NON-WOVENS FROM COTTON FIBRES FOR ABSORBENT PRODUCTS OBTAINED BY THE NEEDLE-PUNCHING PROCESS

Paul Kiekens *
Maria Zamfir **

*University of Ghent, Department of Textiles, Belgium
Technologiepark – Zwijnaarde 9, 9052 Ghent, BELGIUM
E-mail: paul.kiekens@rug.ac.be

**Technical University of Iasi, Faculty of Textiles, Romania
53 D-tru Mangeron blvd, 6600 Iasi, ROMANIA
E-mail: mariazamfir_ro@yahoo.com

Abstract

The use of non-wovens as absorbent products is increasing, as is the consumption of cotton fibres as raw materials for these products. This paper presents some results concerning the obtaining of absorbent non-woven products made from cotton fibres. A fibrous web was formed by the superposition of cotton bands as a short layer. Special needle types supplied by SINGER Spezialnadelfabrik GmbH & Co. KG were used during the needle-punching process.
Equations of variation of liquid absorption speed and surface weight have been analysed in order to optimise the needle-punching process of the cotton fibrous webs.

Key words: cotton fibres, non-wovens, needle-punching process, mathematical modelling, optimising.

Introduction

Non-wovens have a great deal of development and growth potential. According to the volume growth rate recorded for non-wovens in the period 1990 - 2000, production of non-wovens will increase by 5% to 7% in the period up to 2010. From the point of view of EDANA, over 38.8% of non-woven products (such as hygiene and medical products) are disposable [1].

Almost all of these products are produced by spun-bonding, spun-lacing, melt-blown or thermal calendering technologies. Fibres of cotton, polyester, polypropylene, viscose and other diverse mixtures are used in medical and hygienic non-woven products. Cotton fibres are utilised as raw materials in up to 20% of the total fibres in production of non-wovens. Cotton fibres are used in medical and hygiene products because of their high absorption capacity, comfort, softness, chemical resistance and biodegradability. These fibres can be of raw cotton, very clean cotton, recoverable cotton, bleached cotton of high quality, ultra-white cotton, or ultra-white cotton without absorption capacity [2, 3].

The vegetal impurities of the cotton fibres, and the development of other types of fibres, have reduced the use of cotton in medical and hygiene non-wovens. Specific high-performance installations must be applied when processing the cotton fibres in order to eliminate impurities. Cotton fibrous webs can be obtained by wet-laid or dry-laid processes, by continuous carding with/without randomising of the fleece or by cross-lapping processes. Bonding of the fibrous webs is made possible by calendering, hydro-entanglement, or needle-punching technologies.

Nowadays there are many non-woven products with natural fibres acceptable to the human body. In addition, many structures (including cotton absorbent media situated between spun-bonded or melt-blown non-wovens) have been obtained in order to increase the volume offered on the world market.

The increase in the application of cotton fibres for non-wovens is due, among other factors, to the hydro-entanglement technology that allows not only the bonding of the fibrous web but also to mechanical cleansing of the cotton fibres, thanks to the high pressure of water involved in the process. Other technologies, including modified needle-punching technologies, are also used because of the interest of companies which manufacture non-wovens in discovering their technical limits.

For domestic end-uses, the cotton fibres consist of 60% of all raw materials. The question arises as to why, for non-wovens used as medical and hygiene products, is it impossible to use more natural fibres than synthetic fibres, if the human body finds them more comfortable, and such fibres are safe for the environment.

In general, the main characteristics of the cotton fibres used by various non-woven manufacturers to produce medical and hygiene products are as follows: 1.75 den (Nm=5143) fineness, 3.74 cN/fibre to 22 cN/fibre breaking strength, average length of fibres of between 12.7 mm and 25.4mm, and 1.27 g/cm^3 average specific weight [2, 3].

Needle-punching process

Mechanical bonding refers to the strengthening of the web by inter-fibre friction as a result of the physical entanglement of the fibres.

Needle punching is a process of bonding non-woven web structures by mechanically interlocking the fibres through the web. Barbed needles, which are mounted on a board, punch fibres into the web and are then withdrawn, leaving the fibres entangled. The needles are spaced in a non-aligned arrangement, and are designed to release the fibre as the needle board is withdrawn.

The needles enter and leave the web while it is trapped between two plates called a bed plate and a stripper plate (Figure 1). The web is pulled through the needle loom by drawing rolls.

