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THE OPTIMIZATION OF PLUSH YARNS BULKING PROCESS

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Abstract: *This paper presents the experiments that were conducted on the installation of continuous bulking and thermofixing "SUPERBA" type TVP-2S for optimization of the plush yarns bulking process. There were considered plush yarns Nm 6.5/2, made of the fibrous blend of 50% indigenous wool sort 41 and 50% PES. In the first stage, it performs a thermal treatment with a turboprevaporizer at a temperature lower than thermofixing temperature, at atmospheric pressure, such that the plush yarns - deposed in a freely state on a belt conveyor - are uniformly bulking and contracting.*
It was followed the mathematical modeling procedure, working with a factorial program, rotatable central composite type, and two independent variables. After analyzing the parameters that have a direct influence on the bulking degree, there were selected the pre-vaporization temperature (coded x_1,^oC) and the velocity of belt inside pre-vaporizer (coded x_2, m/min). As for the dependent variable, it was chosen the plush yarn diameter (coded y, mm). There were found the coordinates of the optimal point, and then this pair of values was verified in practice. These coordinates are: $x_{1optim} = 90^oC$ and $x_{2optim} = 6.5$ m/min. The conclusion is that the goal was accomplished: it was obtained a good cover degree for double-plush carpets by reducing the number of tufts per unit surface.

Key words: *woollen carpet, double plush technology, mathematical model, yarn diameter.*

1. INTRODUCTION

Using modern technologies and performing equipment to obtain qualitatively plush carpets *with reduced manufacturing costs* represents a priority for any trading company that has as object of activity to produce and trade carpets.

The real value of a carpet is determined by its physical and mechanical properties: carpet mass and thickness; behaviour in static and dynamic regime; resistance to friction wear; resistance to tufts pulling; charging with static electricity; soiling sensitivity; capacity of thermal and phonic insulation [1]

By analyzing the advantages and disadvantages of manufacturing technologies for mechanically woven carpets, one can conclude that double-plush weaving technology is recommended when wishing to satisfy higher and higher customers' demands from the standpoint of comfort and other utilization characteristics offered by carpet.

The tendency is to accomplish an optimal fabric cover coefficient with a reduced number of tufts per unit surface. It is therefore necessary *to increase the plush yarn volume* by various methods. The present work synthesize the experiments carried out on plush yarns Nm 6.5/2, made of the fibrous blend of 50% indigenous wool sort 41 and 50% PES. The research is unique in Romania and was done between 2009-2010 at S.C. INCOV S.A. Alba Iulia – the biggest carpet manufacturer in our country till 2014.

Bulking and thermofixing the plush yarns determine the increase of dimensional stability, an improvement of tinctorial affinity, an increased regularity of carpet surface aspect, a better resistance to friction wear and an increased comfort at carpet exploitation [2, 3].

2. MATERIALS AND METHOD

The installation of continuous bulking and thermofixing “SUPERBA” performs, in the first stage, a thermal treatment by means of a thermo-vaporizer at a temperature lower than the thermofixing temperature and at atmospheric pressure, such that the yarns freely deposed on a belt conveyor are uniformly bulking and contracting.

The main parameters that can be adjusted at this installation and have a direct influence upon the bulking degree are:

- moving velocity of woollen yarns layer (v_1= 0- 750 m/min);
- belt conveyor velocity inside pre-vaporizer (v_2= 5.5-8.6 m/min);
- pre-vaporization temperature (t_1 = 90-99^{0}C);
- vapor temperature in the thermofixing tunnel (99.1- 150.24^{0}C).

There were chosen as independent variables: x_1- pre-vaporization temperature (^{0}C) and x_2 – velocity of belt conveyor in pre-vaporizer (m/min) because previous researches showed that they have the greatest influence on bulking process of plush yarns. The dependent variable y (mm) is the diameter of the plush yarn Nm 6.5/2, obtained from the fibrous blend 50% indigenous wool sort 41and 50% PES.

We have used the factorial program, *rotatable central composite type*, with two variables at five variation levels (-1.414, -1, 0, 1, +1.414). It was used the central composite design because it is very efficient and provides much information in a minimum number of required runs. The existence of five central points (x_1=0, x_2=0) helps the researcher to improve the precision of the experiments. A design is called “rotatable” if the variance of the estimated response depends on the distance from the centre of the design.

