth	h_1	1-0
2	Neckline width	w_1	1-1’
3	Shoulders to waistline	h_2	2-4
4	Waistline to hemline	h_3	4-6
5	Garment length	h_4	1-6’’
6	Shoulders width	w_2	14-14’
7	Bust line width	w_3	3-3’
8	Waistline width	w_4	4-4’
9	Hipline width	w_5	5-5’
10	Hemline width	w_6	6-6’
11	Shoulder angle	α_D	α

In order to indicate a predictive relationship that can be exploited in practice correlation analysis was carried out. Correlation coefficients were calculated for all pairs of variables (table 3 and table 4).

One can see in the table 3 and table 4 that parameters of dress are depended on the parameters of the fashionable figure, though the nature of correlation varies for the different parameters. The parameters with the highest level of correlation (direct or inverse) were selected out for subsequent experiments.

Table 3 Correlation of the parameters (part 1)

Dress	Figure											
	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}	H_{11}	H_{12}
h_1	-	1.0	-	-	-	-	-	-	-	-	-	-
w_1	-	-	-	-	-	-	-	-	-	-	-	-
h_2	-	-	0.50… 0.84	0.54… 0.68	0.52… 0.93	0.55	0.66	0.55	-	-	-0.54	0.68… 0.81
h_3	-	-0.53	0.66	0.51… 0.59	-0.54; 0.59	-0.76; 0.65	0.89	0.52… 0.70	0.70… 0.74	-0.71; 0.74	-0.55	-0.52; 0.63… 0.93
h_4	0.57	-0.58	0.71	0.52… 0.60	0.53… 0.68	-0.75; 0.65	-0.51; 0.87	0.77	0.58… 0.73	-0.68; 0.77	-0.65	-0.52; 0.58… 0.94
w_2	-	-	-	-	-	-	-	-	-	-	-	-
w_3	-	-	-	-	-	0.59	-	-	-	-	-	-
w_4	-0.64; 0.58	-0.55; 0.63	-	-	-0.69	-0.61; 0.66	-	-	-	-	-	-
w_5	-	-	-	-	-	-	-	-	-	-	-	-
w_6		0.51	-0.55; 0.61	-0.50	-0.75	-0.51; 0.57	-0.57; 0.75	-	-	-	-	-0.72; 0.64… 0.82

Table 4 Correlation of the parameters (part 2)

Dress	Figure										
	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	α
h_1	-	-	-	-	-	-	-	-	-	-	-
w_1	1.0	-	-	-	-	-	-	-	-	-	-
h_2	0.76	0.53…0.66	0.56…0.78	0.63…0.68	-	0.56…0.77	0.55…0.60	0.51…0.60	-	-	-
h_3	0.85	0.75	0.65	0.54…0.71	-	-0.69; 0.55…0.75	-0.89; 0.71	-0.94; 0.54	-0.94; 0.64	-	-0.57
h_4	0.50…0.87	0.67…0.77	0.53…0.71	0.52…0.77	-	0.54…0.78	0.69	0.52	0.57	-0.83	-0.59
w_2	-	1.0	-	-	-	-	-	-	-	-	-
w_3	-	-	-0.85	1.0	0.65	-0.54	-	-	-	-	-
w_4	-	-	0.58…0.60	0.70	1.0	-	-	-	-	-	-
w_5	-	-	-	-	-	1.0	-	-	-	-	-
w_6	0.72	-0.50; 0.70	0.51	-0.56; 0.52…0.73	-0.50	0.60…1.0	0.60…0.66		0.54		-0.72; 0.51
α_D	-	-	-	-	-	-	-	-	-	-	1.0

perfect direct linear relationship: +1;
strong direct linear relationship:+0.80…+0.88;
moderate direct linear relationship: +0.60;
– zero correlation;
moderate inverse linear relationship: -0.60;
strong inverse linear relationship: -0.80…-0.88;
perfect inverse linear relationship: -1.0.

Experimental

In order to estimate the conditional expectation of dependent variables, which are parameters of the creative sketch of fashionable clothing item, given the independent variables, which are parameters of the fashionable figure sketch, regression analysis was performed.

Simple linear regressions were obtained by using an option “Add Trendline” in Excel. Method of least squares, which is used in Excel, assures to find a theoretical line that best fits the experimental points. The R-squared values are close to 1, which is a good fit. Thus, the equations might be used in order to calculate the parameters of the creative sketch of fashionable clothing item given the parameters of the fashionable figure sketch. The graphs and equations of the linear regressions one can see in the figure 2.

Main characteristics of the multifactorial experiments, which were performed separately in each decade under consideration, one can see in the table 5. Three independent variables that were selected based on results of the correlation analysis were considered per each experiment. The experiments were carried out according to the experimental plans in the table 6. Every parameter of a fashionable dress sketch on the graphic image of the certain fashionable figure was measured twice. Multiple linear regressions are obtained by using the Analysis ToolPack "Data Analysis" in Excel (table 7, fig. 3).

