SORPTION KINETICS AND CAPACITY OF HIGHLOF COTTON FABRICS

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Abstract

The study of a liquid behaviour inside textiles is important for using this materials. Sorption kinetics and capacity are studied in this contribution. Perpendicular laid textile structures Struto are compared with cross-laid and needle punched nonwovens.

Introduction

Studied materials were produced from 50 % of bi-component bonding fibres and 50 % of base fibres, namely polyethyleneterephtalate (PES), gray cotton or bleached cotton, respectively. The sorption kinetics in various fabric directions related to the fibre orientation was studied using tensiometer KRUSS K12. Influence of the base fibres, fabric structure as well as of the orientation on the sorption properties is shown and discussed in this paper.

Sorption

The sorption is the effect, when liquid penetrates into a textile structure. It has two phases, adsorption and absorption [1]. The liquid is transported into porous textile material using capillary forces by adsorption. It is observed in the moment after a contact of a textile material with liquid, when the physical forces work between liquid and material. Absorption is the phenomenon, when come on chemical bonding of liquid on fibres.

Sorption Evaluation

The absorption measuring is described in the Edana standard 10.1-72. This method covers the evaluation of the behaviour of nonwoven fabrics in the presence of liquids [2]. This can be done by testing for:

- Liquid absorbency time. It is the time required for a sample of absorbent material to become completely wetted by the test liquid.
- Liquid absorptive capacity. It is measured the weight of liquid that is absorbed per unit weight of the test absorbent or by percentage, after a standard time or after the time needed to wet completely the material.
- Liquid wicking rate. It is measured the capillary of the test material, i.e., the speed at which the liquid is transported into the fabric.

Liquid Absorptive Capacity

Measuring equipment:

- Wire gauze of dimensions 120 mm x 120 mm.
- Dish with test liquid for lazing in the wire gauze with the sample attached.
- Suitable wetting glass with cover
- Stop watch

Procedure parameters:

- Sample parameters (100 x 100) mm
- minimal weight of the sample 0.01 g
- the gauze with sample is placed 20 mm below liquid surface
- the measuring time 60 s
- the time of hanging freely to drain vertically 120 s
- the calculation of liquid absorptive capacity:

$$W_A = \frac{M_n - M_k}{M_k} \cdot 100, \qquad (1)$$

where W_A is liquid absorptive capacity, M_k is average weight of 5 original samples, M_n is average weight end of the test.

Sorption Kinetics

The liquid transport in the fibre structure was described by Lucas and Washburn in the first half this century [3]. These theory reduces the liquid motion in the porous material to the liquid motion in one capillary. The result of this theory is in the following differential equation:

$$\frac{dh}{dt} = \frac{a}{h} - b, \qquad (2)$$

where dh/dt is the liquid transport speed in the capillary, a,b are constants, h is the high of liquid in the capillary and t is time. Constant a is $r\gamma\cos\Theta/4\eta$, where r is the capillary diameter, γ is the liquid surface tension, Θ the angle between liquid surface and the capillary axis and η is dynamic viscosity. The constant b is $r^2\rho g\cos\beta/8\eta$, where ρ is liquid density and β is angle between capillary axis and perpendicular line to the liquid surface. The solution of equation (2) under the condition b=0 is the relation:

$$h = K \cdot t^{1/2}, \qquad (3)$$

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where h is the high of liquid in the capillary, K is a constant characterising capillary parameters and t is time.

Tensiometer KRÜSS K-12

It is possible to measure the contact angle between liquid and solid. We can measured liquid surface tension and adsorption, respectively sorption kinetics with the measuring apparatus tensiometer KRŪSS K-12 [4]. The measuring system contains measuring and processor unit. The last is connected with the computer, where is installed the program K121 to the data processing.

The tensiometer measures the sorption kinetics on the principle of Lucas – Washburn equation.

Measuring Equipment. The tested sample is fixed into the sample clamp. The sample vessel is filled with the tested liquid and put into the thermostat vessel in the measuring unit. The sample in the clamp is fixed into the balance fixing clamp, which is placed inside the measuring head of the measuring unit. The balance system is unlocked. The thermostat vessel with liquid is lifted so that the surface of the test liquid is just under the lower edge of sample. The edge must be parallel to the liquid surface, and after that the measuring can start. The liquid surface is lifted that it touches the lower sample edge. Liquid starts to transport into the sample and the balance system measures the liquid weight during the time. A diagram is displayed. It is possible to convert the data to the form of eq.(3) using the program K121.

