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MATHEMATICAL MODELING OF SOME INFLUENCE FACTORS OF YARN IRREGULARITY

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Abstract: *The design of fiber mixtures and the estimation of the characteristics of the yarns obtained is a current issue, taking into account that commercial companies receive orders for small quantities of products, which means changing the mixing recipes, changing the adjustments of the machines but also knowledge of the characteristics of the yarns that will be obtained. Blends of cottonised flax and cotton in the context of the evolution of the textile market can be considered an important opportunity for the textile industry. Mathematical modeling used to optimize yarn parameters is based on the central program, compound, rotable with two variables. Within the program used the independent variables considered are the percentage of cottonised flax in the mixture (x_1) and the yarns count (x_2) and the dependent variable is the Uster irregularity of the yarns*

Key words: *flax, cotton, blending, yarns, count, mathematical modeling, Uster irregularity*

1. INTRODUCTION

The priority of using flax in human history as a textile plant and the wide spread of this use in antiquity and in the latest stages of the development of society have the most complete justification in the physic-mechanical and esthetic properties, which give flax products specific characters perfectly suited to the field for use. High breaking resistance, silky shine, flexibility and thermal conductivity characterise the flax fibres. Due to this features and because it grow in wet and cool areas was named “North silk”.

Flax fibers are natural, ecological, non-toxic and biodegradable cellulosic materials. They easily absorb and release moisture, burn without leaving any residue.[1]

Flax products comfort derived from their high absorption and transfer of body moisture. The air permeability of the flax products is superior to that of cotton, generating one of the basic physiological properties: gas exchange comfort. The natural color of the technical fibers is an important indication of their quality. So, light colours, light-yellow, light-gray are specific to high-quality fibers.

These characteristics have led to a global approach to extensive research on the expansion of the area of use of flax fibers not only in yarns, fabrics, knits, but also for technical articles. Flax is not only environmentally friendly but is particularly agreeable to wear and is antiallergic [2],[3]. The flax is the most resistant textile fiber; it lasts a long time without deforming. The air contained in the fiber is a natural isolate. This explains the coolness of flax during summer and comfort in winter. Easily dye into bobbin and has multiple maintenance advantages. No contraction at wash (if the yarns have been sufficiently prepared for dyeing or bleaching) and colors have good resistance.

In recent years has increased interest in obtaining yarns from flax-cotton mixtures, because cotton is the natural fiber closest to flax in terms of physic-mechanical and chemical characteristics.[4], [5].

Flax combines several variable parameters, dependant on climate, growing conditions of the plantation, variety, a.s.o:

- the proportion of fiber in the trunk

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- the morphological structure of the elementary fibers (length, count, the thickness of the primary and secondary wall)
- the size of the fiber beam
- chemical composition of the fiber (the cellulose content, type and quantity of accompanying substances)

The operation which produces the extraction of elementary fibers and which adapts the characteristics of flax fibers to the characteristics of cotton fibers is called ”cottonisation”.

In general, cottonisation is carried out by mechanical or combined chemical-mechanical methods and the use of enzymes has been intensively studied in recent years. The enzymatic method is an increasingly used method due to the increased interest of consumers and producers in environmental protection. More than that, specific reactions that take place are controllable reactions. Enzymes can also be considered as biocatalysts. All flax constituents (cellulose, hemicellulose, pectin, a.s.o) are biodegradable by enzymes.

The use of enzymes in the textile industry is more common due to temperature and pH conditions it is asking for and because of the ability to replace strong organic and inorganic chemicals. The usual working temperature of enzymes is 40-50 °C that leads to a considerable decrease in energy consumption. Wastewater resulting from enzymatic treatments is also biodegradable.

The workability of the fibers is the final way to assess the technology of ”cottonisation” [6]. However, on the other hand, the adoption of suitable spinning parameters can correct the different deficiencies inherent in such raw materials

2. EXPERIMENTAL PART

The following study aims to highlight the qualitative characteristics of the yarns. [6], [7], [8]

Classical analysis of the simultaneous action of yarns’ count and the flax ratio on yarns’ irregularity requires a large number of experimental variants. This is a good reason for the planning of experiences.

