PERPENDICULAR-LAID OF NONWOVEN FABRICS
Part I. The Relationship Between Thermal, Compressional Properties and Blend Ratio
of PES and Cotton Fibers.

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الألمــف الغير منسـوجة الناتجة بالرص العمودى بى

الجزء الأول : العلاقة بين خواص الأنضفاط وأنخواص الحرارية للألمشة المخلوطة من شعيرات البولى اسـتر والقطن المعاد فتــبحه .

الخلاصـة :

يهتم هذا البحث بتقديم تكنولوجيا جديدة لأتاج الأقمشة الصناعية الغير منسوجة عن طريق رص الشعيرات رأسيا وتينها حراريا .

ثبت أن جودة الأنمشة المختبرة والمتجة بهذا الأسلوب تكون دالة فى :

1) الموصلية الحرارية (λ) .   2) المقاومة الحرارية (r) .   3) رجوعية الأنضفاط (Zs) .

ثبت أن نموذج شعيرات البوليمتر (الكثافة الطولية 0.55 دتكس ، 6.7 دتكس) ذات تأثير واضـح على العـراص الحرارية الـسابقة حيث أنه   بزيادة النسبة المئوية للشعيرات الناعمة تنخفض (λ) ، فى حيـن أن زيادة النسبة المئوية للشـعيرات الغشـنة تحسـن خواص الأنضفاط (Zs) وترفع المقاومة الحرارية (r) ينما نفمى النسبة المئوية للقطن المعاد فتنحه والمخلوطة مـع البولى استر يرفع مقاومة الأقمشة للعزل الحرارى .

ثبت أيضا أن أعلى مقاومة للأنضفاط تحتق اذا كان كل من حمل الضغط واتجاه الشعيرات فى اتجاه واحد .

ABSTRACT

This paper describes the technology of perpendicular-laid nonwovens STRUTO and some properties of the textiles.   The textiles show improved quality as thermo-insulating materials in automotive industry.

The quality of tested fabrics has been studied in terms of thermal properties, i.e., thermal conductivity (λ) , and thermal resistance (r) ; compressional properties, i.e., compressive rigidity and/or elastic recovery ; and blend ratio. The results indicated that high thermal resistance, low thermal conductivity, and high elastic resilience recovery can be achieved using STRUTO technology and fibers of different fineness and/or different blend ratio.

The fiber arrangement in textiles influences their compressive behaviour to a considerable extent. Compressive rigidity is higher if the directions of fibers and the load are the same.

1. INTRODUCTION

Industrial and technical textiles cover a very wide range, as shown in Table I [1]. These materials can utilize the novel properties of the nonwovens resulting from the new manufacturing properties.

The heat insulating nonwovens are usually made from reprocessed fibers, mainly of animal origin. To a certain degree cellulosic fibers are also used. However, synthetic fibers make only a minute percentage of the allover material composition of these nonwovens. The materials used include, among others, coarser wool, animal hairs, garnetted wool textiles, rags, cotton spinning waste, reprocessed cotton textiles, viscose rayon staple fiber noils. various waste blends, etc. In this work, reprocessed blends containing synthetic fibers will be used.

If, however, the tensile strength of the nonwoven fabric is not the main criterion, then cotton-type viscose rayon staple can frequently be used. Cotton imports certain softness to the nonwovens, and if this softness is required, medium quality cottons are used with advantage. If high strength or high abrasion resistance is needed, then polyester staple fibers (usually in blend with a less expensive material) are adopted.

Waddings, paddings and thermal insulation textiles, these products are passing almost entirely into the sphere of nonwoven textiles. They are characterised by a very loose arrangement of fibers and by a great bulk that makes for their good thermal-insulation properties. In nearly instance technology based on perpendicular-laid fibrous webs are used. Because of lower manufacturing costs, the STRUTO fabrics are usually preferred. These fabrics are manufactured most frequently by thermical bonding, using thermoplastic fibers or fibers with lower melting temperature. If necessary, the strength can be increased using supporting material. In this case, the supporting material is fed into the bonding chamber simultaneously with perpendicular-laid web and both are combined in one process.

1.1 What is STRUTO ?

Perpendicular-laid bulky nonwoven fabric of a new and outstanding properties. It consists of fibers predominantly oriented perpendicular to the textile plane.

The term STRUTO comprises an original way of forming the fiber sheet, the forming machine, the thermobonding through-air chamber and the voluminous textile itself. The STRUTO textile consists of fibers ordered in upright formed lamellae, so that a predominant portion of the fibers are oriented perpendicularly to the textile area.