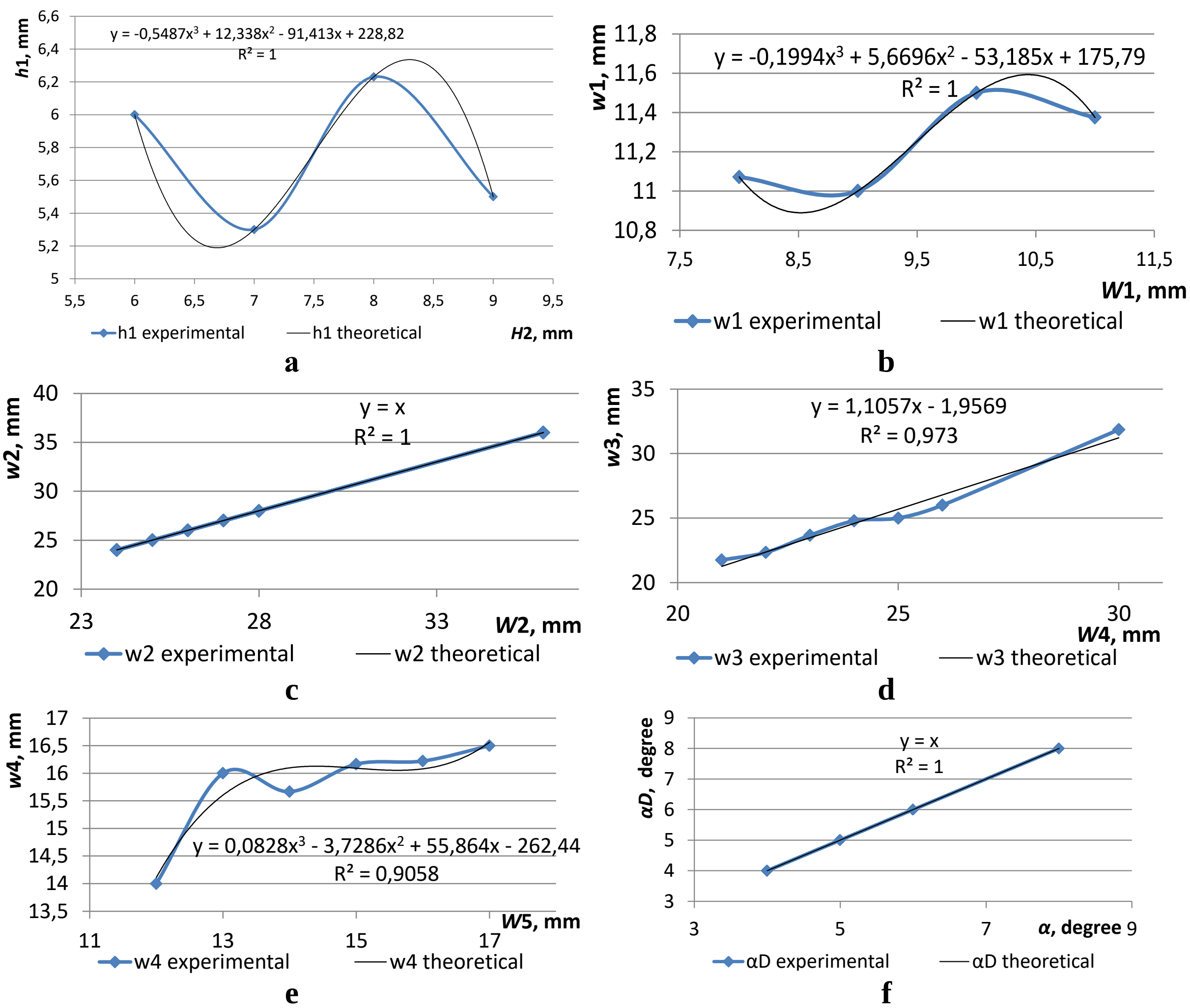


Fig. 2. Graphs to illustrate dependence of dress parameters on parameters of fashionable figures (1960): a) h_1; b) w_1; c) w_2; d) w_3; e) w_4; f) α_D

Table 5 Main characteristics of experiments (1960)

Characteristic	h_2						h_3						h_4					
	H_3	X_1	H_5	X_2	H_{12}	X_3	H_7	X_1	W_2	X_2	W_6	X_3	H_7	X_1	H_{12}	X_2	W_6	X_3
Basic level, z_{oi}	8	0	15	0	175	0	17	0	30	0	27	0	22	0	175	0	27	0
Range, Δz_i	2	–	4	–	13	–	2	–	6	–	5	–	7	–	13	–	5	–
High level, z_{imax}	10	+1	19	+1	188	+1	29	+1	36	+1	32	+1	29	+1	188	+1	32	+1
Low level, z_{imin}	6	-1	11	-1	162	-1	15	-1	24	-1	22	-1	15	-1	162	-1	22	-1

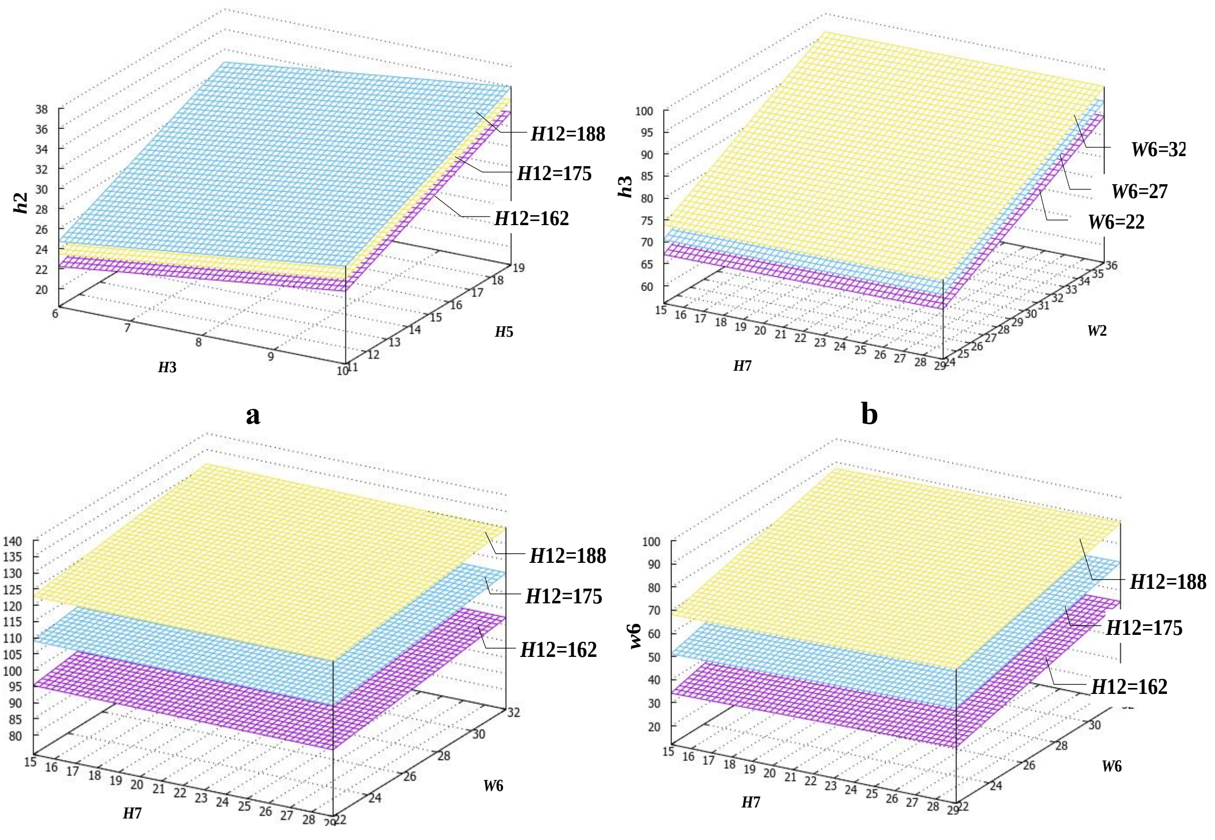
Table 6 Plans of experiments (fragment)