For the mathematical model identification and the optimisation of the yarns' parameters, it has been used a central rotational programme compound with two independent variables. [9], [10]. The independent variables (usually technological parameters) can take two or more numerical values in the analysed period. The dependent variables have values evaluated by equations. Elaboration of empirical models is based on regression analysis and includes the following steps: optaining the experimental data; their statistical processing; interpretation of the results.

Within the program used we chose as independent variable x_1 - cottonised flax ratio and x_2 - yarns count.

The cottonisation was done with the help of enzymes in six different variants. Each type of enzyme acted on one of the natural cellulose companions and/or superficially on cellulosic substrate, allowing quick removal of pectino-lignos cement and fibers individualization.

At the base of the experimental programs, were taken into account the possibilities of the equipment. Setting the variation domains for the independent variables was done taking into account the previous experiences of specialists in the field [11], [12]

It were performed determination about the length, the count and the breaking force of the fibers. The experimental results were statistically tested in order to eliminate aberrant values. It was used Grubbs test. [13], [14]

The physical-mechanical characteristics of the flax fibers before the cottonisation process are presented in table 1.

Table 1

Initial characteristics of flax fibres

Row material	Fiber length (mm)	Fibers’ count (tex)	Breaking load (cN)	Tenacity (cN/tex)
Flax tow	190	2,6	34	20

Following application of cottonisation treatments on flax fibers were made some physical-mechanical analysis for the fibers length, the fibers count and the breaking load. [13]. For the determination of fiber length, was applied the standardized method for measuring the length of the individual fiber. For the determination of the fibers count was applied the standardized gravimetric. For the determination of the breaking load was used the individual fiber method. The average values are presented in table 2

Table 2

Characteristics of flax fibres after enzymatic treatment

Variant	1	2	3	4	5	6
Fiber length	37,875	35,195	34,93	29,8	30,237	33,565
Yarn's count	685,25	696,75	739,25	739,75	856,25	956,5
Breaking load	28,175	28,6	28,675	29,05	29,125	29,975

A diagram of the fiber length is shown in the figure 1

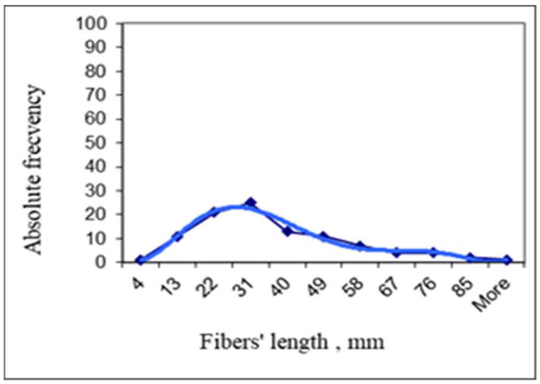

Fig 1. Flax fiber length diagram

The distribution of the fibers' length is similar regardless of the treatment applied.

The influence of enzymatic cottoning treatment on the fineness of flax fibers is demonstrated suggestively in figure 2.

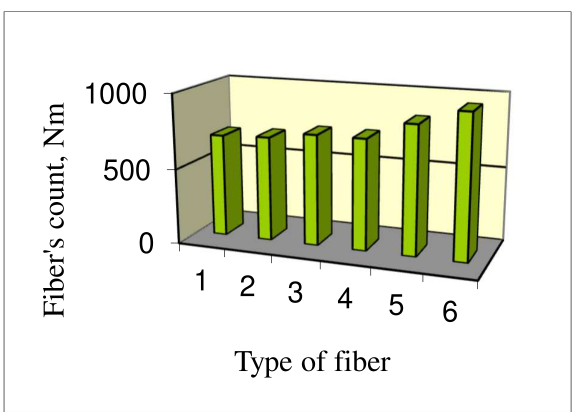

Fig 2. Variation of fiber fineness depending on the type of enzyme treatment

A diagram of the breaking load of flax fibres is presented in figure 3.