TECHNICAL TEXTILES

Fully-fashion knits	Nets	Body protection	Industrial textiles	Filter textiles	Packing material	Geotextiles	Medical textiles	Transport textiles	Industrial heat protection	Military textiles
cars	fishing nets	helmets	grinding wheels, abrasive wheels	dust catchers	bags	drainage textiles	plasters - upper textile layer - bottom textile layer	belts tarpaulins	packing bands (tapes)	camouflage nets - without leafs - with leafs
boats	aerial nets	heat protection	- abrasive bands	textiles for liquid filtration	tubular nets - for bread - for fruits - for meat	- pipes - mattresses	material prosthesis	conveyer belts	coat stations rockets	microwaves
airplanes	agricultural nets	low temperatures protection	- abrasive sheets	paper filters	- for smoked goods - for Christmas tree	erosion protection	filters for dialysis	tires ventilating flaps	asbestos	aeronautical bags
robots	nets for the building industry	protection against injury by a saw or by a knife	adhesive tapes		nets for pallets	- wind - sand	plaster replacement	nets for cars seat heating		rockets
seats - banners - flags - traffic lights	curtain buildings	protecting vests	oil mats			consolidation - of roads - of railways - bags with sand	dressings	airshield chairs		
wires	protection against stones	protection against rays	roof covering			- concrete bags	elastic bandages	sandwich-type walls		
- wind	anti-dazzle nets	protection against bunting	back side of carpets			- concrete tubes	tendons ligaments	container covers		
- type structures	containers	water protecting garments (for divers)	parquette buntings			- concrete roofing slabs	nets for the surgery	ducks		
	bird protecting nets	warning vests				grass seed	implantable reservoirs			
	snow protecting nets	anti-slippage protection				heating for plants	filters for blood transfusion			
	sun protecting nets					sound deadening				
	camouflage nets					glass house covers				
	nets for cars					slope protection				
	grass collecting nets					sun filters				
	anti-slippage nets					shading nets				
	splash protecting curtains					bark protection				

Table (I)

A typical continuous production line consists of a carding machine or of another source of the web, of the perpendicular lapper and of the thermobonding through-air chamber (Fig. 1), [2].

The carded web, made of a mixture of basic and of thermoplastic bonding fibers, is brought towards the perpendicular lapper. This device folds the web into perpendicularly oriented lamellae. This sheet of lamellae, which is more or less pressed together, is led into the thermobonding chamber for strengthening.

1.2 More About STRUTO Technology

A properly mixed blend of basic and bonding fibers is processed by a carding machine (1). The carded web is formed using perpendicular lapper (2) into a textile sheet on the conveyor belt of the thru-air thermobonding chamber (3). After passing through the chamber, the STRUTO textile is cooled, cut and wound up (4).

Two kinds of perpendicular lappers have been developed at Nonwoven Department, Technical University of Liberec, CZ. The vibrating lapper STRUTO-V (Fig. 2) forms the carded web into exactly upright oriented folds. Practically unlimited intake speed is the main advantage of the rotating lapper STRUTO-R (see Fig. 3).

A supporting textile sheet can be brought from below onto the conveyor belt of the bonding chamber The sheet is then linked together with the STRUTO textile during the bonding process. Thus the composite material is produced in one process.

1.3 Application of STRUTO Textiles- examples
- Cushioned furniture and automotive industry.
- Replacement for polyurethane foam.
- Clothing industry - thermo-insulating and filling material.
- Blankets, quilts, cushions and pillows-filling material.
- Building industry - thermo and sound-insulating material.
- Filters.

1.4 Important Technical Data
1.4.1 Raw materials

All the kinds of virgin and waste fiber materials processable by carding. The blends of fibers containing 10 - 40% of thermobonding fibers.

1.4.2 Web intake speed

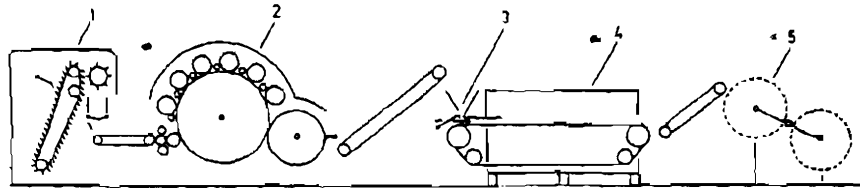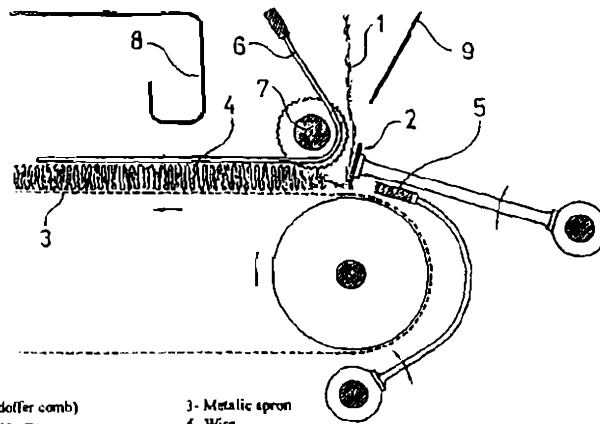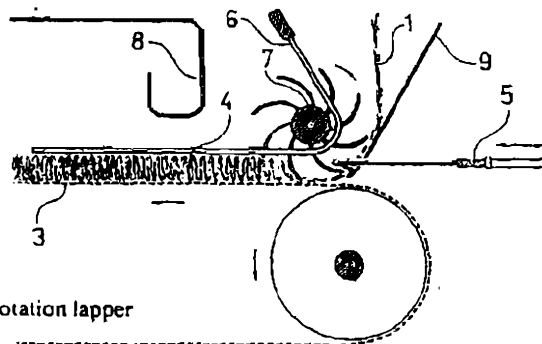|	
STRUTO -V	max. 30 m/min.
STRUTO-R	unlimited

