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Development of a New 3D Nonwoven for Automotive Trim Applications

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1. Introduction

Nowadays, the automotive manufacturers have to take into account the legislation on End Life Vehicle (ELV), especially the European Directive 2000/53/CE which constraints all automotive products to be at 85% recyclable and at 95% reuseable by January 2015 (EU Directive, 2000). The automotive multilayer structure used for automotive trim applications, fabric (PET) / foam (PU) / backing fabric (PA), does not offer ability for recycling or reusing and the question that has to be asked is "Could the PU foam used in the automotive trim applications be replaced by a mono component spacer material?" One answer is to propose an eco-friendly solution presenting a mono material product. Moreover, this new product has to answer to the automotive specifications in terms of lightness, formability and cost. Some solutions for PU foam replacement have been proposed, such as spacer fabrics presenting a vertical orientation of the yarns (weaving and knitting technologies) or a vertical orientation of the fibers (nonwoven technology). The vertical orientation of the fibers will improve the mechanical properties of the fabric especially for the compressional ones. Critical analyses between the different 3D textiles technologies show that the nonwoven technology provides the best industrial solution in terms of cost and productivity. Regarding the 3D nonwoven products, the "on the market" ones present drawbacks that do not allow them to answer positively to the initial question concerning the replacement of the PU foam. Indeed, the structure of these 3D nonwovens does not present a perfect vertical orientation of the fibres (Njeugna, 2009). Consequently, these products do not offer a maximal resilience in terms of compression properties.

In this context, a French consortium composed of research laboratory (LPMT as project leader), textile industrialists (N. Schlumberger, AMDES, Protechnic, Landolt, Dollfus & Müller, Rhenoflex Dreyer), textile technical centre (IFTH[1]) has been formed to develop an eco-friendly 3D nonwoven which would not present the previous drawbacks. This new 3D nonwoven could be used to replace polyurethane foam classically used in automotive trim applications. This consortium has been supported by the Alsace Textile Cluster, the Alsace

[1] IFTH : Institut Français du Textile Habillement, www.ifth.org

Region and the "Département du Haut-Rhin". This collaborative research project, named VERTILAP, has been labelled by the French competitiveness cluster "Vehicle of the Future" in 2006 and the French "Fibres Innovative cluster" in 2009.
This chapter will present the state of the art of the technical textiles classically used as automotive trim such as seat and door panel upholsteries. The manufacturing processes and the specifications of these automotive multilayer fabrics will be exposed. Their methods of characterization will be presented. The description of the PU foam and the problem it raises will be highlighted. The state of the art of the existing 3D textiles for PU foam substitution, processes and products will be detailed. This chapter will also present the principle of the VERTILAP® process and the experimental procedure which has been used to realise the VERTILAP® products. Methods and tools of characterization that have been developed in order to evaluate the physical and compression properties of this new material will be exposed. The comparative study that has been carried out between the VERTILAP® products and the classical automotive fabrics in the case of monolayer and multilayer structures will be detailed too.

2. Bibliographical study

2.1 Textiles used for automotive upholsteries

The textile fabric is an interesting material for automotive industry regarding its functionality (lightness, acoustic and thermal insulation, etc.) and its mechanical behaviour. It is used in three main components of the car: the interior, the engine compartment and the pneumatics (Némoz, 1999). The car interior has significantly evolved since the last decade and has become one of the key elements of the customer purchasing. Nowadays, the consumer pays special attention to the environment inside the car. Therefore, the factors of comfort, beauty (harmony of colours and designs) and security have become main factors in the sale of a vehicle. Since 90s, the car manufacturers have significantly increased the use of textiles in the interior trim. Actually, the weight of an European vehicle includes 11 kg of textiles on a surface of 16 m². Textile fabrics used for the seat are employed on a visible surface of 3.8 m² while those used for the door panel are employed on a visible surface of 1.7 m². (DGE, 2005), (Fung & Hardcastle, 2001)
This study aims to present the state of the art on the technical textiles classically used as seat and door panel upholstery in the car interior. Examples of automotive seat and door panel are illustrated on Fig. 1 and 2.

(a) (b) (c)

Fig. 1. Automotive seat: structure (a), foam cushion (b), automotive complex (c)

Fig. 2. Example of an integral door panel

Different methods of construction of seat and door panel are listed in the literature review (Fung & Hardcastle, 2001). The seat trimming can be realised thanks to the "foam in fabric" technique, the direct joining technique or the injection moulding technique. The "foam in fabric" technique consists on slipping the automotive complex on the seat cushion. The direct joining technique consists on spraying a solvent adhesive either on the automotive complex, either on the foam cushion or both in order to link them together. In the case of injection moulding technique, the foam is directly injected into the automotive complex previously placed in a mould. Textile-insert low pressure moulding, using polypropylene resin, is used to produce a covered door panel in a single operation.

The automotive complex (Fig. 3) is usually composed of a decorative fabric made of polyester, polyurethane foam and a backing fabric made of polyamide. The polyurethane foam is generally a thin layer with a thickness between 2 mm to 8 mm and a mass per unit area of about 200 g/m². The foam gives the flexibility and the soft touch while the backing fabric gives the dimensional stability to the multilayer structure. In case of "foam in fabric" technique, the backing fabric contributes to facilitate the slippage of the cover laminate on the foam cushion. The backing fabric is not necessary used in the case of door panel upholstery. (Caudron, 2003), (ITF, 1990)

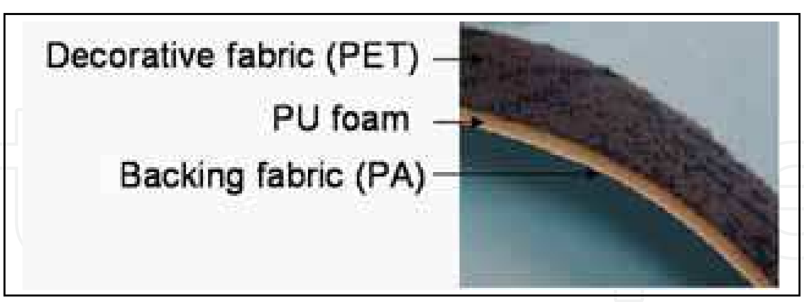


Fig. 3. The automotive complex

The automotive complex can be produced thanks to different techniques (Hopkins, 1995). Some of them are well known as the flame lamination and the dry lamination processes. In the flame lamination process (Fig. 4), the textile layers and the PU foam are linked together using the PU foam as an adhesive. This process has the disadvantage to generate toxic gases. The maximal speed can reached 25 m/min. In the dry lamination process (Fig. 5), hot melt adhesives (web, film, powder) are used to bind the textile layers and the PU foam. This process does not generate toxic gases as the flame lamination one but its main drawback is its cost. The maximal speed can reached 16 m/min.