Code of independent variables			Plan 1						Plan 2						Plan 3					
			Independent variables, mm			*Dependent variable* ***h*₂**, *mm*			*Independent variables, mm*			*Dependent variable* ***h*₃**, *mm*			*Independent variables, mm*			*Dependent variable* ***h*₄**, *mm*		
x_1	x_2	x_3	H_3	H_5	H_{12}	1	2	mean	H_7	W_2	W_6	1	2	mean	H_7	H_{12}	W_6	1	2	mean
+	+	+	10	19	188	37	36	36.5	29	36	32	96	96	96	29	188	32	128	128	128
–	–	–	6	11	162	22	22	22	15	24	22	64	64	64	15	162	22	91	91	91
+	+	–	10	19	162	33	33	33	29	36	22	90	89	89.5	29	188	22	122	121	121.5
+	–	–	10	11	162	25	25	25	29	24	22	72	72	72	29	162	22	98	98	98
+	–	+	10	11	188	29	28	28.5	29	24	32	90	89	89.5	29	162	32	122	121	121.5
–	+	+	6	19	188	32	31	31.5	15	36	32	94	93	93.5	15	188	32	131	130	131.5
–	+	–	6	19	162	32	31	31.5	15	36	22	87	88	87.5	15	188	22	121	122	121.5
–	–	+	6	11	188	25	25	25	15	24	32	77	77	77	15	162	32	106	106	106

Table 7 Regression models

Dependent variable	Decade	Individual figure	Standard figure	R^2
1	*2*	*3*	*4*	*5*
***h*2**	1920	$15.83+0.46W_6+0.46H_5$	$15.83+0.46T_{56}+0.46(T_6-T_7)$	0.97
	1930	$24.21+H_4+0.63H_5-0.22W_3$	$24.21+(T_{11}-T_6)+0.63(T_6-T_7)-0.22T_{450}$	0.95
	1940	$21.79+0.33H_3+0.63H_5-0.03H_{11}$	$21.79+0.33(T_5-T_{11})+0.63(T_6-T_7)-0.03T_{24}$	0.96
	1950	$17.24+0.83H_5+0.23W_3-0.18W_4$	$17.24+0.83(T_6-T_5)+0.23T_{450}-0.18T_{99}$	0.93
	1960	$-9.20+0.81H_3+H_5+0,09H_{12}$	$-9.20+0.81(T_5-T_{11})+(T_6-T_7)+0.09T_1$	0.97
	1970	$12.83+0.70H_3+0.61H_5+0,15W_2$	$12.83+0.70(T_5-T_{11})+0,61(T_6-T_7)+0.15T_{53}$	0.74
	1980	$-0.88+1.06H_3+H_4+H_5$	$-0.88+1.06(T_5-T_{11})+(T_{11}-T_6)+(T6-T_7)$	0.99
	1990	$10.06+0.50H_5+0.06H_{12}$	$10.06+0.50(T_6-T_7)+0.06T_1$	0.96
	2000	$15.00+1.04H_5+0.08W_8$	$15.00+1.04(T_6-T_7)+0.08T_{90}$	0.96
	2010	$14.28+1.01H_5$	$14.28+1.01(T_6-T_7)$	0.83
***h*3**	1920	$-108.49+0.10H_8-0.23H_9+0,99H_{12}$	$-108.49+0.10(T_{18}-T_9)-0.23(T_9-T_{21})+0.98T1$	0.96
	1930	$-283.72+0.22H_5+2.04H_{12}-0.43W_4$	$-283.72+0.22(T_6-T_5)+2.04T_1-0.43T_{99}$	0.99
	1940	$-196.15+0.65H_8+1.39H_{12}-0.06W_6$	$-196.15+0.65(T_{18}-T_9)+1.39T_1-0.06T_{56}$	0.97
	1950	$-492.50+2.83H_{12}+3.00W_6$	$-492.50+2.83T1+3.00T56$	0.75
	1960	$8.01+0.02H_7+1.83W_2+0.68W_6$	$8.01+0.02(T_{103}-T_{18})+1.83T_{53}+0.68T_{56}$	0.94
	1970	$-308.71+1.96H12+0.42W6$	$-308.71+1.96T1+0.42T56$	0.99
	1980	$-998.81+0.04H_9+5.64H_{12}+0.18W_6$	$-998.81+0.04(T_9-T_{21})+5.64T_1+0.18T_{56}$	0.99
	1990	$1826.56-0.13W_6+1.88W_8-8.81H_{12}$	$1826.56-0.13T_{56}+1.88T_{90}-8.81T_1$	0.98
	2000	$-1130.13+5.58H_{12}+0.11W_6$	$-1130.13+5.58T_1+0.11T_{56}$	0.99
	2010	$-902.45+5.65H_{12}+0.27W_4+0.55W_6$	$-902.45+5.65T_1+0.27T_{99}+0.55T_{56}$	0.99
***h*4**	1920	$-111.87+0.21W_4+0.12W_2+1.11H_{12}$	$-111.87+0.21T_{99}+0.12T_{53}+1.11T_1$	0.99
	1930	$-248.61+0.09W_2+2.01H_{12}-0.18W_4$	$-248.61+0.09T_{53}+2.01T_1-0.18T_{99}$	0.99
	1940	$-216.46+1.64H_{12}+0,38W_2+0.27W_4$	$-216.46+1.64T_1+0.38T_{53}+0.27T_{99}$	0.97
	1950	$-266.83+1.83H_{12}+1.10W_4+1.25W_6$	$-266.25+1.83T_1+1.10T_{99}+1.25T_{56}$	0.70
	1960	$-92.34-0.05H_7+1.06H_{12}+0.78W_6$	$-92.34-0.05(T_{103}-T_{18})+1.06T_1+0.78T_{56}$	0.97
	1970	$-304.68+2.18H_{12}+0.19H_5$	$-304.68+2.18T_1+0.19(T_6-T_7)$	0.99
	1980	$-971.41+0.11W_2+5.67H_{12}+0.04W_3$	$-971.41+0.11\mathrm{T}_{53}+5.67\mathrm{T}_1+0.04\mathrm{T}_{450}$	0.99
	1990	$1881.94-8.94H_{12}-0.14W_4+0.58W_6$	$1881.94-8.94T_1-0.14T_{99}+0.58T_{56}$	0.99
	2000	$-1043.12+4.70H_{12}+3.42W_4+1.83W_6$	$-1043.12+4.70T_1+3.42T_{99}+1.83T_{56}$	0.90
	2010	$-890.50+5.76H_{12}-0.09W_4+0.77W_6$	$-890.50+5.76T_1-0.09T_{99}+0.77T_{56}$	0.99