The experiments were carried out according to an experiment matrix (Table 1) for two independent variables. Mathematical modeling was used to optimize the plush yarn bulking process [4,5,6]. The general form of the 2-variables second order regression equation is:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_{11} x_1^2 + b_{22} x_2^2 + b_{12} x_1 x_2 + \varepsilon \quad \textbf{(1)}$$

It was determined the second order regression equation based on the matrix of experiments:

$$y = 0.726975 + 0.002091 x_1 - 0.00096 x_2 - 0.0014 x_1^2 + 0.00015 x_2^2 - 0.0005 x_1 x_2 \quad \textbf{(2)}$$

Table 1. *Matrix of experiments*

No.	Independent variables				Dependent variable		
	x_1 (^{0}C)		x_2 (m/min)		y_{mas} (mm)	y_{calc} (mm)	Δy (%)
	code	real	code	real			
1	-1	92	-1	6	0.725	0.72379094	0.17
2	1	94	-1	6	0.728	0.72897244	-0.13
3	-1	92	1	6.5	0.725	0.72287694	0.29
4	1	94	1	6.5	0.726	0.72605844	-0.08
5	-1.414	90	0	7	0.717	0.72121859	-0.59
6	1.414	96	0	7	0.726	0.72713123	-0.16
7	0	95	-1.414	5.5	0.726	0.7280286	-0.28
8	0	95	1.414	8	0.722	0.7253222	-0.46
9	0	95	0	7	0.726	0.72697462	-0.13
10	0	95	0	7	0.728	0.72697462	0.14
11	0	95	0	7	0.726	0.72697462	-0.13
12	0	95	0	7	0.726	0.72697462	-0.13
13	0	95	0	7	0.728	0.72697462	0.14

In the last column of Table 1 there are written the values of Δy , computed with the following formula:

$$\Delta y = \frac{y_{mas} - y_{calc}}{y_{mas}} \cdot 100 \ (\%) \qquad \textbf{(3)}$$

The value Δy shows the difference between the measured value of yarn diameter (coded y_{mas}) and the computer value of diameter (coded y_{calc}). It is noticed that Δy can be positive or negative.

The significance of the coefficients for the regression equation (2) was tested by the Student test, accordingly to the Table 2.

Table 2. *Significance test for the coefficients of the regression equation*

	t_i	Coefficients of regression equation
t_{c0}	3029061	b_0 significant
t_{c1}	13938.33	b_1 significant
t_{c2}	-6380	b_2 significant
t_{c11}	-8114.71	b_{11} significant
t_{c22}	-8672.46	b_{22} significant
t_{c12}	-1666.67	b_{12} significant

The critical value for Student test was taken from a table: $t_{\alpha;\nu} = t_{0.05;\,6} = 1.94$.

The model adequacy was verified by means of the Fisher-Snedecor test and with percentage deviations. The computed value $F_c = 3.27$ is higher than the critical value taken from the table $F_{\nu1,\nu2,\alpha} = F_{12;12;0.05} = 2.69$.

The mathematical model conformity degree was verified by the same test. The computed value F_c is 11.47, which means that it is smaller than the critical table value $F_{tab} = F_{\nu1,\nu2,\alpha} = 15.98$.

Also the Fisher-Snedecor test was used to verify the deviation of the sampling data from the mean (average) value. The computed value $F_c = 21.82$ is higher than the critical value from the table, $F_{tab} = F_{0.05;12.4} = 5.91$ which indicates that the deviations are due to the independent variables and not to some experimental errors [5].

In the end, it was computed the correlation coefficient $r_{ymas;ycalc} = 0.79123$ by *Microsoft Excel* application. This value shows a pretty good agreement between the experimental and predicted values from the model.