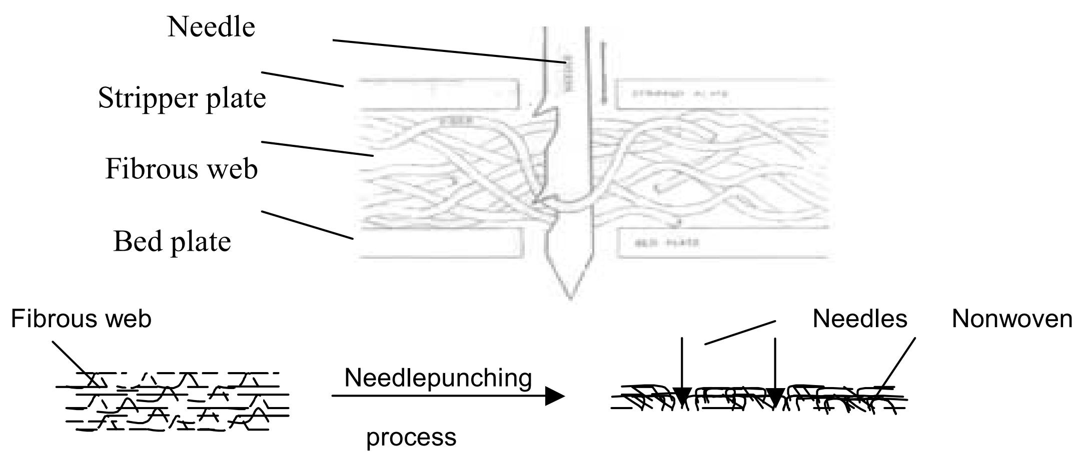


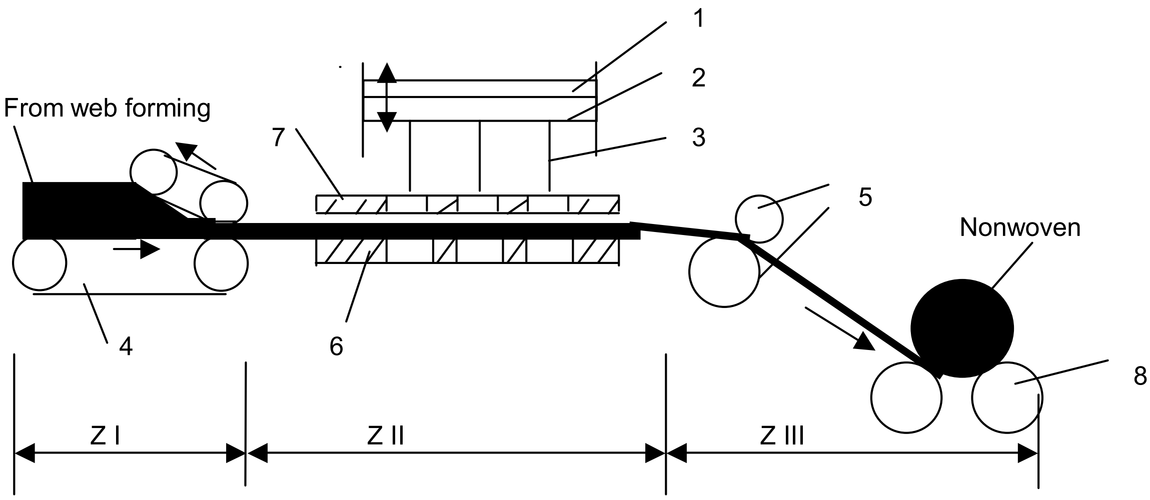
Figure 1. The start point of the needle-punching process (Basic needle-punching process)

Fibrous webs, which are characteristically bulky, are obtained by forming processes of:
- carding, cross-lapping or carding-cross-lapping;
- air laid, except pulp fibrous webs;
- spun-bonded webs.

The needle-punching process is illustrated in Figure 2. This mechanical interlocking is achieved by thousands of barbed felting needles repeatedly passing into and out of the web.

The main component parts of a classical needle loom are as follows, with a brief description of each:

- The needle board, that is, the base unit into which the needles (ranging in number from 500 per metre to 7,500 per metre of machine width) are inserted and held. The needle board then fits into the needle beam that holds the needle board into place.
- The bed plate and stripper plate. The web passes between two plates, the bed plate on the bottom and the stripper plate on the top. Corresponding holes are located in each plate, and it is through these holes that the needles pass in and out. The bed plate is the surface the fabric passes over when the web passes through the loom. The needles carry bundles of fibres through the bed plate holes. The stripper plate does what the name implies; it strips the fibres from the needle so the material can advance through the needle loom.
- The web feeding and fabric take up mechanisms that are typically driven rolls, and which facilitate the web's motion as it passes through the needle loom.