Fig. 1 : A typical continuous production line with STRUTO.

1- Feeder.   2- Carding machine.   3- STRUTO lapper.

4- Through-air chamber.   5- Take-up mechanism.

Where ,
1- Carded web   2- Saw (doffer comb)   3- Metalic apron
4- STRUTO (Lamellae)   5- Packing arm   6- Wire
7- Feeding roller   8- Cover of heating room 170°C 9-Guide

Fig. 2 : Vibrating lapper - STRUTO.

Where :
5- Pressure bar   7- Rotation lapper

Fig. 3 : Rotation lapper - STRUTO.

1.4.3 Properties of STRUTO textiles

Thickness	8 - 40 mm
Area weight	max. 1500 g/m^2
Density	8 - 50 kg/m^3

1.4.4 Dimensions of machines

Working width	1100 mm (STRUTO-R or STRUTO-V)
Length	3350 mm
Width	1900 mm
Height	1700 mm
Installed power input	31 kW
Temperature range	100 - 200 °C
Output speed	0 - 2.2 or 1 - 6 m/min.

1.5 Advantages of STRUTO When Compared with Traditional Technologies:

1- Better functional properties (bulkiness, compression resistance, resilience, heat insulation, filling properties).

2- Lower raw material consumption.

3- Processability of various fiber materials (including recycled fibers) and bonding fibers.

4- Lower cost of machinery, lower energy consumption, smaller installation and utilization surface when compared with traditional plant consisting of cross-lapper, needling machine and/or spraying device with much longer drying oven.

5- Easy recyclability and good hygienic properties when compared with polyurethane foam.

1.6 Shape of Lamellae

During folding of the carded web the rate of thickening lamellae depends on the input speed of the web and the outlet speed of the conveyor. The height of the lamellae depends on the width of the gap between conveyor and upper plate and on the movement frequency of the device. Various shapes of lamellae can be obtained depending on the geometry of the device and the shape of the pressing bar. The shape of the lamellae influences the properties of the textile, especially its compressive rigidity. Various possible shapes of lamellae are shown in Figs. (4a - 6a).

In addition to the variability in the shape of the lamellae various ways of strengthening or reinforcing the product are possible. In Figs. (4_b - 6_b) there are three possibilities of strengthening:

Fig. 4.

Shape (I)

Shape (II)

Shape (III) ⊢
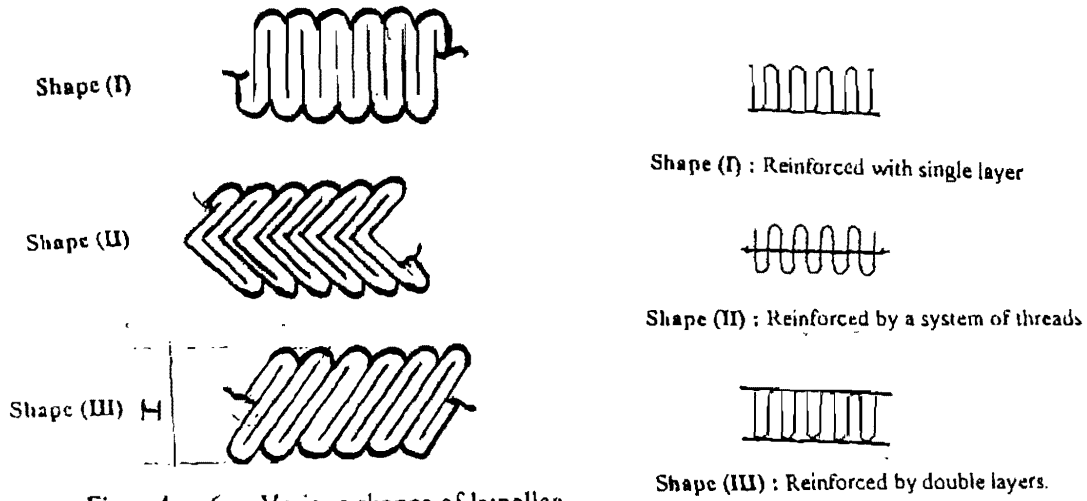
Figs. 4a - 6a : Various shapes of lamellae.