Procedure parameters:

- sample parameters (30 x 30 x 5) mm
- the measuring time 300 s

Experiment

Tested Materials

There were produced three types of Struto textile. They are produced from 50 % bi-component bonding fibre wellbond 4,4 dtex and 50 % of based fibres namely bleached and gray cotton and PES 2,7 dtex. The same fibre composition were used for producing needle punched textile.

Liquid Absorptive Capacity Measuring

The Struto textiles (area weight 500g/m^2, thickness 30mm) with different based fibres were tested with this method. The results are collected in table 2. There was cut from Struto textile thin layer, see in fig. 3, (bleached cotton, mass per unit area 10g/m^2, thickness 5 mm). It was compared with needle punched textile (bleached cotton, mass per unit area 10g/m^2 and thickness 5 mm) using this test method. The results are in the table 3.

Measuring conditions:

- liquid temperature 20˚C
- air temperature 27˚C
- relative humidity 52 %

It was made five measuring on each sample. The average values of liquid absorptive capacity W_A were calculated from this experimental date using the equation 1.

Sorption Kinetics Measuring

There were cut three types of samples from the Struto. In the (x,z) plane, see in figure1, in (y,z) plane, see in figure 2. This samples had mass per unit area 10g/m^2, thickness 5 mm. The thin section (mass pet unit area 10g/m^2, thickness 5 mm) was cut from this textile, see in figure 3. The needle punched textile is in the figure 4. The samples were tested using tensiometer to compare their sorption kinetics. The list of these samples is in the table 1. The results are in graphs 1 - 4.

Measuring conditions:

- liquid temperature 20˚C
- air temperature 24˚C
- relative humidity 80 %

It was made five measuring on each type of such samples. The sorption kinetics was recorded in graphs 1-4 as dependence of adsorption capacity W_A on time.

Results

The material from bleached cotton has the best absorptive capacity, we can see in the table 2. This material and material with PES fibres have better adsorptive capacity W_A than the material from gray cotton. The reason for it is that gray cotton has not good sorption properties (graph 1) and in the structure is a lot of neps from gray cotton. They defence to the liquid sucking into the structure. The PES fibres do not form the neps by carding and the porous space is more open for the liquid.

The thin Struto layer has better adsorption properties than the needle punched textile. The Struto textile structure is more open for liquid sucking tested by this method. The results are in the table 3. The cross-laid fibres in needle punched textile defence liquid sucking into the textile.

The Results of Measuring Sorption Kinetics

Commentary to the Graph 1 in the Figure 6. There are the curves of the samples from the groups 1, 9 and 17 in table 1. These samples are from the Struto section parallel with (x,z) plane, shown in figure 1. The adsorption is measured along the z axis. The bleached cotton samples (1) curves show that the quick adsorption runs in first 20 seconds. A lot of liquid is adsorbed during this time. Then is the speed of adsorption

reduced. The amount of adsorbed liquid increases slowly. The adsorption procedure is not stationary even after 300 seconds. The gray cotton samples (9) curves show that almost all liquid is adsorbed in first 10 seconds. Than the amount of adsorbed liquid increases slowly. After 150 seconds is the adsorption almost finished. The PES (17) samples curves is the same as for gray cotton.

This same sorption kinetics have the tested samples from groups 2, 10, 18 and 3, 11, 19 and 4, 12, 20.

Commentary to the Graph 2 in the Figure 7. There are the curves of the samples from the groups 5 and 21 in the table 1. These samples are from Struto section parallel with the (x,y) plane, see in figure 4. There is no sample from gray cotton, group 13, because the quality of this textile does not admit to prepare a thin section in the plane (x,y). The adsorption is measured along the x axis. There is not so big difference between the adsorption properties of samples 5 and 21. The structure has stronger influence on adsorption than the type of material. The amount of adsorbed liquid into the material with bleached cotton (5) increases during the whole measuring process and does not finish after 300 seconds. The material with PES (21) adsorb quickly in the first 40 seconds of the measuring. Than the adsorption goes slowly, but does not finish and continue after 300 seconds.

