BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI

Tomul LIX (LXIII)

Fasc. 3

TEXTILE. PIELĂRIE

2013 **Editura POLITEHNIUM**

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
PUBLISHED BY
"GHEORGHE ASACHI" TECHNICAL UNIVERSITY OF IAŞI
Editorial Office: Bd. D. Mangeron 63, 700050, Iaşi, ROMÂNIA
Tel. 40-232-278683; Fax: 40-232-237666; e-mail: polytech@mail.tuiasi.ro

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BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
BULLETIN OF THE POLYTECHNIC INSTITUTE OF IAŞI
Tomul LIX (LXIII), Fasc. 3 2013

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UNCONVENTIONAL SURFACE TREATMENT FOR WORSTED YARNS

BY

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Received: August 8, 2013
Accepted for publication: September 12, 2013

Abstract. This paper presents the results concerning the tenacity and breaking elongation of worsted yarns after plasma treatment. There are three types of fibrous blends: 90% wool + 10% relon (nylon 6), 80% wool + 20% relon and 100% relon. For mathematical modelling it was used a rotatable central composite design with two independent variables. Because of the differences between the chemical structure of wool fibres and nylon 6 fibres, the dynamometric characteristics changed in different ranges for these three types of yarns, depending on the degree of surface modification.

Key words: surface modification, plasma treatment, worsted yarns, tenacity, breaking elongation.

1. Introduction

The research activities related to yarns manufacturing have a clear objective – to create a diversified range of wool type yarns by adopting three

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This paper is the full version of the paper published in abstract only at Technical Textiles – Present and Future Symposium, Iaşi, October, 2013

main strategies: (a) blending wool fibres with new types of fibres; (b) designing new structures/technologies; (c) applying different types of surface treatments: conventional (chemical) or unconventional (laser, gaseous fluorine, cathodic pulverization, electronic bombardment, plasma) .

Plasma can be defined as an ionized gas with equal density of positive and negative charges, a mixture of free electrons, ions, radicals, UV radiation, etc. The principle of plasma treatment consists of creating a direct contact between the textile material and a very reactive medium, inside special designed equipment (Caraiman, 1997; Hocker, 2002).

The advantages of plasma treatment versus traditional chemical methods are: low costs, high efficiency in surface modification for the majority of polymers, and an environmentally friendly method. The effects in textile materials can be evaluated when measuring the surface rugosity, friction coefficients, weight loss, dynamometric properties, electrical characteristics, absorbtion features, etc. (Kan & Yuen, 2006; Shah & Shah, 2013).

This kind of treatment can be done in research laboratories or in industrial companies, for raw materials (fibres), yarns, woven textiles, knitted textiles, technical textiles. Main parts of the plasma equipment that can be found at Faculty of Textiles & Leather Engineering and Industrial Management are shown in Fig. 1.

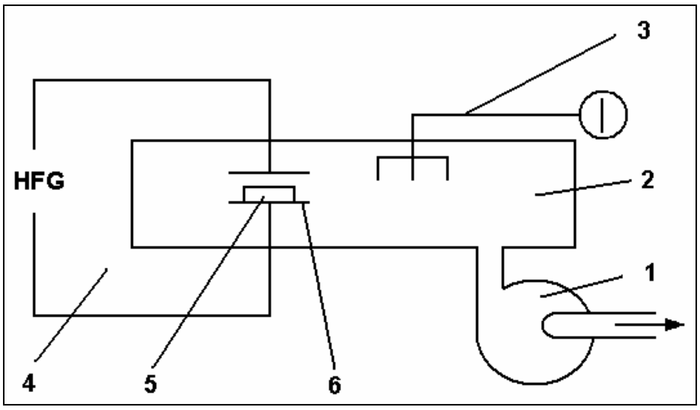

Fig. 1 − Plasma treatment equipment (Caraiman, 1997): *1* – vacuum pump; *2* – plasma room; *3* – electronic vacuum meter; *4* – conductors; *5* – textile material; *6* – electrodes; *HFG* – high frequency generator.

The generator HFG applies through electrical conductors (4) a voltage to the electrodes (6). The textile material (5) is placed inside the room (2) where plasma medium is generated when vacuum pump (1) is working. The level of the pressure is read by the help of the electronic vacuum meter (3).

The pressure used during experiments was set and maintained constant at 200 mtorr.

2. Materials and Methods

There were tested worsted yarns made from three types of fibrous blends:

V_1 – 90% wool, 10% nylon 6 (relon);

V_2 – 80% wool, 20% nylon 6 (relon);

V_3 – 100% nylon 6 (relon).

All variants were processed by classical wool combing technology; the linear density of the yarns is 28 tex x 1.

For the mathematical modeling of worsted yarns dynamometric properties (tenacity and breaking elongation), it was used a rotatable central composite design with two independent variables: X_1 electrical power (W); X_2 time (sec). The codes and the real values of these two independent variables are given in Table 1. Technically speaking, the encoding covers the entire domain of existence of the considered variables.

Table 1

Codes and Real Values for the Independent Variables

Parameter	UM	Code	Encoded values				
			−1.414	−1	0	+1	+1.414
Power	W	X_1	100	160	300	440	500
Time	Sec.	X_2	120	146	210	274	300

The dependent variables are:

$Y_{1,2,3}$ – the tenacity (cN/tex) of worsted yarns V_1, V_2 and V_3;

$Y_{4,5,6}$ – the breaking elongation (%) of worsted yarns V_1, V_2 and V_3.

The matrix of experiments for tenacity is given in Table 2, and the matrix of experiments for breaking elongation is presented in Table 3.

Table 2

Design of Experiments for Tenacity - Variants V_1, V_2 and V_3

Nr.	Code X_1	Real X_1	Code X_2	Real X_2	Y_1 Measured [cN/tex]	Y_2 Measured [cN/tex]	Y_3 Measured [cN/tex]
1	−1	160	−1	146	6.66	7.89	17.49
2	+1	440	−1	146	5.90	5.93	15.48
3	−1	160	+1	274	6.73	7.87	16.98
4	+1	440	+1	274	6.37	7.75	17.42
5	−1.414	100	0	210	7.18	8.17	19.52
6	+1.414	500	0	210	5.36	7.22	16.74
7	0	300	−1.414	120	5.92	7.23	16.31
8	0	300	+1.414	300	7.79	6.78	16.40
9	0	300	0	210	7.19	7.34	17.26
10	0	300	0	210	7.02	6.71	18.08
11	0	300	0	210	6.72	7.02	17.81
12	0	300	0	210	6.47	6.79	17.43
13	0	300	0	210	7.24	6.93	18.16

Table 3

Design of Experiments for Breaking Elongation – Variants V_1, V_2 and V_3

Nr.	Code X_1	Real X_1	Code X_2	Real X_2	Y_4 Measured [%]	Y_5 Measured [%]	Y_6 Measured [%]
1	−1	160	−1	146	12.2	13.5	21.7
2	+1	440	−1	146	10.6	12.3	19.6
3	−1	160	+1	274	12.4	15.4	20.5
4	+1	440	+1	274	12.0	12.7	21.5
5	−1.4144	100	0	210	12.1	15.0	21.1
6	+1.414	500	0	210	9.9	14.4	22.5
7	0	300	−1.414	120	10.8	13.7	22.4
8	0	300	+1.414	300	14.6	12.8	21.5
9	0	300	0	210	12.8	13.6	20.3
10	0	300	0	210	12.1	13.2	19.8
11	0	300	0	210	12.7	13.0	20.5
12	0	300	0	210	11.6	13.6	20.6
13	0	300	0	210	11.5	12.0	20.3

3. Results and Discussions

The results were analyzed by using the regression equation type:

$$Y_0 = b_0 + \sum_{i=1}^{k} b_i \cdot x_i + \sum_{\substack{i,j=1 \\ i \le j}}^{k} b_{ij} \cdot x_i \cdot x_j + \sum_{i=1}^{k} b_{ii} \cdot x_i^2 \tag{1}$$

The experimental data processing was done according to a second-order polynomial model (Cojocaru, 1986; Taloi, 1987). The computing was automatically achieved by Minitab Statistical Software. The validation of the models was obtained by using tests t (Student) and F (Fisher). The adequacy was validated with F-test.

For tenacity of yarns, the experimental data led to the mathematical models given below:

$$Y_1 = 6.928 - 0.4617\, x_1 + 0.3981\, x_2 - 0.3659\, x_1^2 \tag{2}$$

$$Y_2 = 6.958 - 0.4279\, x_1 + 0.1455\, x_2 - 0.3676\, x_1^2 + 0.46\, x_1 x_2 \tag{3}$$

$$Y_3 = 17.8113 - 0.6877\, x_1 - 0.8084\, x_2^2 + 0.6125\, x_1 x_2 \tag{4}$$

For breaking elongation there were obtained the following equations:

$$Y_4 = 12.3261 - 0.6389\, x_1 + 0.8718\, x_2 - 0.6174\, x_1^2 \tag{5}$$

$$Y_5 = 13.1030 - 0.581\, x_1 + 0.666\, x_1^2 \tag{6}$$

$$Y_6 = 20.1050 + 0.521\, x_1^2 + 0.846\, x_2^2 + 0.775\, x_1 x_2 \qquad (7)$$

Analyzing the results, it is noticed that parameters of plasma treatment (power and time) have a great influence upon tenacity and breaking elongation.

The better response at plasma treatment was registered at tenacity for worsted yarns with 20% polyamide (V_2) and 100% polyamide (V_3). The maximum level of tenacity for both types of blends was attended at 100 W in 184 sec, and 250 sec respectively. The yarn containing 100% relon reach the maximum value more quickly if compared to the yarns V_1 and V_2 – so it is more efficient economically speaking.

Computed values of Y_1, Y_2 and Y_3 used the eqs. (2),…,(4) for the optimal points calculated by *Minitab Statistical Software*.

Table 4
Optimal Domains for Tenacity of Worsted Yarns

Type of yarn	Optimal point X_1	Real value X_1, [W]	Optimal point X_2	Real value X_2, [sec]	Computed value for tenacity [cN/tex]
V_1	−0.64609	210	1.41421	300	7.7113
V_2	−1.41421	100	0.62662	250	7.9819
V_3	−1.41421	100	−0.41427	184	19.004

As for the breaking elongation, the values of the coefficients in eqs. (5),…,(7) are slightly bigger than the coefficients of the equations computed for tenacity (2),…,(4). This means that the influence of the unconventional treatment is a little bit higher. It is interesting that Y_5 appears not to be influenced by time (X_2).

4. Conclusions

1. This study continues a previous research concerning the influence of cold plasma treatment upon wool fibres and yarns.
2. The plasma treatment changes the surface morphology of textile fibres (wool, polyamide) so the physical-mechanical characteristics are depending on its duration and intensity.
3. Worsted yarns with little amount of chemical fibres (10% or 20%) treated in plasma medium have a higher tenacity and a better elongation, levels compared to yarns with a bigger percentage of polyamide. The advantage of using small percentages of relon is that these yarns have also a good hygroscopicity and the character specific to wool fibres.
4. The research underlines the idea of replacing the traditional chemical treatments with environment-friendly treatment as plasma.

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TRATAMENT NECONVENŢIONAL DE SUPRAFAŢĂ PENTRU FIRELE TIP LÂNĂ PIEPTĂNATĂ

(Rezumat)

Această lucrare prezintă rezultatele referitoare la tenacitate (cN/tex) şi alungirea relativă la rupere (%) a firelor tip lână pieptănată după tratamentul în mediu de plasmă. Sunt testate trei tipuri de amestecuri fibroase: 90% lână + 10% relon (nylon 6), 80% lână + 20% relon şi 100% relon. Pentru modelarea matematică a fost utilizat un program central compus rotabil cu două variabile independente. Pentru că există diferenţe în ceea ce priveşte structura chimică a fibrelor de lână şi a celor de relon (nylon 6), proprietăţile dinamometrice se modifică în mod diferit pentru cele trei variante, depinzând de gradul de modificare a suprafeţei.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 3, 2013
Secţia
TEXTILE. PIELĂRIE

ANALYSIS AND MATHEMATICAL MODELLING OF WATER SORPTION IN FLAX, HEMP AND JUTE, AN IMPORTANT PROPERTY OF THESE TECHNICAL YARNS

BY

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Received: August 5, 2013
Accepted for publication: September 3, 2013

Abstract. Yarns of flax, hemp and jute offer the possibility of obtaining ecological products. Flax and hemp assure conditions for the effective exploitation of national natural resources and the support of the re-launching program for the cultivation of the plants from which flax and hemp fibres are extracted. In the present paper the properties of sorption of the yarns and the mathematical modelling of this process are analyzed.

Key words: flax, hemp, jute, sorption, regression.

1. Introduction

When considering possible uses of the fibres and yarns and for their manufacture it is important to know their water sorption capacity (Manualul inginerului textilist, 2002). Therewith, the water content of fibres and yarns raises problems related to the quantitative reception of materials.

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This paper is the full version of the paper published in abstract only at Technical Textiles – Present and Future Symposium, Iaşi, October, 2013

The moisture content of the fibres depends on the atmospheric conditions. It is directly dependent on the air pressure, relative humidity and air temperature. The accumulation of water vapours on and inside fibres influences their quality because it leads to the modification of some of the properties of the fibers, especially of the mechanical ones (Mâlcomete, 1995; Ionescu-Muscel, 1990; Vlad, 1964).

The compactness of the fibres in yarns changes the wetting process. Thus, duration of the stationary in water until equilibrium influences the quantity of water inside of yarns.

This research presents the process of the sorption of water by yarns made of flax, hemp and jute fibres, because this is one of the most important properties of the textile materials. The aim of this paper is the mathematical modelling of the water sorption in flax, hemp and jute yarns.