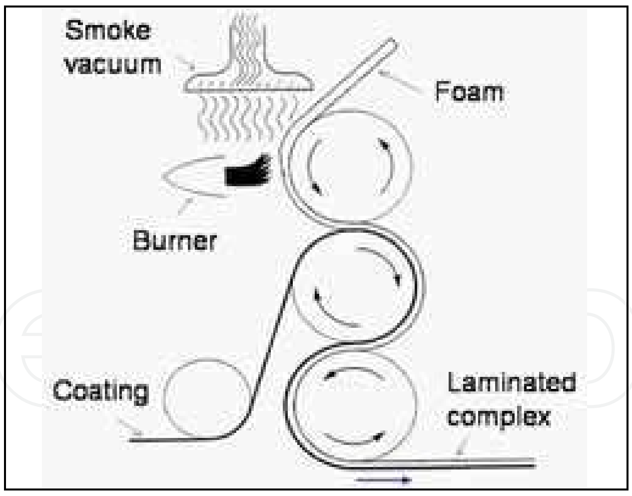


Fig. 4. The flame lamination process

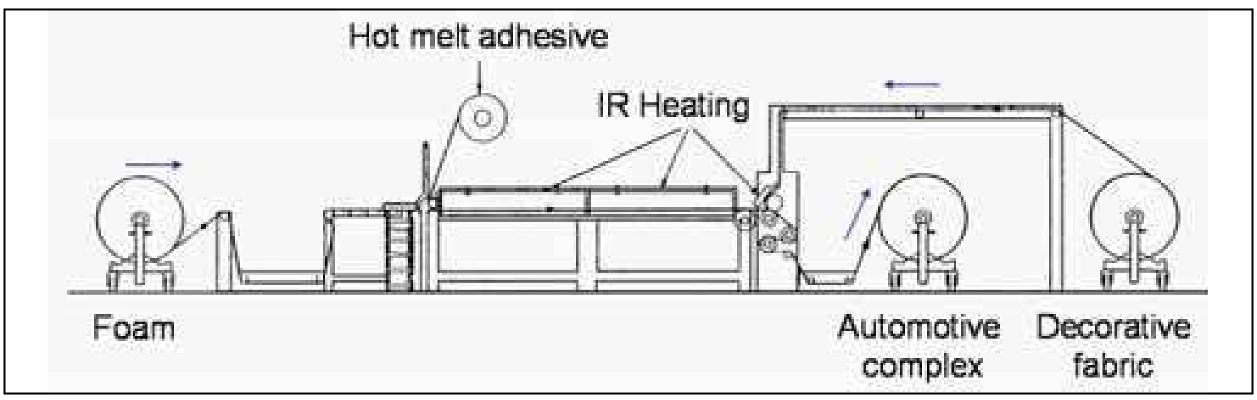


Fig. 5. The dry lamination process

It is important to note that the specifications and the characterisation tools of the automotive complex are specific to each car manufacturer. These specifications take into account the legislation of the markets, the security, the quality of the products and their cost (Faucon, 1995). For example, they have to be fire-proof, as light and as cheap as possible. Their quality is evaluated thanks to specific characterisation such as the mechanical behaviour (compression, tensile, flexibility, etc.), the physical behaviour (colour fastness, air permeability, etc.), the fogging, etc. International standard methods of characterisation of flexible cellular polymeric materials used in the automotive industry are well known such as:

- Determination of stress-strain characteristics in compression (ISO 3386/ 1, 1986)
- Determination of tensile strength and elongation at break (ISO 1798, 1983)
- Determination of compression set (ISO 1856, 2000)
- Determination of burning behaviour of interior materials. (ISO 3795, 1989)
- Etc.

2.2 The problem of the PU foam

The PU foam, thanks to its specific characteristics, is the key element of the multilayer fabric in terms of comfort and mechanical behaviour especially for the compression ones. It is obtained thanks to a chemical reaction between an isocyanate and a polyol (Fig. 6). The expansion of the foam is due to the reaction between the isocyanate and water. After this expansion, the foam will present a cellular structure which can be characterised by opened or closed cells (Fig. 7). (Recticel, 2009), (Berthier, 2009)

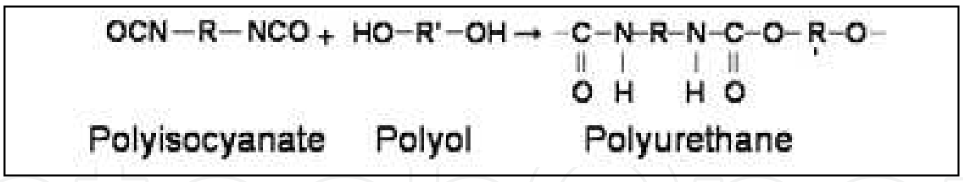


Fig. 6. Chemical polyaddition reaction of the formation of the PU foam

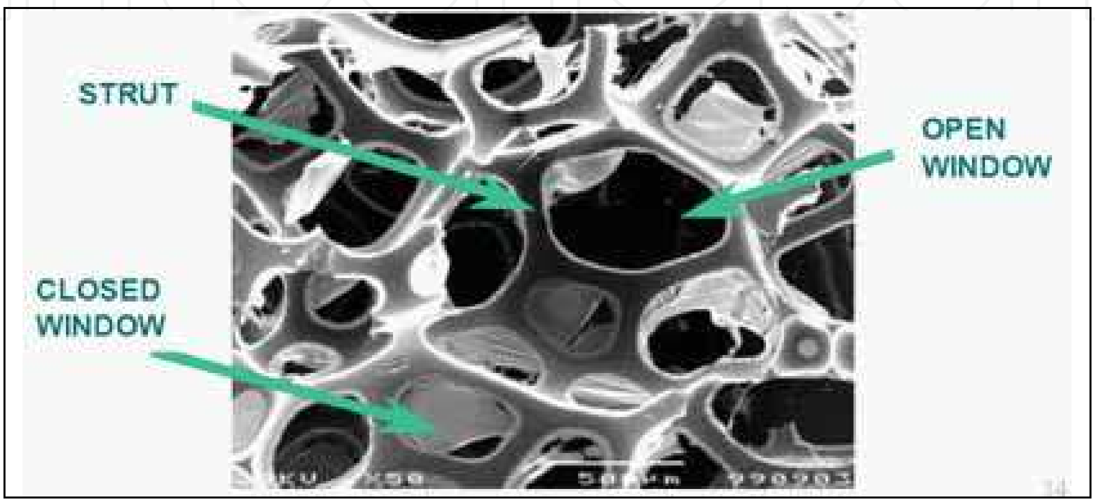


Fig. 7. Microscopic structure of the PU foam

The main problem of the PU foam is partly the toxic gases it generates during its manufacturing process as previously mentioned but also the recycling of the automotive complex at the end life vehicle. In fact, the recycling processes of such products require a delamination step of the different layers (PET, PU, PA). This operation is not optimal because some PU foam remains on the textile fabrics. It is also important to note that the machines used for the recycling are very expensive. On another hand, it is difficult to completely recycle the PU foam in spite of the developments which have been carried out on this way. Nowadays, some foam manufacturers like RECTICEL is developing new method to produce PU foam by using biochemical compounds (Persijn, 2008). It is already the case with their foam PURECELL® which contains at least 20% of natural compounds. Beyond this new development stay the ethical problem of the massive agricultural exploitation for the industry.