This same sorption kinetics have the tested samples from groups 6 and 22.

Commentary to the Graph 3 in the Figure 8. There are compared the sorption kinetics of the samples from Struto sections from all planes. The liquid is absorbed into each sample along two different axes. The tested samples contain bleached cotton. These Struto samples are compared with the samples cut from needle punched textile with bleached cotton, see in figure 5. The needle punched samples (7,8) have better adsorption properties than the samples from Struto textile. There are two types of Struto samples (5,3), which have better adsorption than the other Struto samples. The liquid is sucked into the material in the x axis direction by the sample 5. There are a slight gaps between folds in this direction and the liquid is transported into this big porous space, shown in figure 10. The sample 3, section from the (y,z) plane, is created from a number of the web folds. Between the folds are a slight gaps witch are open to adsorption along the z axis, shown in figure 11. There is the group of samples which have comparable adsorption in the graph 3. They are the samples 1, 2 and 6. It is interesting that by the sample cut from the (x,z) plane (group 1 and 2), shown in figure 12, have the same adsorption ability in both adsorption directions, along x and z axis. This sample is created from one or two card layers. The structure is given by the structure of card layer, which is more isotropy than the structure of samples in figure 10 and 11. The sample 4 has the worst adsorption. The anisotropy structure defends to the liquid transport in the perpendicular direction to the fibres.

Commentary to the Graph 4 in the Figure 9. There are compared the sorption kinetics by the samples cut from Struto textile with PES from all planes and adsorbed liquid each in two directions. These Struto samples are compared with the samples cut from needle punched textile with PES, see in figure 5. The adsorption goes along the x and y axis. We can see that by the materials with PES have the structure of textile stronger influence on adsorption then the type of material. The needle punched textile adsorbs in first seconds more liquid then the Struto samples in all measuring process. The adsorption continue during the measuring process and does not finish after 300 seconds. The sample 21 has the best adsorption from Struto samples.

Ising Model Monte Carlo Simulation of Liquid Wicking into a Fibre Mass

The wicking of a liquid into a fibrous materials can be investigated using modern tools of Statistical physics. One of them is Ising Model Monte Carlo simulation. The first successful attempts at applying Ising Model to wetting were achieved in the early seventies [5] by Gallavotti, while the droplet dynamics have been studied using this tool towards the and of eighties [6]. The application of this method to investigate wetting and wicking phenomena of a two dimensional fibre assembly was done in [7].

Computer experiments in this work are focused on the influence of fibre orientation on the wicking dynamics. To reach this objective we have modelled the liquid motion inside a fibre mass that is partially dipped into a liquid layer. Fibres of this mass are of equal length and are randomly located in the space but they contain constant angle with the vertical direction to the liquid surface.

The three-dimensional Ising Model consists of a regular cubic lattice of size $W \times H \times L$ (width x high x length). Distances in the lattice are measured in natural scale, it means in the lattice units $l.u.$. Each of the lattice cell, denoted by index i, represents liquid $(S_i = 1)$, air $(S_i = 0)$ or fibre $(S_i = 3)$ particle alternatively. Variables S_i are called spins. Each particle interacts with their 26 neighbours organised into a supercube via exchange energies $J(S_i, S_j)$.

One can write for the system Hamiltonian as

$$H = \sum_{\langle i,j \rangle} J\left(S_i, S_j\right) + G \sum_i z_i, \qquad (4)$$

where indices i and j run over the all interacting couples of cells and the final term $G \sum_i z_i$ describes the liquid particles only with the uniform gravity field, heaving the

gradient *G*. The gravitational energy components $G.z_i$ of a liquid spin *i* are proportional to the value of their vertical co-ordinates, z_i.

The exchange energies are chosen in a manner, that assumes attraction between liquid and fibre mass and between liquid – liquid and gas – gas couples of cells, while repulsion exists between liquid - gas, and fibre gas particles. The values for the exchange energies were simulation runs these exchange energies values are kept constant. A stochastic process, constrained by particle conservation; governs the model evolution. Conservation is maintained by using long – range Kawasaki spin – exchange dynamics described in [6].