2. Materials and Methods

The paper studies two types of yarns with the same length density (55.5 tex), one from hemp and the other from flax, yarn flax 50 tex and yarn jute 333.3 tex. Duration for stationary in water was the same for all the studied yarns: 1 min, 5 min, and 10 min. For each type of the yarn and duration were made ten measurements. The samples with the same length were weighted in dry state and after the wetting. In the processing of the experimental data on loading with water of the yarns from flax, hemp and jute was used the statistical program SPSS (Statistical for the Social Sciences), version 19, under Windows operating system (Slabu, 2007; Lungu, 2001). This program SPSS is easy to operate, it presents the results in tables and graphs easier to follow and includes techniques and procedures from simple processing until the certain complex statistics. In each case, the availability of a bivariate regression with the independent variable (mass of sample in dry stage) and the dependent variable – mass of the sample after wetting one minute, five minutes or ten minutes were studied.

3. Results and Discussions

Based on the experimental data using the software SPSS were obtained the regression equations that expresses properly the behaviour to the moisture content of the yarn analyzed. The tested textile yarns and the resulted equations are presented in Table 1.

Table 1

The Tested Textile Yarns and the Resulted Equations

Type of yarns	Wetting duration	Equations	Coefficients			
			R−Corelation coef.	R Square Determination coef.	Student test value, t for x coefficient	Fisher−Snedecor F 1 and 8 degree of freedom, 95% confidence interval
55.5 tex (Nm 18), flax yarn	1 min	(1): Y = 2.517 X −0.021	0.830	0.689	4.207	17.699
	5 min	(2): Y = 2.688 X −0.012	0.934	0.873	7.429	55.107
	10 min	(3): Y = 2.798 X −0.008	0.949	0.900	9.438	72.046
55.5 tex (Nm 18), hemp yarn	1 min	(4): Y = 2.436 X −0.027	0.775	0.601	3.472	12.054
	5 min	(5): Y = 3.069 X −0.041	0.779	0.607	3.515	12.358
	10 min	(6): Y = 3.534 X −0.062	0.709	0.503	2.843	8.083
50 tex (Nm 20), flax yarn	1 min	(7):Y = 2.1951X −0.007	0.756	0.571	3.262	11.762
	5 min	(8):Y= 2.5860 X −0.009	0.753	0.567	3.237	10.478
	10 min	(9): Y = 2.7520 X−0.014	0.765	0.585	3.356	11.263
333.3 tex (Nm 3), jute yarn	1 min	(10): Y = 2.236 X −0.350	0.859	0.738	4.749	22.553
	5 min	(11): Y = 2.598 X +0.329	0.932	0.869	6.598	43.540
	10 min	(12): Y = 2.949 X +0.080	0.919	0.845	6.598	43.540

F_t = 5.32 for 1 and 8 degree of freedom and 95% confidence interval (Biji & Biji, 1979).

A comparative study will be made and for the flax yarn 55.5 tex there will be presented in detail the regression analysis performed with SPSS software that contains five tables and a graphical representation type scatergrama for each regression equation. For the wetting times of 1 min, 5 min, 10 min, the following regression equations were obtained:

$$Y = 2.517\ X - 0.021 \qquad (1\ \text{min}) \tag{1}$$

$$Y = 2.688\ X - 0.012 \qquad (5\ \text{min}) \tag{2}$$

$$Y = 2.798\ X - 0.008 \qquad (10\ \text{min}) \tag{3}$$

For every regression equation, the analysis was performed by showing statistical data in tables, as follows:

For the regression eq. (1): Y = 2.517X −0.021 (1 min wetting time) were obtained: statistical data in Tables 2,…,5.

Table 2 shows the independent variable x (as the dry mass of the sample) and the working method − of the smallest squares.

In Table 3 are specified the values of the correlation coefficient of Pearson's R, which is 0.83 and measures the correlation between the variables studied, respectively the connection is strong and positive. The coefficient of determination (R2) is 0.689 and reflects that the almost 70% of the total variance of the measured values for the dependent variable (mass of sample after one minute wetting) is due to the influence of the independent variable. This coefficient reflects the predictive power of the studied model. Namely the change of the determination coefficient is not significant when other variables are added in the model. The value of over 17 of the test Fisher−Snedecor (Table 4) as compared to the tabulated value Ft = 5.32 for the same degrees of freedom (df1 = 1, df2 = 8) and the same statistical certainty (95%) (Biji & Biji, 1979), reflects that the eq. (1) expresses satisfactorily the process.

Table 2

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X− dry mass of the flax yarn 55.5 tex[a]	Y−mass of the flax yarn 55.5 tex after 1 min wetting	The smallest squares

a. All requested variables entered; b. Dependent Variable: Y

Table 3

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.830[a]	0.689	0.650	0.00806793

a. Predictors: (Constant), X−dry mass of the flax yarn 55.5 tex

In Table 4 are specified the components of dispersion ANOVA analysis, the variation of the dependent variable due to the independent variable, the residual variation due to the influence of other variables and all their residual amount which is the sum of squared the differences between the values measured of the dependent variable and its values computed with the equation of regression.

In Table 5 are presented the unstandardized coefficients of the mathematical model (regression constant and regression coefficient), standard regression coefficient, and the t−test to verify the statistical hypothesis that the unstandardized coefficients of this model are different from zero and also are provided the confidence intervals for the estimates non−standard of the linear regression.

Table 4
ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	0.001	1	0.001	17.699	0.003[a]
Residual	0.001	8	0.000		
Total	0.002	9			

a. Predictors: (Constant), X−dry mass of the flax yarn 55.5 tex.; b. Dependent Variable: Y−mass of the flax yarn 55.5 tex after 1 min wetting

Table 5
Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Conffidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
1 (Constant)	−0.021	0.034		−0.622	0.552	−0.099	0.057
X−dry mass of the flax yarn 55.5 tex	2.517	0.598	0.830	4.207	0.003	1.137	3.897

a. Dependent Variable: Y−mass of the flax yarn 55.5 tex after 1 min wetting

The scatergrama in Fig. 1 shows the graph of the cumulated probabilities of the standardized residuals, where the points distributed over the line have the tendency to overstate the reality, and those below the line under estimated it.

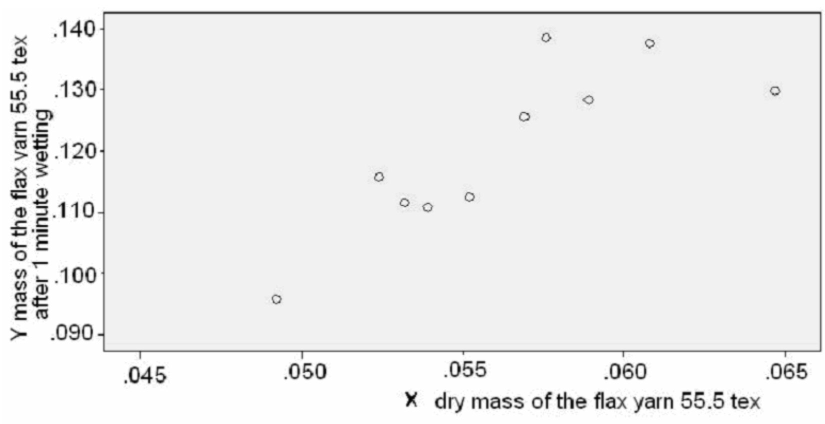

Fig. 1 − Scatergrama for regression eq. (1).

For the regression eq. (2): $Y = 2.688X − 0.012$ (after 5 min wetting) the following data was obtained:

Table 6

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.934[a]	0.873	0.857	0.00488162

Predictors: (Constant), X−dry mass of the flax yarn 55.5 tex

Table 7

ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.001	1	0.001	55.107	0.000[a]
Residual	0.000	8	0.000		
Total	0.002	9			

a. Predictors: (Constant), X−dry mass of the flax yarn 55.5 tex.; b. Dependent Variable: Y−mass of the flax yarn 55.5 tex after 5 min wetting

Table 8

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Conffidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
1 (Constant)	−0.012	0.020		−0.587	0.573	−0.059	0.035
X−dry mass of the flax yarn 55.5 tex	2.517	0.598	0.934	7.423	0.000	1.853	3.522

a. Dependent Variable: Y−mass of the flax yarn 55.5 tex after 5 min wetting

Data analysis in Tables 6,…,8 has concluded that eq. (2) expresses correspondingly the connection between mass of the yarn 55.5 tex in the dry state and after 5 min wetting because the calculated values of tests Fisher−Snedecor and Student exceed the tabulated values for the same degrees of freedom (1 and 8).

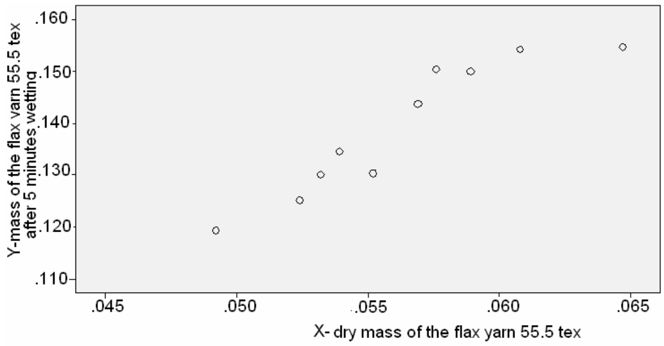

Fig. 2 − Scatergrama for the regression eq. (2).

For the regression eq. (3): $Y = 2.798X - 0.008$ (after 10 min wetting) the following data was obtained:

Table 9
Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.0949[a]	0.900	0.888	0.00444547

a. Predictors: (Constant), X−dry mass of the flax yarn 55.5 tex

Table 10
ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	0.001	1	0.001	72.046	0.000[a]
Residual	0.000	8	0.000		
Total	0.002	9			

a. Predictors: (Constant), X−dry mass of the flax yarn 55.5 tex.; b. Dependent Variable: Y−mass of the flax yarn 55.5 tex after 10 min wetting

Table 11
Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Conffidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
1 (Constant)	−0.008	0.019		−0.421	0.685	−0.051	0.035
X−dry mass of the flax yarn 55.5 tex	2.798	0.330	0.949	8.488	0.000	2.038	3.559

a. Dependent Variable: Y mass of the sample immersed in water 10 min (flax yarn 55.5 tex)

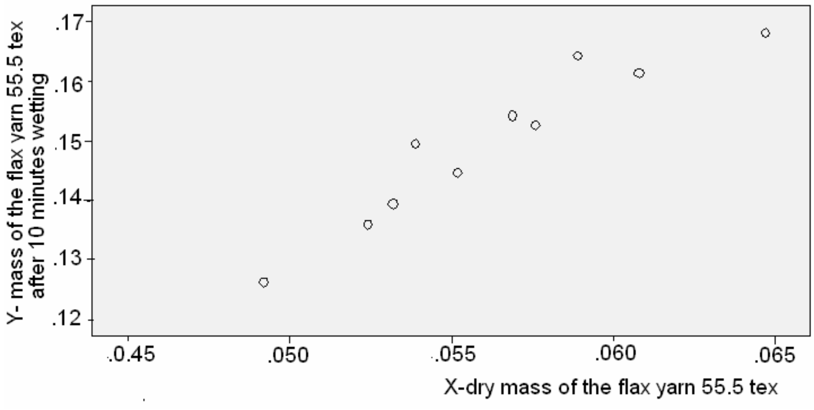

Fig. 3 − Scatergrama of the regression eq. (3).

Further on are studied comparatively the sorption process for the proposed yarns from flax, hemp and jute. In Table 1 are centralized all the determined equations, the calculated values of the correlation coefficients, the bivariate determination, the Student t test and Fisher−Snedecor test. The correlation coefficient R has values between 0.709 and 0.949 meaning a strong positive relationship between the independent variable and that dependent.

Influence of the other factors is from 13 to 49%, the predictive power of mathematical models studied is beyond 70% for the flax yarn 55.5 tex and jute yarn 333.3 tex. For the hemp yarn 55.5 tex and the flax yarn 50 tex, the coefficient of determination has values ranging from 0.5 and 0.6, which means that the predictive power of the mathematical models is lower in these cases.

The mathematical models are adequate, because the value of the Fisher−Snedecor test, calculated as the ratio between the dispersion caused by regression and the dispersion of the measured values deviation from regression is higher than the F_t value listed for the same degrees of freedom, and a statistic confidence of 95%, see Table 1.

First of all, comparative analysis was performed following the behavior towards moisture of the yarns with the same length density of 55.5 tex (Nm 18), one from hemp and other from flax. Analysis of the corresponding sets of equations allows the following comments:

− Regression equations corresponding of the stationary interval in water of 1 min has comparable values of regression coefficients for the two types of yarns. This means similar moisture absorption velocities.

− At duration of stationary in water of 5 and 10 min the amount of water absorbed by the hemp yarn is higher, as reflected by the coefficients of the independent variable x, from the equations of regression, which is higher by about 20% for the hemp yarn in comparison to that of the flax yarn. This may be due to higher speed of water sorption by hemp yarn.

− Correlation coefficient values between 0.7 and 0.94 (Table 1) show a strong link between the two variables of the regression equations.

− In the case of the two yarns from hemp and flax with the same length density 55.5 tex, the coefficient of determination has values ranging from 0.6 and 0.9 and reflects the predictive power of the model studied. These values reflect the fact that 60% to 90% of the total variation of the measured values for the dependent variable (wet mass of the yarn 55.5 tex from flax and hemp) is due to the independent variable, the dry mass of these yarns. This means that the influence of other factors is 10% to 40%. For the all of the six equations established for flax and hemp yarn with the same length density (55.5 tex) t−statistic values were calculated to verify the significance of the regression coefficient of the independent variable x. In all cases, the calculated value of this statistic is higher than the standardized value, see Table 1. Therefore, the review coefficients are significant.

The mathematical model represented by the regression eqs. (1),…,(6) express satisfactorily the absorption process of water by yarns from hemp and flax for 1 min, 5 min and 10 min immersion. This is confirmed by the calculated values of Fisher−Snedecor test (which compares the experimental dispersion and the deviation from the regression) that are higher than the standardised value (for 1 and 8 degrees of freedom and a significance level of 95%), see Table 1.

In case of the thinner yarn of 50 tex (Nm 20), the three regression equations established are (7), (8), (9). They have significantly the regression coefficient of the independent variable tested by the value of t statistics, (Table 1). The mathematical model approximated by these equations expresses satisfactorily the analysed process, as reflected by values calculated for Fisher−Snedecor test, see Table 1.