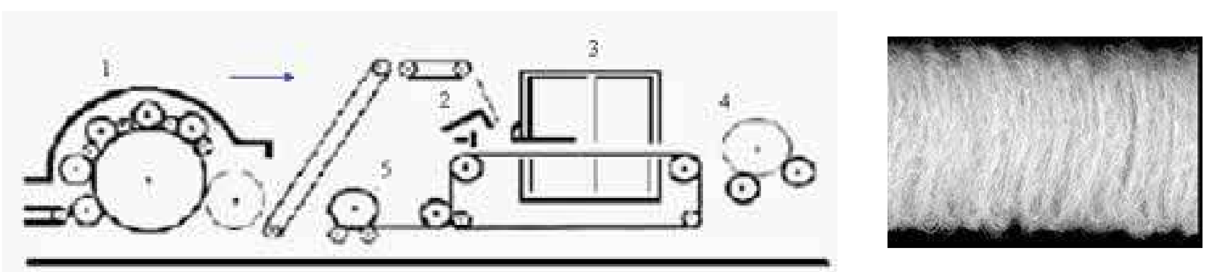
The PU foam has many serious drawbacks such as flammability, gases emissions due to the laminating processes. These problems lead to the question of its replacement by a new product. A key aspect of this new product is not to alter the product functionality. It means that the new product should present at least mechanical properties, especially compressional properties closed or equal to the actual automotive multilayer fabric. Another key aspect is to propose an environmentally friendly solution for complex fabric composed of a mono material product. This new product has to answer to the automotive specifications in terms of weight, formability and cost. In this context, industries and researchers all around the world are developing new products which could substitute the PU foam. (Kamprath, 2004), (Persijn, 2008)

2.3 Existing solutions to the PU foam replacement

The 3D textiles offer a good solution to the recycling issue of the multilayer products using PU foam because of their specific structure as spacer fabric. In fact, they present a vertical orientation of the yarns (weaving and knitting technologies) or a vertical orientation of the fibres (nonwoven technology). This vertical orientation will provide a good mechanical behaviour especially in term of compression. Analyses of the existing solutions have been carried out by textile industrialists and the obtained results show that the 3D textile technologies offer the best solution in terms of product quality and cost. It appears that the nonwoven technology provides the most interesting solution in terms of mechanical properties, cost and productivity. The nonwoven products issued from the 3D technology are known as (Struto, 2007), (Santex, 2007), (Karl Mayer, 2007), (Vasile et al., 2006). They can be divided in three categories: carding and vertical lapping processes, stitch-bonded processes and needle-punched processes.

- Carding and vertical lapping processes

STRUTO®, Santex WAVEMAKER® and V-Lap® technologies are vertical lapping system whereby a carded web is pleated in order to create 3D structure (Fig. 8 and 9). A thermal treatment is applied on the pleated structure in order to obtain the final product. The V-Lap® technology is closed to the STRUTO® one.



1 Card; 2 Vertical lapping system; 3 Oven; 4 3D nonwoven; 5 laminating layer.

Fig. 8. The STRUTO® process (left) and product (right)

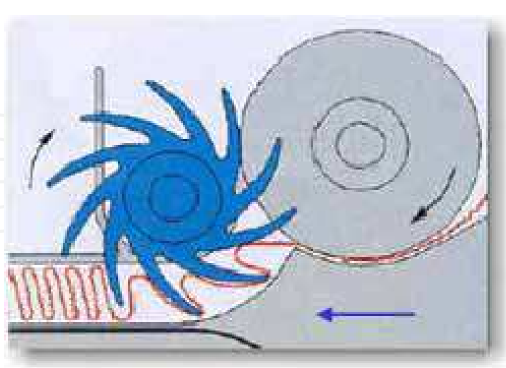
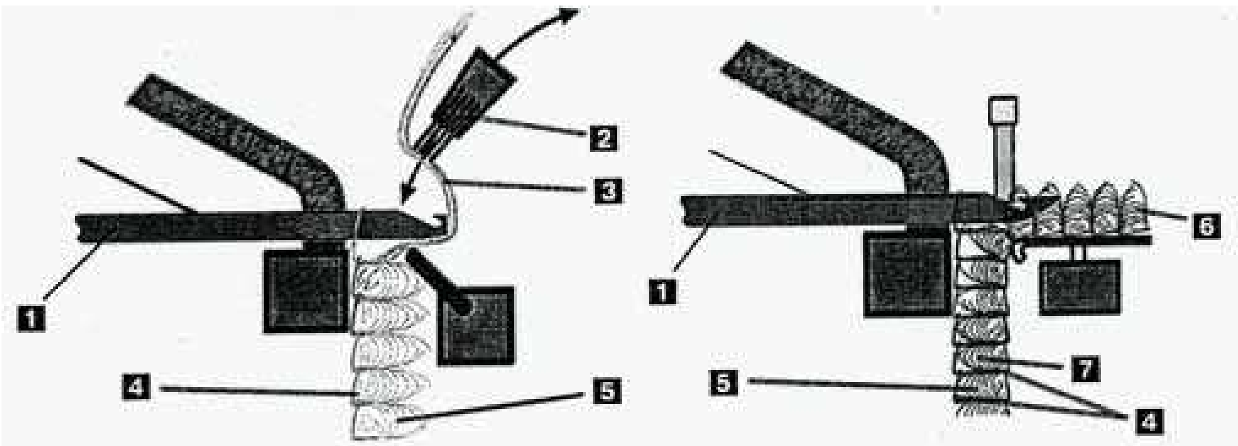


Fig. 9. The Santex WAVEMAKER® process

- Stitch-bonded processes

KUNIT and MULTIKUNIT are stitch-bonded technologies developed by Karl Mayer Textilmaschinenfabrik GmbH. The principle of these techniques is based on the principles of the stitching and the knitting technologies (Fig. 10). The KUNIT fabric presents a stitch side and a pile side. This fabric is used as base material for MULTIKUNIT production.



1 Compound needle; 2 Brush bar; 3 Fibre web; 4 Stitch side; 5 Pile side; 6 KUNIT nonwoven; 7 MULTIKUNIT nonwoven.

Fig. 10. The KUNIT (left) and MULTIKUNIT (right) processes

- Needle-punched process

NAPCO® is a needle-punched technology developed by the textile machinery manufacturer LAROCHE. The NAPCO® process consists to link two pre-needle nonwovens thanks to a fibrous bridge (Fig. 11). The obtained 3D structure is mainly used for composite application.

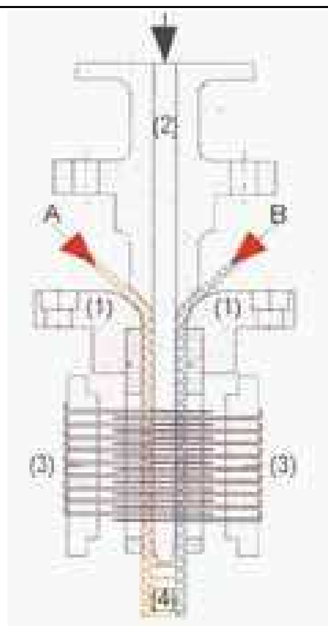
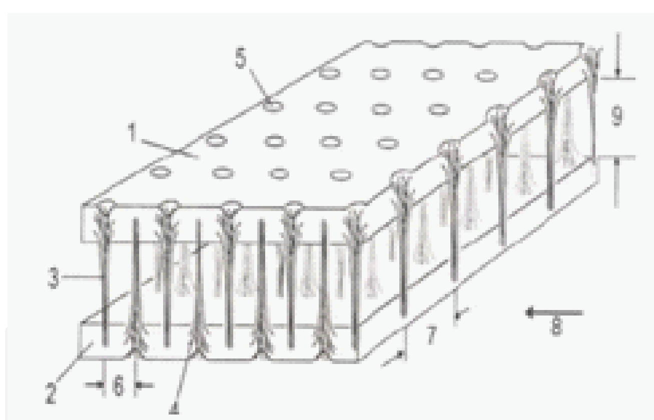
	
A and B are pre-needle nonwovens; 1 Stripper plate; 2 Spacer tables; 3 Needles' area; 4 Fibres' bridges.	1 Top layer; 2 Bottom layer; 3 Connecting layer (bridge fibres from 1); 4 Bridge fibres from 2; 5 Needle stitch; 6 Distance between bridge fibres depending on stitch depth; 7 Distance between bridge fibres depending on needle density; 8 Take-out direction; 9 Product thickness depending on the spacer's width.