1	***2***	***3***	***4***	***5***
***w*2**	1920-2010	W_2	T_{53}	1.00
***w*3**	1920-1990	W_4	T_{99}	1.00
	2000	$10.89–0.11H_6+0.12W_5+0.51W_6$	$10.89–0.11(T_7-T_{103})+0.12T_{55}+0.51T_{56}$	0.77
	2010	W_4	T_{99}	1.00
***w*4**	1920-1990	W_4	T_{99}	1.00
	2000	$-8.23+1.50H_2+0.23H_6+0.50W_4$	$-8.23+1.50(T_4-T_5)+0.23(T_7-T_{103})+0.50T_{99}$	0.73
	2010	W_4	T_{99}	1.00
***w*6**	1920	$7.60–0.10H_{12}+1.75W_6$	$7.60–0.10T_1+1.75T_{56}$	0.79
	1930	$-519.60+2.60H_{12}+W_4$	$-519.60+2.60T1+T99$	0.99
	1940	$-76.29+0.33H_{12}–0.21W_4+1.79W_7$	$-76.29+0.33T_1–0.21T_{99}+1.79T_{56}$	0.83
	1950	$13.11+0.71W_6–0.03W_4–0.02H_{12}$	$13.11+0.71T_{56}–0.03T_{99}–0.02T_1$	0.85
	1960	$-221.66+0.14H_7+1.31H_{12}+1.90W_6$	$-221.66+0.14(T_{103}-T_{18})+1.31T_1+1.90T_{56}$	0.73
	1970	$-63.96+1.09W_2+1.09W_4+4W_7$	$-63.96+1.09T_{53}+1.09T_{99}+4.0T_{180}$	0.96
	1980	$125.09–3.84H_3–1.70H_5–0.72W_1$	$125.09–3.84(T5-T_{11})–1.70(T_6-T_7)–0.72T_{54}$	0.86
	1990	$-13.97+0.09H_{12}+0.90W_6$	$-13.97+0.09T_1+0.90T_{56}$	0.92
	2000	$6.57–0.40H_{12}+4.67W_6$	$6.57–0.40T_1+4.67T_{56}$	0.98
	2010	$19.33+0.38H_2+0.58H_5$	$19.33+0.38(T_4-T_5)+0.58(T_6-T_7)$	1.00
α_D	1920-2010	α	$arcsin(T_{72}/T_{31})$	1.00



c **d**

Fig. 3. Graphs to illustrate dependence of dress parameters on parameters of fashionable figures (1960): a) h_2; b) h_3; c) h_4; d) w_6

Results

The regression models are verified by using Fisher-test. Results of the test (table 6) prove advisability of using the models in order to calculate the parameters of the sketch of fashionable clothing item.