Shape (I) : Reinforced with single layer

Shape (II) : Reinforced by a system of threads

Shape (III) : Reinforced by double layers.

Figs. 4b - 6b : Reinforcing of STRUTO by threads and doublin

1-STRUTO (150 g/m²)

8-Air-laid spray PET

(150 gm/m²)

7A-Needle felt (150 gm/m²)

Load (kg/m²)

Fig. 7 : Thickness-Pressure relationship.

9-polyurethane foam (150 gm/m²)

1-STRUTO (150 gm/m²)

8- Air-laid spray PET (150 gm/m²)

RECOVERY TIME (MIN)
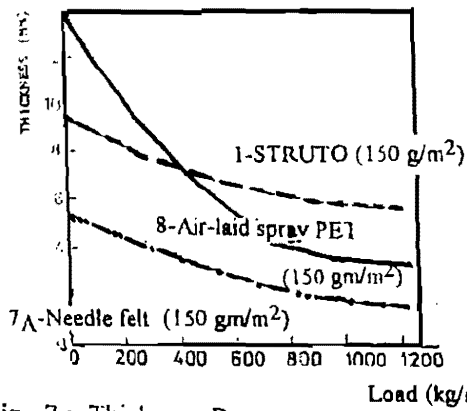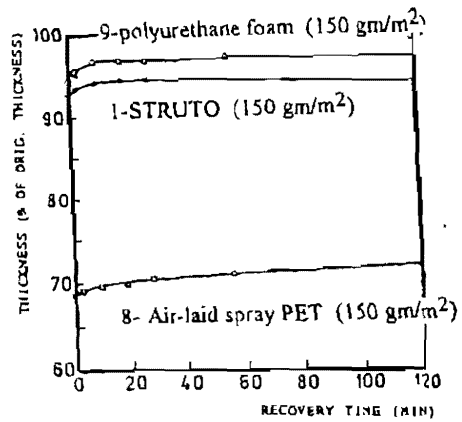
Fig. 8 : Results of single loading - unloading

- - Reinforcing by a system of threads incorporated during the textile formation - content of threads is less than 1 weight percent [3].
- Doubling the textile STRUTO with a reinforcing textile is also possible during the production process.

2. EXPERIMENTAL PART

2.1 Compressional Properties

The compression behaviour is the most important feature of the perpendicular-laid textiles. Some important end-use characteristics of nonwovens, as thermal and sound insulation and filling properties depends on the thickness of the textile and on its capability to retain the volume when or after having been compressed.

The following methods have been employed to characterize compressive behaviour of the materials:

1- Static stepwise loading - unloading.

2- Dynamic loading - high number of loading cycles.

Elastic recovery of the materials Z_s has been measured after every loading test.

$$Z_s = h_2 / h_0 \cdot 10^2 \qquad (1)$$

where h_2 is the material thickness after loading (function of time),

and h_0 is the original thickness.

The samples 0.2 x 0.2 m are repeated compressed to the chosen value of thickness. Deformation is expressed in percent of original thickness. Elastic recovery of the material is measured in time 11 min. through 24 hours. The elastic recovery after 25000 loading cycle and 24 hours of relaxation are shown in Fig. (7).

2.2 Thermo-insulation Properties

The area weight of bulky textile depends on the design, structure, compression and compressive behaviour. Some properties of textile such as thermo-insulating and filling properties are functions of the textile mass per unit area (thickness). An example of this dependence is the reduction of thermal resistance of a textile sample due to its compression.

Thermal resistance is defined as follows:

$$R = A \cdot \Delta T / Q = L / 1 \qquad (2) \quad where:$$

T is the difference in temperature on both surfaces of the textile (k).

Q the amount of heat passing through the textile material in a given time unit (J/s).

L the textile thickness (m).

1 the thermal conductivity ($Wm.^{-1} \cdot k^{-1}$) defined from

$$Q = 1 \cdot A \cdot \Delta T / L \qquad (3) \quad where:$$

A is the area of the sample.

5. RESULTS

5.1 Thickness-Pressure Relationship of STRUTO.

Plotted in Fig. 9 examples of the relationship between thickness and pressure. generally for all fabrics this form of curves is obtained, i.e., thickness tends to decrease as pressure increases, and that the decrease in thickness is large at the begining then at lower rate as pressure increases. This may be attributed to the collapse of the protruding hairs at low pressures, then to fabric flattening at high pressure.

Due to the upright orientation of fibers, the STRUTO textiles show outstanding compressive rigidity and high degree of resilience after repeated loading.

In Fig. (7), the load-thickness dependence for various kinds of tested non woven textiles is shown. In Fig. (8), the elastic recovery of STRUTO (1), the polyurethane foam (9) and the air-laid spray bonded bulky textile (8) after 25000 compressive loading cycles are compared (the compression is by 50% of its original thickness in each cycle). It is clear that STRUTO textiles show lower loss of thickness during the loading -unloading cycles, i.e., the compressive resistance of bulky textiles consisting of fiber predominantly laid in the sample area depends on the bending rigidity of fibers. A possibility for increasing this important property consists in constructing fiber sheets of fibers mainly oriented perpendicular to the textile area.