Fig. 11. The NAPCO® process (left) and the obtained 3D structure (right)

The 3D nonwoven technologies allow producing bulky nonwoven presenting a low density with a maximal resilience. However, the "on the market" 3D nonwovens obtained through the existing vertical lapping processes present drawbacks (structure behaviour) that do not allow them to answer positively to our initial question concerning the replacement of the PU foam. Indeed, their vertical orientation is not optimum and the structure could be crushed when vertically compressed with a significant shear moment between top and bottom surfaces. Consequently, this work aims to answer positively to this question by developing a new 3D nonwoven obtained through a patented process VERTILAP® of the N. Schlumberger Company (Dumas et al., 2007). The VERTILAP project aims to develop a new pleated 3D nonwoven. This project has been conducted in order to involve the different partners when their skills and know-how were needed in the project. Automotive upholsteries for headrest and door panels have been also realised in order to demonstrate the taylorability and formability of the VERTILAP® 3D nonwoven.

3. Presentation of the VERTILAP® process

The VERTILAP® process (Fig. 12) is a vertical lapping system whereby a tow or a web is pleated thanks to folding elements. The process is composed of four main functions:

- The opening and defibering of the tow
- The verticalisation of the tow
- The extraction and condensation of the pleats
- The thermobonding and the lamination of the 3D pleated structure.

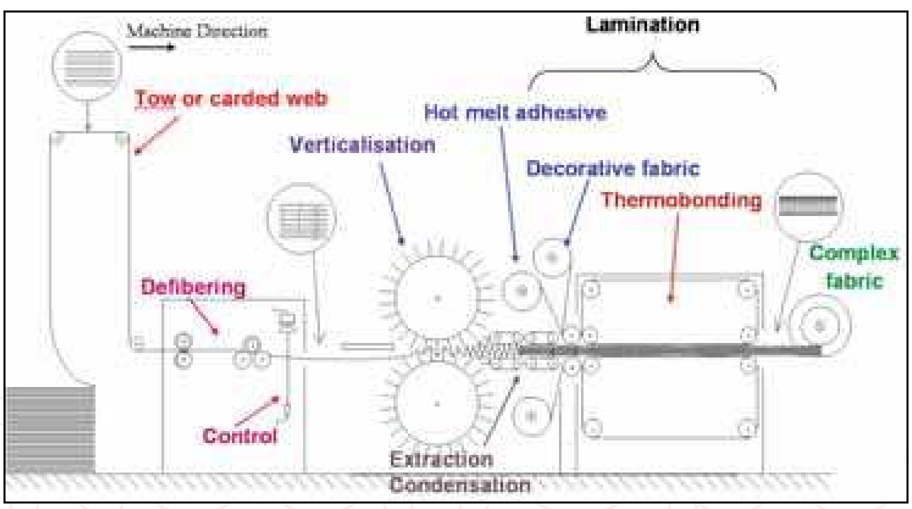


Fig. 12. The VERTILAP® process

The opening of the tow will allow spreading the filaments on the creel. To obtain a good product's homogeneity, the tow's section must be spread as evenly as possible.
The defibering function is a filament separating zone. It is necessary to individualise the filaments inside the tow. The defibering principle (Fig. 13) consists to separate the filaments by driving them into a tensioning separating zone. The filament separating cylinder set is composed of a cylinder with square threading, topped by a rubber coated pressure roller on which a pneumatic pressure is applied. Along the contacting generator, zones where the filaments are alternately nipped and released are successive. If we consider two neighbouring filaments, one will be tightened a little before the other and release a little

before the other, so that their crimping are not any longer facing each other and will not reimbricate any more. The tension to carry out in this defibering zone must be lower than the filament elastic limit. This function of the machine has a considerable influence on the tow quality. (NSC, 2007)

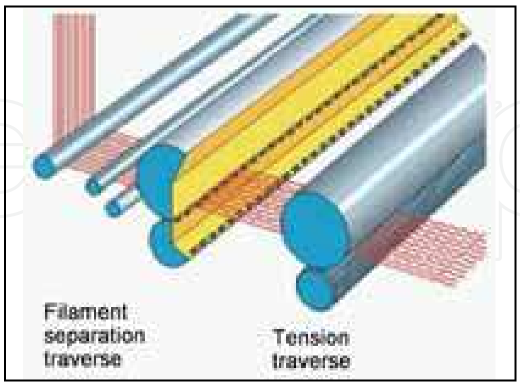


Fig. 13. The defibering principle

After being defibered, the tow is verticalised in order to create the pleats. These last ones are then extracted from the verticalisation zone and condensed to obtain the pleated structure. At this step, additional layers can be joined by thermo binding on the 3D pleated structure to fix it and to obtain the final multilayer fabric. In this process, the thermal treatment is essential in the formation and the fixation of the pleats and the 3D structure.
In this study, the VERTILAP® process is presented as an experimental prototype of 20 cm width. As input, tow was a bi-component co-polyester/ polyester presenting a count of 90 ktex and a filament's count of 4.4 dtex. The experimental prototype is suitable for tows presenting a count lower than 30 ktex. A filament separation technique has been developed to divide the initial tow of 90 ktex into finer ones. The tow has been pleated under the glass transition temperature of the co-polyester sheet which is 73°C. The obtained 3D nonwovens present a thickness of 6 mm. The laminating function was done separately thanks to a flatbed laminating system (Meyer Company, 2007) provided by Protechnic Company (Fig. 14). The 3D nonwovens have been laminated with external layers made of polyester and co-polyester hot melt adhesives. The VERTILAP® experimental prototype has been controlled through the following parameters: tow's count, speeds before and after the verticalisation zone, temperature of the verticalisation zone. The laminating process has been regulated through the speed, the pressure and the temperature.

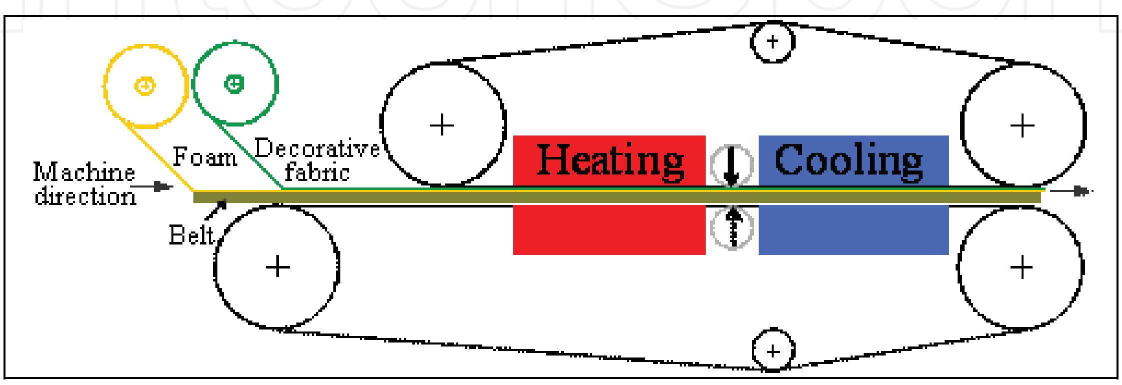


Fig. 14. The laminating process

Two kinds of VERTILAP® products have been manufactured: the monolayers and the multilayers. The obtained multilayer products have always been made of 100% polyester in order to facilitate their recycling.