From the analysis of the equation coefficients, there can be formulated the following conclusions:

- The sign (+) for the coefficient b_1 and the sign (–) for the coefficient b_2 show that the two independent parameters have a different influence on the resultative variable y, i.e. the increase of yarn diameter is more significant when the temperature increases and the yarn velocity through the vaporizer decreases.
- The ratio between the coefficients of the quadratic terms and the free term indicates a variation rate of the yarn diameter of 0.19% due to temperature modification, and of 0.02% due to the modification of the standing time in the pre-vaporization zone.

The response surface of the regression equation has a parabolic shape like a bowl that opens downward (shown in Figure 1). Its maximum has the coordinates: $x_1 = -1.41$ and $x_2 = 1$, corresponding to the pair of natural values:

- $x_{1optim} = 90^0C$
- $x_{2optim} = 6.5$ m/min.

Figure 2 puts in evidence the influence exerted by x_1 and x_2 that act simultaneously upon y.

Figures 3 and 4 show the influences of these two working parameters that act independently on the plush yarn diameter.

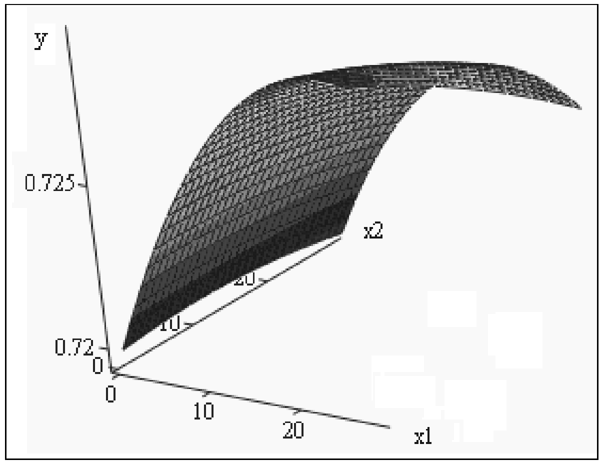

Fig. 1: *Response surface of the second order regression equation*

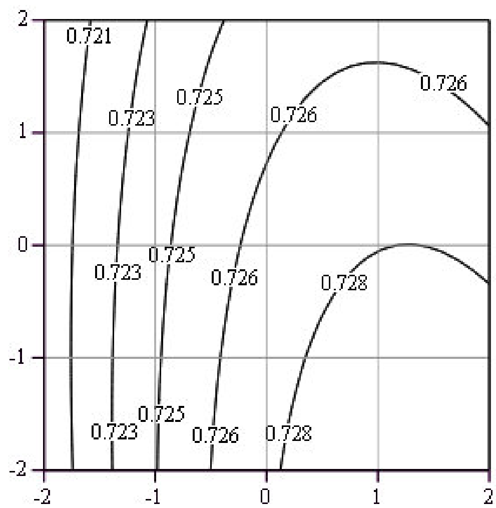

Fig. 2: *Influence of temperature (x_1) and belt velocity through the pre- vaporizer (x_2) on the plush yarn diameter*

