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The rationale behind using natural polymeric materials in shoe production

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Abstract. In this paper, we have studied the modern natural polymeric materials which are used for producing component parts and the uppers of shoes. Having taken into account functional, economical, production and customer requirements for purpose-made shoes, we have identified a range of characteristics of leather qualities. They make it possible to provide rationalization for technological solutions, aimed at decreasing the risk of raw materials culling at all stages of a manufacturing procedure, decreasing resources and energy consumption when making products of a desired quality: tensile strength, tensile strength of surface, extension at tensile strength, water resistance of flexible leather, hygroscopicity.

1. Introduction

Under the conditions of raising quality standards of shoes with given qualities, possibilities of their certification and taking into account an increasing competition on the market, a conscious approach to shoe production becomes especially important.

It is a complex task to make sure that shoes are ergonomic. This task is solved at all production stages. It starts with constructing or choosing lasts for shoes and choosing materials for component parts of the uppers and the bottom halves of shoes [1].

Nowadays, shoe production, including purpose-made shoes, is connected with using the polymeric materials of natural, artificial and synthetic origin, as well as their combinations [2-8].

Natural leather, made of animal skins, has traditionally been considered one of the best materials for shoe making. Its properties and peculiarities of its structure determine the high quality of the finished product. Chrome-tanned leather of various kinds is the most frequently used in shoe production. It can be characterized by excellent hygienic qualities, beautiful visual appearance, an endurance of its form, softness, durability and resistance to the weather [2]. For instance, the leather for the uppers can endure 4-5 million creases without being damaged. Such a resistance to creasing is a result of the way how collagen fibres are arranged within the leather structure. Collagen is a polymer of biological origin. The spaces which exist between individual structural elements of the dermis, so-called pores, provide high air and water vapour permeability, excellent thermophysical qualities, and this also contributes to the hygienic qualities of shoes. Natural leather is easily moulded due to its resilience and plasticity. As a result, there is a good contact between the leather and shoe lasts there are not any creases and wrinkles.

It is possible to increase the quality of shoes by improving the endurance of their form, their hygienic and aesthetic properties. To achieve this, the leather or the uppers made of leather are exposed to various stimuli, e.g. high-frequency discharge plasma sources of low pressure [9]. Influence on the formation of



certain properties of leather materials is also possible in their production due to the use of modern chemical materials that provide the receipt of material with predicted properties [10-15].

Thus, the data analysis revealed a large variety of natural polymeric raw materials and the urgent need for an informed approach to the selection of these materials in the production of shoes. This will improve the quality of finished shoes for different purposes.

2. Materials and methods

2.1. Materials

The materials under study have been the materials of natural origin, which have been widely used when producing the uppers of purpose-made shoes. The products assortment of natural leather is represented by the leather with natural surface (raw material – cow hide):

- **1** the hydrophobic leather «Vodogray» (technical specifications of Ukraine 19.300307856-007:2005) of chrome tanning; it is highly hydrophobic (resists to humidity for at least 3 hours); it is used for producing purpose-made military shoes, as well as sports and commercial shoes, shoes for hunters, fishers, tourists; it provides a reliable protection and comfort in any extreme conditions [16];
- **2** the Russian leather (yuft) of combined tanning methods for the uppers of shoes; used for making the shoes for military and work purposes [17];
- **3** the chrome tanned heatproof Russian leather for the uppers of shoes; used for making military and professional shoes [18];
- **4** the chrome-tanned leather for the uppers of shoes; used for producing the shoes for military servants [19];
- **5** the chrome-tanned leather for the uppers of shoes for military servants [20], which is used in the non-aggressive environment.

2.2. Methods

The quality parameters of natural leather have been analysed using standard methods of shoe material testing and standard equipment [21-24].

For analysis of leathers mechanical properties a method [21] for determining the tensile strength, elongation at 10 MPa and tensile strength of leather surface (the main indices of the mechanical properties of natural leather) has been chosen. This method is applicable to all types of leather. The testing parameters: speed of extension – 100±20 mm/min, maximum tensile stress – 980 H, load cell – 0-100 kg, labor part of sample - 5×50 mm, parallel experiments – not less than 4).

The rationale behind using certain materials for shoe making has been provided using the technique of multi-criteria compromise optimization [25]. This method is used in the form of the following generalized objective function when searching for the optimal technological parameter value or values in the case when there are more than two quality parameters for compromise optimization:

$$Y_{gen,r} = \sqrt{\sum_{j=1}^m (1 - D_{jr})^2 * W_j^2}, \quad (1)$$

where $Y_{gen,r}$ – is the generalized objective function value for the r -th parameter, and in case of searching for optimum it approaches ($Y_{gen}, r \rightarrow 0$) and allows us to measure the proximity of this point to the hypothetical optimal value in the form of the code, which equals 1; D_{jr} – brought to the interval 0-1 value of the j -th feedback (quality parameter) in the r -th test of this experiment, depending on the aim chosen for a given quality parameter this value is calculated using different formulae; W_j – the value of the j -th quality parameter (feedback) virtually equals $1/j$; m – the number of criteria of feedbacks quality.