In this spin – exchange dynamics are two spins chosen at random on the liquid – gas. Than we compute the energy change, $\delta H = H(x') - H(x)$ where *H(x)* is Hamiltonian of previous configuration *x,* and *H(x¢)* is the total energy of the configuration after a spin exchange. These Hamiltonians are given by equation (4). If a random number *Z* uniformly distributed between 0 and 1 is less than the transition probability exp(δH/kT) the chosen spins are flipped, otherwise they are not. In the previous expression k denotes Bolztman constant and *T* is a temperature.

Using the above described dynamics, we relaxed initially flat into which is partially dipped a fibre mass by applying *t* Monte Carlo steps (MCS) per lattice cell. One such a step represents in average one attempt for spin – exchange of each cell. The liquid layer thickness is 10 *l.u* . Fibre mass is composed of fibres of equal length (50 *l.u*) with equal declination with respect to the liquid surface. We have generated 10000of fibres inside the lattice box.

Results were obtained in a lattice of *W = 50 l.u* with *L = 100 l.u* applying exchange energies listed in table 4.

We used the gravity field gradient *G = 50* and the product of simulation temperature with Boltzmann constant *kT* having the value 100.

Fig. 13 and 14 shows the morphology of the liquid body on the cross – sections of two fibre masses after 600 MCS. Fig 15 shows us the time development of liquid mass imbibed into a textile material and Fig. 16 is the plot of energy changes dependence on MCS. Results were obtained for two different declination of fibres $\theta = 45^o$ and 90^o.

Conclusion

Material obtained bleached cotton and material from PES fibres have better adsorptive capacity than the material from gray cotton. There is a lot of neps from gray cotton in the structure of Struto. They defence to the liquid sucking into the structure.

The thin layer cut from Struto has better absorptive capacity then needle punched textile.

We can say that for the adsorption in the all textile flat is better by the thin Struto layer then by the needle punched textile. Its structure is more open to the liquid sorption.

The comparison of sorption kinetics in different directions of Struto textile brought us next information about the textile structure and its sorption behaviour. The best sorption kinetics has the thin section cut from the highlof Struto in (x,y) plane, and liquid is sucked along x axis, how we can see in figure 3. There are a slight gaps between folds in this direction and the liquid is transported into this big porous space, see in figure 10. The next is the section cut from Struto in the (y,z) plane and liquid is sucked along z axis, see in figure 4. The fibres are oriented generally in this direction and liquid is easy sucked into the sample. On the other side this anisotropy structure defends to the liquid transport in the perpendicular direction to the fibres.

We have present the application of an Ising Model Monte Carlo method to obtain the information about the wicking dynamics. This dynamics depends on fire orientation like for real textile samples. More detail investigation will unable us to obtain qualitative rules of this phenomenon.

Acknowledgement

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Table 1. The list of sections from Struto textile, which are tested.

Sample	Material	Textile, section plane	Adsorption along axis	Fig.
1	Bleached cotton	Struto, (x,z)	Z	2
2	Bleached cotton	Struto, (x,z)	X	2
3	Bleached cotton	Struto, (y,z)	Z	3
4	Bleached cotton	Struto, (y,z)	Y	3
5	Bleached cotton	Struto, (x,y)	X	4
6	Bleached cotton	Struto, (x,y)	Y	4
7	Bleached cotton	Needle punch. t.	X	5
8	Bleached cotton	Needle punch. t.	Y	5
9	Gray cotton	Struto, (x,z)	Z	2
10	Gray cotton	Struto, (x,z)	X	2
11	Gray cotton	Struto, (y,z)	Z	3
12	Gray cotton	Struto, (y,z)	Y	3
13	Gray cotton	Struto, (x,y)	X	4
14	Gray cotton	Struto, (x,y)	Y	4
15	Gray cotton	Needle punch. t.	X	5
16	Gray cotton	Needle punch. t.	Y	5
17	PES	Struto, (x,z)	Z	2
18	PES	Struto, (x,z)	X	2
19	PES	Struto, (y,z)	Z	3
20	PES	Struto, (y,z)	Y	3
21	PES	Struto, (x,y)	X	4
22	PES	Struto, (x,y)	Y	4
23	PES	Needle punch. t.	X	5
24	PES	Needle punch. t.	Y	5

Table 2. Liquid absorptive capacity measuring (W_A) on the three types of Struto textile with difference based fibres

	Material	W_A [%]
1.	Struto – bleached cotton	1717
2.	Struto – gray cotton	33
3.	Struto – PES	1403

Table 3. Liquid absorptive capacity measuring (W_A) on the section from Struto parallel with (x,y) plane and on the needle punched textile. The based fibres are bleached cotton.