The results of single loading-unloading of the STRUTO (4) are shown in Fig. (9)[3]. As these tests results show, the thickness of STRUTO 4-A and C has been reduced after 50 loading-unloading cycles. This generally undesirable behaviour can be eliminated using a suitable shape of lamellae.

When the Z_s values obtained in the loading and recovery cycles were ranked, it was interesting as may be seen from table III that each fabric maintains it's position.

Table (III) : Ranking of Z_s values

	STRUTO		
	Shape (I)	Shape (II)	Shape (III)
Z_s - loading	44.12%	35.58%	32.23%
Z_s - recovery	38.64%	36.78%	32.41%

The rank correlation coefficient R = 1 and highly significant at the 1% level.

These results indicated that the information obtained from the thickness - pressure relationship in the recovery - cycle would reflect the original nature of the fabrics and that the original differences in structure between fabrics, i.e., shape I, II, and III would remain after compression, and fabrics will rank in the same order.
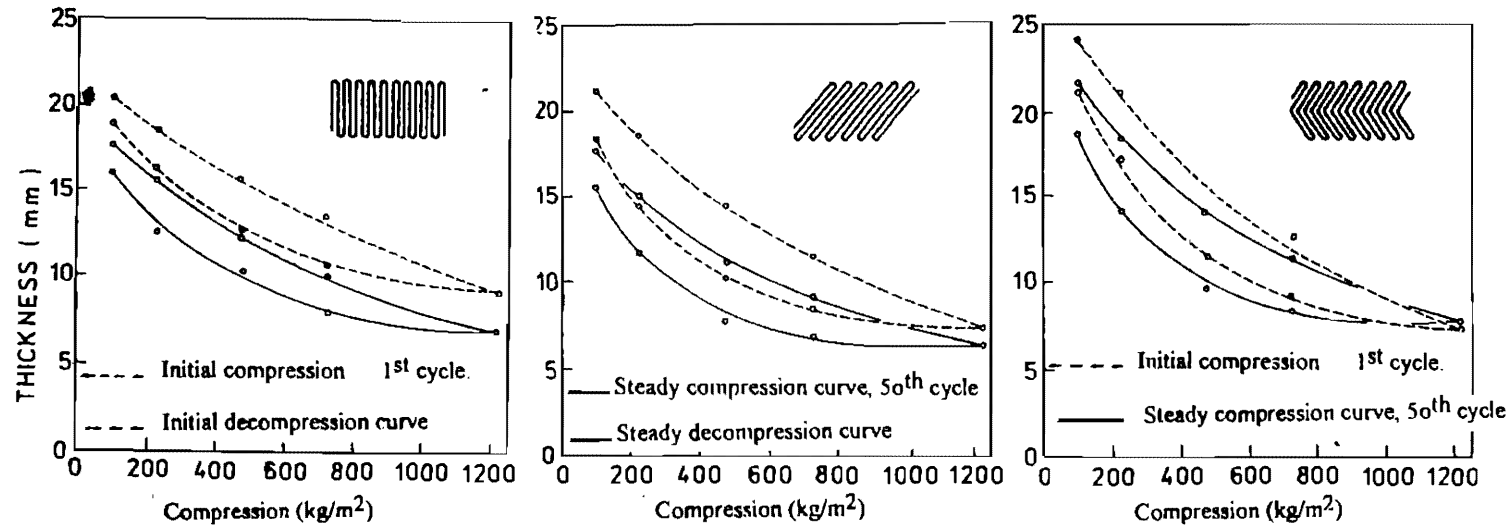
Fig. 9 : Loading - unloading behaviour of STRUTO and the sample structure (various shapes of lamellae in STRUTO).

5.2 Compression of Thick Textile Fabrics Made from Several Layers[7].

5.2.1 Objective

The objective of this part was to investigate an influence of geometrical structure of fiber mass on its compressive behaviour. Tests were carried out to find answers to the following questions:

1- How is the compressive behaviour related to the geometrical structure of the textile bulky products?

2- How does the special geometrical structure of the STRUTO influence their compressive behaviour?

5.2.2 Experiment.

The following materials were examined and compared:

1- Cross-laid hot-air bonded textile bulky layers (predominantly planar orientation of fibers in the plane X,Y (see Fig. 10a).

2- Perpendicular-laid hot-air bonded textile layers STRUTO (5), (predominantly planar orientation of fibers in the plane X,Y (see Fig. 10b).

· Tests were carried out in the following way:

To answer the questions 1 and 2, the cubes were cut out of tested materials with the side length the same as thickness of the products, and compressed in three various directions X, Y, Z, where Z means the direction perpendicular to the product plane.