1 - needle beam; 2 - needle board; 3 - needles; 4 - feed table; 5 - draw-in rollers;
6 - bed plate (lower hole plate); 7 - stripper plate (upper hole plate); 8 - drawing-off rollers
Z I- fibrous web feeding and compression zone; Z II – needlepunching zone;
Z III- drawing-off zone

Figure 2. The needle-loom scheme

Experimental

Russian Medium II Cotton fibres have been utilised for obtaining the non-wovens for absorbent media which were the object of our studies.
The main starting characteristics of the cotton fibres utilised were as follows: 1.706 dtex (Nm=5860) fineness, 3.74 cN/fibre breaking strength, 21.7 km length of breaking, 30 mm average length of the fibres, 11.9% percentage of short fibres, 2.72% percentage of impurities, 0.90 degree of maturity, high degree of white.

To obtain the cotton fibrous webs, a process similar to cotton spinning was adopted. The technological process applied during the research work was a process of feeding/blending/opening, carding, band superposition (linking) and needle-punching.

The experiments took place under the industrial conditions listed below.
A fibrous web of approximately 600 g/m^2 surface weight, obtained by superposition of the short fibrous layer of bands of 0.3 Nm fineness, and superposed over bands of 0.2 Nm fineness, was used for needle-punching. This fibrous web was needle-punched by using a By Water needle loom with the 15x17x40x3 RB22 needle types from the SINGER Spezialnadelfabrik GmbH & Co. KG Company. Other data concerning the needle-punching process are as follows: 11 mm needle penetration depth into the fibrous web, 16 punches/cm^2 needle-punching density, 80 needles/100 cm^2 needle arrangement density on the needle plate; the needle-punching process was applied in two stages as preliminary and final processes.

Because the cotton fibres are difficult to needle-punch without auxiliary means, a cotton gauze woven insertion of yarns 34 Nm fineness, with 110-warp yarns/10 cm, and 64-weft yarns/10 cm was used to support the fibrous web [4, 5, 6, 7].

The experiment took place in conformity with a rotative compound experimental programme, for which the independent variables were as follows:

- X_1 - the frequency of the needle board, expressed in cycles/min;
- X_2 = the feed rate of the fibrous web, as the distance between two successive punches of the same needle in the machine direction (the web displacement direction), expressed in mm.

As dependent variables, two main characteristic features of the needle-punched non-wovens have been analysed:

- the liquid average absorption speed (Y_{AS}) expressed in cm/min;
- the average weight (Y_{AW}) expressed in g/m^2.

EDANA test methods were used to determinate the dependent variables.

The codified and real parameter values are given in Table 1. By using an experimental programme, the equations of regression were obtained for the non-woven characteristics considered as dependent variables, in order to optimise the needle-punching process for a cotton web.

Table 2 gives the following data [8] for each of the 13 experiments of the rotative compound experimental programme:

- the experimental values of the dependent variables (Y_{AS}) and (Y_{AW});
- the deviation A of the calculated values (using the regression equations) in comparison with the experimental values (the values of deviation A must be included in the interval of $\pm$ 10%).

Table 1. Experimental programme

Independent variable	*Codified and real value*				
	- 1.414	-1	0	1	1.414
X_1 (cycles/min)	145	155	179	204	214
X_2 (mm)	4	5	7.5	10	11

Table 2. Experimental programme, dependent variable values, and deviation values

Exp.	$X_{i\ Cod}$		Values$_{xperimental}$ for:		Deviation A (%) for:	
	X_1	X_2	Y_{AS} (cm/min)	Y_{AW} (g/m^2)	Y_{AS} (cm/min)	Y_{AW} (g/m^2)
1	-1	-1	0.39	640.01	4.7179	1.6607
2	1	-1	0.381	645.0	1.3648	0.1346
3	-1	1	0.389	638.0	4.0103	0.1465
4	1	1	0.42	641.5	6.6977	1.4349
5	-1.414	0	0.401	651.0	1.0077	1.0617
6	1.414	0	0.461	631.5	3.1792	0.9252
7	0	-1.414	0.320	660.0	5.8581	1.2408
8	0	1.414	0.51	625.5	6.5124	1.1380
9	0	0	0.462	633.45	0.1515	0.2360
10	0	0	0.4618	637.5	0.1083	0.4008
11	0	0	0.4621	634.0	0.1731	0.1491
12	0	0	0.4595	635.1	0.3917	0.0244
13	0	0	0.4604	633.9	0.1955	0.1649