	Bleached cotton	W_A [%]
1	Struto – thin layer	15480
2	Needle punched t.	4685

Table 4. Exchange energy J (S_i, S_j) values.

	S = 1 liquid	S = 0 gas	S = 2 Fibre
S = 0 gas	5	-40	20
S = 1 liquid	-26	5	-30

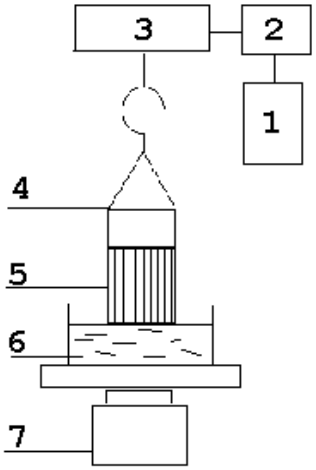

Figure 1. Measuring apparatus Kruss K12 with its parts: 1-computer, 2-processor unit, 3-electronic balance, 4-sample clamp, 5-sample, 6-thermostat vessel with testing liquid,7-lifting stage.

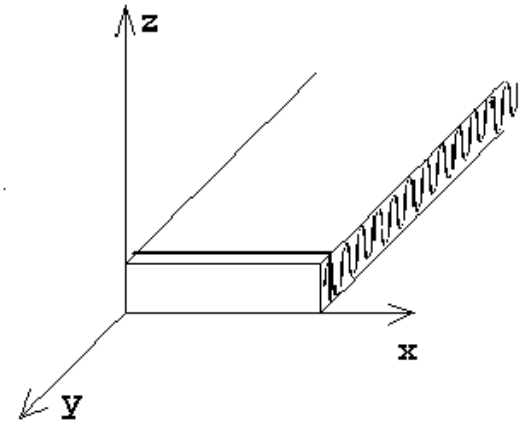

Figure 2. The thin sample section parallel to the (x,z) plane from Struto textile. The adsorption is measured along the x and z axis.

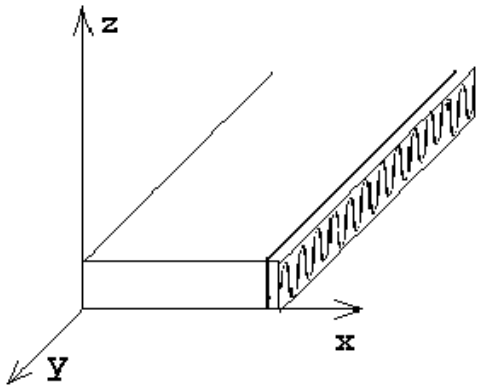

Figure 3. The thin sample section parallel to the (y,z) plane from Struto textile. The adsorption is measured along x and y axis.

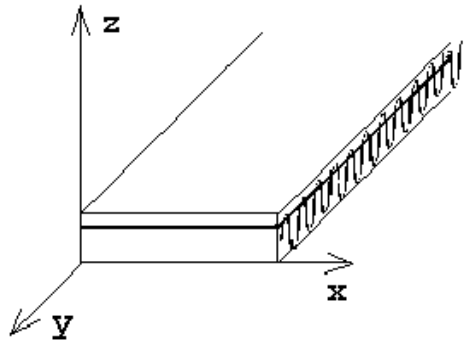

Figure 4. The thin sample section parallel to the (x,y) plane from the Struto textile. The adsorption is measured along the x and y axis.