4. The experimental study

Experimental study has been made in two campaigns of production, A and B, followed by complete characterisation test of the manufactured products. For each campaign, the VERTILAP® products have been compared to automotive PU foams. The tested materials, the methods and tools of characterisation and the obtained results of the comparative study between the VERTILAP® products and the PU foams are presented below. (Njeugna, 2009)

4.1 Tested materials

Five different monolayer 3D nonwovens (NT1, NT2, NT3, NT4 and NT5) have been manufactured in campaigns A and B. From each of them, multilayer products have been prepared using needle-punched, spun-bonded nonwovens and knitted fabric as external layers. Two different monolayer foams (m1, m2) classically used by car manufacturers and representing two kinds of comfort have been tested. The tested automotive multilayer product (Cm) is composed of three layers, decorative fabric (PET) / PU foam / backing fabric (PA). The tested samples are presented in Table 1. The description of the different types of the VERTILAP® multilayer samples is presented in Table 2.

	VERTILAP® products		**PU foams**
	Campaign A	**Campaign B**	
Monolayer	NT1, NT2, NT3, NT4	NT5	m1, m2
Multilayer	L1, L2	L3	Cm

Table 1. The tested samples

NT1, NT2, NT3 and NT4 are 3D nonwoven.

	Samples	Laminating components
Campaign A	L1	NT40 / 3D nonwoven / NT40
	L2	NT44 / 3D nonwoven / NT44
Campaign B	L3	NT40 / 3D nonwoven / T200

Table 2. Description of the VERTILAP® multilayer samples

With:

- NT40 is a needle-punched nonwoven presenting a mass per unit area of 40 g/ m².
- NT44 is a spun-bonded nonwoven presenting a mass per unit area of 44 g/ m².
- T200 is a knitted fabric presenting a mass per unit area of 200 g/ m².

4.2 Methods and tools of characterization

4.2.1 Physical characterization

The pleated structure of the 3D nonwoven obtained thanks to VERTILAP® process has been geometrically described as a triangle after the verticalisation (Fig. 15) and as a loop after the laminating process (Fig. 16). In both cases, the shape has been characterised by the thickness (e_0), the pleat's angle (θ), the rate of condensation, the pitch (p) and the fibrous wall thickness (e_p) which has been neglected in order to simplify the model.

The pleat's angle will indicate the vertical orientation of the pleat. In the case of the triangular shape, the vertical orientation will be reach with a value of the pleat's angle closed to 0°. In the case of the loop shape, the vertical orientation will be reach with a value of the pleat's angle closed to 90°.

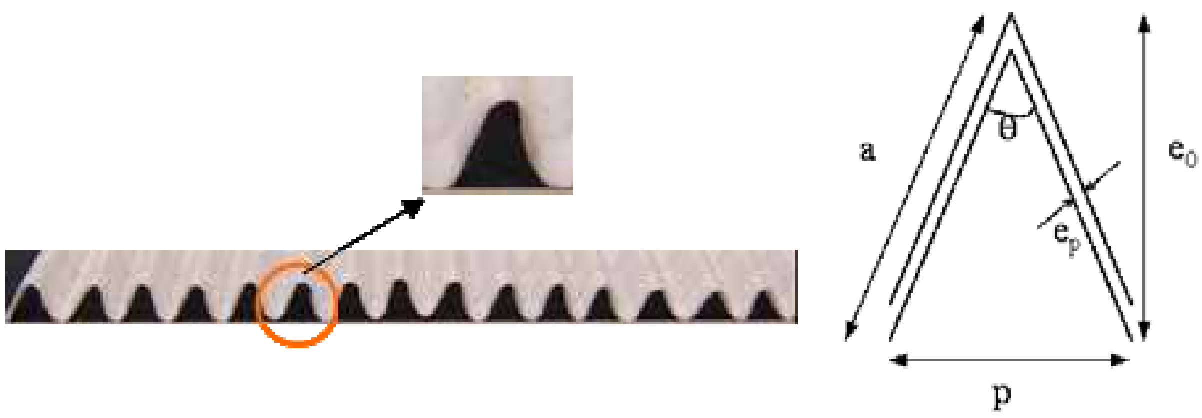


Fig. 15. Geometrical modelling of the pleat after verticalisation process

After the verticalisation process, the geometrical parameters of the pleat have been defined by the following equations:

$$p = \frac{l_r}{n_p} \qquad (1)$$

$$a = \sqrt{(e_0)^2 + (\frac{p}{2})^2} \qquad (2)$$

$$l_a = 2.a.n_p \qquad (3)$$

$$\theta = 2.\arctan(\frac{p}{2.e_0}) \qquad (4)$$

$$Tx_c = 100.\frac{l_a - l_r}{l_a} \qquad (5)$$

Where:
a is the hypotenuse
l_a is the apparent length of the sample when its pleated structure is flattened
l_r is the real length of the sample in its pleated structure

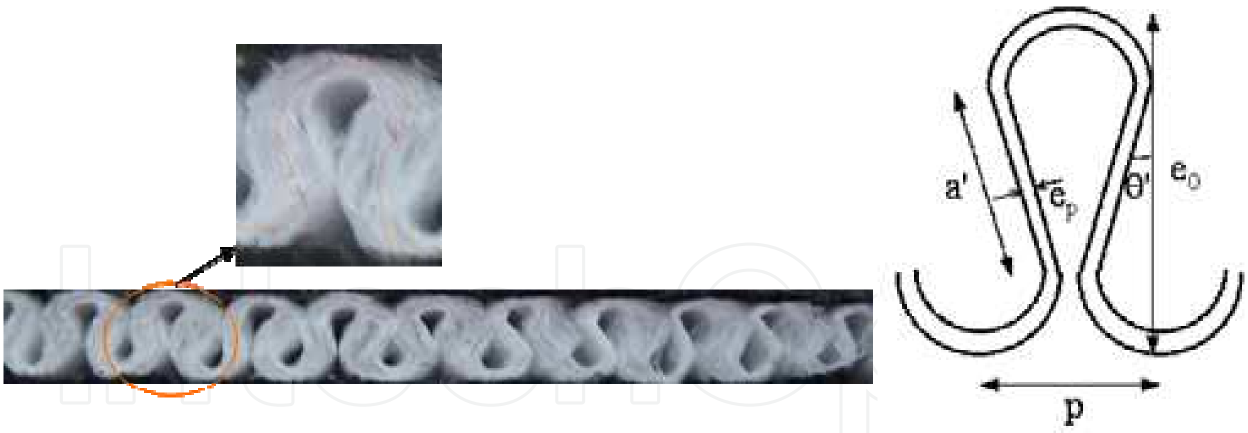


Fig. 16. Geometrical modelling of the pleat after the laminating process

After the laminating process, the geometrical parameters of the pleat have been defined by the following equations:

$$p = \frac{l_r^{'}}{n_p} = 2.r \qquad (6)$$

$$a' = \sqrt{(e_0 - p)^2 + (\frac{p}{2})^2} \qquad (7)$$

$$l_{loop} = \pi.p + 2.a' \qquad (8)$$

$$l_a^{'} = n_p.l_{loop} \qquad (9)$$

$$\theta' = \arctan\frac{p}{2(e_0 - p)} \qquad (10)$$

$$T^{'}x_c = 100.\frac{l_a^{'} - l_r^{'}}{l_a^{'}} \qquad (11)$$

Where:
a is the hypotenuse
l'_a is the apparent length of the sample when its pleated structure is flattened
l'_r is the real length of the sample in its pleated structure
l_{loop} is the length of the loop
In the case of the foam, the cellular structure has been geometrically modelled as a pentagon (Fig. 17) thanks to an adapted method developed from *VISIOCELL®* used by the OEM (Original Equipment Manufacturer) (Recticel, 1999), (Drean, 2006). The foam has been characterised thanks to the horizontal and vertical mean cell sizes. The sizes are measured on different area of the sample and on a group of five adjacent cells. The characteristics of the tested foams are presented in Table 3.
The physical characterisation of the 3D nonwoven has been extended to comfort evaluation which can be evaluated thanks to air permeability (BS 5'636, 1990) and thermal insulation

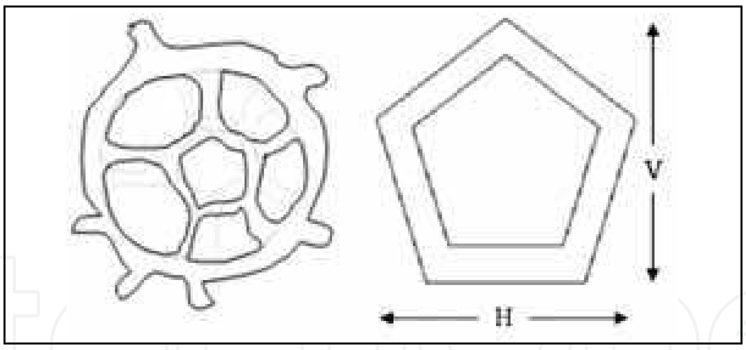


Fig. 17. Geometrical modelling of the PU foam

	m1	m2	Cm
Thickness (mm)	5	5	4
Weight (g/ m^2)	182	180	386
Density (kg/ m^3)	36	36	87
Vertical cell mean size, V(μm)	0.25	0.21	0.25
Horizontal cell mean size, H (μm)	0.25	0.31	0.30

Table 3. Characteristics of the tested foams

(Kawabata, 1980). The air permeability measurement has been performed by using the air permeability tester FX3300 under a pressure of 98 Pa on a surface of 5 cm^2. The coefficient of thermal conductivity (K, unit in W/ m.K) has been measured thanks to the KES-FB7 thermolab II of Kawabata Evaluation System for Fabrics. The measurements were performed at 23°C during 60s on a sample surface of 25 cm^2. The apparatus have been customized in order to minimise the air leakage and the heat losses on the lateral edges (Fig. 18).

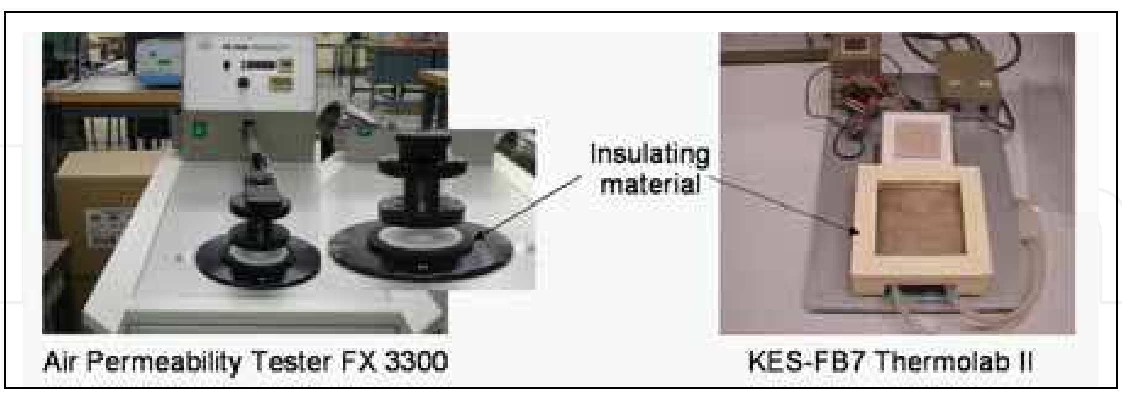


Fig. 18. Customization of testing apparatus for air permeability and thermal conductivity

4.2.2 Compression characterization

The mechanical characterisation has been focused on the compression behaviour because it is the most important property to analyse on the new 3D product if compared with the PU foam. The compression behaviour has been evaluated thanks to two different testing methods; a first method based on the Kawabata recommendations and a second method based on automotive standard ISO 3386/ 1: 1986.

The first testing method has been carried out on the KES-FB3 module. For that, two procedures have been successively defined, the first one using the standard conditions of Kawabata and the second one derived from these conditions. In fact, the standard configuration of the apparatus highlighted during the test an indentation phenomenon on the pleated material (Fig. 19) which was due to the small surface (2 cm^2) of the compression plate in regards with the testing sample structure (100 cm^2): only one or two pleats were under the pressure foot during the test. (Njeugna et al., 2008)

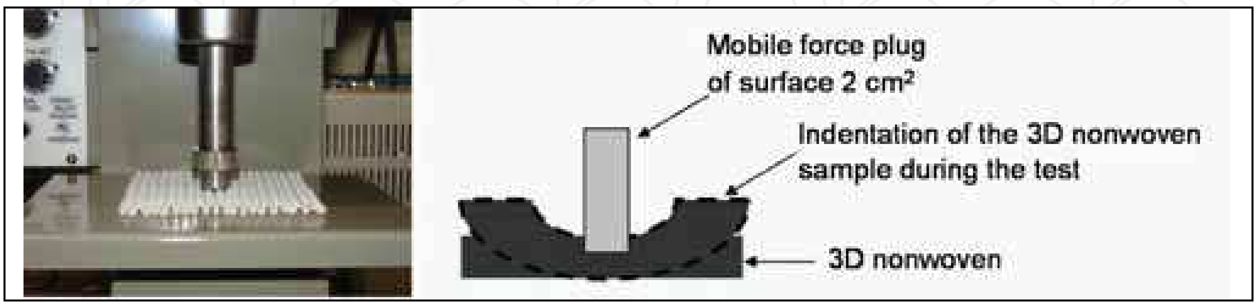


Fig. 19. Standard configuration of the KES-FB3 compression tester

The second procedure consisted on modifying the surface of the compression plates in order to compress the testing sample on its whole surface (Fig. 20). The obtained results avoid indentation phenomenon observed on initial tests. They have also shown the resilient property of the pleated 3D nonwoven. The second procedure has been validated for the compression characterisation. The samples have been compressed under a maximal load of 3 kPa at a speed of 12 mm/ min during one cycle. The results give information on the thickness, the compressibility, the dissipated energy and the resilience of the material.