Table 6 Results of Fisher-test (fragment)

Dependent variable	Decade	*Da*	*Dc*	F_p	F_m
h_2	1920	0.563	0.328	1.714	7.71
	1930	0.938	0.656	1.429	3.84
	1940	0.313	0.344	1.100	3.84
	1950	0.719	0.578	1.243	3.84
	1960	1.063	0.656	1.619	3.84
	1970	11.156	5.734	1.946	3.84
	1980	0.313	0.344	1.100	3.84
	1990	0.250	0.313	1.250	7.71
	2000	1.563	0.453	3.448	7.71
h_3	1920	5.031	2.734	1.840	3.84
	1930	2.906	1.672	1.738	3.84
	1940	3.281	1.859	1.765	3.84
	1950	121.00	30.50	3.967	7.71
	1960	16.906	8.297	2.038	3.84
	1970	2.250	0.813	2.769	7.71
	1980	2.281	1.297	1.759	3.84
	1990	48.219	24.297	1.985	3.84
	2000	0.250	0.188	1.333	7.71
	2010	5.719	3.016	1.896	3.84
h_4	1920	1.531	0.984	1.556	3.84
	1930	0.594	0.516	1.152	3.84
	1940	3.719	2.078	1.789	3.84
	1950	35.719	18.047	1.979	3.84
	1960	12.188	6.031	2.021	3.84
	1970	0.250	0.313	1.250	7.71
	1980	0.656	0.484	1.355	3.84
	1990	39.969	20.172	1.981	3.84
	2000	515.25	257.75	1.999	3.84
	2010	3.410	1.859	1.832	3.84

Graphic images of the fashionable clothing items, which are designed directly on the graphic images of fashionable figures, allow customizing the clothing items for the individual figures by using computer graphic methods. Furthermore, above-mentioned regression models allow constructing the outline of a fashionable dress automatically. Therefore, the next stage of the current research is to develop an algorithm to construct the outline of a fashionable dress of a given decade using the set of body measurements as an input data and a vector graphic editor as a tool.

Conclusion

Correlation analysis proved right the main hypothesis of the study: the parameters of the fashionable dress sketch are dependent on those of fashionable figure sketch. Validity of the various regression models (simple linear regressions as well as multiple regressions) those were obtained as results of the experiments is confirmed by Fisher-test. Thus, the input data to develop the algorithm of automatic designing the outline of the fashionable dress for given decade and specific body measurements are gathered.

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2.5 CONCEPTUAL MODEL FOR FORMATION OF GRAPHIC OBJECTS IN FRACTAL GRAPHICS

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Introduction

Modern processes of artistic clothing design cannot be imagined without the use of informational technology. Moreover, such processes often handled by means of fractal geometry. There are a number of papers, which are devoted to the application of fractals in fashion, apparel design, and some related industries [1-9].

Examples of using fractal images as a means of artistic expression in fashion design are well described in scientific literature such as [1, 2, 6]. Furthermore, authors visualized the fractal algorithm to design clothing material using fractal filters of graphic editors. Fractal prints were implemented to design the material of clothing model that was sewn as a result of the study [3].

The classifier of elements of symmetry and homology as the principles of constructing the fractal image is formed. Layout structures of the fractal organization of models in the clothing collection are constructed. Proportional correlations, which were determined by authors, have been applied to design women's clothing. The correlations were presented in form of symbols, which became the basis for the creation of an artistic shape [4].

Fractal graphic as an innovative technology of clothing design is discussed in papers [5, 7]. The use of non-linear creative sources such as fractals might be considered as a mean to design clothing items [8]. Besides, fractals are used to describe the interrelationships between garment classes in form of a graphic model of assortment transformation, which allows investigating the whole class of garments by investigating the smaller one [8].

However, mathematical description of formation of graphic objects such as clothing items in fractal graphics is yet to be performed.

Method

The basis of the parameterization process of complex objects, which the clothing is, is fractal dimension [10]. Due to the lack of exact geometric self-similarity of fractals in the costume's form, it is necessary to observe their topological or statistical similarity.

Topology studies objects whose properties do not change under deformations occurring without ruptures and gluing. Consequently, the topological dimension of the set d_T is a geometric dimension, which per unit exceeds the dimension of a section that divides this set into two non-connected parts, with the topological dimension of the point assumed to be zero. Then that of the line is $d_T = 1$, the one of the plane is $d_T = 2$, and the one of the 3D surface is $d_T = 3$ [10], etc. Thus, the geometric and topological dimensions are integers.

When the ratio that provides a statistical index of objects complexity is not an integer it is necessary to consider some other dimensions. In accordance with [11] objects in which the topological dimension is less than Hausdorff are called fractals. In addition, the fractal dimension is a fractional number that characterizes the "porosity" or the density of an object, that is, how an object fills in the space of attachment. An example of a fractal dimension of a set is shown in the fig. 1.

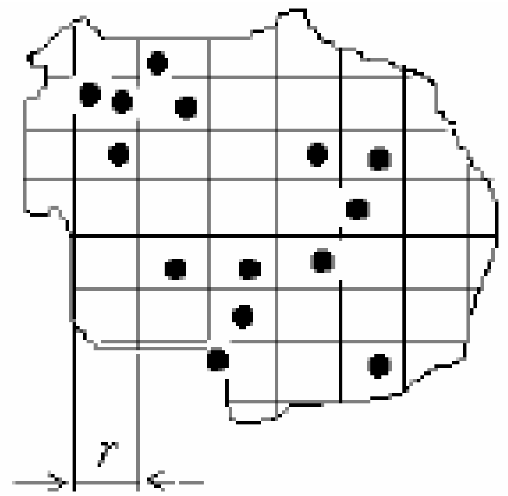

Fig.1. Fractal dimension of a set

In general, the fractal dimension is calculated by the expression [10]:

$$d_H = \lim_{r \to 0} \frac{\ln N(r)}{\ln(1/r)}, \tag{1}$$

where N – number of cells containing at least one element of a set;

r – linear size of identical cells.

The limit of the function (1) is determined by *r* approaching 0.

The procedure for counting the number of cells containing at least one element of a set is called scaling [10].

It should be noted that in natural objects, in contrast to the ideal mathematical fractals, the basic element and the iterative rule are absent. Stochastic scaling takes place and the objects are stochastic or self-defect fractals.

