STUDY OF THE PLASMA TREATMENT INFLUENCE ON THE STATIC FIBER/METAL FRICTION COEFFICIENT

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REZUMAT. În lucrare s-a efectuat un studiu privind tratarea în mediu de plasmă a fibrelor de polipropilenă, în variante diferenţiate prin parametrii de lucru ai instalaţiei, rezultând producerea unor modificări apreciabile ale coeficientului de frecare static fibră/metal. Pe baza rezultatelor obţinute în cele 64 de variante experimentale, s-au stabilit parametrii instalaţiei Corona, care au influenţat în mod semnificativ procesul: puterea activă a instalaţiei şi numărul de cicluri parcurse de probă în zona de tratament. Din acest motiv, studiul efectuat s-a axat pe evidenţierea modului de influenţă a celor doua variabile independente asupra proprietăţilor fibrelor de polipropilenă, precum şi determinarea unor condiţii de optimizare a acestora. În acest scop s-a utilizat programarea factorială, prin adoptarea unui program central compus rotabil, cu două variabile independente (x_1 – numărul de cicluri, Nc; x_2 – puterea activă, Pa, W) și o variabilă dependentă (y_1-coeficientul de frecare static fibra/metal, μ_s). Studiul efectuat, evidențiază faptul că tratamentele în mediu de plasmă produc modificări pe suprafaţa şi în structura fibrelor şi implicit afectează proprietăţile acestora.

Cuvinte cheie: coeficient de frecare static, plasma, programare factorială, fibre polipropilenice.

ABSTRACT: The work studies plasma treatment of polypropylene fibers in variants with different working parameters of the installation, resulting in the generation of significant modifications of the static fiber/metal friction coefficient. Based on the results obtained in the 64 experimental variants, one establishes the parameters of the Corona installation that have influenced significantly the process: installation active power and number of cycles through the treatment area. Accordingly, the performed study has focused on showing off the influence on the two independent variables on the polypropylene fibers properties, as well as on the determination of certain conditions to optimize them. With this aim in view, one uses the factorial programming, by adopting a rotable compound central program with two independent variables (x_1 – number of cycles, Nc; x_2- active power, Pa, W), and a dependent variable (y_1 – fiber/metal static friction coefficient, μ_s).

The performed study reveals that plasma treatment induces modifications of fiber surface and structure and implicitly affects their properties.

Keywords: static friction coefficient, plasma, factorial programming, polypropylene fibers.

1. INTRODUCTION

Plasma can be used to convert the heat energy in electric energy by means of magneto-hydrodynamic converter or of thermo-ionic converter [1]. The devices with plasmas generated through low-pressure gas discharge are widely used in industry, in applications like nitriding, ionic implantation, thin films deposition, surface corrosion [2]; [3]. The radio-frequency plasma discharges in low-pressure gas are widely used in electronic industry to produce microchips [4].

Such a process is low-pressure plasma technology, an eco-friendly and advantageous way to modify the materials' surface at microscopic level without using manual operations or chemical products. By using this technique, it becomes possible to clean, activate, engrave or modify the surface of different materials in a controllable and reproducible manner [5]. Practical utilization of plasma implies the development of plasma systems available and competent on the market. Nowadays there are such systems, especially in research laboratories, and plasma utilization in industry has increased rapidly during the last period [6], [7], [8].

Modification in plasma of polymeric materials used as textiles, membranes, foils, unwoven or composite materials, etc, permits to optimize numerous properties [9], [10].

Among the textile utilizations of polypropylene, stands out in relief mainly the sector of carpets and floors coatings, due also to the development of interweaving technique, very adequate for these products

2. MATERIALS AND METHODS

The materials used in this study are wool-type polypropylene fibers of 6 dtex/60 mm, which have been previously degreased to remove the preparation applied on fibers during their fabrication. Plasma treatment of polypropylene fibers was carried out on a HF = CORRONA CG-20, ARCOTEC GmbH Rotweg.

One uses for optimization the factorial programming, by adopting a rotable compound central program with two independent variables (x_1 – number of cycles, Nc; x_2 – active power, Pa) and a dependent variable, y_1 – fiber/metal static friction coefficient. Table 1 presents the levels with coded and real values of the independent variables.

Table 1. Coded and real values of independent parameters

Code / **Independent parameter**	-1.414	-1	0	+1	+1.414
x_1 – nr. cicluri (Nc)	7	8	10	12	13
x_2 – puterea activă (Pa)	240	340	620	900	1000

Experiments were performed by maintaining constant the following parameters:

- distance between electrodes – 6 mm;
- electrode type - ceramic;
- backing electrode - insulated support;
- backing electrode speed- 10 m/min.

Table 2 presents the experimental matrix based on the level of variation of the two independent variables, with 13 experimental variants [11].

The order of executing the experimental variants was random, to avoid the appearance of systematic errors. The effect of treatments was investigated through laboratory tests, the determined properties being the dependent variables, namely y_1 – fiber/metal static friction coefficient.