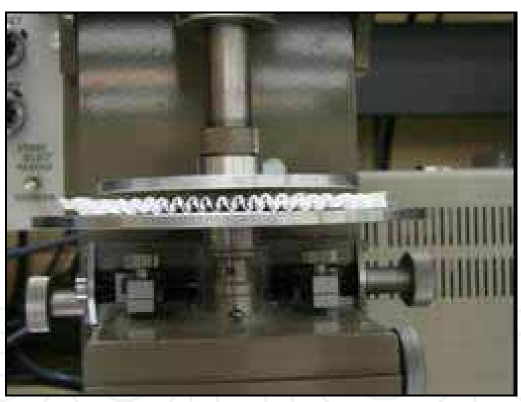


Fig. 20. Customization of the KES-FB3 compression tester

The second testing method has been carried out on a universal screw driven testing machine (Instron 33R4204) fitted with 5 kN load cell (Fig. 21). The solicitation speed was at 12 mm/ min. The tests have been performed in static mode. A sanding paper has been fixed on the surface of the fixed compression plate of the Instron machine in order to eliminate any slippage of the sample during the test. The samples have been compressed up to 50% of their initial thickness then decompressed at the same speed until the plates come back to their initial locations. Five cycles of compression have been performed with a rest time of 10s between each cycle. The stress deformation curves have been plotted. The maximal stress at 50% deformation of the initial thickness and the dissipated energy have been determined.

Fig. 21. INSTRON 33R4204 testing device

4.3 Comparative study: VERTILAP® products vs. PU foams

4.3.1 Campaign A

Production of the VERTILAP® products has been made in two steps respectively dedicated to the preparation of the feeding tow and to the manufacturing of the 3D nonwoven. The feeding tows have been prepared thanks to a simple manual technique whereby the initial tow of 90 ktex has been divided into finer tows presenting a count from 9 ktex to 18 ktex. The obtained tows have been defibered in a converting machine (NSC, 2007) in order to improve the quality of the filament opening. During the manufacturing process, the speeds before and after the verticalisation zone have been varied. A digital camera has been used to observe the products throughout the processing range. These observations have shown irregularities in the formation of the compacted 3D structure. It has also been observed that the outgoing product was still hot at the output of the machine. This observation has allowed showing that the condensation process was not fully controlled. The single 3D nonwovens have been laminated under a speed of 2 m/ min at 150°C. The hot melt adhesive was a 25 g/ m² co-polyester web with a melting temperature of 120/ 125°C.

The geometrical modelling of the pleated 3D nonwoven has shown that they present a pleat's angle of 41°, a rate of condensation of 65% and a number of pleats/ cm of 2.2. The pleats in the laminated structure present an angle of 57° and a rate of condensation of 77%. The pleat's angle and the rate of condensation have respectively increased of 28% and 16% after the laminating process.

The results of the physical characterisation have shown that, in the case of monolayer products (Fig. 22), the 3D nonwovens are thicker and more comfortable in terms of air permeability than the PU foams. They are less comfortable in terms of thermal insulation compared to m1 sample. The PU foams are twice lighter than these new products.

In the case of the laminated products (Fig.), the VERTILAP® products are thicker and more comfortable in terms of air permeability and thermal insulation than the tested multilayer foam (Fig. 23). They are also heavier than the tested foam.

The results of the compression behaviour on one cycle test (KES-FB3) have shown that, in the case of monolayer products (Fig. 24), the 3D nonwovens and the PU foams globally present the same resilient behaviour. The PU foams are more compressible than the tested 3D nonwovens and they dissipated less energy. This last result shows that the 3D nonwovens will present better characteristics in term of soft touch compared with the PU foams.