In order to determine the fractal dimension, the choosing of the methods of parametrizing complex objects must be done given following restrictive conditions: fractional structures; critical thresholds of a system (bifurcation); topology of the system plasticity. The fractional (structural) dimension, when considered as the Hausdorff dimension d_0, is given by the expression [10]:

$$d_0 = \lim_{r \to \infty} \frac{\log N(r)}{\log(1/r)}, \quad (2)$$

where N – minimal number of elements, each one of which is r size, needed to cover the set under study.

The limiting condition for fractional decomposition is a condition that the topological dimension d_τ is less than d_0. Then the object is fractal.

The geometric way of parametrizing the Hausdorff dimension characterizes the sequence of steps for constructing a known fractal, the Koch curve (fig. 2). It is obtained as a result of the sequential construction of a triangular tooth on the initial segment of unit length and the resulting segments of thrice smaller size.

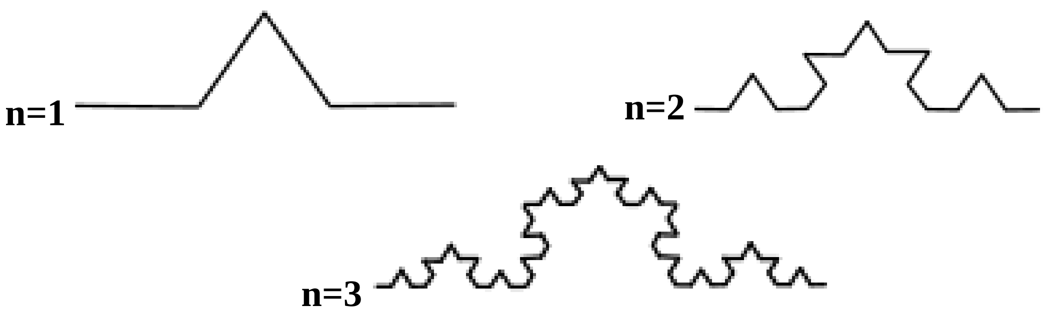

Fig. 2. The first iterations of the Koch curve, which has an approximate Hausdorff dimension of 1.2619

Consequently, the lengths of segments, which are formed at the *n*-th step, is $r_n = 1/3^n$. The number of elements of the structure, which are the fracture points, is $N(r_n) = 4^n$. The points form the Koch curve.

The Hausdorff dimension of an object is $d_H = ln4 / ln3 \approx 1.26$, and its topological dimension $d_\tau = 1$. Thus, the condition $d_\tau < d_H$ is executed.

To examine the fractality of an object it is expedient not to use Mandelbrot definitions and formula (1), but simply to calculate its so-called dimension of self-similarity [12]:

$$D = \frac{ln N}{ln n}, \quad (3)$$

where N – number indicating how many times the number of identical elements of the structure increases in the transition to the next step,

n – number indicating how many times the linear scale of these elements decreases.

Then, for the objects depicted in the fig. 3 $D = 1$ is the object is a segment; $D = 2$ is the object is a square, and $D = 3$ if the object is a cube.

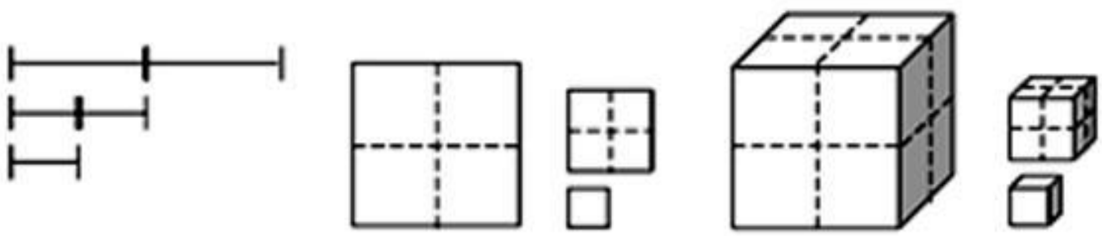

Fig. 3. Three consecutive steps of fragmentation

Since fractal is not any self-similar fractional objects, but only those in which the dimension of self-similarity is a fractional value, then the objects depicted in the fig. 3 are not fractals.

The fractal dimension always takes an intermediate value between the topological dimensions of those objects from which it is removed and to which it approaches, illustrating the Sierpinski triangle (fig. 4). The Sierpinski triangle contains the following step-by-step sequence: triad → hexagram → fractal iterations [12].

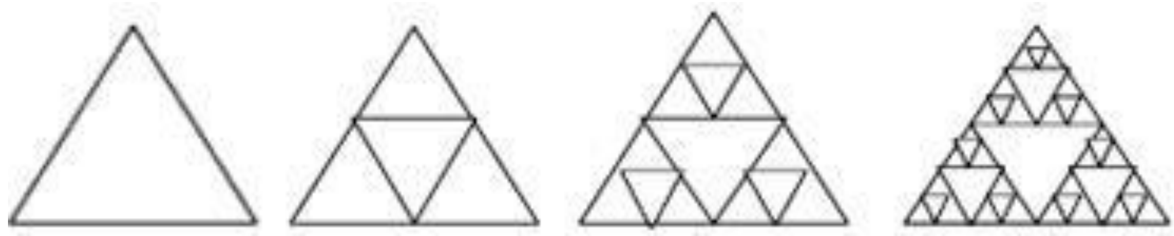

Fig. 4. Sierpinski triangle

Then, the use of formula 1 gives $d_H = ln3/ln2 \approx 1.58$. The topological dimension d_τ of the carpet construction lines is $d_\tau = 1$. Therefore, the condition $d_\tau < d_N$ is executed.

Thus, the geometric method of the sequence of steps is appropriate for composite analysis of the fractal dimensions of clothing seamlines.