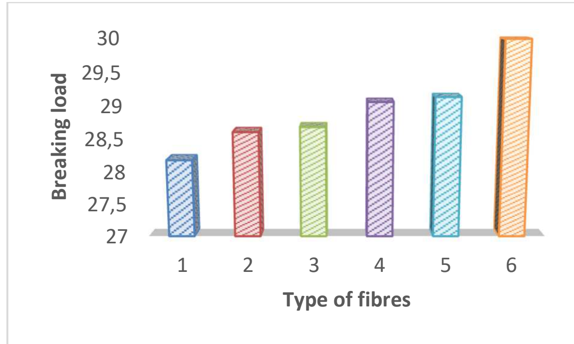

Fig. 3. Breaking load variation

To identify mathematical models and optimizing technological parameters a central, compound, rotable with two independent variables was used. Mathematics patterning has been realised in MathCAD 2000 Professional. The program contains 13 different experiments from which five parallel experiments has been mode at independent parameters central values. [15],[16], [17],[18].

Area of variations of the independent variables is: 25%-60% for cottonised flax ratio and 15-40 for yarns count [19].

The real values and the code one for the two parameters are presented in Table 3

Table 3

The real values and the code one for the independent variables

Cod value	-1,414	-1	0	1	1,414
x_1, %	25	30	42	54	60
x_2, Nm	15	18	27,5	36	40

The values used in the experiments and the answers are presented in Table 4

Table 4

Experimental matrix

	Independent variable				Dependent variable
	x_1 cod	x_1 real	x_2 cod	x_2 real	U(%) B2
1.	-1	30	-1	18	14,54
2.	1	55	-1	18	18,96
3.	-1	30	1	36	17,7
4.	1	55	1	36	22,66
5.	-1,414	25	0	27,5	19,76
6.	1,414	60	0	27,5	20,59

7.	0	42,5	-1,414	15	19
8.	0	42,5	1,414	40	21,76
9.	0	42,5	0	27,5	18,8
10.	0	42,5	0	27,5	19
11.	0	42,5	0	27,5	17
12.	0	42,5	0	27,5	18
13.	0	42,5	0	27,5	17

In table 2 the following notation was made:

- U – yarns Uster irregularity % [20]

Experimental variants were processed under similar conditions and in a random order. For each variant, the physic-mechanical properties of the yarns, according to the standardized methodology, were determined. Average values were determined for the analyzed characteristics. Testing aberrant values was done with the Dixon test, the extreme values being eliminated.

The utilisation of MathCAD program allowed the obtaining of the regression equation coefficients, based on experimental values:

$$y(x_1, x_2) = 17,9649 + 1,3192\, x_1 + 1,34533\, x_2 + 0,6658\, x_1^2 + 0,7684\, x_2^2 + 0,135\, x_1 x_2 \quad (1)$$

The significance of the regression equation coefficients was tested using Student test.
The critical table value for the test $t_{\alpha,\nu} = t_{0,05;6} = 2,132$.
Coefficient t_{c12} is smaller than the critical value, so it is insignificant and it was removed

The regression equation obtained is:

$$y(x_1, x_2) = 17,9649 + 1,3192\, x_1 + 1,34533\, x_2 + 0,6658\, x_1^2 + 0,7684\, x_2^2 \quad (2)$$

The experimental values that represent the dependent variable are presented in Table 4. The adequacy of the model was checked using the Fisher test and the percentage deviations are also presented in Table 5.