5.2.3 Results and discussion.

The load-deformation curves of different directions X, Y, Z, are different (figs. 11 to 13). Differences among curves of cross-laid textile layers, the fibers of which predominantly lay in the plane of the product, show an anisotropy in the compressive rigidity. The smallest rigidity occurs in the "Z" direction.

Load-deformation curves of the STRUTO (5) show smaller differences among X,Y,Z directions (range 6.66) than curves of Cross-laid textiles (6)- (range 9.98) and Needle punched fabrics out of textile wastes (7-B)-(range 15.71), and mostly the highest rigidity in the Z direction. That is the reason why the STRUTO textile an be found useful. This fact is possible to use to answer the second question.

5.3 Relation between Blend Ratio and Thermal properties.

In an attempt to find out whether there is a relation between the blend ratio and thermal properties, two parallel analyses have been made. In the first, the blend ratios 0:100, 33:67, 50:50, 67:33, 100:0 of 0.55 dtex and 6.7 dtex, PES, as well as the thermal properties (thermal conductivity and thermal resistance) were studied. In the second, the same
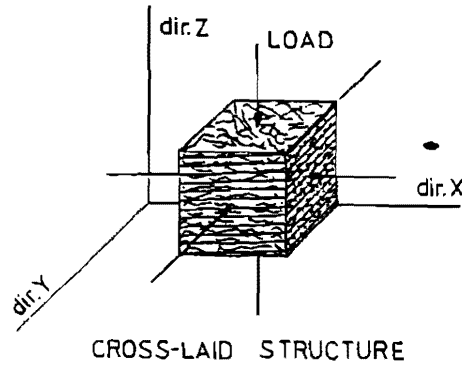
Fig. 10.

CROSS-LAID STRUCTURE

Fig. (10-a) : Shows the influence of geometrical structure of fiber mass on its compressive behaviour (cross-laid, fabrics).

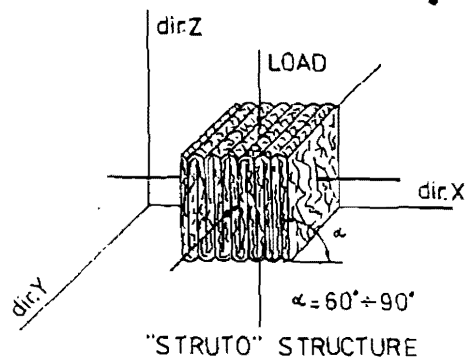$\alpha = 60° \div 90°$

"STRUTO" STRUCTURE

Fig. (10-b) : Shows the influence of geometrical structure of fiber mass on its compressive behaviour [STRUTO (5)].
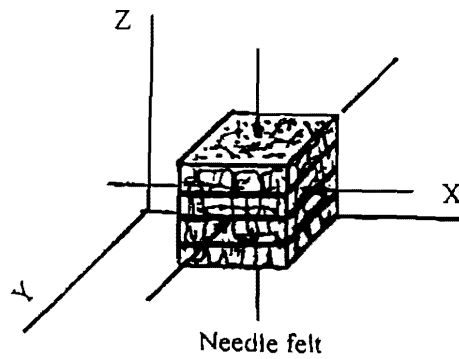

Needle felt

Fig. (10-c) : Shows the influence of geometrical structure of fibre mass on its compressive behaviour [Needlepunched fabric 7-B].

3. FABRIC GROUPS

Details of the nine fabric groups selected for this study are listed in Table II.

Table II

Fabric Group	Fabric Content	End Use	No. of Fabrics
1- STRUT (1) (150 g/m²)	70% PET, 6.7 dtex, 65 mm, 30% co-PES	Insulation material	1
2- STRUTO (2) (150 g/m²)	80% mixture of 0.55 dtex and 6.7 dtex, PET; 20% bonding POP, 2.5 dtex	Unknown	1
3- STRUTO (3) (500 g/m²)	0; 80; 20:60; 40:40; 60:20; 80:0 PES and recycled cotton; 20% POP, 2.5 dtex	Unknown	5
4- STRUTO (4) (150 g/m²)	A- 80% PES, 6.6 dtex, 20% bi-component bonding fiber PES-co PES, shape of lamellae, see fig. 4a. B- ditto, shape of lamellae, see Fig. 5a. C- ditto, shape of lamellae, see Fig. 6a.	Unknown	3
5- STRUTO (5)	80% PES, 11 dtex, 65 mm, 20% bonding POP, 2.5 dtex, 60 mm.	Unknown	1
6- Cross-Laid	80% PES, 1.7 dtex, 40 mm, 20% bonding POP, 2.5 dtex, 60 mm.	Unknown	1
7- Needle felt (150 g/m²)	A- POP, 11 dtex, 65 mm. *B- Recycled POP, 9.3 dtex, 6.4 mm, 301.4 to 2848.8 g/m²	Geotextile Geotextile	1 4
8- PNT (150 g/m²)	Air laid spray, bonded PET	Unknown	1
9- PUR	Polyurethane foam 25 kg/m³	Unknown	1
Total number of Tested Fabrics			19

* All tested fabrics were produced at the Laboratory of the Nonwoven Dept., Technical University, Liherec, CZ; except fabric 7-B which was produced in Egyptex, Egypt.