Since the basis of the fractal transformation process are stochastic objects, for which the dimension of self-similarity is a fractional value, the quantitative parameter of the nonequilibrium structure of the form is the information dimension d_1 of nonlinear dynamical systems. Accordingly to [10]:

$$d_1 = \lim_{r \to 0} \frac{H(r)}{log_2(1/r)}, \tag{4}$$

where r – the covering element; $H(r)$ – the Shannon entropy.

$$H(r) = -\sum_{i=1}^{n(a)} p_i \, log_2 \, p_i \, . \tag{5}$$

where n – element number; r – the metric of the point.

With decreasing coverage $r \to 0$ and the increase in the number of elements of this coating $N(r)$, the Shannon entropy increases indefinitely $H(r) \to \infty$. However, its boundary is the value of the information dimension d_1.

Since the critical thresholds of the investigated system "costume" characterizes entropy, it is expedient to consider the synergistic principle of bifurcation development.

In the language of synergy, the decay of the system, its destruction is accompanied by its entrance into the dynamic (critical) bifurcation state (bifurcation points), where the past system is gone, and the future one is not yet. It is in this critical dynamic state of "deterministic chaos," where the line between the actual and the potential, the part and the whole, simple and complex, is being erased, the system "chooses" the path (attractor) of its further evolution and crystallizes as a "new" system [13].

In this connection, mathematical interpretation of critical thresholds states is important [13]. Analysis of the kinetics of control parameters in synergetic systems of different physical nature shows that in most cases the system condition, the control parameter (generalized parameter of the system condition) is subject to a two-dimensional scaling ratio. In this case, the construction of bifurcation diagrams in a two-dimensional generalized space {X_j, Y_j} is possible. In this case, the coordinates of the bifurcation points must satisfy two-dimensional scaling relations [11]:

$$X_{j+1} - X_j \cong G_X * \left(X_j - X_{j-1}\right), \qquad (6)$$
$$Y_{j+1} - Y_j \cong G_Y * \left(Y_j - Y_{j-1}\right),$$

where X_j – the control parameter; *Yj* – measured value; *j* – the order of bifurcations; G_X and G_Y scale factors.

The analysis shows that G_X and G_Y can take values of constant, conditional-constant, monotone-variable and stochastic-variable variables. In each of these cases, the dependence of *Y*(*X*) will have its kinetic features.

For the case of constant and conditionally constant values of the large-scale transformations (6), we construct a generalized dependence of the phase transitions of the Landau class. As it was showed by L. D. Landau [12], in the vicinity of the bifurcation value X_* of the control parameter *X*, the information parameter (measured value) *Y* can be described by the relation:

$$Y \approx \left|X - X_*\right|^{-\nu}, \qquad (7)$$

where ν – the critical phase transition factor.

The distance between the coordinates of the zero and *i* (*j* + 1) points of bifurcations is as follows:

$$\begin{aligned} X_{j+1}-X_0 &= \left(X_{j+1}-X_j\right)+\left(X_j-X_{j-1}\right)+\left(X_{j-1}-X_{j-2}\right)+\ldots+\left(X_1-X_0\right) \\ Y_{j+1}-Y_0 &= \left(Y_{j+1}-Y_j\right)+\left(Y_j-Y_{j-1}\right)+\left(Y_{j-1}-Y_{j-2}\right)+\ldots+\left(Y_1-Y_0\right) \end{aligned}, \quad (8)$$

where $\{X_0;Y_0\}$ and $\{X_1;Y_1\}$ are two initial bifurcation points.

Then, taking into account the equation (6):

$$\begin{aligned} X_{j+1}-X_0 &= G_X^{j-1}\left(X_1-X_0\right)+G_X^{j-2}\left(X_1-X_0\right)+G_X^{j-3}\left(X_1-X_0\right)+\ldots G_X^{0}\left(X_1-X_0\right) \\ Y_{j+1}-Y_0 &= G_Y^{j-1}\left(Y_1-Y_0\right)+G_Y^{j-2}\left(Y_1-Y_0\right)+G_Y^{j-3}\left(Y_1-Y_0\right)+\ldots G_Y^{0}\left(Y_1-Y_0\right) \end{aligned}. \quad (9)$$

It is obviously that

$$\begin{aligned} X_{j+1}-X_0 &= \left[G_X^{j-1}+G_X^{j-2}+G_X^{j-3}+\ldots+1\right]*\left(X_1-X_0\right) \\ Y_{j+1}-Y_0 &= \left[G_Y^{j-1}+G_Y^{j-2}+G_Y^{j-3}+\ldots+1\right]*\left(Y_1-Y_0\right) \end{aligned}. \quad (10)$$

Thus, one can obtain the equations as follows:

$$X_{j+1}-X_0=\left(X_1-X_0\right)*\frac{1-G_X^j}{1-G_X}, \quad Y_{j+1}-Y_0=\left(Y_1-Y_0\right)*\frac{1-G_Y^j}{1-G_Y}, \quad (11)$$

which allows one to write:

$$G_X^J=1-\frac{X_{j+1}-X_0}{X_1-X_0}\left(1-G_X\right), \quad G_Y^J=1-\frac{Y_{j+1}-Y_0}{Y_1-Y_0}\left(1-G_Y\right). \quad (12)$$

After transformations we obtain the dependence of *Y*(*X*) for a wide class of critical phenomena:

$$Y_{j+1}-Y_0=\frac{Y_1-Y_0}{1-G_Y}\cdot\left\{1-\left[1-\frac{X_{j+1}-X_0}{X_1-X_0}\left(1-G_X\right)\right]^{\frac{\ln G_Y}{\ln G_X}}\right\}. \quad (13)$$

For a quasistationary transformation of self-similarity ($G_X \approx$const, $G_Y \approx$const), a generic covering that satisfies all bifurcation points can be obtained:

$$Y = Y_0 + \frac{Y_1 - Y_0}{1 - G_Y} \cdot \left\{ 1 - \left[1 - \frac{X_{j+1} - X_0}{X_1 - X_0} (1 - G_X) \right]^{\frac{ln G_Y}{ln G_X}} \right\}. \qquad (`14)$$

Assuming that the critical index in the silhouette characteristic is equal to 3*n* formula (12), the shape of the costume is equivalent to formula (3), provided that the scale factor r=0.5 in the entropy of $H(r)$ is applied. In addition, formula (12) allows one to investigate a whole class of problems for specific values of initial conditions and values of scale factors.