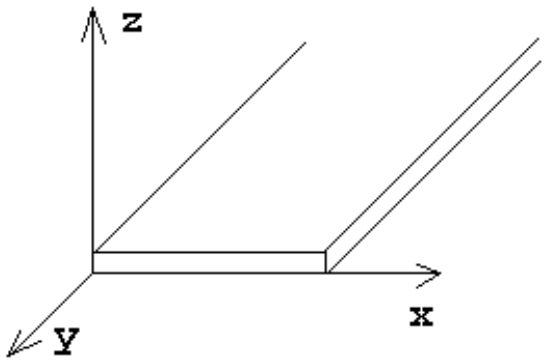

Figure 5. The samples of needle punched textile. The adsorption is measured along the x and y axis.

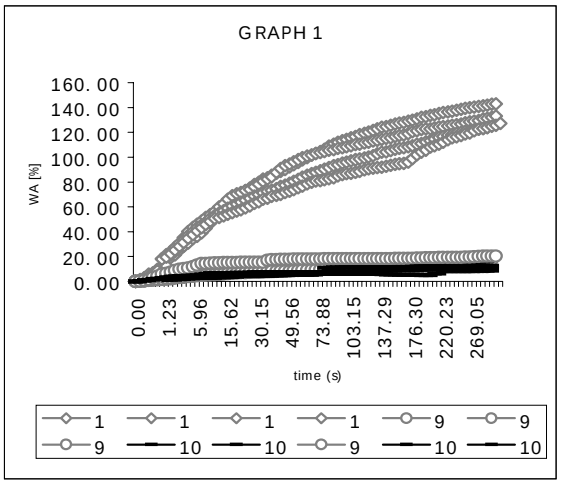

Figure 6. The graph of sorption kinetics: liquid absorptive capacity W_A in dependence on time. There are three curve types of the samples. The sections from Struto parallel with (x,z) plane, see in figure 1. Bleached cotton – curves no.1, gray cotton – the curves no.9 and PES – the curves no.17. The adsorption is measured along z axis.

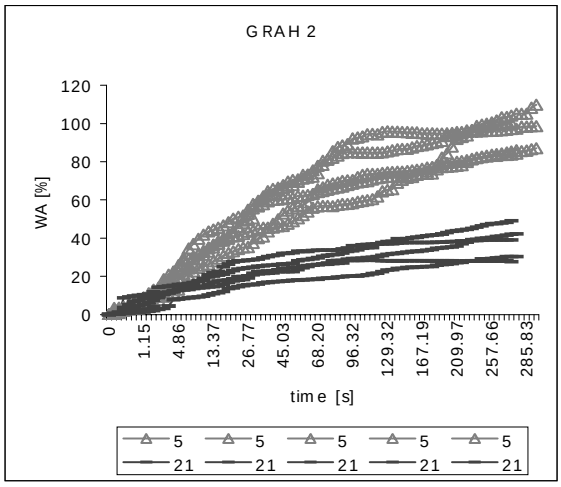

Figure 7. The graph of sorption kinetics: liquid absorptive capacity W_A in dependence on time. There are three curve types of the samples. The sections from Struto parallel with the (x,y) plane, see in figure 4. Bleached cotton – curves no. 5, PES – curves no. 21. The adsorption is measured along the x axis.

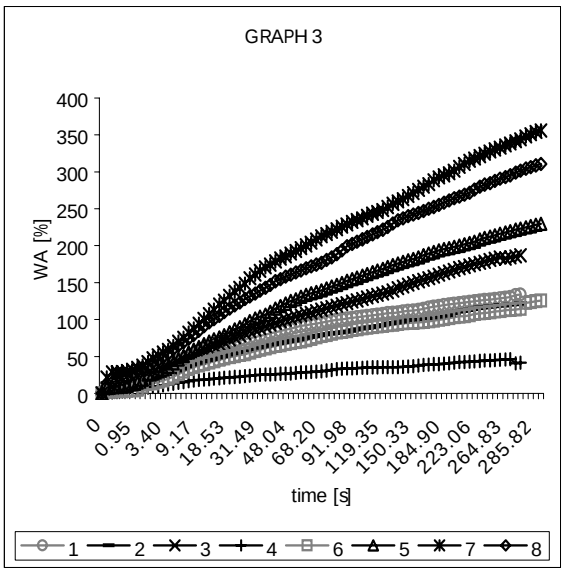

Figure 8. The graph of sorption kinetics: liquid absorptive capacity W_A in dependence on time. There are compared the sorption kinetics by the sections from Struto textile, see in figure 2-4, and needle punched textile, see in figure 5. The materials contain bleached cotton. The adsorption is measured in all directions. The curve numbers are the sample numbers in table 1.