4. TEST METHODS

The physical test methods used during nonwoven characterisation were as follows:

- Basis weight   : BS 3432 (1980)
- Thickness   : BS 4817 (1972)
- Stress - Strain   : According to Ref. [5]
- Thermal properties : According to Ref. [6]

treatment was made but the blend of recycled cotton and polyester fibers was used in the study. The results obtained are shown in Tables III and IV. It is clear from Table III that the thermal conductivity decreases with increasing the ratio of fine fibers, while the thermal resistance increases with the increase of the ratio of coarse fibers (6.7 dtex). This indicates that there is good correlation between thermal properties and blend ratio of 0.55 dtex and 6.7 dtex, PES fibers.

Table IV. The Influence of ratio 0.55 dtex : 6.7 dtex, PES fibers on Thermal conductivity, thermal resistance and thickness (area weight 170 g/m^2) [4]

Ratio of fibre fineness 0.55 : 6.7 dtex	Thermal Condutivity (W. m^{-1}. K^{-1}) . 10^3	Thermal Resistance (W^{-1}. K . m^2) . 10^3	Thickness (mm)
0 : 100	42.7	410	17.5
33 : 67	33.2	416	18.8
50 : 50	30.9	358	11.0
67 : 33	29.0	309	8.9
100 : 0	27.4	203	5.5

Table V. The influence of blend ratio of PES : Cot. on thermal properties of STRUTO (3).

Ratio PES : Cot. : POP	Thermal Conductivity (W. m^{-1}. K^{-1}) . 10^3	Thermal Resistance (W^{-1}. K . m^2) . 10^3	Thickness (mm)
0 : 80 : 20	29.03	395.7	11.43
20 : 60 : 20	32.26	395.6	12.73
40 : 40 : 20	33.60	430.9	14.30
60 : 20 : 20	30.05	435.3	13.02
80 : 0 · 20	31.84	453.5	14.42

Table VI. The influence of area weight on thermal properties of fabric 7-B.

Area Weight (g / m^2)	Thermal Conductivity (W. m^{-1}. K^{-1}) . 10^3	Thermal Resistance (W^{-1}. K . m^2) . 10^3	Thickness (mm)
301.4	32.45	196.667	6.383
768.4	34.27	293.167	9.992
916.5	38.05	283.167	10.733
1010.4	36.38	328.833	11.833

Fig. 11.

$Z_X = 37.04\%$

$Z_Y = 13.85\%$,

$Z_Z = 39.29\%$

dir.X

dir.Y   Needle-punched (7-B)

dir.Z $Z_Z > Z_X$ and Z_Y

Cross-laid 18 kg/m^3 (6)

$Z_Z > Z_X$ and Z_Y

$Z_X = 26.19\%$

$Z_Y = 30.44\%$

$Z_Z = 36.17\%$

Fig. 12.

STRUTO (5)

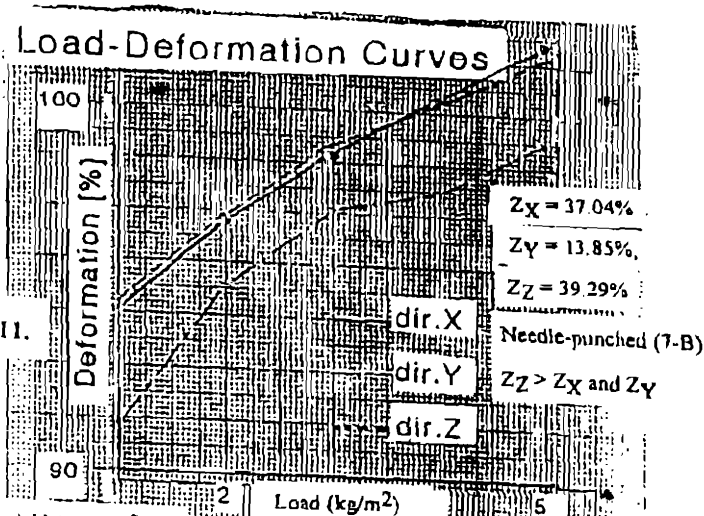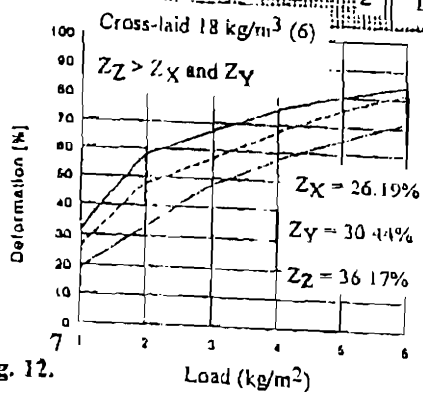$Z_Z = Z_Y > Z_X$