For example, for $X_0=Y_0=0$, and for the case of conservative large-scale silhouette transformations $G_Y = G_X^{-1} = 2$:

$$\frac{Y}{Y_1} = \frac{X}{2X_1 - X}. \qquad (15)$$

Thus, it was found that equation (14) corresponds to equation (12) for v=1 and can be used to predict the kinetics of phase transitions as one of the tasks of synergetic systems in relation to basic silhouettes of costume shapes.

Result

It is known [11] that the physical properties of the shape are described by correlation functions. Consequently, the correlation dimension d_2 characterizes the ordering of the internal structure of the object. To determine the correlation dimension, we use the correlation integral [10]:

$$C(r) = \lim_{N \to \infty} \frac{1}{N^2} \sum_{i,j=1, i \neq j}^{N} \eta\left(r - \left|X_i - X_j\right|\right), \qquad (16)$$

where N – number of classes of the silhouette shape of the "costume" system;

X_i, X_j – position vectors of the points *i* and *j;*

$\eta(Y)$ – Heaviside function (the function of belonging to the interval *r*).

The value $C(r)$ determines the relative number of pairs of points, the distance between which is no greater than *r*. The limit is computed as follows:

$$d_2 = \lim_{r \to \infty} \frac{\ln C(r)}{\ln(1/r)} \tag{17}$$

If the limit exists, then the value d_2 will be the correlation dimension of the silhouette.

The third limiting condition for the study of fractal systems is the topology of ordered structures of an object, which is considered from the standpoint of the continuity of topological transformations of the shape of the "costume" system by equivalence relations [14] for studying the nonlinearity of the transformation of silhouette forms.

In the Euclidean geometry, the figures that are obtained from each other by motion are considered equivalent. These figures have the same metric properties. The set of equivalence classes is called the factor-set *X* in relation to equivalence ~:

$$X/\sim = \{Ka / a \in X\}, \tag{18}$$

where *X* – a plurality; /~ equivalence relation;

Ka – classes of pairwise equivalent elements;

a – an element.

The investigated set of *N* silhouettes of the shape, according to recommendations [15], consists of 26 silhouettes; the linear size of the identical cells *r* of the system of silhouette additions is equal to 0.5 cm.

The number of classes of the factor set of silhouette shapes corresponds to the number of base silhouettes: *Cu*0, *Cu*1, *Cu*2, *Cu*3. The continuity of the reflection of the basic silhouettes among themselves provides the property of raising the homotopy starting from *Cu*0 [14], which is subject to a two-dimensional scaling relationship (see formula 6).

Large-scale factors G_X and G_Y can take the value of constant values in pairwise equivalent increments between basic silhouettes, conditional-constant quantities in the trivial stratification of a particular silhouette, monotone-variables – in the locally-trivial modification of derivative silhouettes, stochastic variables – in correcting the shape of body surface.

The methods of parametrization of silhouette shapes correspond to the conditions for determining the fractal dimension.

The first condition is the fractional structure of the values of the silhouette eases *ПCu*, which confirms the calculation algorithm in the classes of silhouettes of dresses at the bust line: *ПCu*0: (1.5; 2.0; 2.5), *ПCu*1: (2.5; 3.5; 4.0), *ПCu*2: (4.5; 5.0; 5.5); *ПCu*3: (6.0; 6.5; 7.0).

The second condition is the bifurcation of the system of eases that is marked as *Пcu*. The eases are bifurcation points 2.0; 3.5; 5.0; 6.5 with preservation of interval 3*r*.

The third condition – the topology of the system is confirmed by the affiliation of the same boxing algorithms of silhouette eases, both within a single silhouette, and in various assortments. In particular, it is 5.0 for *ПCu*1, *ПCu*2; 6.5 – *ПCu*1, *ПCu*2, *ПCu*3; 7.0 – *ПCu*1, *ПCu*2; 8.0 – *ПCu*2, *ПCu*3.

Scaling *ПCu* sets for a dress contains 5 elements of sets in each of four boxes: *ПCu*0; *ПCu*1; *ПCu*2; *ПCu*3. Extreme elements of the interval sets provide continuity of flow in the limits of silhouette. The topological dimension d_τ in the classes of silhouettes containing three elements of sets is 4x3 = 12, respectively, in the scaling of sets d_0 contains 4x5 = 20 elements. The limiting condition $d_\tau < d_0$ is observed. Therefore, *ПCu* is a fractal of the geometric structure of the shape.

Conclusion

Based on the revealed patterns of nonlinear processes of the flow of silhouette shapes in the topological space $n \leq 3$, the notion of topological, smooth, and lump-linear varieties coincides, which allows to extend the properties of the covering to the study of stochastic fractals of the morphological structure of the shape.

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F. H. Barwa recommends publishing a monograph nt. "Innovative technologies and sustainability in textiles and apparel". The published monograph will be a valuable source of information about innovative technologies in the development of textile materials.

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Khmelnytskyi City Council recommends monograph entitled "Innovative technologies and sustainability in textiles and apparel". The monograph is valuable source of information regarding the innovations in clothing industry those might be implemented at the sewing enterprises of Khmelnytskyi by future professionals. They are trained using this book to expand their knowledge on the subject.

Oleksandr Symchyshyn
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City of Khmelnytskyi