Table 5

The measured and the calculated values

	measured	calculated	A
1.	14,54	16,87	-2,33
2.	18,96	19,24	-0,28
3.	17,7	19,29	-1,59
4.	22,66	22,20	0,46
5.	19,76	17,43	2,33
6.	20,59	21,16	-0,57
7.	19	17,60	1,40
8.	21,76	21,40	0,36
9.	18,8	17,96	0,84
10.	19	17,96	1,04
11.	17	17,96	-0,96
12.	18	17,96	0,04
13.	17	17,96	-0,96

Value Fc, Fc = 2,7565 , calculated with the equation (3) [8], [9] is greater than the critical value $F_{\nu 1, \nu 2, \alpha} = F_{12;12;0,05} = 2,69$.

$$F_c = \frac{\sum_{i=1}^{n} \left(Ym_i - \overline{Y}m\right)^2}{\sum_{i=1}^{n} (Ym_i - Yi)^2} \quad (3)$$

The individual deviations A, calculated with the equation (4)

$$A = \left| \frac{Ym_i - Y_i}{Ym_i} \right| \cdot 100 \quad (4)$$

are smaller than 10%, which indicates a adequacy of the model.

The degree of concordance of the mathematical model was verified using F'_c statistics calculated with the equation (5)

$$F'_c = \frac{S_{con}^2}{S_0^2} \quad (5)$$

The calculated value 4,4295 is smaller that the critical value $F'_c = F_{\nu 1, \nu 2, \alpha} = F_{3;4;0,05} = 6,39$

To verify deviation of the survey data from the mean value the Fisher-Snedecor test was used. The calculated value $F_c = 14,9668$ is greater than the critical value $F_c = F_{\alpha, \nu 1, \nu 2} = F_{0,05;12,4} = 5,91$ which indicates that the deviations appear due to the independent variables and not experimental errors.

The quality of the mathematical model approximation calculated with the equation (6) [8], [9]

$$S = \sqrt{\frac{\sum_{i=1}^{n} \left(Ym_i - Y_i\right)^2}{n - n_c}} \quad (6)$$

is 1,67 what shows the scattering of experimental values around the regression equation.

The correlation coefficient calculated with the equation (7) [8], [9]

$$r = \frac{\sum_i x_i y_i - n\bar{x}\bar{y}}{(n-1)s_x s_y} \quad (7)$$

are : r_{x1x2}= 0, r_{x1y} = 0,5 and r_{x2y} = 0,51 .

The significance of the simple correlation coefficients is checked using the Student test. The calculated values are smaller than the critical value $t_{\alpha,\nu}=t_{0,05;11} = 2,201$ for t_{x1y} and t_{x2y} show that there is a weak link between variables, t_{x1x2} = 0, so there isn't any correlation between dependent variables.

The square of the correlation coefficient $R^2 = R_{xY}$, called coefficient of determination is 0,25 for the flax ratio and 0,26 for the yarn count. This express the part of the variation of the y variable is due to the respective variable.

The coefficient of multiple correlation calculated with the equation (8) [8], [9]

$$R_{Y\cdot x_1x_2} = \sqrt{1 - \frac{\sum_{i=1}^{n}(Ym_i - Y_i)^2}{\sum_{i=1}^{n}(Ym_i - \bar{Y}m)^2}} \quad (8)$$

is 0,798 . The value of the multiple correlation coefficient is checked with the F test (9)

$$F = \frac{n-k-1}{k} \cdot \frac{R^2_{Y\cdot x_1x_2}}{1 - R^2_{Y\cdot x_1x_2}} \quad (9)$$

The critical value $F_{\alpha, f1,f2} = F_{0,05;2;10} = 4,1$ is smaller than the calculated one 8,78 , which shows that independent variables have a significant influence on the dependent variable. The coefficient of multiple determination 0,637 show that the influence of the two independent variables on the result is 63,7 % , the rest of 36,3 % due to other factors.

The response surface of the regression equation is a elliptic paraboloid because the values of the coefficients of the canonic equation has the same signs. The center of the surface is an critical point with coordinates: x_{1c} = -0,9907; x_{2c} = -0,8754 and the Value of the dependent variable in the centre of the response surface is y_c = 16,7226. The critical point is a maximum one.

The canonical analysis transforms the regression equation in a more simple form and interprets the resulting expression using geometric concepts.

$$y= 16,7226 - 0,9907\, z_1^2 - 0,8754\, z_2^2 \quad (10)$$

In figure no.4 are presented the level curves obtained by the intersection of the answer surface with parallel plans in the limits of the experimental region.