In addition, the graphical-numeral technique (the method of «polygon») has also been used to make a complex assessment of the shoe materials qualities. This technique is based on the combination of the graphical and quantitative methods. The distinctive feature of this technique is the choice of the material-reference standard, which has the best or high enough qualities among the materials being compared. To ensure that the quality assessment of the material under test is objective, the

comparative analysis of the range (in our case six) of parameters, which characterise the most important qualities, is applied. To do this, the centre of the polygon must be found and the shape must be divided into the equal parts with the help of triangles. Each cathetus of the triangle corresponds to the biggest value of a quality parameter of the material- reference standard. The rating of objects under comparison is assigned by measuring the correlation between the area of the shape obtained for each object and the shape area for the object-reference standard.

3. Results and discussion

We have established the nomenclature of natural materials quality parameters in order to provide the rationale behind using them in shoe production. We have taken into account the standard requirements on the correspondence between a material and a reference document or the specified requirements. We have also considered the material compliance with consumer requirements. The order of the parameters choice for establishing the nomenclature of the quality parameters was the following: to identify the obligatory and recommended standardized parameters for the product given and the materials for its production → to analyse if the standardized parameters characterize the correspondence between the material qualities and the consumer and production requirements in an adequate way → the standardized parameters nomenclature completion with the additional parameters, which contribute to the probable assessment of the compliance of a given material with the consumer requirements.

The choice of the quality parameters has been made taking into consideration the purpose and the conditions of use of a product, the consumer requirements analysis, the aims of providing the quality control and imposing the requirements on the products quality parameters.

Considering the functional, consumer, production and economic requirements for the purpose-made shoes, we have identified the range of leather properties parameters for the uppers of shoes, which allow us to provide the objective rationalization for the technological solutions, which decrease both the risks of raw materials culling at all stages of a manufacturing procedure and the consumption of resources and energy when producing a product of a quality needed. In our opinion, the following parameters of reliability and longevity can be classified as such: tensile strength, tensile strength of surface, percentage extension at 10 MPa, water vapour permeability, water resistance of flexible leather, hygroscopicity.

The ergonomic requirements for the uppers of shoes material provide the comfort of a consumer during exploitation of a product. These requirements are realized through such quality parameters (properties) of materials as water vapour permeability, water resistance of flexible leather, hygroscopicity.

When comparing the properties parameters of natural leather for the uppers of shoes (Table 1), using the technique of multi-criteria compromise optimization.

Table 1. Natural leather parameters for the uppers of shoes.

Position (type of leather)	Tensile strength, MPa TS	Tensile strength of surface, MPa, SF	Percentage elongation at 10 MPa, % L10	Water vapour permeability, mg/sm ² . hour VP	Water resistance of flexible leather, min WR	Hygroscopicity, % H
1	19.3	18.2	33	4.3	180	18
2	15.9	14.4	19	2.5	37	12
3	17.7	16.3	20	4.1	35	13
4	15.0	14.0	27	5.0	30	11
5	19.0	17.9	30	5.3	30	20

We have identified the smallest value of the generalized objective function ($Y_{\text{gen},r} = 0,012$), i.e. the first place in our rating, which belongs to the leather «Vodogray». We have also found the biggest value of this parameter ($Y_{\text{gen},r} = 0,063$), i.e. the last place in our rating, and it goes to the Russian leather for the uppers of shoes of combined tanning methods; it is used for producing the shoes for military and work purposes (Table 2).

Table 2. The rating of natural leather of various kinds according to the multi-criteria compromise optimization technique.

Position	Yj						$\Sigma(1-D_{jr})^2$	$Y_{\text{gen},r}$
	TS	SF	L10	VP	WR	H		
1	19.3	18.2	33	4.3	180	18	0.180	0.012
2	15.9	14.4	19	2.5	37	12	5.143	0.063
3	17.7	16.3	20	4.1	35	13	2.932	0.048
4	15.0	14.0	27	5.0	30	11	4.197	0.057
5	19.0	17.9	30	5.3	30	20	1.056	0.029

Another independent technique, graphical-numeral, has been used in order to assess the quality of the natural leather materials. According to this technique, the area of the shape built identifies the quality level of a given material (P_i), and a correlation between the shape area for this material S_i and the shape area for the reference standard material S_e equals the complex quality assessment of the material under test. ($K_i = S_i : S_e$) (Table 3, Fig. 1).

