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METHOD FOR MATHEMATICAL PLANNING OF EXPERIMENTS OF NON-WOVEN CAMEL WOOL FABRIC AND ITS PHYSICAL AND MECHANICAL PROPERTIES

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Abstract: This article describes the properties of natural camel hair fibers and the process of making non-woven fabric from them. At the same time, their physical and mechanical properties were studied by mathematical modeling and experimental results were found

Keywords: camel wool, non-woven cloth, mathematical modeling, adequacy parameter, breathability, heat retention, breaking elongation, thickness, matrix, optimizations

Introduction

In Uzbekistan, on the basis of scientific research, comprehensive measures are being implemented in the direction of developing competition in the light industry and the wool processing industry, growing wool and processing it, obtaining non-woven materials based on wool and improving their physical and mechanical properties[1,2].

A mathematical model is a mathematical representation of reality [3-6], one of the variants of a model as a system, the study of which allows obtaining information about some important systems. A mathematical model, in particular, is designed to predict the behavior of a real object, but always represents one or another degree of its idealization[7].

Elements of mathematical modeling have been used since the very beginning of the emergence of the exact sciences: the word "algorithm" comes from the name of the medieval Arab scientist Al-Khwarizmi (al-Khwarizmi Abu Abdal Muhamed bin Mussa al Majusi, 787 -c. 850). The rebirth of mathematical modeling occurred in the late 40s - early 50s of the XX century and was mainly due to two reasons[7-10].

Methods

The purpose of experiment planning is to create a mathematical model in the form of an equation that relates the optimization parameter to the factors. This equation is also called the response function. In general, the response function, which is also the optimization parameter (y), can be represented by the expression

$$y = f(x_1, x_2 \dots \dots, x_{12}) \qquad (1)$$

where x_1, $x_2 \dots\dots$, x_{12} are independent variable factors.

The simplest model is a polynomial, which is linear with respect to unknown coefficients and thus simplifies the processing of observations.

The polynomial can be of the first, second or higher degree. The polynomial coefficients are calculated from the results of the experiments.

At the first stage of planning - determining the direction of movement to the optimum and a steep ascent along the response surface - it is most expedient to approximate the unknown response function with a polynomial of the first degree. A polynomial of the first degree in a general form is expressed by an equation.

$$y = b_0 + b_1x_1 + b_2x_2 + \ldots + b_Rx_R + b_{12}x_1x_2 + b_{13}x_1x_3 + \ldots + b_{12} \ldots x_1x_2 \ldots x_{12} \quad (2)$$

For two factors, this equation has the form

$$y = b_0 + b_1x_1 + b_2x + b_2x_2 + b_{12}x_1x_2 \quad (3)$$

For the convenience of recording the conditions of the experiment and processing the experimental data, the levels of the factors are encoded. The coded sign of the factor xi is determined by the expression:

$$x_i = \frac{\tilde{x_i} - \widetilde{x_i^0}}{\varepsilon_i} \quad (4)$$

where ($\tilde{x_i}$) - is the natural sign of the i -th factor;

(x_i^0) – natural value of the main level of the i -th factor;

E_i is the interval of variation of the i -th factor.

In the coded form, the upper level is denoted by +1, the lower -1, and the main one by 0. The number N of all combinations of factor levels, a, and the number of experiments in a full factorial experiment, is determined by the expression

$$N = m^R \quad (5)$$

where; m is the number of levels of each factor;

R is the number of factors.

A full factorial experiment allows you to quantify opinion effects and all interaction effects. For a full factorial experiment of type 22, the regression equation taking into account interaction effects is represented by expression (3).

We will carry out mathematical modeling and optimization of the physical and mechanical properties of non-woven fabric from camel wool, depending on the input factors: surface density, x_1 -g/m^2; thickness x_2 -mm.

The optimization parameters are:

y_1– breaking load, N;

y_2– breaking elongation, %;

y_3 – air permeability, cm^3/(cm^2*sec);

y_4 – heat retention, %;

Table 1 shows the levels and intervals of factor variation.