The constant level curves allow the assessment of dependent variable y under the conditions imposed by independent variables x_1 and x_2. By calculating the metric invariants of the regression equation, we obtain S≠ 0, so the section will be an ellipse. The coefficients of the canonical equation are subunits, so the maximum point will be included in the experimental region.

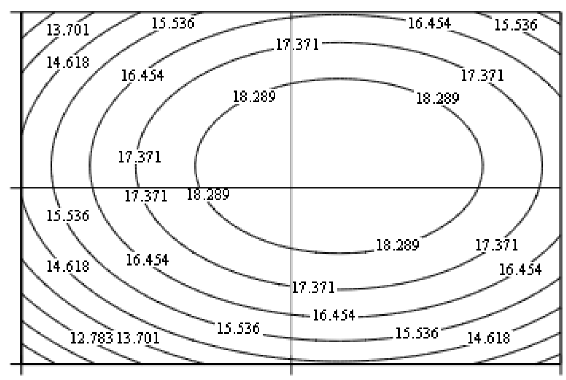

Fig. 4. The level curves – The variation of the yarn irregularity

The residue diagram is presented in figure 5.

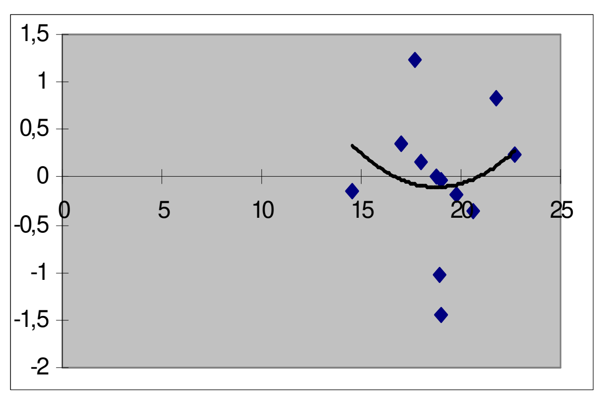

Fig. 5. The residue diagram

The residues were calculated with a significance level α = 0,5. The residues have small values, which express a good adjustment of the experimental data. Residues have both positive and negative values witch express no overestimation or underestimation of the experimental data.

3. CONCLUSION

The analysis of the regression equation coefficients shows that:

- The influence of the two independent parameters, x_1 (flax ratio) and x_2 (yarn's count) on the dependent variable Y (Uster Irregularity) manifests in the same way. (+ sign both coefficient b1 and coefficient b2)

Both increasing the flax ratio and increasing the yarn count lead to increasing the Uster irregularity of the yarn

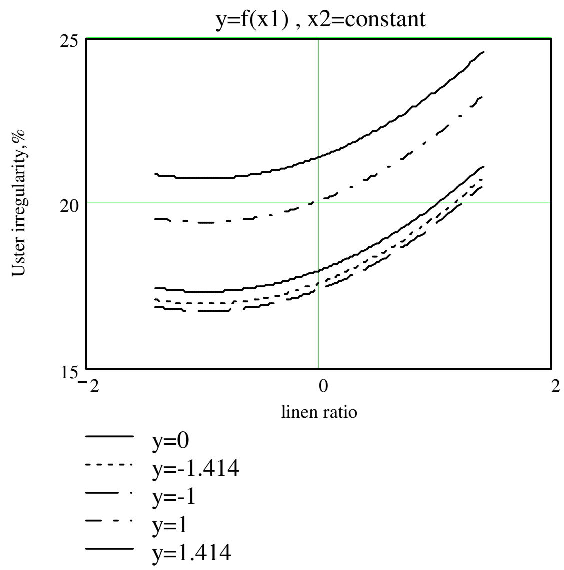

Fig. 6. The dependence of the goal- function on all significant values of x_1 parameters

- The flax ratio has an approximate influence with the yarn count on the Uster irregularity of the yarns. The flax ratio changes the dependent variable with 13,19 % and the yarn count changes the dependent variable with 13,53%. Increasing the values of the two variables increases the resulting.
- The existence of quadratic form for both parameters indicates that the response surface defined by the obtained mathematical model , is well-formed, reinforcing the hypothesis regarding the influence of both parameters on the dependent variable;