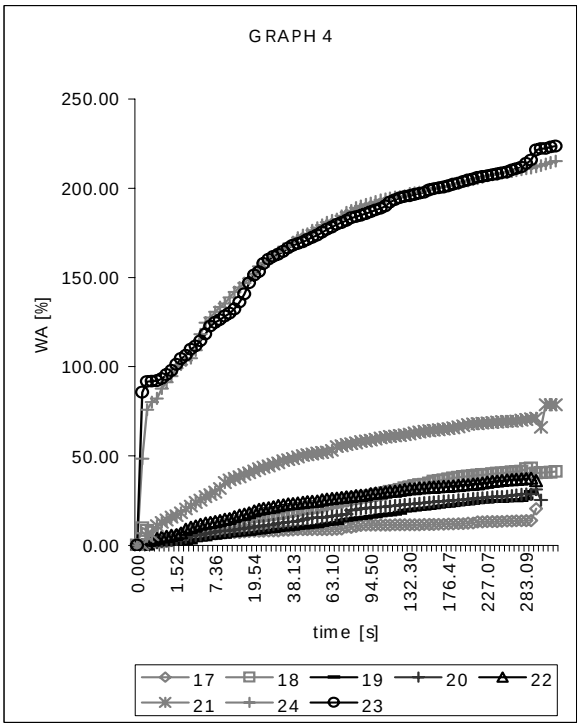

Figure 9. The graph of sorption kinetics: liquid absorptive capacity W_A in dependence on time. There are compared the sorption kinetics by the sections cut from Struto textile, see in figure 2-4, and needle punched textile, see in figure 5. The materials contain PES based fibres. The adsorption is measured in all directions. The curve numbers are the sample numbers in table 1.

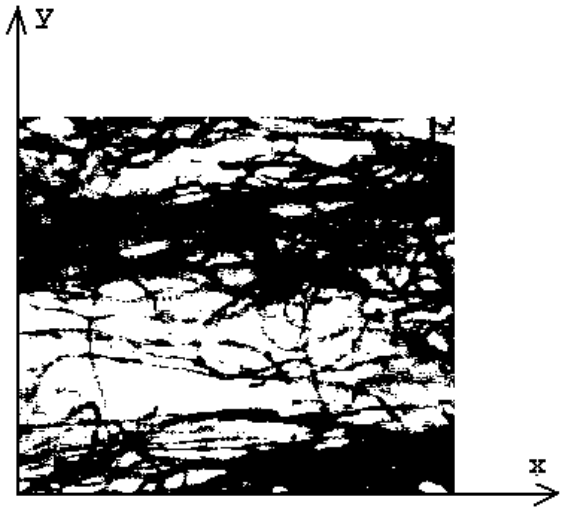

Figure 10. The structure of Struto section parallel with (x,y) plane.

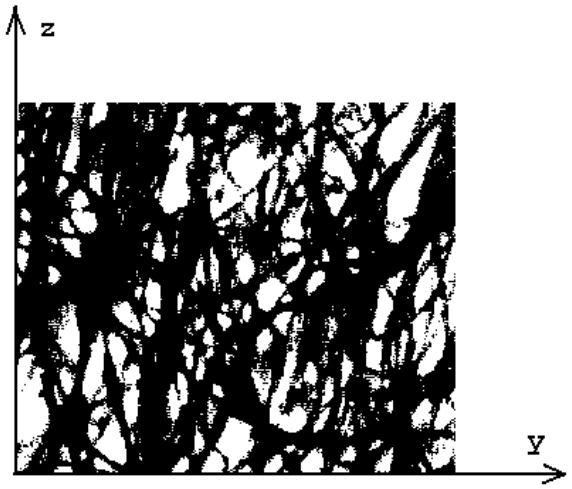

Figure 11. The structure of Struto section parallel with (y,z) plane.