Results

Table 1

Levels and intervals of factor variation

Factors	code designation	Variation intervals	Factor levels		
			Upper +1	Main 0	Lower - 1
Surface density, g/m^2	x_1	54,8	554,8	500	445,2
Thickness, mm	x_2	0,3	2,8	2,5	2,2

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Table 2 presents the planning matrix and the results of the experiments. Consider the procedure for processing the results of the experiment in the absence of duplication [11].

The processing of the results of the experiment in the knitted case was carried out in the following sequence.

table 2

Planning matrix and test results

Experience number	x_0	x_1	x_2	x_1 x_2	y_1	y_2	y_3	y_1
1	+	+	-	-	401	19	72,6	63
2	+	-	+	-	306	18	76,3	51
3	+	-	-	+	280	19	81,3	40
4	+	+	+	+	396	16	70,6	61

Discussion

1. Calculation of the variance S_y^2 of the reproducibility of the experiment.

To do this, it is necessary to perform several parallel experiments at the zero point (in the center of the plan) and calculate the variance S_y^2 of the reproducibility of the experiment:

$$S_y^2 = \frac{1}{n_0-1}\left[\sum_{u=1}^{n_0}(y_u - \bar{y})^2\right] \quad (6)$$

Where n_0 is the number of parallel experiments at the zero point;

y_u is the value of the optimization parameter in the th experiment;

$\bar{y}$ is the arithmetic mean of the optimization parameter (n_0) of parallel experiments.

Table 3-6 shows the results of calculating the variance S_y^2, respectively, for the four optimization parameters:

Table 3

Auxiliary table for calculating the variance S_y^2 of the optimization parameter y_1 - breaking load

Experience number in the center of the plan	y_u	$\bar{y}$	$y_u - \bar{y}$	$(y_u - \bar{y})^2$	S_y^2
1	369	$\frac{\sum_{u=1}^{3} y_u}{3} = \frac{1123}{3}$=374,3	-5,3	28,09	$\frac{\sum_{u=1}^{3}(y_u-\bar{y})^2}{n_0-1} = \frac{74,67}{3-1}$ = 37,335
2	381		6,7	44,89	
3	373		-1,3	1,69	

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	$\sum_{u=1}^{3} y_u = 1123$			$\sum_{u=1}^{3} (y_u - \bar{y})^2 = 74{,}67$	

S_y^2 = 37,335 for y_1;
S_y^2 =0,3334 for y_2;
S_y^2 =55,47 for y_3;
S_y^2=19 for y_4;

2. Calculation of the coefficients of the model.
Free member b_0 is determined by the formula

$$b_0 = \frac{1}{N} \sum_{i=0}^{n} y_j \quad (7)$$

The regression coefficients characterizing linear effects are calculated by the expression

$$b_i = \frac{1}{N} \sum_{j=1}^{N} x_{i_j} y_j \quad (8)$$

The regression coefficients characterizing the effects of interaction are determined by the formula

$$b_i = \frac{1}{N} \sum_{j=1}^{N} x_{i_j} x_{l_j} y_j \quad (9)$$

where, i,l are numbers of factors;
j is the row or experience number in the planning matrix;

Table 4

Auxiliary table for calculating the variance S_y^2 optimization parameters y_2– elongation at break

Experience number in the center of the plan	y_u	$\bar{y}$	$y_u - \bar{y}$	$(y_u - \bar{y})^2$	S_y^2
1	18	$\frac{\sum_{u=1}^{3} y_u}{3} = \frac{53{,}4}{3} = 17{,}8$	0,2	0,04	$\frac{\sum_{u=1}^{3} (y_u - \bar{y})^2}{n_0 - 1} = \frac{0{,}24}{3-1} = 0{,}12$
2	17,4		0,4	0,16	
3	18		0,2	0,04	
	$\sum_{u=1}^{3} y_u = 53{,}4$			$\sum_{u=1}^{3} (y_u - \bar{y})^2 = 0{,}24$	