The intensity of the connection between y − dependent variable and x − independent variable is reflected by the correlation coefficient R and has values between 0.753 and 0.765, which is a strong correlation in this case. The coefficient of determination between 0.571 and 0.585 shows that influence of the other factors is about 42− 43%.

In comparison with the thicker yarn of 55.5 tex, the thin yarn of 50 tex (Nm 20), the rate of the water sorption is reduced for the same duration of wetting. This may be due to greater compactness of the thin yarn.

The jute yarn 333.3 tex (Nm 3) has allied behavior towards of moisture with the flax yarn 55.5 tex (Nm 18), see equations: (10), (11), (12) beside of (1), (2), (3), (Table 1). This is based on the fact that the values of the coefficient of correlation R are close in the case of these two yarns. Influence of the other factors in the case of jute yarn, is situated between 15 and 27%, as the coefficient of determination is included between 0.73 and 0.84. To the flax yarn 55.5 tex the influence of the other factors is between 10 and 32%, because the coefficient of determination has values ranging from 0.68 and 0.90.

4. Conclusions

The regression equations established on the basis of experimental data allow predicting without other experiments of the yarn mass for jute yarn (333.3 tex), flax yarns (55.5 tex and 50 tex), hemp yarn (55.5 tex), after 1 min, 5 min, 10 min moistening.

One can calculate the dry mass of these yarns if their mass in wet condition after one moistening specified intervals is known. These equations may be useful in commercial transactions allowing the instant calculation of the net mass for the marketed yarns from flax, hemp and jute.

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ANALIZA ŞI MODELAREA MATEMATICĂ A ABSORŢIEI APEI ÎN FIRELE TEHNICE DE IN, CÂNEPĂ ŞI IUTĂ, O PROPRIETATE IMPORTANTĂ A ACESTORA

(Rezumat)

Firele de in, cânepă şi iută oferă posibilitatea de a obţine produse ecologice. Inul şi cânepa asigură condiţii pentru exploatarea eficientă a resurselor naturale naţionale şi susţinerea programului de re-lansare pentru cultivarea plantelor din care sunt extrase fibrele de in şi cele de cânepă. În lucrarea de faţă este analizată proprietatea de absorbţie a apei de către firele de in, cânepă şi iută cu utilizare în diverse domenii ale tehnicii şi nu numai, realizându-se modelarea matematică a acestui proces. Ecuaţiile stabilite pot fi utilizate în tranzacţiile comerciale permiţând calcularea instantanee a masei nete pentru firele comercializate din in, cânepă şi iută.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 3, 2013
Secţia
TEXTILE. PIELĂRIE

SIMULATION MODEL FOR THE LOOMS INTERFERENCE PROBLEM BASED ON REWARDS COLORED PETRI NETS

BY

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Received: August 30, 2013
Accepted for publication: September 11, 2013

Abstract. A weaving machines (looms) interference problem is treated in this paper. For a group of looms allocated to the weaver (loom operator), two indicators must be evaluated: the looms efficiency and the work loading for the weaver. Two different approaches are available: analytical approach, based on Markov chains, and simulation. To address the looms interference problem, a stochastic rewards colored Petri nets model is proposed in this paper. On compared with others Petri nets models (see for example, Caşcaval, 1999; Caşcaval & Caşcaval, 1999; Caşcaval & Ciocoiu, 1999; Caşcaval & Ciocoiu, 2000b; Caşcaval & Caşcaval, 2005), this new simulation model is simpler from graphical point of view and easier for software implementation.

Key words: weaving machines (looms), looms interference problem, colored Petri nets, stochastic rewards Petri nets.

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This paper is the full version of the paper published in abstract only at Technical Textiles – Present and Future Symposium, Iaşi, October, 2013

1. Introduction

The weaving process is a discrete event because the warp yarns and the filling yarn break off at random instants. In case a loom is down because a yarn has broken, the loom operator remedies the broken yarn and then starts up the loom again. In other words, a weaving machine (loom) is a system with repair. The problem of allocation of looms to the weaver is a very important one in a large weaving mill. The prediction of the loom efficiency and the weaver work loading according to the number of looms allocated to the weaver is a machines interference problem. This important problem is widely treated in textile literature, from both a theoretical point of view and practical one (Bona, 1993; Caşcaval & Ciocoiu, 2000a; Caşcaval & Ciocoiu, 2000b).

The analytical approach for the machines interference problem is based on the theory of queues. The standard model is a Markov chain for which the steady–state probabilities are required. For a Markov chain with s states, a system with s linear equations must be solved. This method is simple in essence but, unfortunately, the state space of the Markov chain increases rapidly (Bona, 1993; Caşcaval, 1999; Caşcaval, 2013). For any sizable practical problem s becomes very large and the solution time becomes very long, so that, the classical approach is difficult to apply. Approximate techniques able to tolerate the largeness or avoid it are necessary is these cases (Caşcaval, 2013).

The simulation is a complementary approach for the machine interference problem. As a simulation model, the formalism of Petri nets can be used (Caşcaval, 1999; Caşcaval & Ciocoiu, 2000b). A new simulation model based on stochastic coloured Petri net formalism is proposed in this paper.

This paper is organized as follows. In Section 2 the weaving machines interference problem is defined. Section 3 presents a new model of the weaving process based on the formalism of both coloured Petri nets and the stochastic rewards Petri nets. Finally, some conclusions regarding this work are drawing in Section 4.

2. Problem Formulation

Consider a weaving process completely known from a statistical point of view. The stochastically model of the weaving process includes six primary random variables, as follows:

• The working time broken by a breakage of the warp yarns (WTW) − let λ_W be the breakage rate of the warp yarns;

• The working time broken by a yarn breakage into the shed (WTS) − let λ_S be the breakage rate of the filling yarn into the shed;

• The working time broken by a filling yarn breakage between the prewinder and the active package (WTP) − let λ_P be the rate of these filling yarn breakages;

• Time to remedy a warp yarns breakage (TRW) – let μ_W be the remedying rate of the warp breakages;

• Time to remedy a filling yarn breakage into the shed (TRS) – let μ_S be the remedying rate of filling yarn breakages into the shed.

• Time to remedy a filling yarn breakage between the prewinder and the active package (TRP) – let μ_P be the remedying rate of this kind of filling yarn breakages.

Suppose we know the distribution functions for all these six primary random variables, including the parameters λ_W, λ_S, λ_P, μ_W, μ_S, and μ_P. For only one loom served by a weaver, the efficiency (*EF*) is given by the following equation:

$$EF = \frac{1}{1 + \frac{\lambda_W}{\mu_W} + \frac{\lambda_S}{\mu_S} + \frac{\lambda_P}{\mu_P}} \times 100, \ [\%] \tag{1}$$

When the weaver serves two or more looms, a loom interference time may occur reducing the efficiency of the looms. In that case, we have to solve a prediction problem regarding the efficiency of the looms, and the weaver work loading, according to the number *m* of looms allocated to the weaver.

To simplify this prediction problem, the following assumptions are widely accepted:

• the yarn breakage events are stochastically independent;

• a loom is either up or down, with no intermediate states.

3. Simulation Model Based on the Petri Nets Formalism

For a simulation approach, the weaving process for this group with *m* looms allocated to the weaver can by model by using Petri nets. Note that, the formalism of Petri nets is a powerful mathematical modeling language for description of the discrete-event systems. Such a simulation model for the looms interference problem is presented in (Caşcaval, 1999; Caşcaval & Caşcaval, 1999; Caşcaval & Ciocoiu, 1999; Caşcaval & Ciocoiu, 2000b; Caşcaval & Caşcaval, 2005), where the description is based on the rules of stochastic coloured Petri nets (Jensen, 1992). In this work, a simplified modelling is proposed by using a feature specific to the stochastic reward Petri nets (RPNs) that makes specification more convenient (Delaney & Vaccari, 1999; Trivedi, 2002). So, a transition of the Petri net may have a *guard* (also called an *enabling function*) that is marking-dependent. A transition is enabled in a marking only if its guard (a Boolean condition) is satisfied, in addition to the constraints imposed by input arcs. This feature provides a powerful means to simplify the graphical representation and to make the Petri net easier to be understood.

To model the weaving process as a discrete-event one, seven states have to be considered for each weaving machine:

− The loom is working;

− The loom has stopped because a warp yarn is broken – a weaver intervention is necessary;

− The loom has stopped because the filling yarn is broken into the shed – a weaver intervention is necessary;

− The loom has stopped because the filling yarn is broken between the prewinder and the active package – a weaver intervention is necessary;

− The loom is stopped and the warp breakage is under remedying;

− The loom is stopped but the filling yarn breakage into the shed is under remedying;

− The loom is stopped but the breakage between the prewinder and the active package is under remedying.

Considering these states, the weaving process for a group with *m* looms allocated to the weaver can be modelled by a stochastic reward colored Petri net as presented in Fig. 1. The places in this Petri net have the following meanings:

• P_{warpUp} − reflects the machines without warp breaks.

• P_{shedUp} − reflects the machines without filling break into the shed.

• P_{prewUp} − reflects the machines without filling break between the prewinder and the active package.

• P_{warpDn} − reflects the weaving machines down because of a warp breakage.

• P_{shedDn} − reflects the weaving machines down because of a filling breakage into the shed.

• P_{prewDn} − reflects the weaving machines down because of a filling breakage between package and prewinder.

• $P_{warpRem}$ − reflects the machines which have a broken warp yarn under remedying.

• $P_{shedRem}$ − reflects the machines with the filling yarn into the shed under remedying.

• $P_{prewRem}$ − reflects the machines with the filling yarn between the prewinder and the package under remedying.

• P_{weaver} − reflects the state of weaver (when all the looms are working, the worker is available).

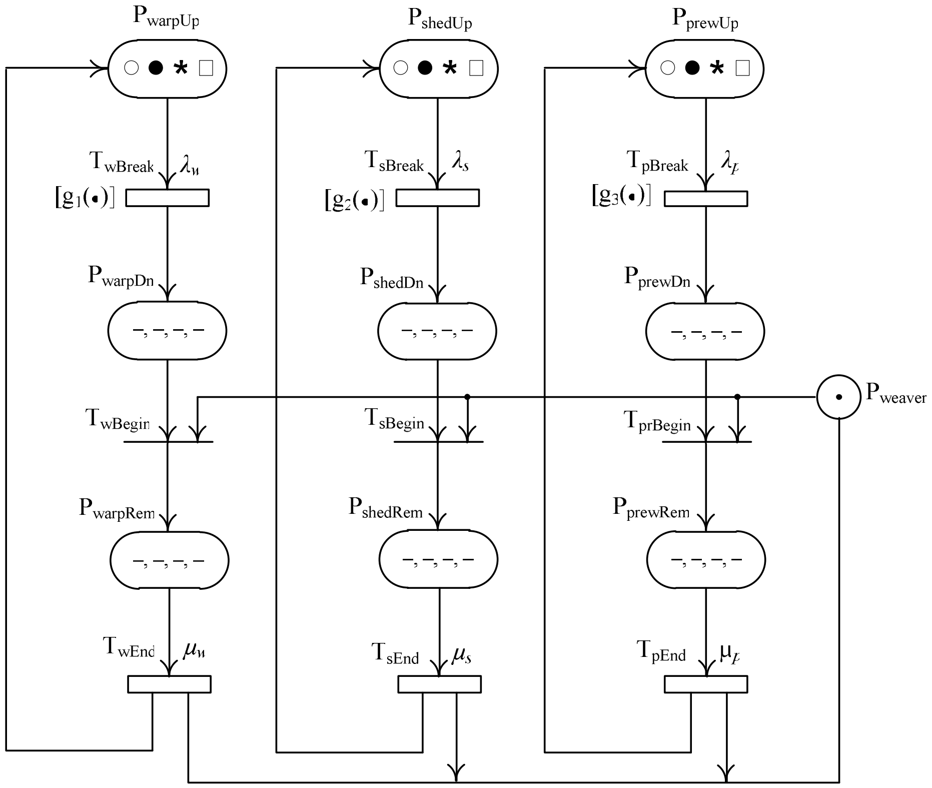

Fig. 1 − Stochastic reward coloured Petri net for the looms interference problem (m = 4).

The transitions in this Petri net have the following meanings:

• T_{wBreak} − a warp breakage has occurred.

• T_{sBreak} − the filling yarn has broken off into the shed.

• T_{pBreak} − the filling yarn has broken off between the prewinder and the active package.

• T_{wBegin} − the warp yarn remedy has started.

• T_{sBegin} − the filling yarn remedy into the shed has started.

• $T_{prBegin}$ − the filling yarn remedy between the prewinder and the package has started.

• T_{wEnd} − the warp yarn remedy has finished.

• T_{sEnd} − the filling yarn remedy into the shed has finished.

• T_{pEnd} − the filling yarn remedy between the prewinder and the package has finished.

In Fig. 1, the four looms we have considered are identified by specific symbols: °, •, *, and □. Note that, in a colored Petri net, a transition can be fired for only one system (represented by a specific symbol or color) at a time.

The Boolean functions, g_1, g_2 and g_3 have the following meanings:

• $[g_1(s)]$: $\# P_{shedUp}(s) > 0$ AND $\# P_{prewUp}(s) > 0$
• $[g_2(s)]$: $\# P_{warpUp}(s) > 0$ AND $\# P_{prewUp}(s) > 0$
• $[g_3(s)]$: $\# P_{warpUp}(s) > 0$ AND $\# P_{shedUp}(s) > 0$

where $s \in \{1, 2, ..., m\}$ is one of the loom for which the transition from the working state to a down state is checked for firing.

On compared with the Petri nets presented in (Caşcaval, 1999; Caşcaval & Caşcaval, 1999; Caşcaval & Ciocoiu, 1999; Caşcaval & Ciocoiu, 2000b; Caşcaval & Caşcaval, 2005), this model is simpler and easier to understand.

4. Conclusions

The model of the looms interference problem presented in this paper describes the weaving process in the more simple case, without filling break tolerance, without other facilities such as the automatic filling repair of the yarn breakage into shed, with only one weaver etc. But, this model can be extended to cover these complex problems of looms interference. For example, if more loom operators (say *n*) serve the group of *m* weaving machines, then in the Petri net presented in Fig. 1, the place P_{weaver} must have *n* as initial marking.