Mathematical models of the interdependence of independent variables x_i and dependent/resultative variables y_i were obtained by processing experimental data with CAV1 software [12].

Table 2. **Experimental matrix**

Experimental variants	**Independent variables**			
	x_1 - [Nc]		**x_2 - [Pa]**	
	Code	**Real**	**Code**	**Real**
1.	-1	8	-1	340
2.	1	12	-1	340
3.	-1	8	1	900
4.	1	12	1	900
5.	-1.414	7	0	620
6.	1.414	13	0	620
7.	0	10	-1.414	240
8.	0	10	1.414	1000
9.	0	10	0	620
10.	0	10	0	620
11.	0	10	0	620
12.	0	10	0	620
13.	0	10	0	620

3. RESULTS AND DISCUSSIONS

Friction force is the force that opposes to the tendency of a body to move as related to another body with which it comes into contact. It depends on the pressure force normal to the contact surface between the two bodies, as well as on other factors, such as: body's nature, surface aspect, presence of some pellicles, etc, all being reflected in the static friction coefficient that characterizes the initial moment of the motion, and the dynamic coefficient for motion condition.

Bigger friction forces between the fibers of a half-finished product or a yarn result in:

- diminution of yarn torsion while maintaining the same tenacity;
- improvement of tensile strength simultaneously with the increase of yarn elasticity;
- increase of raw material reliability due to the utilization of fibers with superior characteristics;
- safer control of yarns motion within the draft field;
- preservation of half-finished products' structure;
- stability of wrapping structures.

Table 3 summarizes the measured mean values and the values computed by means of the regression equation of the analyzed parameter, as well as the percentage deviations that will establish the adequacy of the mathematical model for the studied process.

Table 4 presents the coefficients of the regression equation resulting from processing the data of experimental matrix, as well as their significance established with Student test.

Table 3. **The values of fiber/metal static friction coefficient**

Experimental variant	y_{m1}	y_{c1}	A [%]
1.	0.357	0.352963	1.130940
2.	0.354	0.351601	0.677673
3.	0.356	0.337047	5.323870
4.	0.368	0.350686	4.705020
5.	0.327	0.338729	3.586810
6.	0.338	0.347409	2.783640
7.	0.359	0.359013	0.003483
8.	0.326	0.347113	6.476380
9.	0.315	0.320682	1.803660
10.	0.324	0.320682	1.024220
11.	0.321	0.320682	0.099208
12.	0.323	0.320682	0.717789
13.	0.320	0.320682	0.212981

Table 4. **Coefficients of the regression equation and their significance**

Coefficient		Statistic t_c	Statistic $t_{tab(n,a)}$	Significance
b_0	0.32068200	204.459	$t_{tab(0.05;4)} = 2.132$	significant
b_1	0.00306925	2.47528		significant
b_2	-0.00420775	3.39346		significant
b_{12}	0.00375000	2.13850		significant
b_{11}	0.01119700	8.41918		significant
b_{22}	0.01619550	12.1776		significant

After eliminating insignificant coefficients, one obtains the equation of response surface:

$$y_1 = 0,320682 + 0,003069 \cdot x_1 - 0,004207 \cdot x_2 + \\ +0,011197 \cdot x_1^2 + 0,016195 \cdot x_2^2 + 0,00375 \cdot x_1 \cdot x_2 \qquad (1)$$

The mathematical model is adequate, as it respects the conditions:

– $F_c^{'}$=2.92925; $F_{tab(0.05;12;12)}$=2.69; $F_c^{'} > F_{tab}$;

– all percentage deviations are below 10%.

The coordinates of the stationary point (O’) are x_{1s} = - 0.16195; x_{2s} = 0.148654 - code values, and x_{1s}= 9.676; x_{2s}= 662- real values with response, point of minimum: μ_s= 0.32012.

The angle of axes rotation, α = - 18.4391°, with the new coordinate system:

$$X_1 = 0,316297.(x_1 + 0,16195) + 0,94866.(x_2 - 0,148654) \qquad (2)$$

$$X_2 = 0,948660.(x_1 + 0,16195) - 0,316297.(x_2 - 0,148654) \qquad (3)$$

The quadratic equation written in canonic form has the expression:

$$Y - 0,32012 = 0,0168206\, X_{12} + 0.0105719\, X_{22} \qquad (4)$$

Since the coefficients B_{11} and B_{22} have the same sign, the response surface represents an elliptic paraboloid (Fig. 1). The lines of equal significance/equi-significance lines are ellipses, their centers representing the minimum value of the parameter to be optimized; the signs of the both coefficients is positive (Fig. 2).

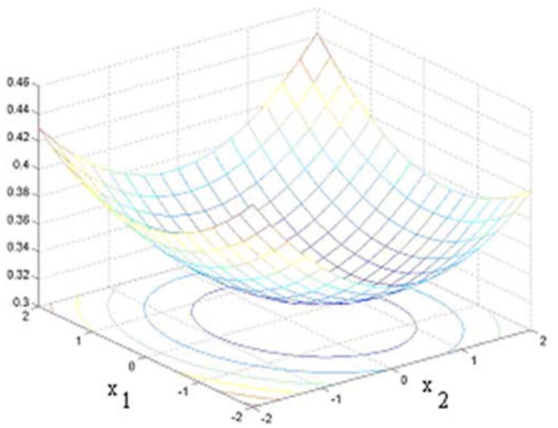

Fig. 1. Variation of static frequency coefficient as function of Nc and Pa.