From Table 2, it can be observed that all the deviations of the theoretical values from the experimental values (A) expressed in per cent are less than 10% for each experiment of the experimental programme.
The average value of the deviation A is of 2.64442% for liquid absorption speed, and of 0.67058% for the average weight.

Results

The variation of the liquid absorption speed (Y_{AS})

The variation of the liquid absorption speed (Y_{AS}) in function of the needle-punching parameters is analytically described by the equation of regression (1), which is an equation of the first and second degree as follows [8]:

$$Y_{AS} = 0.461 + 0.015\ X_1 + 0.029\ X_2 - 0.018\ X_1^2 - 0.041\ X_2^2 + 0.013\ X_1X_2 \quad (1)$$

The coefficients of the equation of regression (1) were tested by the Student test, with the table value of 2.132, for a level of significance $\alpha = 0.95$ and $v = 4$ degrees of freedom.
The feed rate of the fibrous web (variable X_2) significantly influences the liquid absorption speed. This influence is evidently visible by the coefficients of the terms of first and second degree and of the interaction term.
However, the liquid absorption speed is mainly influenced by the feed rate parameter (X_2), owing to both terms, of the first and second degree. The influence of the feed rate is higher than the influence of the frequency of the needle board (X_1) by 2.0 times owing to the term of the first degree, and 2.27 times owing to the term of the second degree. Considerable influence is given by the interaction term (X_1X_2), and its positive coefficient shows the increasing tendency of the liquid absorption speed on the cumulative action of both parameters. The equation of regression (1) was validated by the deviation A expressed as a percentage.
The value of the correlation coefficient is $R_{Y.X1,\ X2} = 0.9394$, and the multiple determination coefficient has the value of $d_{Y \cdot X1,\ X2} = R^2_{YSA.X1,\ X2} = 0.88244$.
These values signify that the liquid absorption speed is influenced in 88.244% by the needle-punching process parameters (because of the compactness effect of the fibres), and in 11.76% by other parameters (those which could include the characteristics of fibres).

The mathematical model (1) describes an elliptical parabolic dependency with a maximum point.
The maximum values of the liquid absorption speed are obtained for $X_1 = 0.575$ and $X_2 = 0.449$ co-ordinate values.
The real co-ordinates of the critical point obtained by optimisation are as follows: $X_1 = 197$ cycles/min, $X_2 = 8.62$ mm. The liquid absorption speed for these co-ordinates is $Y_{SA} = 0.476$ cm/min.
This critical point is a technological maximum point, and is situated within the experimental domain.
The variation of the liquid absorption speed as a function of the independent variables selected of the needle-punching process is shown in Figure 3, Figure 4, and Figure 5, respectively as graphical 3D, 2D and 1D representations, the last as functions of the X_1 variable for different X_2.

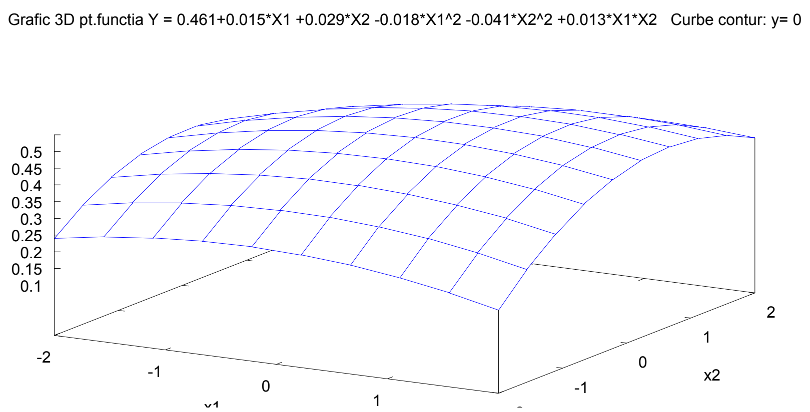


Figure 3. Graphical 3D representation of the equation (1) describing the liquid absorption speed (Y_{AS})