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MODEL DE SIMULARE PENTRU PROBLEMA INTERFERENŢEI MAŞINILOR DE ŢESUT BAZAT PE FORMALISMUL REŢELELOR PETRI STOCASTICE

(Rezumat)

Această lucrare prezintă un studiu asupra problemei de interferenţă a maşinilor de ţesut. Pentru un grup de maşini alocate unui ţesător, trebuie să se evalueze randamentul maşinilor şi gradul de ocupare a muncitorului. În acest scop se pot utiliza două metode: una analitică care foloseşte teoria modelor Markov, şi alta bazată pe simulare numerică. Pentru rezolvarea problemei de interferenţă a maşinilor se propune un model bazat pe noi facilităţi privind reţelele Petri stochastice colorate. În comparaţie cu alte modele de reţea Petri prezentate în literatură, acest model este mai uşor de înţeles, mai simplu din punct de vedere al reprezentării grafice şi al implementării software.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 3, 2013
Secţia
TEXTILE. PIELĂRIE

WOVEN FILTER FABRICS WITH FUNCTIONAL DESIGN

BY

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Received: August 1, 2013
Accepted for publication: September 4, 2013

Abstract. The woven fabrics meant for filter manufacturing are characterized by a determined functionality. The relation between structure, properties and usage represents a criterion of designing and selection in a manner that corresponds to their destination. The properties of filter medium about the mounting system are important for the mechanical implementation of the filter, respectively the filter medium set up on the support frame.

Functional design of the woven filters, with reference to the mounting, requires a compliance criterion concerning to an overall design of the product, which to allow a uniform takeover of the operating efforts and to provide safety during functioning.

Key words: woven filter fabric, pore area, weave structure, double layer, tubular.

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This paper is the full version of the paper published in abstract only at Technical Textiles – Present and Future Symposium, Iaşi, October, 2013

1. Introduction

The filtration as a component of a technological process covers a wide field in industry and also in research work. The type of the filtering equipment and filtering fabric used determines the quality of the filtration. On its turn, the membrane (the filtering layer) acts depending on its structure, the process conditions, the type of the chemical agent, the temperature, pressure, flow speed and on the characteristics of the filtered liquid.

When considering the complexity of the filtration phenomenon both for liquid or solid phase and for aerosol, and also the great diversity of the industrial branches that use the filtration process, the huge importance of the filtering fabrics is outlined.

The woven fabrics meant for filter manufacturing are characterized by a determined functionality. The relation between structure, properties and usage represents a criterion of designing and selection in a manner that corresponds to their destination.

The woven filtering media are products that can be differentiated by structure and properties in close conformity with the requirements and specifics of the process they function in (Adanur, 1995; Harracks & Anand, 2000; Behera & Hari, 2010; Cioară & Cioară, 2009). Necessarily, the filter structure is associated with the principle by which the separation of the particles from the blend takes place (surface filtering or depth filtering).

2. Materials and Methods

Woven filter media are products that are differentiated by structure and properties in strict accordance with the requirements and particularities of the process in which they operate. The filter medium structure is necessarily associated with the principle used to separate the mixture particles. The resulting filter medium and the sets of different properties define its quality and respectively its functionality (Cioară & Cioară, 2009; Condurache *et al.*, 2004; Medar & Ionescu, 1986). For an objective evaluation of the filter media quality (functionality), three groups of properties have been identified as follows:

− properties related to filter medium mounting system type. Those properties are important for the mechanical implementation of the filter respectively the filter medium set up on the support frame. Among the key properties of this group there are: stiffness, tensile strength, tear resistance, burst strength, abrasion resistance, vibration stability, elongation, the edges stability;

− properties related to the type of application, that is taking in consideration the compatibility between the filter medium and the processed medium. In this category fall the following properties: chemical stability, thermal stability, biological stability, dynamic stability, adsorption, absorption, operational safety and security, electrostatic characteristics, reuse capability, price;

− properties addressing specific filtrations process particularities underlining the filter medium capacity to comply with required demands. The most important properties of this group are: the smallest particle retained, retention efficiency, the structure of filter media, particle shape, used filtering mechanisms, flow resistance, porosity of filter media, permeability, tendency to clog, filter−cake discharge characteristics.

For each filter medium, depending on the field of use and the requirements in service, only some of these properties are necessary. As a result, the design of woven textiles intended to be used as filter media must be made in accordance with the functionality criteria, ensuring priority to the properties requested by the process.

The function to be durable, considered a secondary function, is determined by the structural characteristics of the woven filter fabric, but equally by the operating conditions.

For industrial installations such as filtering installations for the mining, oil, pulp and pharmaceutical industry it is important that the changing rate of the filters is the lowest possible.

The filters are changed when a major clogged affects the filtering process or when the filter is mechanically destroyed. The mechanical destruction of the filters can occur when the clamping system does not ensure a uniform distribution of the usage requirements or the clamping system causes additional stress and so, it allows the appearance of vulnerable areas (Cioară *et al.*, 2003; Cioară *et al.*, 1991).

The functional design of filters with respect to the mounting requires compliance with the following criteria:

− an overall design of product, in order to enable the uniform takeover of the exploitation requests;

− a product design that ensures the safety in functioning of the installation.

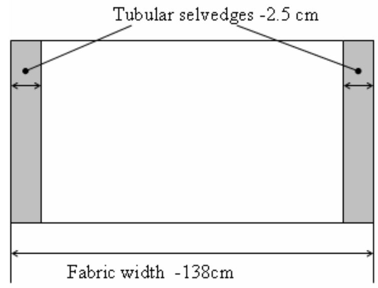
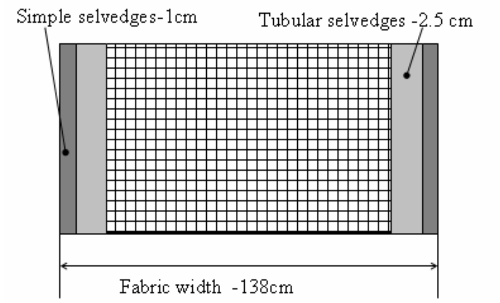
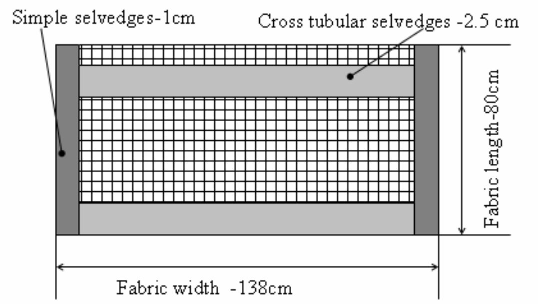
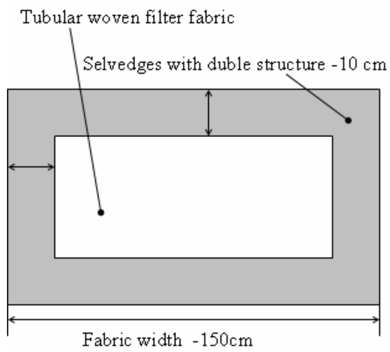
For certain categories of industrial filters, a fixing or a clamping system that eliminates these vulnerabilities is designed.

3. Results and Discussions

This paper presents some products with weave structures adapted to the fixing systems in industrial filtration plants. Table 1 presents the graphical sketches of such products.

The first category of woven filter fabrics with a special structure is used to filter oil drilling fluids: woven filter fabric 40 mesh, 50 mesh, 60 mesh with tubular selvedge. These woven filter fabrics are attached to the vibrating frames which exercise a cyclical pressure on filter. The stress cycle causes the fatigue phenomenon of the fabric. The drilling fluid exerts a pulsating pressure which acts on the filter.

Table 1
The Design of Different Types of Woven Filter Fabric

<table>
<tr><th>Type of woven filter fabric</th><th>Graphical representation</th></tr>
<tr><td>Woven filter fabric with tubular selvedge</td><td>
</td></tr>
<tr><td>Woven filter fabric with simple and tubular selvedge</td><td>
</td></tr>
<tr><td>Woven filter fabric with simple and cross tubular selvedge</td><td>
</td></tr>
<tr><td>Woven filter fabric with tubular structure as background
and selvedge with double structure as frame</td><td>
</td></tr>
</table>

The working conditions for these categories of woven filter fabrics are:
− the fluid flow of the emulsion is 12−35 l/s;
− the temperature of the fluid is 50−60ºC;
− the frequency of vibrations is 1500 vibrations per minute;
− the amplitude of vibrations is 30 mm.

For these reasons the filters required a design that decreased the stress in the mounting areas and a uniform distribution of the filtrate on the surface of the filter medium.

A solution for fixing of filters in frame was designing of tubular selvedges. Fixing bars with a diameter ϕ=16 mm are placed in these selvedges.

On the other direction the woven filter fabric is fixed by pressure with rubber seals that are pretensed at a known value. A uniform takeover request during operation is ensured from the start. The finished fabric width is correlated with the frame size in which the woven filter fabric is fixed. Table 2 presents the characteristics of the woven filter fabrics 40, 50 and 60 mesh with tubular selvedge.

Fig. 1 shows a picture of a woven filter fabric 40 mesh, where the tubular selvedge can be seen. Figs. 2, 3 and 4 illustrate the programming schemes for woven filter fabric with tubular selvedges. In all programming schemes, the drawing of weave structure is reduced to any number of patterns for background and selvedge weave, so that the representation of the woven fabrics is more suggestive.

Table 2
Woven Filter Fabrics with Tubular Selvedges

Structural properties of woven filter fabric		Woven filter fabric		
		40 mesh	50 mesh	60 mesh
Woven fabric width		138 cm	138 cm	138 cm
Selvedge width		2.5 cm	2.5 cm	2.5 cm
Weave structure	Background	Basket 2/2 2/2	Plain 1/1	Twill 2/2
	Selvedge	Tubular	Tubular	Tubular
Fibre type		Monofilament polyamide		
Yarns diameter	Warp	0.15 mm	0.15 mm	0.15 mm
	Weft	0.15 mm	0.15 mm	0.15 mm
Yarns density	Warp	32 threads/cm	20 threads/cm	23.6 threads/cm
	Weft	32 threads/cm	20 threads/cm	23.6 threads/cm
Pore area		0.1122 mm^2	0.1225 mm^2	0.0794 mm^2
Active filtering surface		28.73%	49%	41.8%
Woven fabric weight		98 g/m^2	65 g/m^2	76.8 g/m^2

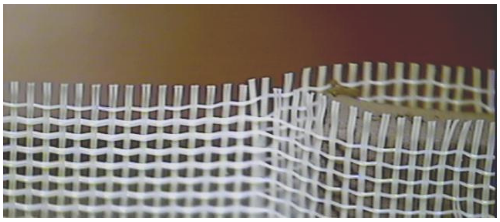


Fig. 1 − Woven filter fabric 40 mesh with tubular selvedge.

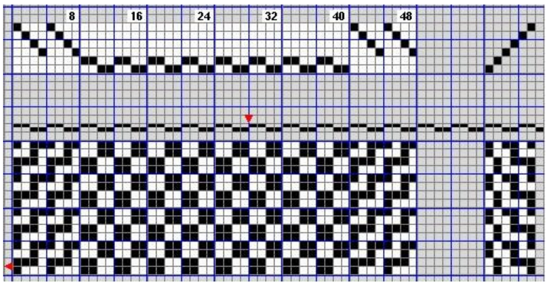


Fig. 2 − The programming scheme for a woven filter fabric 40 mesh with tubular selvedges.

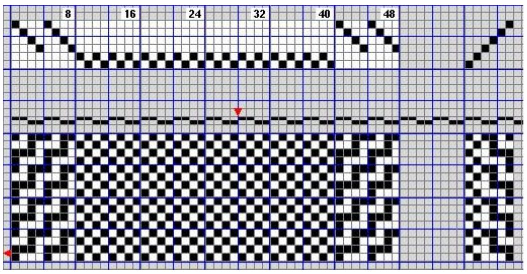


Fig. 3 − The programming scheme for a woven filter fabric 50 mesh with tubular selvedges.

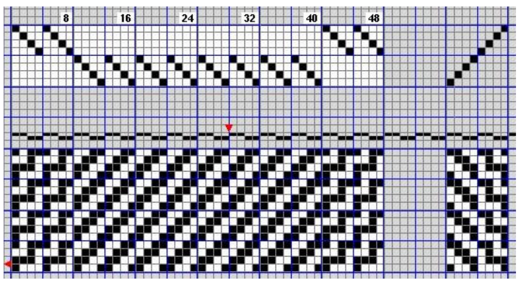


Fig. 4 − The programming scheme for a woven filter fabric 60 mesh with tubular selvedges.

The woven filter fabrics of fineness 120 mesh are fine fabrics. In their exploitation they are supported by coarser supports. A design to enhance the efficiency of these filters requires a mounting system similar to the previous examples. Also, bidirectional reinforcing grids can be inserted in order to remove the filter holder, which will take the load off the filter itself. In case of filters over one meter wide, the clamping rod can be placed in the fabric selvedges. The woven filter fabrics with an opening smaller than 0.5 −1 m can have a transversal selvedge.

Table 3 presents the structural properties of the woven filter fabric 120 mesh reinforced with transversal and bidirectional system, both selvedges having tubular weave structure.

In Fig. 5 is shown a reinforced woven filter fabric 120 mesh with tubular selvedges and in Fig. 6 its programming scheme is presented.