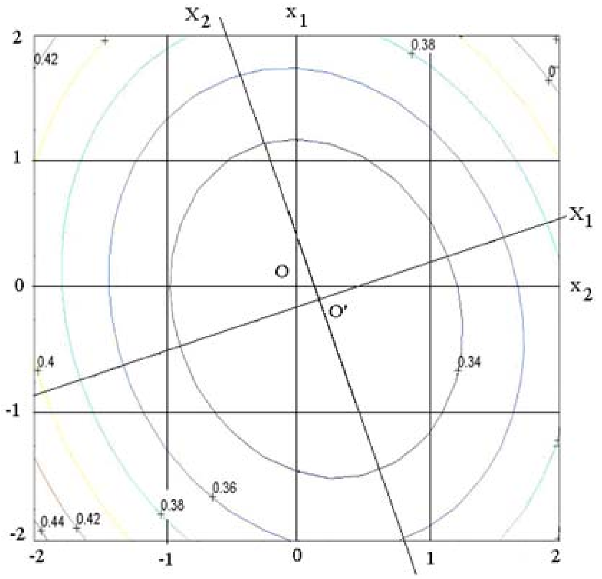

Fig. 2 Curves of equal significance of the response surface $y_1 = f(x_1, x_2)$.

From the analysis of the obtained mathematical model, one can conclude that:

− In the linear part are present the both linear terms, which, having opposite signs, have a contrary influence on the analyzed parameter: variable x_1 determines the increase of the response when it takes values within the interval (0÷1.414), and a decrease for values (–1 ÷ 0). For the variable x_2, the friction coefficient increases for x_2 within the limits (–1.414÷ 0) and decreases for x_2 within the interval (0÷ 1.414).

− The quadratic terms, both positive, will determine the increase of the resultative/resulting variable within the entire experimental space, irrespective of the sense of independent variables variation.

− The interaction between the two variables influences the dependent parameter, in the sense of its increase when both variables have the same sign, and the decrease of the response when they have different signs.

− One can see in figure 3 that the form of the diagram of static friction variation in terms of the number of cycles for x_2 = const is almost the same, marking a minimum in the centre of the experimental region. Yet, there is a difference related to the level of values, which increase by about 8% when the active power varies from 620 W to 1000 W.

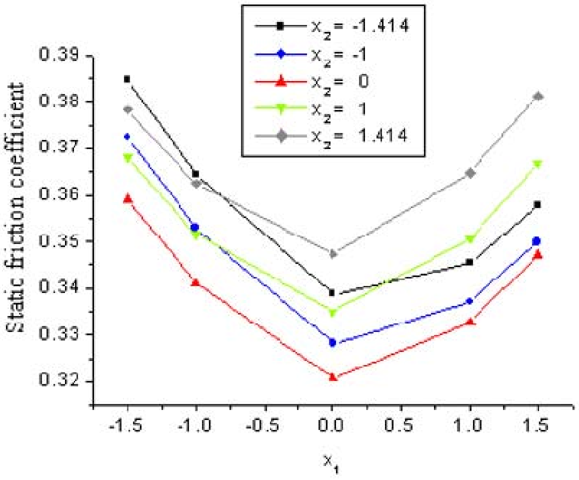

Fig. 3. Variation of static friction coefficient with the parameter x_1 for x_2 = const.

The statistic connection between the static metal/fiber friction coefficient is shown off by the coefficient of multiple correlation:

$-R_{y,x_1,x_2} = 0.8115$, the significance being certified by F test;

$-F_c = 9.642$; $F_{tab(0.05,\,2.10)} = 4.1$; $F_c > F_{tab}$.

The coefficient $R^2_{y,x_1,x_2} = 0.66$ shows that the analyzed parameter is influenced by the two variables, x_1 and x_2 in proportion of 66%, the rest of about 34% being the result of other influences.

4. CONCLUSIONS

1) The new techniques of materials' preparation and modification appeared during the last decade consist, in the main, in the modification of fibers surface properties without important structural changes.

2) Plasma technology is an eco-friendly advantageous method for the modification of material surface at microscopic level, realizing certain effects: cleaning, roughness, generation of radicals, polymerization.

3) By means of plasma treatment, the polypropylene fibers records important increases, above the witness sample, in the case of static friction coefficient.

4) The canonic analysis of the response surface allows establishing favorable values of the analyzed function and gives the orientation of parameters' modification, a real working tool for the considered technology.

5) Variation of x_1 and x_2 imposed by the experimental space determines the increase of static friction coefficient. According to level curves, the response variation is faster for the modification of the number of cycles, than for the modification of installation active power.

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