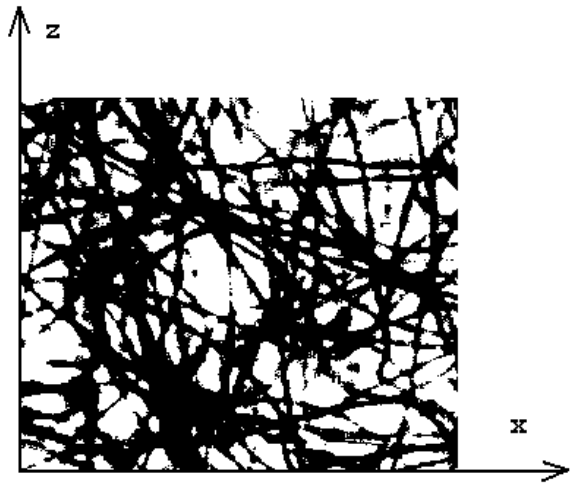

Figure 12. The structure of Struto section parallel with (x,z) plane

Figure 13. Vertical and horizontal cross – section of textile sample model after 600 MCS. Horizontal cross – section belongs to the high 150 l.u. Fibres of the sample are parallel with the original liquid surface ($\theta = 90^{\circ}$).

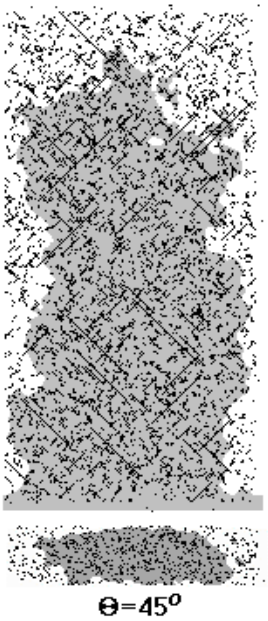

Figure 14. Liquid imbibitioin after 600 MCS into the textile sample model. Each fibre of this model contains the angle $\theta = 45^{\circ}$ with the axis perpendicular to the original liquid surface.

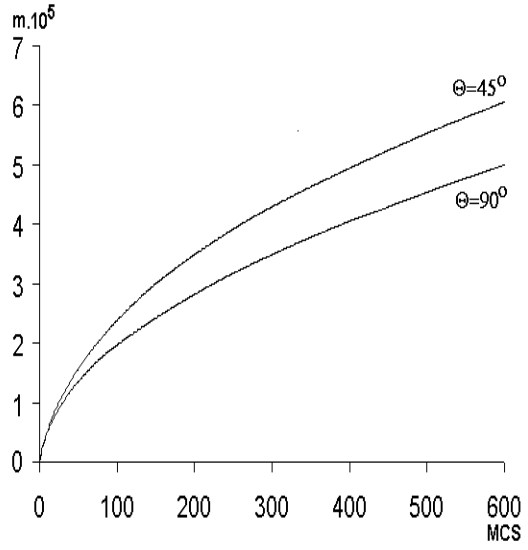

Figure 15. The dependence of liquid mass imbibed into a fibre mass on MCS. Two results are introduced in this figure:for parallel with liquid surface ($\theta = 90^{\circ}$) and for fibres declined on $\theta = 45^{\circ}$.

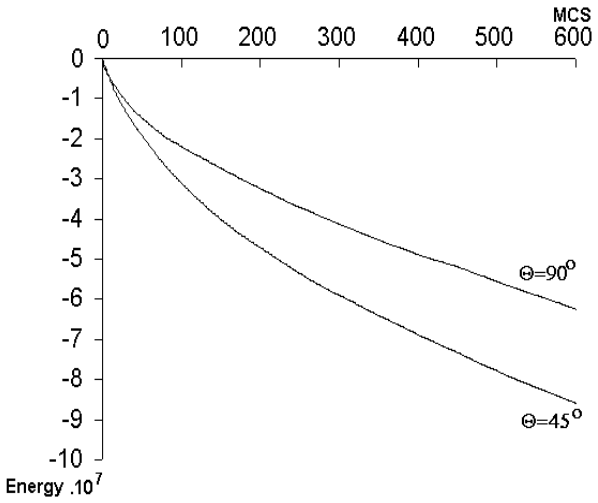

Figure 16. The relationship between systems energy changes and MCS. Results are plotted for fibres parallel with liquid surface ($\theta = 90^{\circ}$) and for fibre mass with fibre declination $\theta = 45^{\circ}$.