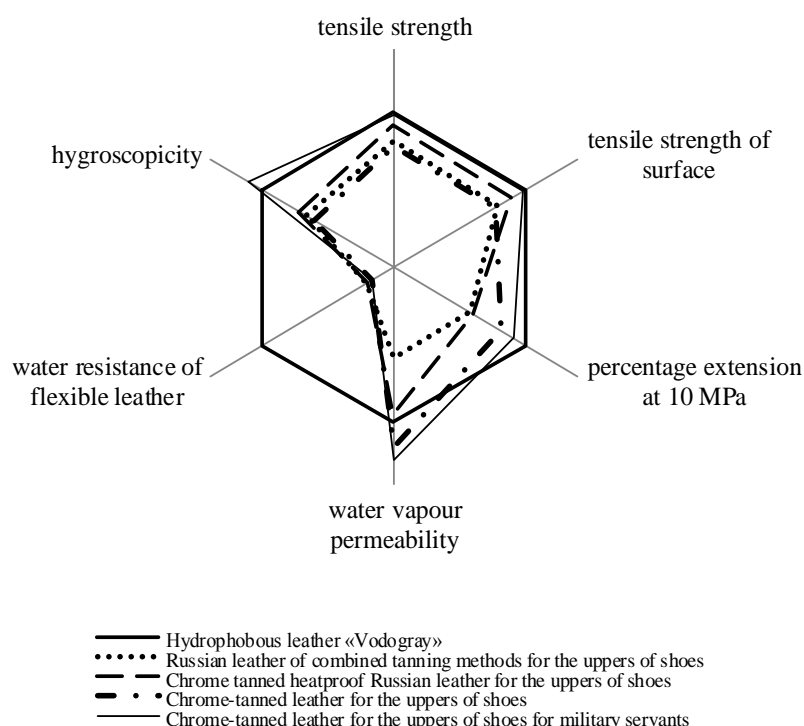


Figure 1. Making the complex assessment of the natural leather qualities

As a result of using the graphical-numerical technique (Table 3, Fig. 1) we have found the correlation between a shape area for each type of natural leather and a shape area for the reference standard leather (hydrophobic leather «Vodogray»): the Russian leather of combined tanning methods for the uppers of shoes – 43,7%, the chrome tanned heatproof Russian leather for the uppers of shoes – 50,9%, the

chrome-tanned leather for the uppers of shoes – 59,7%, the chrome-tanned leather for the uppers of shoes for military servants – 93,3%.

Table 3. The complex quality assessment of the natural leather.

Index	Position									
	1		2		3		4		5	
	$P_i=P_e$	K_i	P_i	K_i	P_i	K_i	P_i	K_i	P_i	K_i
TS, 10 MPa	1.93	1.00	1.59	0.82	1.77	0.92	1.5	0.78	1.9	0.98
SF, 10 MPa	1.82	1.00	1.44	0.79	1.63	0.90	1.4	0.77	1.79	0.98
L10, %	33	1.00	19	0.58	20	0.61	27	0.82	30	0.91
VP, mg/sm ² ·hour	4.3	1.00	2.5	0.58	4.1	0.95	5	1.16	5.32	1.24
WR, min	180	1.00	37	0.21	35	0.19	30	0.17	30	0.17
H, %	18	1.00	12	0.67	13	0.72	11	0.61	20	1.11
Si, sm ²	52.5		23.0		26.7		31.4		49.0	

According to the results of the multi-criteria compromise optimization, the natural hydrophobic leather «Vodogray» has been chosen the reference standard material. It has the best value of the generalized objective function ($Y_{gen,r} = 0,012$), which is conditioned by its excellent parameters of reliability and longevity (tensile strength 1,93 MPa, tensile strength of surface 1,82 MPa, percentage extension at 10 MPa 33%), as well as by its ergonomic and hygienic qualities (water vapour permeability 4.3 mg/cm²·hour; water resistance of flexible leather 180 minutes; hygroscopicity 20 %).

It should be noted that there the correlation has been found between the indices of the generalized objective function and a polygon area. Its correctness has been proved by the value of approximation validity: for the natural leather $R^2 = 0.8880$, which is > 0.7500 (Fig. 2).

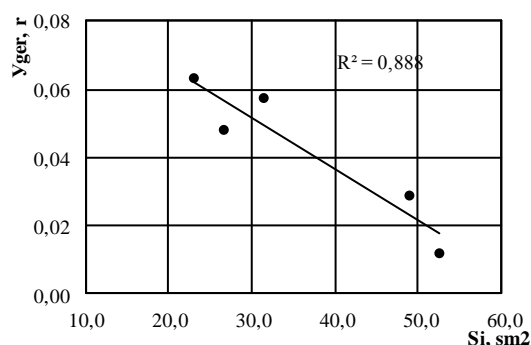


Figure 2. The correlation between the index of the generalized objective function and a polygon area

4. Conclusions

Using the statistic processing of the most important parameters for shoe materials with the help of the two independent techniques: the multi-criteria compromise optimization in the form of the generalized objective function and the complex assessment in the form of the graphical-numerical «polygon» technique we have provided the rationale behind using those polymeric materials of the natural origin which are the most capable of providing the high quality and ergonomics of purpose-made shoes: the hydrophobic leather «Vodogray» and the chrome-tanned leather for the uppers of shoes for military servants.

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