Table 3
Woven Filter Fabrics 120 mesh with Functional Design

Structural properties of woven filter fabric		120 mesh with tubular selvedges	120 mesh with transversal pockets
Woven fabric width		130 cm	138 cm
Selvedge width		3cm	1cm
Fibre type		Monofilament polyamide	
Yarns diameter	Warp	0.07 mm	0.07 mm
	Weft	0.07 mm	0.07 mm
Reinforced yarns diameter	Warp	0.15 mm	0.15 mm
	Weft	0.15 mm	0.15 mm
Yarns density	Warp	48 threads/cm	48 threads/cm
	Weft	48 threads/cm	48 threads/cm
Reinforced yarns density	Warp	2 threads/cm	2 threads/cm
	Weft	2 threads/cm	2 threads/cm
Pore area		0.0191 mm^2	0.0191 mm^2
Active filtering surface		44 %	44 %
Woven fabric weight		37.13 g/m^2	37.13 g/m^2

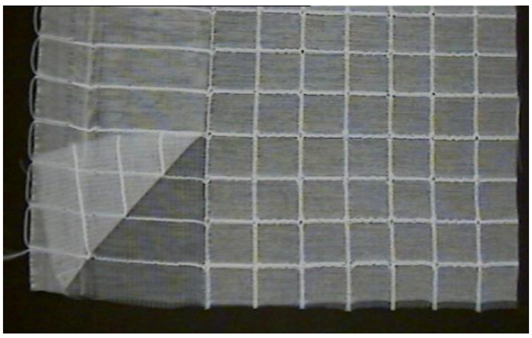


Fig. 5 − Reinforced woven filter fabric 120 mesh with simple and tubular selvedges.

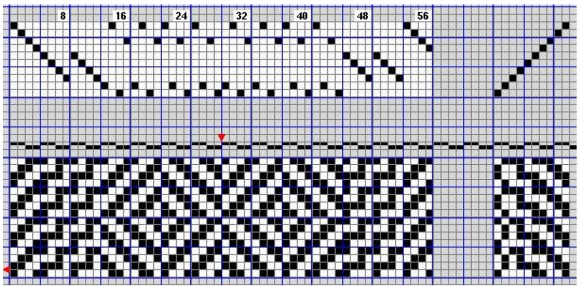


Fig. 6 − The programming scheme for a woven filter fabric 120 mesh with tubular selvedges.

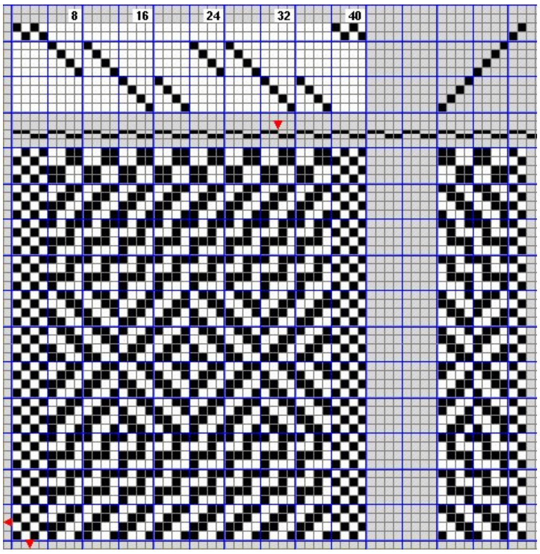


Fig. 7 − The programming scheme for a woven filter fabric120 mesh with reinforced yarns and transversal pockets for fixing rods.

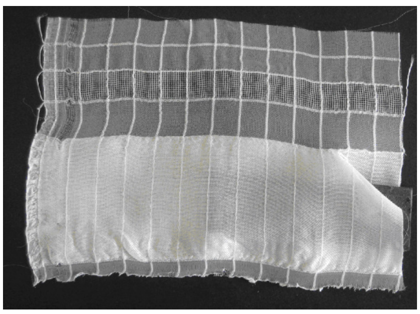


Fig. 8 − Reinforced woven filter fabric 120 mesh with tubular pockets, transversal positioned on woven fabrics.

A third category of woven filter fabrics is 30 mesh with a double structure, which was adapted to pulp industrial plants. Table 4 presents its structural properties. These woven filter fabrics have the selvedges in shape of the frame for the mounting system. In the mounting frame, the weave structure has a stitched double layer construction. In the filtration area, the weave structure is composed from two unstitched layers. These woven filter fabrics require the accurate calculation of all filter areas for a precise matching at installation.

Table 4

Woven Filter Fabrics 30 mesh with Double Structure

Structural properties of woven filter fabric		
Woven fabric width		140 cm
Frame borders width		10 cm
Fibre type		Monofilament polyamide
Yarns diameter	Warp	0.3 mm
	Weft	0.3mm
Yarns density	Warp	12×2 threads/cm
	Weft	12×2 threads/cm
Pore area per layer		0.2844 mm^2
Active filtering surface per layer		40%
Woven fabric weight		273.2 g/m^2

The superposition of the two layers cannot be made so that the pores of the two layers correspond accurately. When the retained cake material by filtered fluid appears, the operation becomes a mechanism of depth filtration.

The programming scheme for a double layered woven filter fabric 30 mesh with stitched double layered selvedges is presented in Fig. 9. Fig. 10 shows a cross–section of the woven filter fabric, in which the unstitched double layered structure for background of the woven filter fabric and the stitched double layered structure for its selvedge can be observed.

Fig. 10 – Cross–sectional view of a double layered woven filter fabric with stitched double layered selvedges.

4. Conclusions

1. The quality and efficiency of the filtering process are variables which depend on the functional characteristics of the woven filter fabrics and the parameters of the filtration system.

2. The function of durability, considered to be a secondary function, is determined by the structural characteristics of the woven filter fabric, but equally by its operating conditions.

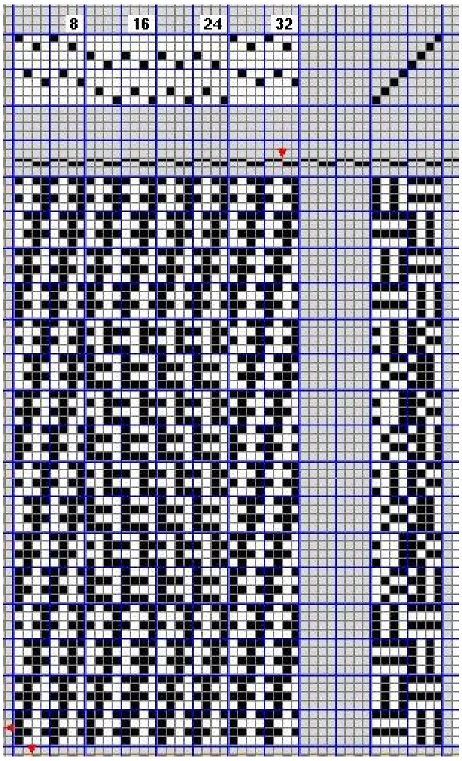


Fig. 9 − The programming scheme for a double layered woven filter fabric 30 mesh with stitched double layered selvedges.

3. The functional design of the woven filter fabrics involves on the one hand a design of the filter surface with imposed data for shape and size of pores, and on the other side, a design which to correspond with the mounting system from installation.

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FILTRE ȚESUTE CU DESIGN FUNCȚIONAL

(Rezumat)

Țesăturile filtrante sunt produse caracterizate prin excelență de o funcționalitate determinată. Calitatea şi eficiența procesului de filtrare sunt indicatori care depind de caracteristicile funcționale ale filtrelor şi de parametrii tehnologici ai instalației de filtrare. Funcția de a fi durabil, considerată ca funcție secundară este determinată de caracteristicile structurale ale filtrului dar în egală măsură şi de condițiile de exploatare ale acestuia. Pentru anumite categorii de filtre industriale se proiectează odată cu structura filtrantă şi un sistem de prindere sau de susținere care să elimine aceste vulnerabilități. În lucrare sunt prezentate câteva produse cu structuri adaptate la sistemele de fixare în instalațiile de filtrare industrială.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi" din Iaşi
Tomul LIX (LXIII), Fasc. 3, 2013
Secţia
TEXTILE. PIELĂRIE

COMPARISON OF COMPRESSION BEHAVIOUR OF HIGHLOFT NONWOVENS AND PU FOAMS

BY

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Received: August 28, 2013
Accepted for publication: September 16, 2013

Abstract. The aim of this work is to study high loft nonwovens which could be used to substitute the polyurethane (PU) foams used in bed mattresses interior applications or other industrial applications. The compression and recovery behaviour using static force loading of through−air thermal bonding nonwoven fabrics and polyurethane foams have been studied. The nonwoven fabrics show lesser compression resistance than polyurethane foams. High loft nonwovens are much bulkier (a higher amount of air in the structure) than PU foams, so textile fabrics can be compressed easier under the same pressure. Instead, the short−term and long−term compression recovery percentages of high loft nonwovens are closer to polyurethane foams. The percentage of long−term compression recovery is over 90%. During its manufacturing process, the PU foams partly generate toxic gases and have serious drawbacks such flammability. Therefore, the nonwoven fabrics could be an alternative to polyurethane foams in bed mattresses interior applications.

Key words: compression, recovery, high loft nonwoven, PU foam.

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This paper is the full version of the paper published in abstract only at Technical Textiles – Present and Future Symposium, Iaşi, October, 2013

1. Introduction

Nowadays, the social, the economical and the environmental circumstances constrain the industrial manufacturers to develop and promote ecological products.

The materials currently used inside a bed mattress are complex materials generally composed of more layers. One of these layers is polyurethane foam with different thickness. The foam gives the flexibility and the soft touch. So, the PU foam, thanks to its characteristics, is the key element of multilayer fabric in the term of comfort and mechanical behaviour especially for the compression ones.

The main problems of the PU foam refer to the toxic gases it generates during its manufacturing process and also the serious drawbacks, such as flammability (Njeugna *et al*., 2011). These problems lead to the idea of its substitute by other products like highloft nonwovens.

A key of these textile materials is not to alter the product functionality. This alternative should present at least mechanical properties, especially compression properties closed or equal to the PU foams. Furthermore, it must meet the requirements of the mattresses industry in terms of weight and cost.

Highloft nonwovens are defined as a low density fibrous structure characterized by a high ratio of thickness to mass per unit area. This is accomplished by bonding or interlocking of fibres using mechanical, chemical, thermal or solvent means or combination thereof. Ideally, highloft nonwovens should be soft, bulky, permeable and at the same time sufficient resistance to mechanical actions (Dipayan, 2010).

In application, the fibres are often compressed to create the necessary number of contacts among themselves in order to withstand the mechanical load. Then, when the load is removed, the fibres must recover their original arrangements, this way the fibrous structure remaining soft, bulky, permeable etc.

This paper presents a study of compression behaviour of the highloft nonwovens and PU foams used for bed mattresses or other industrial applications. The compression and recovery behaviour using static force loading of through−air thermal bonding nonwovens and PU foams will be studied. The results of this study will be analysed and based on these results a comparison between nonwovens and polyurethane foams will be carried out.

2. Materials and Methods

Two nonwovens N1 and N2 and two PU foams F1 and F2 were used in the present study.

Table 1 presents the main physical characteristics of highloft nonwovens made from bicomponent co−polyester bonding fibres 4.8 dtex and polyester fibres 6.7 dtex. Table 2 indicates the characteristics of the tested PU foams.

Table 1
Characteristics of Highloft Nonwovens

Sample code	Fineness [dtex]	Bonding	W [g/m^2]	T [mm]	ρ_N [kg/m^3]
N1	4.8/6.7	Thermal (Through−air)	400	40	10
N2	4.8/6.7	Thermal (Through−air)	600	55	11

Table 2
Characteristics of PU Foams

Characteristic	F1	F2
Weight, [g/m^2]	1200	2100
Thickness, [mm]	55	50
Density, [kg/m^3]	22	42

The samples were tested to determine their weight (W) and thickness (T) according to EDANA standards (ERT 40.−90, 1999; ERT 30.5−99, 1999). Then, the density of the samples was calculated with:

$$\rho_N = \frac{W}{T}, \text{ [kg/m}^3\text{]} \tag{1}$$

The compression behaviour characteristics were tested according to ASTM D 6571−01. This test method provides an inexpensive alternative for highloft nonwovens and PU foams to determine compression resistance and recovery properties, thus better predicting their performance in the finished product.

3. Results and Discussions

Table 3 shows the values of compression resistance, elastic loss and compression recovery (short−term and long term) of the tested nonwovens and PU foams.

Table 3
Compression and Recovery Properties

Type	Compression resistance [%]	Elastic loss [%]	Short term compression recovery [%]	Long term compression recovery [%]
N1	26.32	18.42	84.68	90.32
N2	24.40	17.51	93.34	94.36
F1	46.28	2.2	97.20	99.70
F2	60.87	4.55	96.89	98.14

The results are presented also as histograms. The nonwovens obtained through thermal−bonding are much bulkier (a higher amount of air in the structure) than PU foams, so these textile materials can be compressed easier under the same pressure (Debnath & Madhusoothanan, 2009). Therefore, the compression resistance increases with the increase in fabrics density (Fig.1).

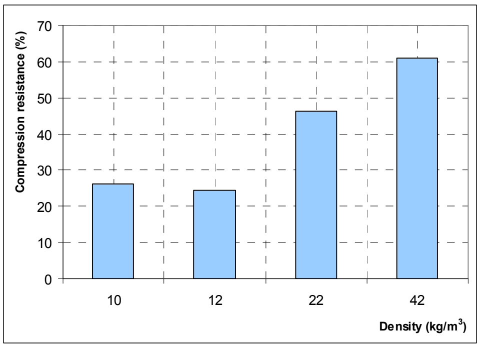

Fig. 1 − The variation of the compression resistance with fabric density.

The compression of highloft nonwovens occurs mainly due to the bending of the individual fibres and slippage between the fibres. The bonds formed between every contacting fibre in the thermo−bonded highloft result in a significant increase in its structural integrity.

Concerning the polyurethane foams, we can notice that the foam F2 has a higher compression resistance than foam F1, so the foam F2 is more comfortable than foam F1.

A comparison between the recovery properties of nonwovens and PU foams is shown in Fig. 2 and Fig. 3.

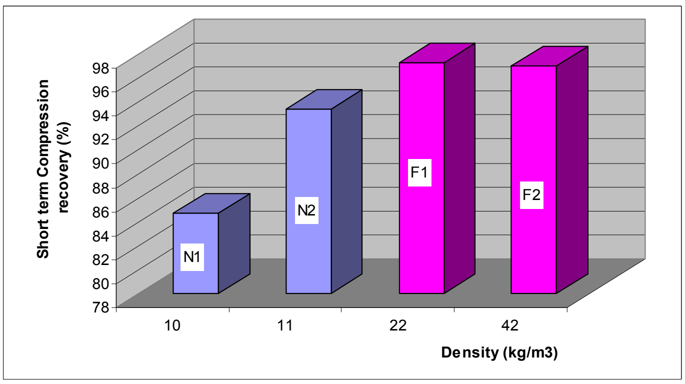

Fig. 2 − Comparison between the short term compression recovery property of nonwovens and PU foams.