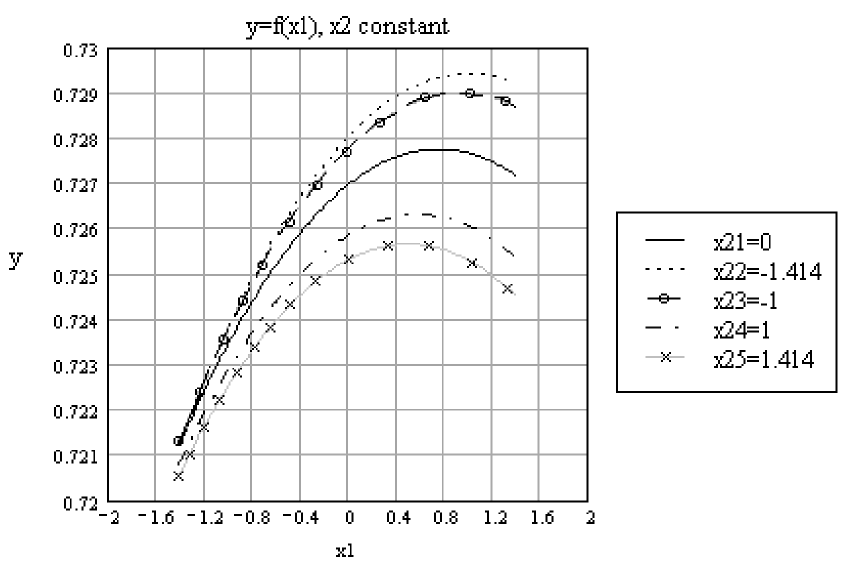

Fig: 3. *Influence of pre-vaporization temperature on the plush yarn diameter*

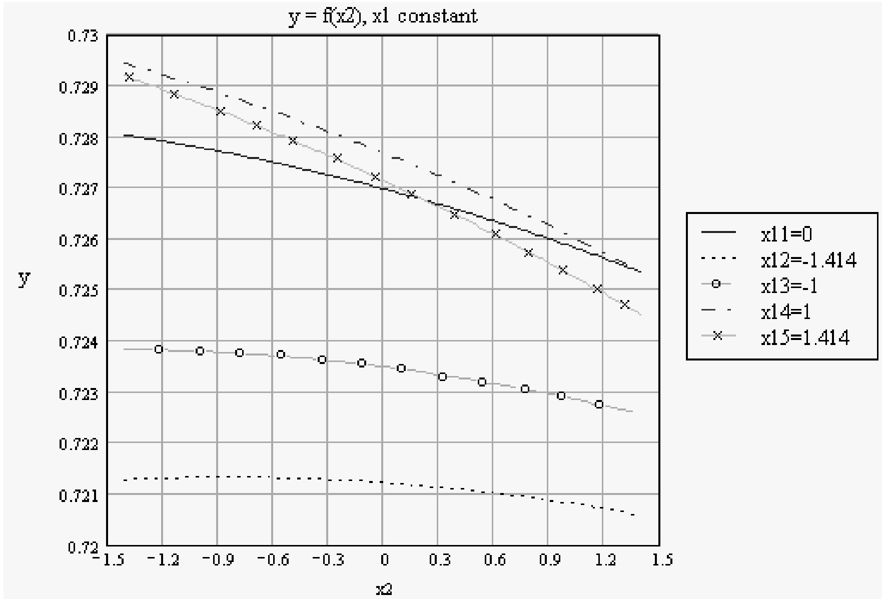

***Fig: 4**. Influence of belt velocity through the pre-vaporizer (x_2) on the plush yarn diameter*

From the previous graphics, one can notice that the optimum values of the yarn diameter increase through the pre-vaporizer are obtained for the pair of coded values: x_1 = -1.414 and x_2= 1, and x_1 = 0, x_2= 1.414 respectively, corresponding to the pair of natural values:

- $x_1 = 90^0$C and x_2 = 6.5 m/min;
- $x_2 = 95^0$C and x_2 = 8 m/min.

Since the value of the parameter x_2 = 8m/min is close to the maximum admissible working speed of pre-vaporizing and thermofixing installation, we recommend the utilization of the pairs of values: $x_1= 90^0$C and x_2= 6.5 m/min, which provides the optimum value for the resultative, as well as a reduced power intake.

Then we proceeded to the verification of optimal values. With this aim in view, we made temperature and velocity adjustments resulted from optimization, and the measured value of the yarn diameter was of 0.749. The computed value of 0.726 represents an increase by 3.2%, which leads to the conclusion that the process optimization according to the mathematical model was accomplished.

3. CONCLUSIONS

The goal of this research was to accomplish an optimal cover degree for double-plush carpets by reducing the number of tufts per unit surface.

This paper presents a bulking method for the plush yarns Nm 6.5/2, obtained from the fibrous blend 50% indigenous wool sort 41 and 50% PES.

Experiment planning carried out on the installation of continuous bulking and thermofixing “SUPERBA” was based on the matrix specific to the factorial program, rotatable central composite type, with two variables at five levels of variation. After mathematical modeling procedure, it was found the optimum point with the coordinates (in natural values): pre-vaporizing temperature of 90^0C (coded x_1) and belt velocity in pre-vaporizer of 6.5 m/min (coded x_2).

Checking up in practice the optimal values for working parameters x_1 and x_2 has shown that in reality there is an increase of plush yarn diameter with 3.2% higher than the value estimated based on the second order regression equation.

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