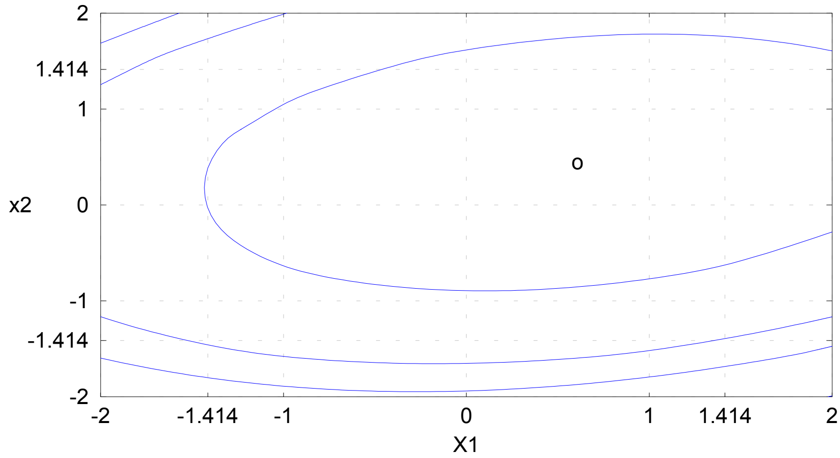


Figure 4. Graphical 2D representation of the equation (1) describing the liquid absorption speed (Y_{AS})

The experimental area of the liquid absorption speed is represented by the curves of constant level with values of Y_1 = 0.3 cm/min, and segments of the curve with values of Y_2 = 0.4 cm/min, and Y_3.= 0.25 cm/min. The considerable influence of the feed rate is evident.

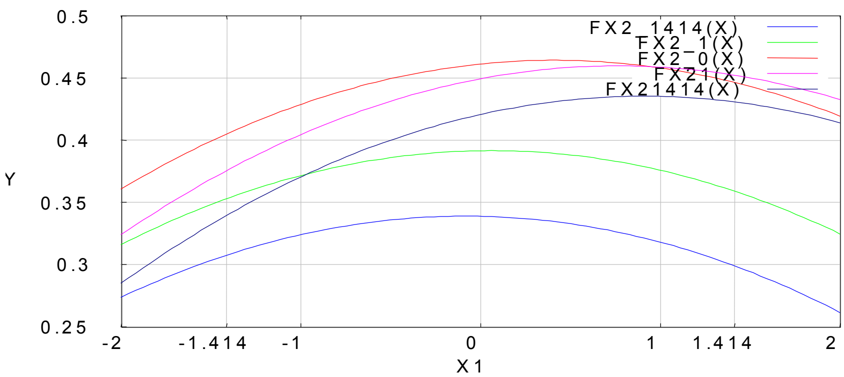


Figure 5. Graphical 1D representation of the equation (1) describing the liquid absorption speed (Y_{AS})

The maximum values of the liquid absorption speed are obtained for the values of the independent variables situated within the (0…1) interval.

The variation of the average weight

The variation of the average weight (Y_{AW}) in the function of the needle-punching process parameters is expressed by the equation of regression (2) as follows [8]:

$$Y_{AW} = 634.945 - 2.385\, X_1 - 6.787\, X_2 + 2.886\, X_1^2 + 3.636\, X_2^2 \qquad (2)$$

The average weight, similar to the liquid absorption speed, is mainly influenced also by the feed rate X_2, owing to the terms of the first and the second degree. The term of the first degree influences the value of the average weight 2.284 times higher, and the term of second degree 1.26 times higher than the frequency of the needle board (X_1), expressed in cycles/min. The compound term X_1X_2 does not at all influence the variation of the average weight.

Equation (2) has been validated by the deviation A which is less than 10%, having an average value of 0.67058% for all the 13 experiments.
The critical point is a minimum point situated within the experimental domain. The co-ordinates of the critical point are as follows: X_1 = 189 cycles/min, X_2 = 9.8 mm, and the average weight for them Y_{AW} = 631.285 g/m^2.

The correlation coefficient for the average weight characteristic is $R_{YAW.\ x1,\ x2}$ = 0.7591, and the multiple determination coefficient has the value of $d_{Y.x1,\ x2} = R^2_{Y.x1,\ x2}$ = 0.57623. These values showed that the needle-punching parameters influenced the average weight only by 57.623%, whereas they influenced those of the other parameters by 42.377%. The influence of 57.623% shows again that it is difficult to needle-punch the cotton fibres even if special needles are used. The non-woven average weight is influenced by the average weight of the fibrous web fed to the needle-punching equipment.