The values of the compression recovery on short term and long term for the polyurethane foams are higher than those for highloft nonwovens for the same recovery time. This is due to the higher compression resistance and more reproducible behaviour of PU foams than nonwovens.

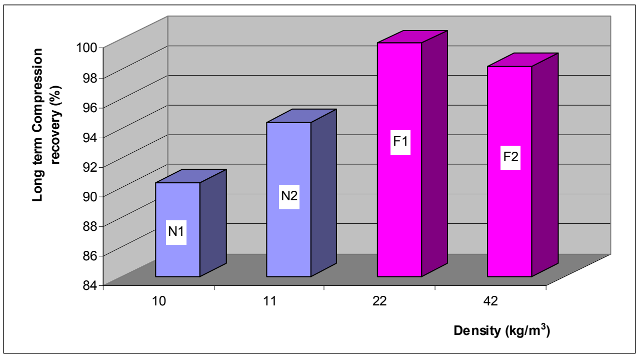

Fig. 3 − Comparison between the long term compression recovery property of nonwovens and PU foams.

The low reproducibility of the behaviour of highloft nonwovens can be explained by the significant dispersion of physical properties of these textile materials. Even so, the highloft nonwoven demonstrates remarkable high recoverability. The percentage of long−term compression recovery is over 90%.

4. Conclusions

In this study an inexpensive method has been used to test the polyurethane foams and highloft nonwovens to determine compression and recovery properties. The comparison results showed that the nonwovens are less resistance to compression than polyurethane foams due to higher amount of air in the structure. On the other hand, it has been shown that the nonwovens have recovery properties closer to polyurethane foams, for the same time available to recovery. It can be said that the highloft nonwovens could be a good candidate to replace PU foams in the bed mattresses interior applications. More accurate results for compression behaviour of nonwovens and polyurethane foams can be obtained at a constant rate of deformation.

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STUDIU COMPARATIV ÎNTRE NEȚESUTE VOLUMINOASE ŞI SPUME POLIURETANICE PRIVIND COMPORTAREA LA COMPRESIUNE

(Rezumat)

Scopul acestei lucrări este de a studia nețesutele voluminoase ce ar putea fi utilizate ca substituent al spumelor poliuretanice (PU) folosite în aplicații ca interiorul saltelelor pentru pat sau în alte aplicații industriale. S-a studiat comportarea la compresiune şi revenire din compresiune în regim static a materialelor nețesute obținute prin termoconsolidare cu aer cald şi a spumelor poliuretanice. Materialele nețesute prezintă o rezistență la compresiune mai mică decât spumele poliuretanice. Nețesutele highloft sunt mai voluminoase (o cantitate de aer mai mare în structură) decât în cazul spumelor poliuretanice, astfel că produsele textile pot fi comprimate mai uşor sub aceeaşi presiune. În schimb, procentul revenirii din compresiune pe termen scurt şi pe termen lung al nețesutelor voluminoase este apropiat de cel al spumelor poliuretanice. Procentul de revenire din compresiune pe termen lung este peste 90%. De-a lungul procesului de obținere, spumele poliuretanice generează, parțial, gaze toxice şi prezintă serioase dezavantaje cum ar fi inflamabilitatea. De aceea, materialele nețesute ar putea fi o alternativă a spumei poliuretanice în aplicațiile de interior al saltelelor pentru pat.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 3, 2013
Secţia
TEXTILE. PIELĂRIE

LABORATORY TESTING REFRIGERATOR FOR TEXTILE PRODUCTS

BY

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Received: August 26, 2013
Accepted for publication: September 12, 2013

Abstract. This paper presents the procedure of design, production and testing for an experimental refrigeration system, special designed for textile testing at low temperatures. The numeric data processing was done by using CoolPack program. In order to study the behaviour of textiles at low temperatures it was built a refrigerator with vapour mechanical compression, the simplest construction, but automated with an electronic programmer Dixel which is able to adjust the temperature up to −57°C. The refrigerator has two sensors, one for the evaporator and one for cooling the room – a necessary condition for an accurate testing. It is possible to connect an additional resistance for defrosting which prevents ice formation. Another feature, very important, is how the compressor is cooled; this can be done with the help of an electronic controlled fan. The room where experiments will be done has high-density polyethylene panels, doubled with 100 mm expanded polystyrene. The refrigerator access entry is made of PVC windows fitted with seals. The desired temperature range is between 0 and −35°C.

Key words: refrigeration cycle, mechanical compressor, condensing unit, evaporator.

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This paper is the full version of the paper published in abstract only at Technical Textiles – Present and Future Symposium, Iaşi, October, 2013

1. Introduction

1.1. Short History

The effects of low temperature upon the human body and products were found in the ancient times. In warm climates, it was used snow and ice from mountains for “air conditioning” and food storage.

Cold storage, as a method of conservation, was dated long time ago.

The efficiency of low temperatures was proved when there were discovered animal bodies (mammoths) perfectly preserved over thousands of years.

In the 18th century there were known 10−15 mixtures for temperature decreasing. An example is calcium chloride ($CaCl_2$) mixed with ice which allows a decrease in temperature up to −32.8°C.

Artificial freezing began recently and some of the most important historical data can be considered the following:

− 1748 - William Cullen at the University of Glasgow, Scotland, made the first demonstration of producing the artificial freezing by evaporation of a thermodynamic agent in the partial vacuum;

− 1805 - Oliver Evans of Philadelphia, State of Pennsylvania, USA, made a closed circuit cooling system, with vapor compression;

− 1844 - in a paper, John Gorrie of Florida, USA, described a device for producing ice and cold air necessary for his hospital. This can be regarded as the world's first production machine for cooling and air conditioning;

− 1859 - Ferdinand Carré of France made the first cooling machine in Europe, designed for ice production but operating with a different principle (absorption);

− in the second half of the 19^{th} century, the production of artificial cold is characterized by a great impetus. Thus, in this period it was installed the first refrigeration machine on ships, the equipment being designed for meat transportation from Australia and Argentina to Europe. Perhaps those sailors were the first people who ate frozen meat;

− 1924 - Clarence Birdseye developed an entirely new process for commercially viable quick-freezing in USA; he was the first who invented the double belt freezer for perishable products;

− after the Second World War the freezing preservation industry extends, and were created new devices, machines and processes.

1.2. Application of Low Temperatures

By analyzing the refrigeration phenomena and processes that occur between +100°C and 0 degrees K (−273.15°C), there were established the design procedures of constructive solutions – plant and machinery - that may work within a wide range of temperatures:

□ between + 40°C and + 100°C − heat pumps;
□ between 0°C and +5°C − air-conditioning systems;
□ between − 200°C and 0°C − industrial refrigeration plant:
− the chemical industry, for example, it covers liquefaction processes of air and separation of some of its components;
− in the food industry, there are applications at temperatures ≈ −30°C;
□ between 0 degrees Kelvin and −200°C - cryogenics or deep freezing:
− the upper limit of which is considered to begin the cryogenics is not precisely defined, but several authors consider this limit as:
77K = − 196°C - the boiling point of nitrogen;
80K = − 193°C - boiling temperature of the air;
120K = − 153°C - the boiling point of methane.

One of the coldest temperatures artificially made on Earth was created in 1967 at "Naval Research Laboratory" with a value smaller than 10^{-6}K.

The biggest production of cold is in the industrial segment, and the most important consumers are:
− chemical industry - the largest freezing consumer;
− removal of heat and reaction mixture;
− separation of salts from liquid solutions;
− liquefaction of gas and so on;
− food that requires low temperatures:
→ in the commercial network;
→ in storage of food;
→ in technological processes;
− mining and quarrying where soil is frozen for digging the galleries;
− machine building industry, heat treatment, working with demanding cutting etc.
− construction, in order to freeze the soil, cooling of components before casting the concrete, and so on;
− research laboratories for studying the materials or equipment behaviour in low temperature conditions (Balan, 2000; Balan, 2003; Balan & Porneala, 2003).

For doing the experiments, the temperatures have to be decreased up to −35ºC due to technical and economic difficulties that would involve designing a 2-stage compression refrigerator.

2. Materials and Methods

2.1. Vapour Compression Refrigerators

Artificial freezing is based on the absorption of heat from bodies (spaces) that must be cooled using a liquid called *refrigerant* and then transferring the heat to the environment. In principle, the refrigerant vapor is compressed with compressors, in the next stage is liquefied by cooling in condensing units, and then vaporizes inside of coils (evaporators) installed in cooling spaces. Vaporization done by the absorption of heat determines the decreasing of temperature in that space.

2.2. Construction of the Refrigerator

The easiest refrigerator has at least four components: evaporator (V), compressor (C), condenser (K) and regulator (VL). The most simple design scheme for this type of machine is shown in Fig. 1.

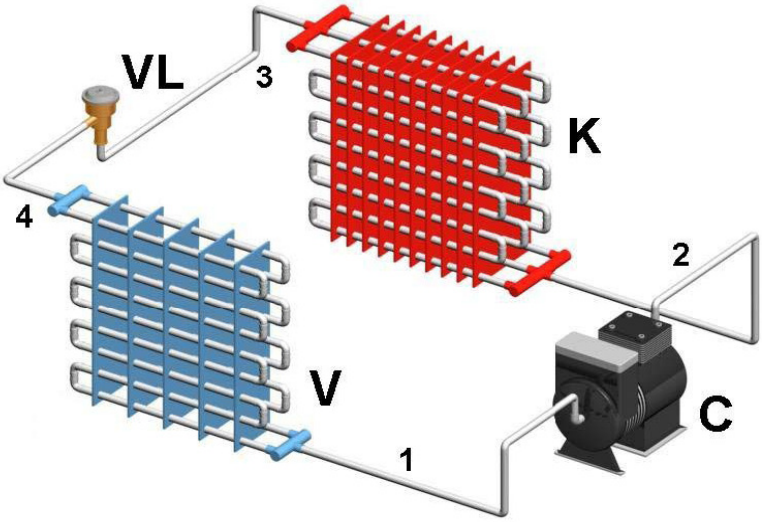


Fig. 1 – Vapour compression refrigerator.

2.3. Compressor (C)

In refrigeration, *compression* is the process of increasing the vapor pressure from the evaporator until it reaches the right level in the condenser. In fact, the evaporator and condenser are creating the interface for the cold environment and the compressor assures the working conditions, bringing the refrigerant to the required pressure for achieving the condensation process.

In Fig. 2 is shown the cross-section of a compressor. It can be seen one electric motor (1) whose rotor (2) is continued with the crankshaft. The rod system is represented by rods pistons (3 and 4). Vapour aspiration is made by moving down the piston which opens the aspiration valve (5) and discharge through the discharge valves (6) when the piston goes up.

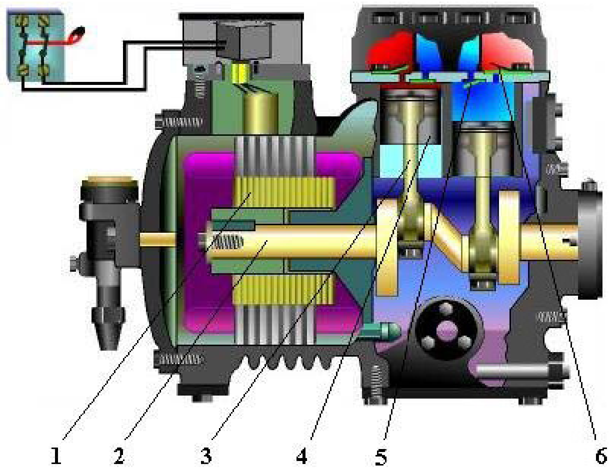


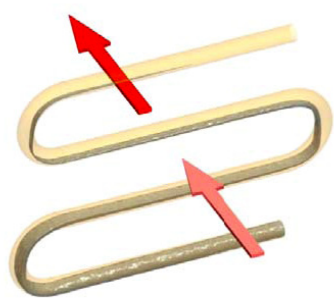
Fig. 2 − Refrigeration compressor.

Warm vapour is discharged from the compressor and goes to the condenser, which is showed in the system - Fig. 1.

2.4. Condenser (K)

Condensation is a thermodynamic process in which the refrigerant changes its state of aggregation from vapor to liquid, making heat transfer to the hot source, represented by the air or water in the condenser (Fig. 2). Condensation has an important effect in heating pumps. The condensation process is shown in Fig. 3; at the beginning takes place the saturation of vapor, followed by the transformation of the vapor into liquid. Then the liquid refrigerant is gradually pushed toward the exit of the machine.

Last portion of the coil is fully filled with liquid (Verdeş, 2007).



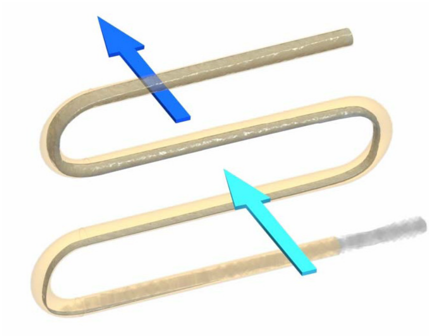


Fig. 3 − The condensation process. Fig. 4 − Vaporization process.

2.5. Evaporator (V)

Vaporization is the process in which the refrigerant changes the state from liquid into vapour by absorbing heat from the cold source, represented by the cooler (air or liquid heat transfer medium). The evaporator is the device that gives the effectiveness of the system.

Vaporization process is shown in Fig. 4. It is noticed that inside the pipe the liquid gradually goes down, reaching the last part of the coil, which will be completely filled with vapour at the end.

2.6. Expansion Valve (VL)

The expansion valve is a simple device. It is a capillary tube in small power systems or an expansion valve in medium or large refrigeration systems.

In Fig. 5 are illustrated these two devices.