y_j – optimization parameter value b_j – m experience;
x_{ij}, x_{lj} - coded values (+-1) of factors I u l b j – m experience.
Calculations by formulas (7), (8) and (9) gave the following values of the coefficients.
1) for y_1: $b_0 = 345{,}75$; $b_1 = 52{,}75$; $b_2 = 5{,}25$; $b_2 = -7{,}75$;
2) for y_2: $b_0 = 18$; $b_1 = 0{,}5$; $b_2 = -1{,}0$; $b_2 = -0{,}5$;
3) for y_3: $b_0 = 75{,}2$; $b_1 = 10{,}4$; $b_2 = -1{,}75$; $b_2 = -0{,}75$;
2) for y_4: $b_0 = 53{,}75$; $b_1 = 8{,}25$; $b_2 = 2{,}25$; $b_2 = -3{,}25$;

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Table 5

Auxiliary table for calculating the variance
S_y^2 of the optimization parameter y_3 - air permeability

Experience number in the center of the plan	y_u	$\bar{y}$	$y_u - \bar{y}$	$(y_u - \bar{y})^2$	S_y^2
1	78,4	$\frac{\sum_{u=1}^{3} y_u}{3} = \frac{223,4}{3}$=74,5	3,9	15,21	$\frac{\sum_{u=1}^{3}(y_u - \bar{y})^2}{n_0 - 1} = \frac{23,21}{3-1} = 11,605$
2	72,5		-2	4	
3	72,5		-2	4	
	$\sum_{u=1}^{3} y_u = 223,4$			$\sum_{u=1}^{3}(y_u - \bar{y})^2 = 23,21$	

Table 6

Auxiliary table for calculating the variance
S_y^2 of the optimization parameter y_4 - heat retention

Experience number in the center of the plan	y_u	y	$y_u - \bar{y}$	$y_u - \bar{y}$	S_y^2
1	52	$\frac{\sum_{u=1}^{3} y_u}{3} = \frac{163}{3}$=54,3	-2,3	5,29	$\frac{\sum_{u=1}^{3}(y_u - \bar{y})^2}{n_0 - 1} = \frac{8,67}{3-1} = 4,335$
2	55		0,7	0,49	
3	56		1,7	2,89	
	$\sum_{u=1}^{3} y_u = 16,3$			$\sum_{u=1}^{3}(y_u - \bar{y})^2 = 8,67$	

3. Checking the statistical significance of the coefficients of the regression equation.

The significance of the coefficients was checked by comparing the absolute value of the coefficient with a confidence interval

Optimization parameter y_1.

Calculate the variance of the regression coefficients

$$S^2\{b_i\} = \frac{1}{N} S_y^2 \qquad (10)$$

Where $S^2\{b_i\}$ is the variance of the i-th regression coefficient;

N – number of rows or experiences in the planning matrix

$$S^2\{b_i\} = \frac{1}{4} * 37335 = 9,33;$$

$$S\{b_i\} = 3,05;$$

Confidence interval in is found by the formula

$$\vartriangle b_i = \pm t_T S\{b_i\} \qquad (11)$$

Where t_T is the tabular value of t - the criterion for the accepted (5% level) significance level and the number of degrees of freedom f_1 which is determined by the expression

$$f = n_0 - 1 = 3 - 1 = 2$$

Taking into account the reduced t_T = 4.3, then

$$\vartriangle b_i = \pm 4{,}3 * 3{,}05 = \pm 13{,}115$$

$$S_0 |b_1| > |\vartriangle b_i|; |b_2| < |\vartriangle b_i|; |b_2| > |\vartriangle b_i|;$$

Conclusion

Therefore, taking into account the statistical significance of the coefficient b_1, we will obtain a model in the form of a polynomial of the first degree.

Thus, the density of the camel wool nonwoven fabric (factor xl) is a positive factor for optimization parameters such as breaking load (y_1), heat retention (y_u) and a negative factor for breathability (y_3) web thickness (x_2) turned out to be a significant factor only for breaking elongation.

Analyzing the data in Table 2, we can conclude that in the case of simultaneous provision of breaking load and heat retention, it is necessary to provide a density of 554.8 g/m2 and a thickness of 2.2 mm. As expected, the maximum air permeability is observed at the minimum density and thickness of the nonwoven fabric: 445.22/m2 and 2.2 mm, respectively.

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