The variation of the average weight as a function of the independent variables of the needle-punching process is shown in Figure 6, Figure 7, Figure 8 and Figure 9, respectively as graphical 3D, 2D and 1D (Figures 8 and 9) representations, the last as functions of the X_1 variable for different X_2.

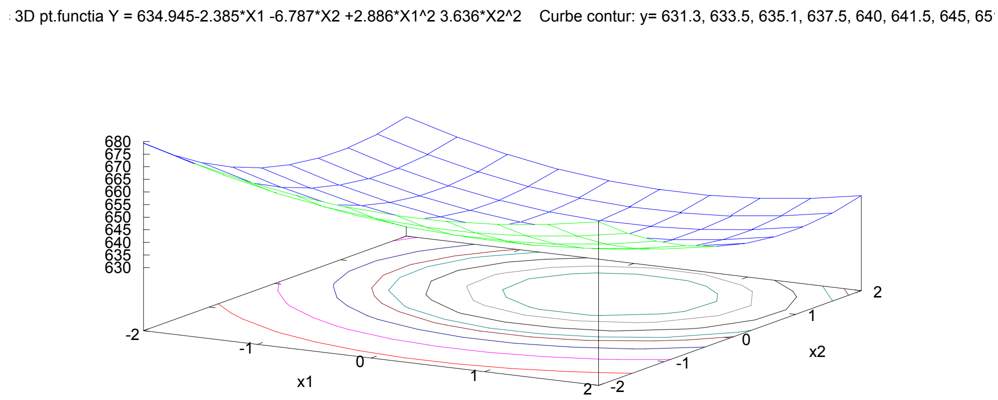


Figure 6. Graphical 3D representation of the average weight variation (Y_{AW})

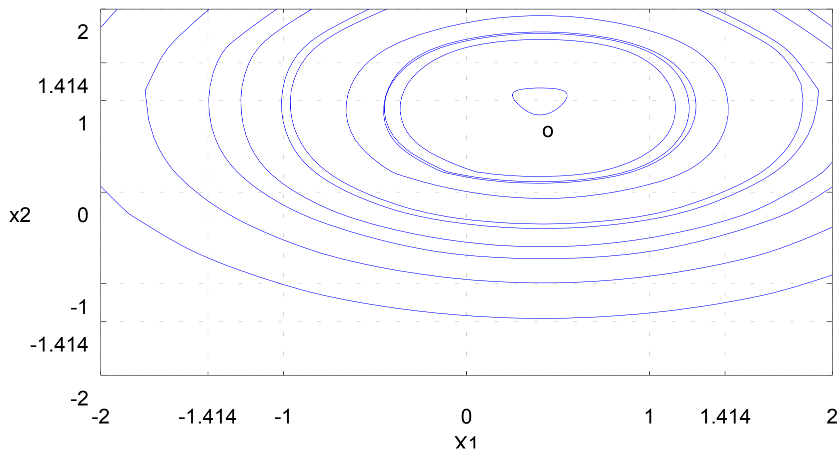


Figure 7. Graphical 2D representation of the average weight variation (Y_{AW})

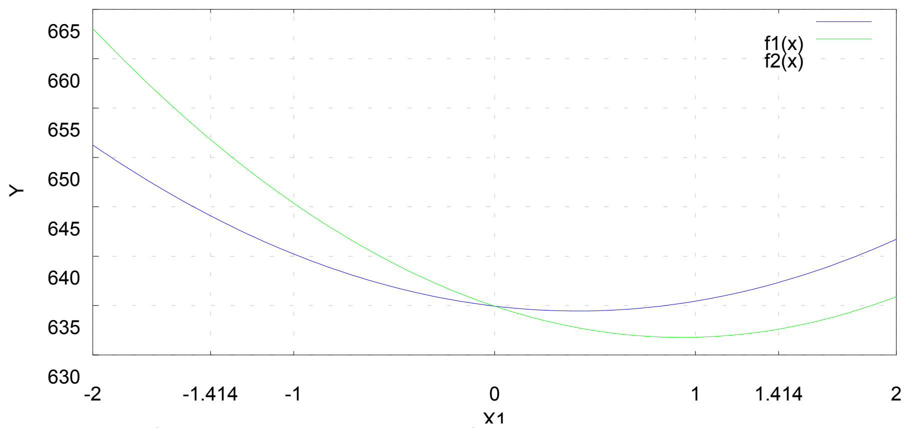


Figure 8. Graphical 1D representation of the average weight variation (Y_{AW})