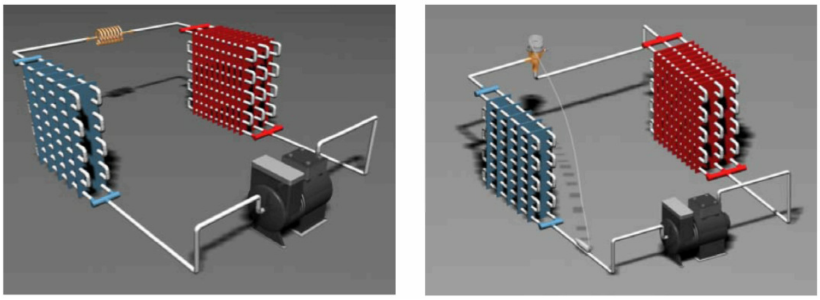


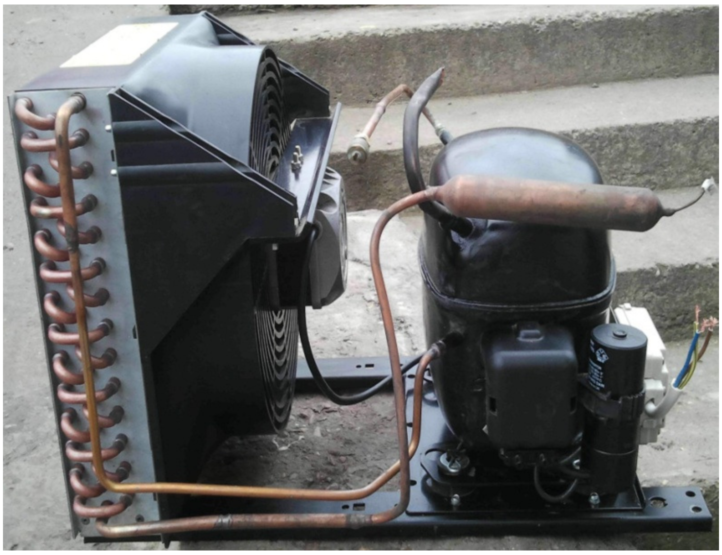
Fig. 5 − Expansion device.

2.7. Refrigerants

To allow a cyclic operation of refrigerators, refrigerants take heat when evaporating and release heat through condensation at low or close to environment temperatures. The refrigerant has specific properties, which differs from other thermodynamic substances used in other types of systems. For this reason, these substances are also known as refrigerants (Balan, 2007; Madarasan & Balan, 1999).

2.8. Construction of Experimental Refrigerator

After data processing for heat load of the room (L = 550 mm, W = 500 mm, h = 500 mm) with Coolpack program (http://en.ipu.dk) the result was maximum 180 Watts for the cooling power at a temperature of −35°C. Thus, a condensing unit from Danfoss (Fig. 6) gives a cooling power of 280 Watts at a temperature of −35ºC (www.danfoss.com).



ASHRAE LBP* 230V, 60Hz, fan cooling F_2

Evap. temp. in °C	-45	-40	-35	-30	-25	-23.3	-20	-15	-10	-6.7	-5	0	5	7.2	10	15	20
Capacity in W		190	343	509	694	762	901	1134	1399								
Power cons. in W		290	383	464	540	565	614	692	781								
Current cons. in A		2.61	2.77	2.98	3.23	3.33	3.54	3.89	4.29								
COP in W/W		0.66	0.90	1.10	1.29	1.35	1.47	1.64	1.79								

EN 12900 Household (CECOMAF)* 230V, 60Hz, fan cooling F_2

Evap. temp. in °C	-45	-40	-35	-30	-25	-23.3	-20	-15	-10	-6.7	-5	0	5	7.2	10	15	20
Capacity in W		146	282	429	590	649	770	972	1200								
Power cons. in W		277	376	462	540	566	616	696	784								
Current cons. in A		2.58	2.75	2.96	3.23	3.33	3.54	3.91	4.32								
COP in W/W		0.53	0.75	0.93	1.09	1.15	1.25	1.40	1.53								

Fig. 6 – Condensing unit.

The construction of enclosure (freezing room) is made from panels of high-density polyethylene, which has a great resistance at high-impact even in very low temperature conditions. This material is suitable for parts working at low mechanical loads.

For hardening polyethylene panels it was used a steel angle profile 30 mm thick, fastened with nut on each end and stuck with silicone that resists at low temperatures. The access in the test chamber consists of a PVC joinery fitted with rivets for sealing and double-glazing. The enclosure is exemplified in Fig. 7.

Due to very low temperature of −35...−30ºC, we had to create an evaporator shown in Fig. 8, made from copper pipe of 12 mm in diameter and 40 m in length, bent by using a hydraulic press. To stiffen this pipe and increase the heat exchange surface, we used a perforated aluminum sheet and a fan.

Fig. 7 – Refrigerator enclosure.

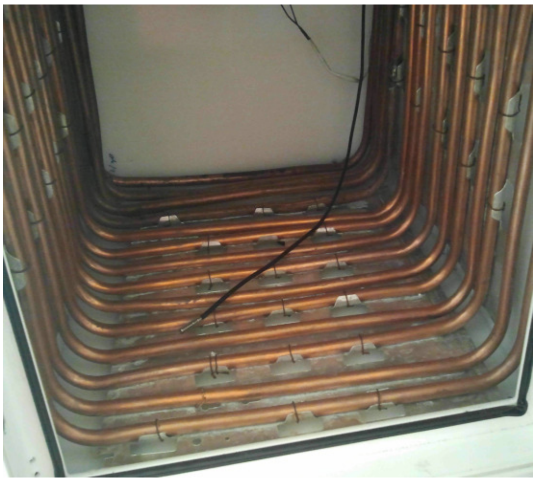


Fig. 8 – Evaporator.

Injection of refrigerant was done by using a Danfoss expansion valve with maximum cooling power of 0.38 kW. Due to the great length of the copper pipe it was chosen a valve with external equalization and MOP at −20°C. The valve is illustrated in Fig. 9.

In order to see the level of moisture in the refrigerator, filter impurities and charge easier we provide a sight glass with moisture indicator and a dehydrating filter shown in Figs. 10 and 11.

All these components are automated with a Dixel digital controller equipped with PTC temperature probe; the installation is shown in Fig. 12.

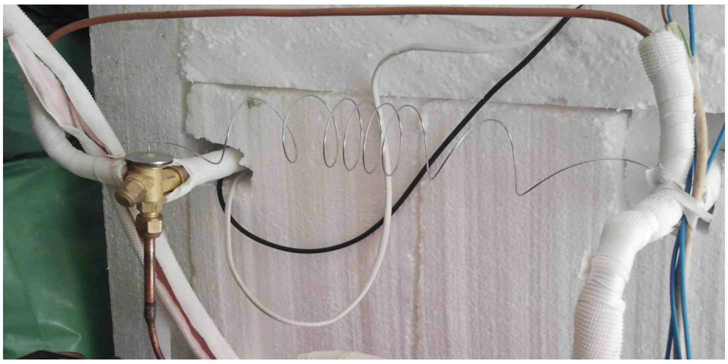


Fig. 9 – Expansion valve.

Fig. 10 – Sight glass.

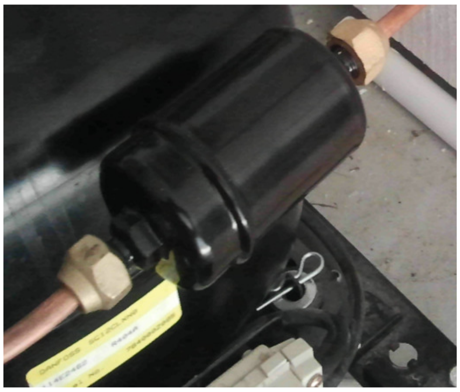


Fig. 11 – Dehydrating filter.

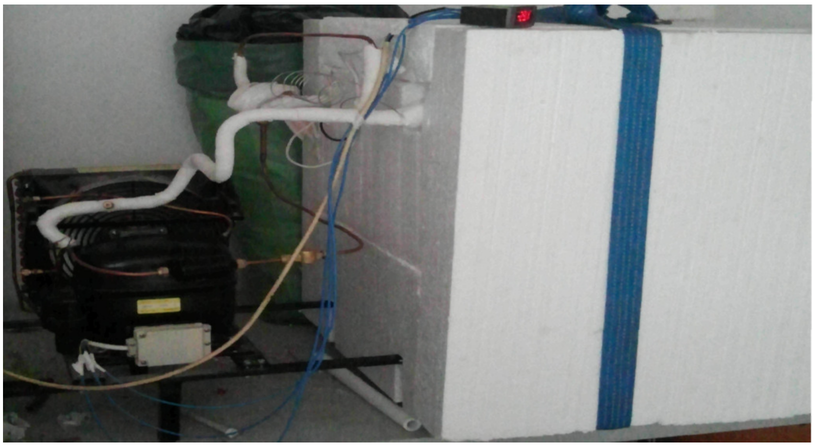


Fig. 12 – Experimental refrigerator.

3. Results and Discussions

All tests made with the experimental refrigeration system proved the following:

− the evaporator needed to be redesign with a new evaporator since the first version did not reach the proposed temperature;

− for an improved heat exchange, a perforated aluminium plate must be installed.

After repeating the testing procedure and making the modifications, the result was the construction presented in this paper.

The refrigerator has a temperature domain presented in Fig.13.

The graph shows that the temperature of −35ºC is obtained after approx. 200 min.

Textile products will be tested in terms of flexural behaviour, draping, etc. For this, the necessary devices will be introduced in the cold room. It will be analyzed the behaviour with a web camera connected to a computer.

Also the cold room will serve for testing the technical textile products regarding the influence of low temperatures on the mechanical properties. The textile products will be kept at low temperatures during different periods of time to determine how these temperatures influence the mechanical characteristics and other features.

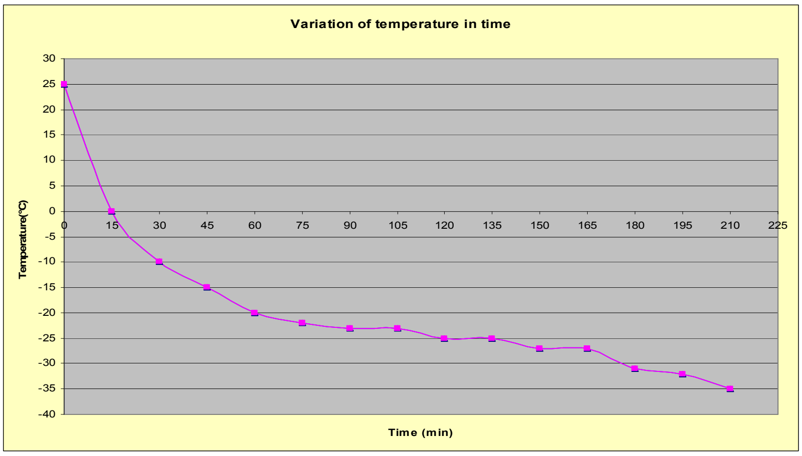


Fig. 13 − Variation of temperature depending on time.

4. Conclusions

Based on the tests with the refrigerator, the following conclusions can be formulated:

− the temperature can be set and maintained constant over time;

− in time, changes in humidity can be followed by moisture sensors;

− refrigerant charge level can be monitored.

For testing textiles in heating and cooling cycles must be provided an air heating device.

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INSTALAŢIE FRIGORIFICĂ DE LABORATOR PENTRU TESTAREA PRODUSELOR TEXTILE

(Rezumat)

Acest articol prezintă proiectarea şi asamblarea unei instalaţii frigorifice, precum şi efectuarea experimentelor la temperaturi joase a produselor textile. Calculul necesarului de frig s-a efectuat cu ajutorul programului *CoolPack*.

Pentru a putea studia comportarea textilelor la temperaturi joase, s-a realizat o instalaţie frigorifică cu comprimare mecanică de vapori, automatizată cu un programator electronic Dixel, capabil să gestioneze o instalaţie frigorifică până la temperaturi de –57ºC (pentru o precizie mai mare este echipat cu două sonde de temperatură, una pentru evaporator şi una pentru camera care trebuie răcită). Suplimentar se poate lega o rezistenţă pentru degivrare pentru prevenirea formării gheţii. O altă opţiune, foarte importantă, este modul de răcire al compresorului – răcirea se face cu ajutorul unui ventilator comandat tot de programatorul electronic. Incinta unde urmează a fi desfăşurate experimentele (camera frigorifică) este alcătuită din panouri de polietilenă de înaltă densitate şi izolată cu polistiren expandat de 100 mm. Sistemul de acces în incintă este confecţionat din tâmplărie PVC, prevăzut cu chedere pentru o bună etanşare.

Domeniul de temperatură care se poate realiza este de 0... −35ºC.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 3, 2013
Secţia
TEXTILE. PIELĂRIE

PRACTICAL ASPECTS RELATED TO THE TESTING OF FRC (FIBRE REINFORCED CEMENTS)

BY

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Received: August 2, 2013
Accepted for publication: September 4, 2013

Abstract. Fibre reinforced cements are currently well known in the building industry. The main advantages of using FRCs refer to improved mechanical behaviour and the possibility of reducing the dimensions of the building elements for a certain level of required strength. When using high performance fibres to reinforce cement, the design stage ensures the selection of the optimum raw material − the type, length density, filament diameter and mechanical characteristics. Another problem related to the production of FRCs is the processing of fibres, namely their mixing with the cement matrix. The study in the paper approaches the problem of producing fibre reinforced cements. The study takes into consideration the production of cement reinforced with glass fibres. It presents and characterises the materials used and it discusses the method of producing fibre reinforced cements. The problems related to the process, their causes and negative influence are presented and discussed. The paper also offers solutions concerning these issues, as well as conclusions regarding the applicability of glass fibres for building elements.

Key words: High performance fibres, fibre reinforced cement, processing, glass rovings.