$Z_X = 15.12\%$

$Z_Y = 21.78\%$

$Z_Z = 21.30\%$

dir.Z

dir.X

dir.Y
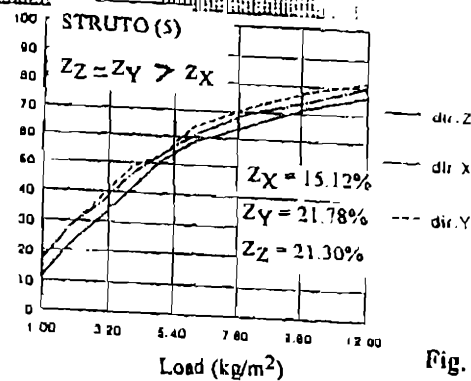
Fig. 13.

Fig. 11-13. Show Load-Deformation Curves of Needle punched (7-B, 2848.8 g/m^2, Cross-laid 18 Kg/m^3 (6), and STRUTO (5).
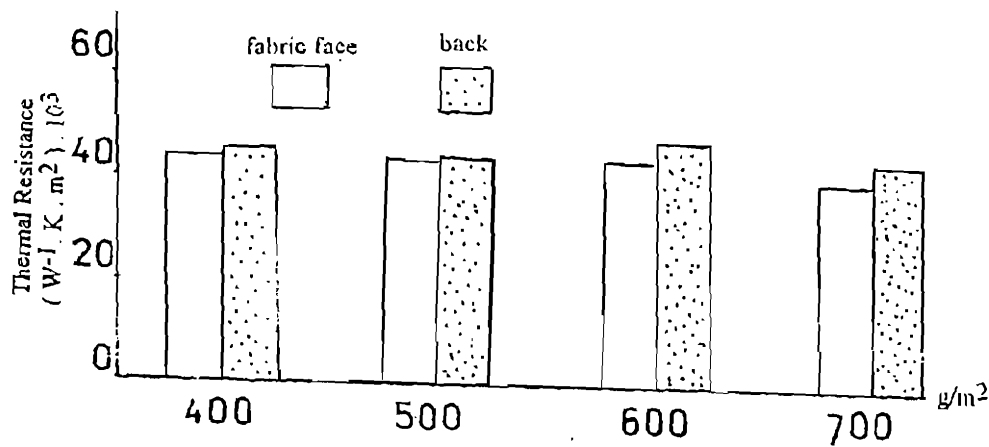

Fig. 14. Thermal Resistance versus Mass per unit area of STRUTO (3), 400-700 g/m^2, 40% PES, 40% Cot. and 20% POP.

Table IV shows the relationship between blend ratio, i.e., 0 : 80, 20 : 60, 40:40, 60 : 20, 0 : 80, of PES and recycled cotton fibers; and thermal properties. Here too, it is clear that the thermal resistance with the decreases of cotton percentage, while the thermal conductivity decreases with increasing the ratio of cotton fibers.

Based on the foregoing, it can be concluded that when a STRUTO acquires high percentage of coarse fibers, the thermal resistance increases also; one would expect a good quality (low conductivity and high resistance). On the other hand, STRUTO of more recycled cotton fibers would have a fair thermal quality.

A further support for this relation can be realized from Table V. This table shows the thermal properties of four varieties of Needlepunched 7-B (3).

The results shown in Fig. (14) show the thermal resistance of four varieties of STRUTO 400, 500, 600 and 700 g/m^2, measured on fabric face and back, respectively. As can be seen the figure reveals one common feature, (X_{face}=430.4.10^{-3} W^{-1}.K.m^2, δ = 33.44.10^{-3} W^{-1}.K.m^2 while X_{back} =441.4.10^{-3} W^{-1}.K.m^2, δ = 31.74.10^{-3} W^{-1}.K.m^2, therefore it was found that : $t_{calculated} < t_{table}$ and highly significant at the 5% level) i.e., there is no significant differences between the readings measured on the fabric face and back. It may be argued why some readings are greater than the others; the answer lies in the fact that the fabric morphology of the two sides is different.

CONCLUSIONS AND RECOMMENDATIONS

Perpendicular-laid textile STRUTO is a new nonwoven technology, which is bringing in a new generation of textiles. The main advantages of the technology consist in low investment, low built-up plant area, low energy consumption and high production rate.

The shown examples of various properties of STRUTO fabrics prove that due to their special fiber arrangement the STRUTO textiles show some special properties. The textiles show improved quality with good applications in thermo-insulating, sound-insulating, filters, furniture and automotive industry.

Very short fibers may be a part of fiber composition up to 10% content. Secondary or waste fibers are processable according to their average length in concentrations of up to 80%.

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