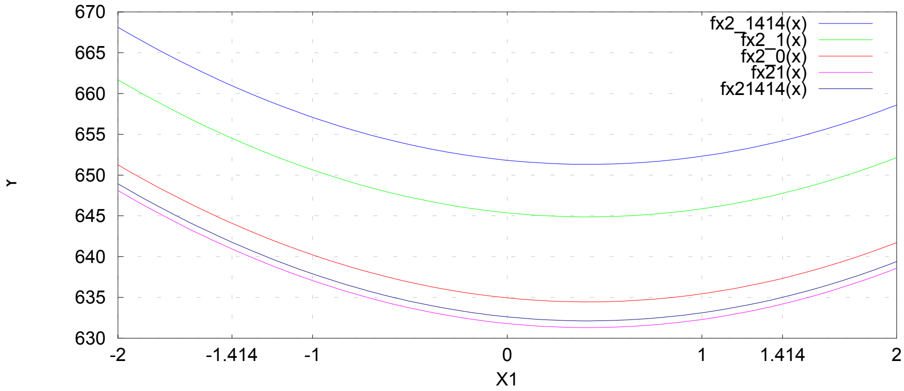


Figure 9 Graphical 1D representation of the average weight variation (Y_{AW})

Conclusions

On the basis of the experimental work carried out, the following conclusions can be drawn:

- The gauze woven fabric, used as support, was not destroyed during the needle-punching process.

- No significant breakages of needles were observed during the needle-punching process. However, regarding the possibility of needle breakage during the needle-punching process, the non-woven products obtained can be used as absorbents for hygienic purposes only if a magnetic feeler (gauge) can be placed just after the needle-punching process. This feeler must be in contact with the non-wovens, and must hold back the broken points of the needles. A number of such feelers are included in certain textile machinery types.

- The needle-punching parameters can influence the non-wovens characteristics, such as the average weight and the liquid absorption speed. A significant influence was determined by the feed rate values.

- The values of deviation between the calculated and the experimental values of the dependent variables were less than 10%, and this indicates that the regression equations obtained for optimising the characteristics of the needle-punched non-wovens (made of cotton fibres) in function of the parameters analysed have been validated.

- The critical points of the characteristics – the maximum (showing the highest value of the liquid absorption speed) and the minimum (showing the lowest value of the average weight) – have their co-ordinates situated closely within the same experimental space, and what is more, within the proximity of the experiment's centre. That indicates that even with less raw material it is possible to achieve a high liquid absorption speed.

- Even if the liquid absorption speed is not as high, an alkaline cleaning of the needle-punched non-wovens can change this by elimination of the natural impurities and the cotton waxes.

- The value of the liquid absorption speed was approximately that of the values of this quantity of some absorbent products manufactured by S.C.A. Mölnlycke AB, Procter & Gamble, Rauscher Pelz.

Acknowledgments

The authors wish to thank the SINGER Spezialnadelfabrik GmBH & Co. KG for providing the authors with special needles, manufactured by them, which were used for bonding the cotton fibrous web, and therefore allowing this research to be carried out.

References

1. http://www.edana.org
2. *** Cotton in Non-woven Industry. Non-woven Industry, June 1996, p. 40-41.
3. *** FibreFibres for Non-wovens. Non-wovens Industry, June 1994, p. 42-62.
4. Zamfir M., Kiekens P., Van Langenhove L., Medical, Hygiene and Protective Apparel Made from Non-wovens. Academia Press, ISBN 90 382 0 307 1, Belgium (2001).
5. Zamfir M., NONTISSÉS. Structures – Caractéristiques – Applications - Nouvelles Technologies. Academia Press, ISBN 90 382 0 306 3, Belgium (2001).
6. Morton G.P., Needle-punched Cottons: Some Fundamental and Practical Consideration. Paper presented at the Durable Needle-punch Conference 1992, 17-18 March 1992 at Charlotte, NC, United States, pp 149-162.
7. Mrština, V., Fejgl, F., Needle-Punching Textile Technology. Amsterdam, 1990.
8. Ciubotaru, G., Zamfir M., TEXPRO Programme. Technical University of Iasi.