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This paper is the full version of the paper published in abstract only at Technical Textiles – Present and Future Symposium, Iaşi, October, 2013

1. Introduction

The advantages of the textile reinforced composites are:

− controlled anisotropy of the textiles which means that their structure materials can be designed so that the fibres are placed on preferential directions, according to the maximum strain;

− the use of textile reinforcements allows to obtain a better weigh/strength ratio compared with the classic materials, such as steel;

− textile materials maintain their integrity and behaviour under extreme conditions – for example, they do not corrode in a outdoor environment, nor vary their dimensions when there are significant temperature variations, nor are they sensible to electro−magnetic fields;

− FRCs present an improved fatigue life.

The materials obtained mixing fibres with concrete are composites with excellent specific properties that are increasingly used in constructions. In Romania, the fibre reinforced concretes increased significantly, with floors as their main domain of use (http://edilcom.infoconstruct.ro/).

The role of the fibre reinforcement in concrete refers to the improvement of material strength, but also the control of the cracking process that leads to superior strength, energy absorption and impact resistance, thermal stability and better fire resistance. The fibre reinforced concretes are obtained by mixing variable quantities of short fibres of different types, lengths and properties.

The basic requirements with reference to the fibres, when improved mechanical strength and the delay of the cracking process are needed, are as follows: good strength and adequate elasticity module, excellent bonding with the matrix, chemical stability and the capacity of sustaining loads for longer periods of time.

By adding a certain amount of fibres, classic concretes can be significantly improved. The fibre influence is reflected especially in the tensile behaviour, flexure strength, cracking resistance and strain.

The fibres can be introduced in two forms: a continuous reinforcement (meshes placed in a layer) or a discontinuous form as short fibres randomly positioned in the concrete mix (Ciobanu, 2003).

The advantages concerning the use of fibres in disperse−reinforced concretes refer to the following aspects:

− the use of fibres increases the tensile and compression strength of the concrete;

− the surface of the disperse−reinforced concrete has an improved behaviour to corrosive substances;

− the use of fibres increases the wear resistance to friction;

− the disperse−reinforced concrete has a superior shock resistance;

− the use of fibres diminish the level of damage caused by reinforcement decorrosion and therefore prolong the life of the buildings;

− the disperse–reinforced concretes correspond to fire safety requirements;

− the use of fibres lowers the weight of the construction elements;

− the use of disperse–reinforced concretes reduces the duration of the construction works (the cut–down can reach even 50%).

The paper presents problems related to the production process of the glass fibre reinforced concrete, their causes, how they affect the behaviour of the composite concrete and the possibilities of eliminating these issues.

2. Materials and Methods

Fibre reinforced concrete is prepared based on the same technological process as common concrete. Still, one must consider that the fibres influence significantly the processability of the concrete element.

The concrete produced for the study included the following raw materials: cement, fly ash as filling agent, river aggregate and sand, glass fibre, plasticizer (an additive used to improve the concrete's processability) and water. The cement type was Portland CEM I 42,5R produced according to SR EN 197−1 A1:2007. The replacement of a percentage of the Portland cement with fly ash is motivated by the cut in production costs and the level of pollution and was intensively studied in the last two decades.

The fly ash (FA) was produced at Holboca Iaşi power plant. The fly ash is an inorganic loss that results from the burn of coal in the power plants (Bărbuţă *et al.*, 2012). It is made of small particles, such as glass, with dimensions varying from 0.01 to 100 microns (Bărbuţă *et al.*, 2012), as illustrated in Fig. 1.

Fig. 1 − Fly ash used at power plants.

The use of ash in concrete brings certain advantages, as well as disadvantages, as follows:

− enhanced concrete processability;

− increased compactness and homogeneity of the concrete;

− improved resistance to fire;

− the strength of the concretes with added ash decreases with the increase of ash in day 3 to 14 after the specimens are produced;

− after 28 days, the strength of the concretes with 10−20% ash is similar to the one of the concretes without ash.

The aggregates were of river gravel origin, with three levels of dimensions: 0−4 mm, 4−8 mm and 8−16 mm, as illustrated in Fig. 2.

Fig. 2 − Aggregates in 3 sizes: 0−4 mm – size I, 4−8 mm – size II and 8−16mm – size III.

The mixing of raw materials was carried out using a concrete mixture machine. The concrete can be produced manually or mechanically. The manual process includes the mixing of sand, gravel and cement with the ash. After obtaining a homogenous mix, the water and the additives were gradually added, the stirring process continuing until the concrete mix has the wanted fluidity. The mechanic mixing improves the quality of the process; it has a lesser impact on the environment and allows for industrial production.

The specimens were produced varying the amount and length of the glass fibre introduced in the mix. The fibres were obtained by cutting 2400 tex roving format to preset length (Fig. 3).

Fig. 3 − Glass roving −2400 tex (www.vetrotextextiles.com).

2.1. Characteristics of the Glass Fibres

The glass fibres are generally used to reinforce polymeric matrixes, their main advantages being good mechanical behaviour and relatively low costs. The disadvantages related to the use of glass fibre reinforcement refer to the low resistance to friction, the lower elastic modulus, as well as a low bonding to the matrix in the presence of water. The bonding can be increased by treating the fibre surface with bonding agents.

The type and shape of the materials used for reinforcement influence significantly the strength of the composites.

The characteristics of the textile materials required for composite reinforcement are (Fangueiro, 2011):

− high tenacity (higher than 70cN/tex)
− low elastic modulus
− good resistance to friction
− dimensional stability at high temperatures (150ºC−200ºC)
− low creep
− resistance to electric isolation agents
− good bonding

Table 1 presents the main physical and mechanical characteristics of the glass fibres – 2400 tex roving.

Table 1
The Characteristics of the Glass Fibres (www.vetrotextextiles.com)

Yarn density, [tex] ISO 1889	Diameter, [μm]	Humidity, [%] ISO 3344
2400	17	≤ 0.20

2.2. Production of the Glass Reinforced Concrete

The reinforced concrete was produced using the mechanical process, following the stages presented in Fig. 4.

The percentage of glass fibre used in the mix was determined based on an experimental matrix and on practical experience resulted from the literature survey. All components were accurately weighed, as illustrated in Fig. 5.

The specimens were casted in forms specific to Romanian standards − 150 mm cubes for compression and split strength and 100x100x150 mm prisms for flexure strength.

The specimens (Fig. 6) were demoulded after 24 h and stored for 7 days in a water tank so that the water covered them.

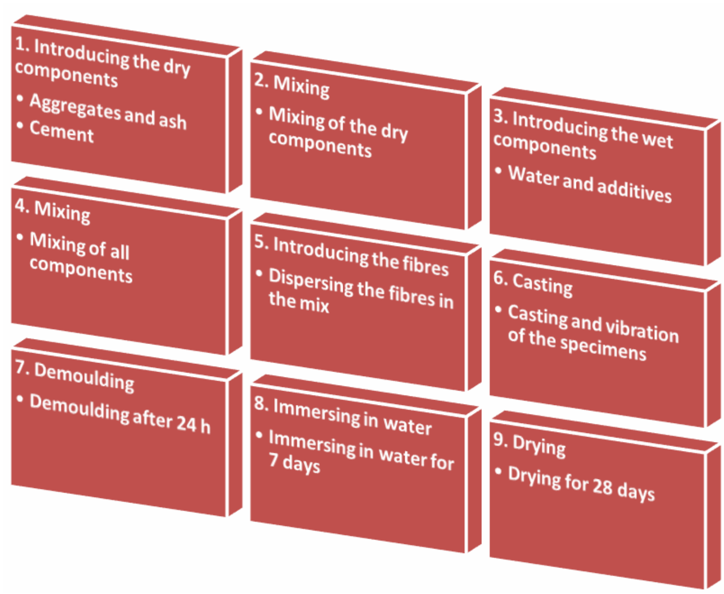

Fig. 4 − Stages of the production of the fibre reinforced concrete.

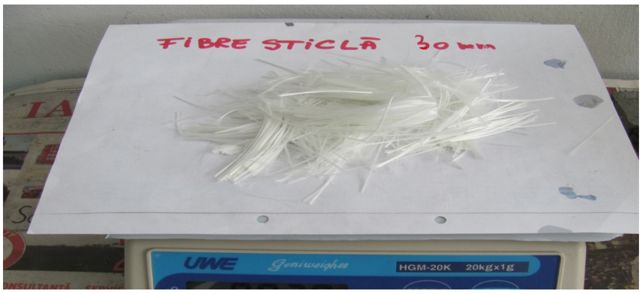

Fig. 5 − Fibre weighing.

Fig. 6 − Glass reinforced concrete specimens – 30 mm fibre length.

Certain problems were encountered during the production of the reinforced concrete specimens. These problems affected significantly the quality of the specimens and their mechanical strength. There were identified the causes of these issues and the ways of eliminating them, that will be discussed below.

3. Results and Discussions

Generally, the production of fibre reinforced concrete requires special measures to avoid the clogging of fibres.

The length and the diameter of the fibres influence significantly the degree of compactness of the concrete. A 'floating' phenomenon appears when the fibres are introduced in the dry mix of cement and aggregate. Part of the fibres float at the superior edge of the mixer and cannot be introduce in the mix. This means that the strength will be lower, as the amount of reinforcement is diminished.

This phenomenon is caused on one hand by the extremely low weight of the fibres and on the other hand, by the air vortexes formed at the mixer's entrance.

In order to avoid this problem, the best solution identified was to mix the fibres with the components in wet state, after the water was added. It must be remarked that the vibrating table was used to improve the compactness of the mix (Fig. 7).

The vibrating table ensures the elimination of the air bubbles, good homogeneity throughout the specimen volume, good bonding between the concrete and the reinforcement fibres. If the vibration is too long, it can cause the clogging of fibres, so the optimum duration of the operation was determined.

Fig. 7 − Vibrating table.

These clogs of fibres (non−homogeneous mixes) have a negative influence on the strength of the disperse−reinforced concrete, thus affecting its behaviour during use. The fibres mixed with the dry components (cement and aggregates) had a non−uniform dispersion and determined the formation on−homogeneous mixes, as shown in Fig. 8.

Fig. 9 presents a concrete mix with improved homogeneity, where the fibres were added at the end in the humid mix. The uniform dispersion is evident in comparison to the mix presented in Fig. 8.

Fig. 8 − Mixing of fibres with concrete – non−uniform distribution − non−homogeneous mix.

Fig. 9 − Aspect of a homogeneous mix.

Table 2 presents an example on how the homogeneity of the concrete mix affects the mechanical properties. The strength of concrete specimens was tested for homogeneous and non−homogeneous mix, for the same fibre length (20 mm) and fibre percentage (1%). The data illustrated in table show that the specimens with higher homogeneity have better compression, split and flexure strength.

Table 2

The Influence of the Type of Mix on the Strength of the Glass Reinforced Concrete

No.	Type of mix	Fibre length [mm]	Percentage of fibre [%]	Flexure f_{ti}, [N/m^2]	Split f_{di}, [N/m^2]	Compression f_{ci}, [N/m^2]
1	Non−homogeneous	20	1	2.34	1.77	34.02
2	Homogeneous			3.36	2.48	40.53

Another aspect affecting the quality of the reinforced concrete is the phenomenon of 'snagging' that is characterised by the fact that the concrete mix forms lumps around bundles of fibres, as illustrated in Fig. 10. This problem is increased if the specimen is less thick and the fibre length is higher. It can be explained by the relatively low amount of concrete in these specimens that favours its bonding with fibre bundles. The solution to this problem is to increase the fluidity of the concrete mix (in normal limits) and also to use additives.

a

b

Fig. 10 − "Snagging" of the concrete mix to fibre bundles: *a* − aspect during specimen casting; *b* − aspect after drying (cross section).

Apart from the factors discussed above, the dimensions, shape and volume fraction of the aggregates also have a certain influence on the properties of the disperse−reinforced concrete. Bigger aggregates tend to cause problems with the bonding between the fibres and concrete. If the aggregate presents diameters superior to the fibre length then the clogging phenomenon is enhanced. The experimental work showed that the aggregates should have up to 10−12 mm diameter.

4. Conclusions

The use of fibre disperse−reinforced concrete has significantly increased in the past decade, including in Romania. This is why it is extremely important to study the characteristics of this type of concretes and their factors of influence.

The paper presents some aspects related to the processability of the glass fibre reinforced concrete. Three major problems were identified when the concrete specimens were produced:

− the floating of a part of the fibres at the entrance of the concrete mixer

− the clogging phenomenon of the glass fibres in the dry mix, that is enhanced if the aggregate used has a diameter superior to the length of the fibre;

− the influence of the homogeneity of the concrete mix on the strength of the specimens;

− the snagging of the concrete to fibre bundles

These problems have a negative influence on the quality of the specimens, significantly reducing their strength. In order to eliminate these problems, the fibres were introduced in the wet mix, the diameter of the aggregate was correlated with the fibre length and additives were used to increase the fluidity of the mix.

The paper is part of an extensive study concerning the optimisation of the reinforcement of concretes with high performance fibres (glass).

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ASPECTE PRACTICE PRIVIND TESTAREA FRC (BETON ARMAT CU FIBRE)

(Rezumat)

Armarea betonului cu fibre este în prezent o tehnologie bine cunoscută în industria de construcții. Principalele avantaje ale utilizării FRC−urilor se referă la o comportare mecanică îmbunătățită şi posibilitatea de a reduce dimensiunile elementelor de construcție pentru un anumit nivel de rezistență necesară. Atunci când se utilizează fibre de înaltă performanță pentru a consolida cimentul, din faza de proiectare trebuie să se asigure selectarea materiei prime optime − tipul de fibră, densitatea de lungime, diametrul filamentului şi caracteristicile mecanice. O altă problemă legată de producția de FRC−uri este prelucrarea fibrelor şi anume amestecarea acestora cu matricea de ciment.

Studiul din lucrare abordează problema producerii betonului ranforsat cu fibre. Studiul ia în considerare producția de beton armat cu fibre de sticlă. Acesta prezintă şi caracterizează materialele utilizate şi discută metoda de producere a betonului armat dispers cu fibre. Problemele legate de procesul, cauzele şi influența negativă sunt prezentate şi discutate în lucrare. Lucrarea oferă, de asemenea, soluții privind aceste aspecte, precum şi concluzii privind aplicabilitatea fibrelor de sticlă pentru elemente de construcție.