To the constant maintenance of flax ratio in blend, maximum Uster irregularity is obtained for code values of the yarn count 1,414 which corresponds to a real value Nm 40

To the constant maintenance of the yarn count, maximum Uster irregularity is obtained for code values of the flax ratio in blend1,414 which corresponds to a real value 60%

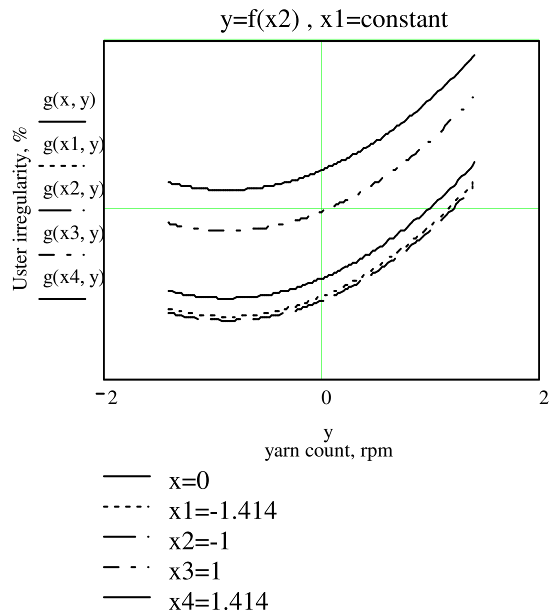

Fig. 7. The dependence of the goal- function on all significant values of x_2 parameters

At a yarn count over a certain value and a large percentage of flax in the blend there is a sharp increase of the Uster irregularity [21]. This is also justified by the fact that over a certain ratio of flax in the blending, the flax fibers are separated and are removed from the yarn structure.[22]

From figures 6 and 7 it can be determined the optimum ratio of flax for the best value of Uster irregularity

Flax is much more difficult to spin than cotton and regarding processing flax – cotton blending, we can say:

- The last years have brought changes in fibers processing related to both technical progress and the requirements of increasing productivity and economic efficiency

- The OE with rotor spinning system is the one that has definitely prevailed due to its advantages: an average increase of the machine productivity, reducing by up to 40% the need of productive space, reduction in amount of waste, a good tolerance for fibers with a wider range of physical and mechanical properties
- to improve the spinning process of flax fibers on cotton spinning machines and also the quality of the yarns it is necessary first of all to improve the properties of the fibers
- when processing cotton and cotton type blends, the transfer of the fibers properties on the yarns characteristics is ensured
- fibers obtained by enzymatic modification of flax have properties that make them suitable for processing on unconventional spinning machines, blended with other fibers
- introduction of a percentage of 30% flax fibers in the blending considerably improves the properties of the whole product;
- 50% flax-50% cotton blends can be processed on open-end spinning machines to obtain yarns with Nm 40 with a suitable quality [13], [23]

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Modelarea matematică a unor factori de influență ai neregularității firelor

Rezumat: Proiectarea amestecurilor de fibre şi estimarea caracteristicilor firelor obţinute este o problemă actuală, luând în considerare faptul că societăţile comerciale primesc comenzi pentru cantităţi mici de produse, ceea ce înseamnă schimbarea reţetelor de amestec, schimbarea reglajelor maşinilor dar totodată cunoaşterea caracteristicilor firelor ce se vor obţine.

Amestecurile de in cotonizat şi bumbac în condiţiile evoluţiei pieţei de textile pot fi considerate o oportunitate importantă pentru industria textilă

Modelarea matematică folosită pentru optimizarea parametrilor firelor are la bază programul central, compus, rotabil cu două variabile. În cadrul programului utilizat variabilele independente considerate sunt procentul de in în amestec (x_1) şi fineţea firului realizat (x_2) iar variabila dependentă este neregularitatea Uster a firului.

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