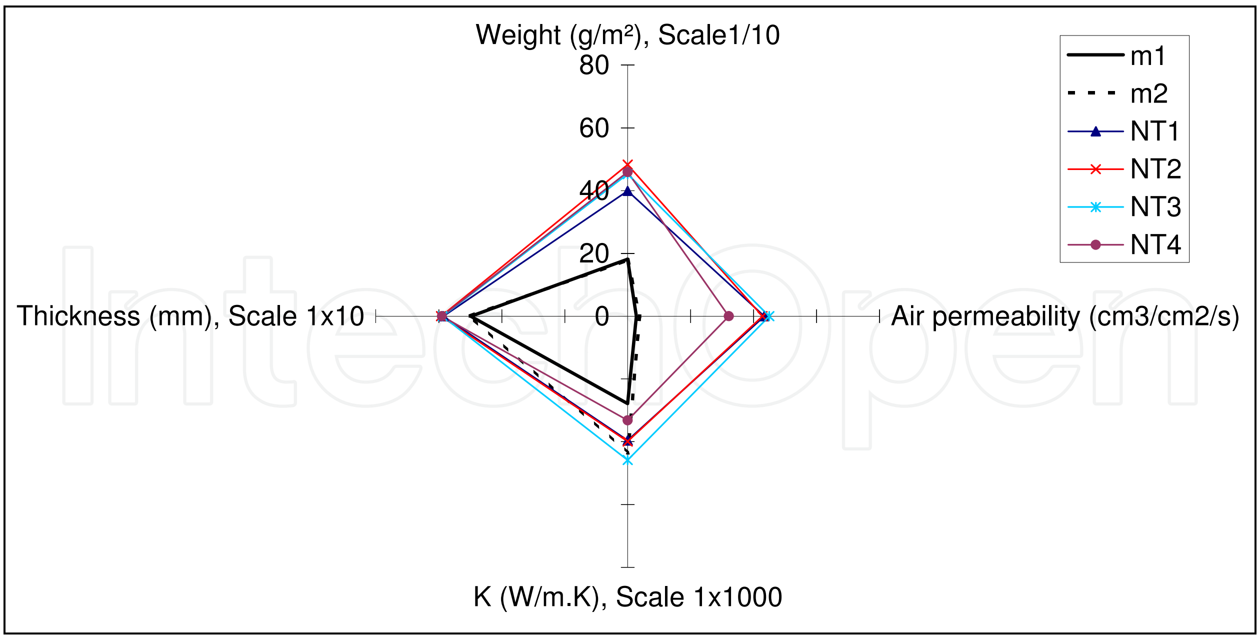


Fig. 22. Physical characteristics of the tested monolayer samples

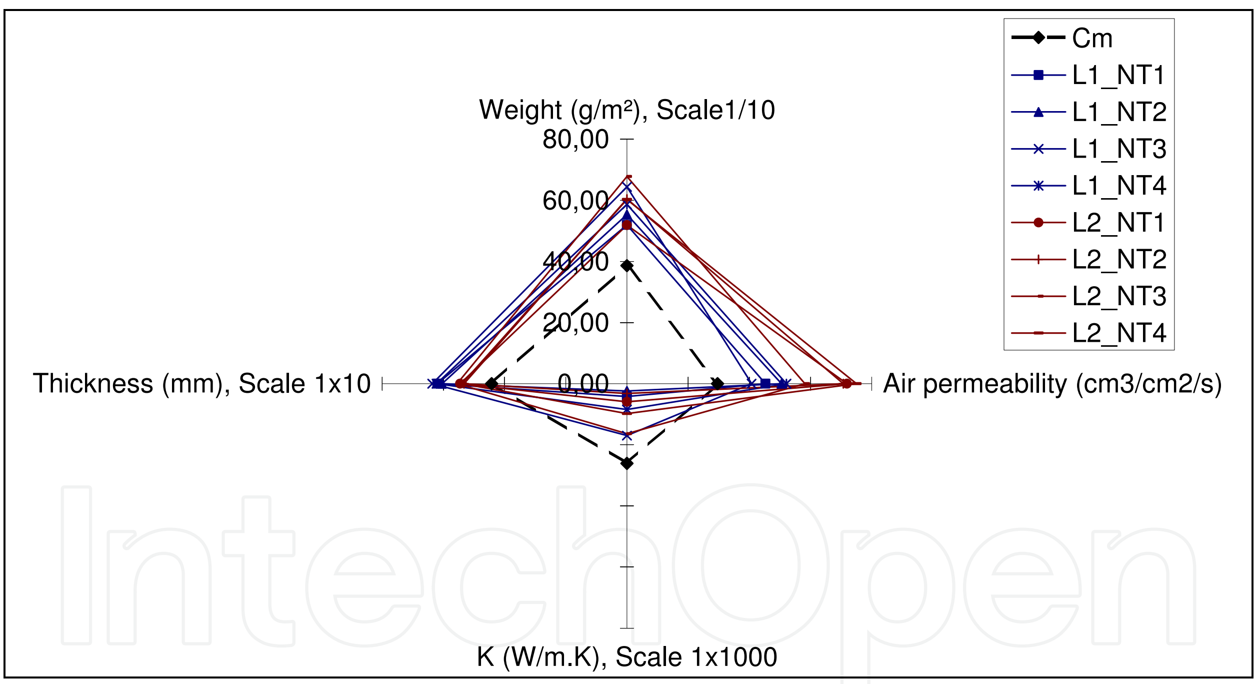


Fig. 23. Physical characteristics of the tested multilayer samples

In the case of the laminated products (Fig. 25), the VERTILAP® products laminated with the needle-punched nonwovens (L1 samples) and the tested foam globally present the same resilient property while the VERTILAP® products laminated with spun-bonded nonwovens (L2 samples) are the most resilient. The foam is more compressible than the VERTILAP® products. The L2 samples and the foam globally present the same characteristic in term of dissipated energy while the L1 samples dissipate the most energy. It can be said that the L1 samples present the same resilient property than the tested foam but they will be more comfortable in term of soft touch.

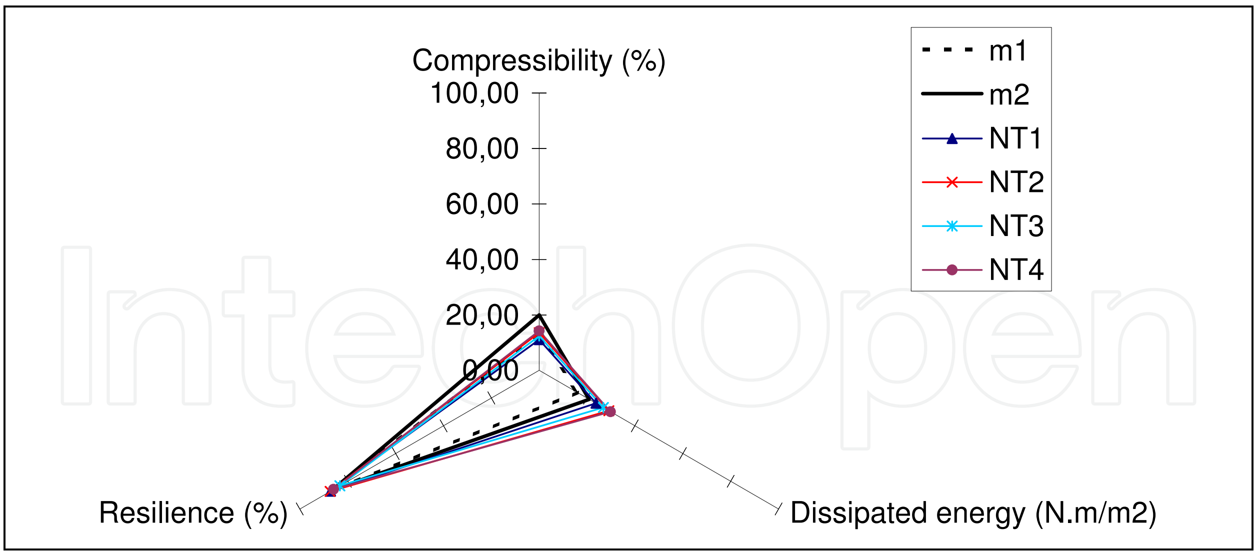


Fig. 24. Compressional characteristics of the tested monolayer samples (KES-FB3)

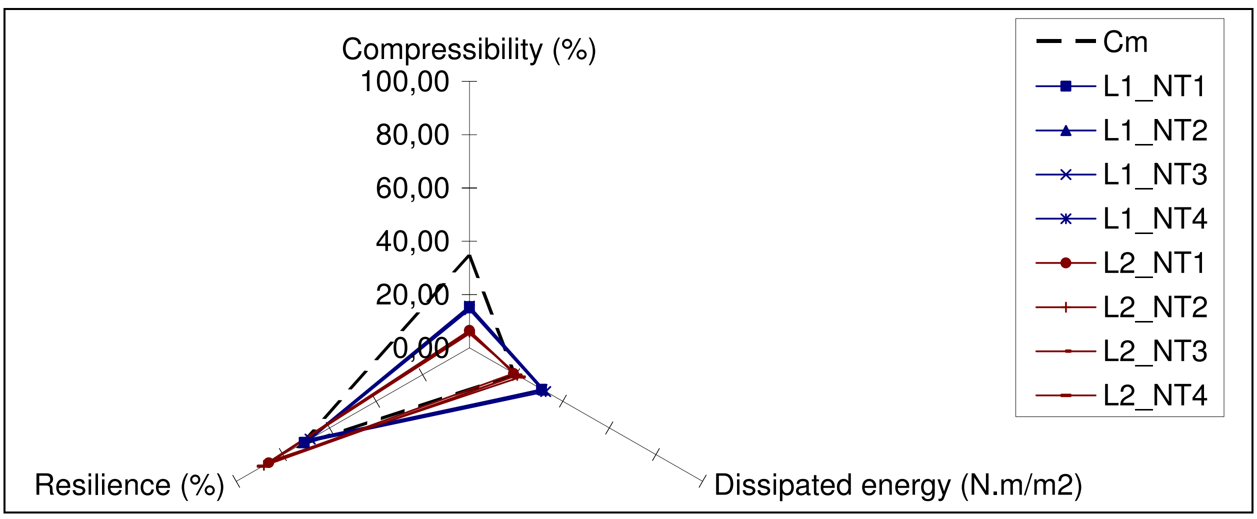


Fig. 25. Compressional characteristics of the tested multilayer samples (KES-FB3)

Regarding the compression test on five cycles, it has also been observed that the VERTILAP® products are more resilient and dissipate more energy than the tested PU foams. These observations have been done in both cases of the monolayer and laminated products (Fig. 26 - 29). The analysis of the raw results has shown differences between the behaviour of the 3D nonwoven and the PU foam. It has been observed an important reorganisation of the fibrous structure in the case of the 3D nonwoven while the cellular structure of the PU foam remained more constant. This reorganisation displays different individual behaviours of the filaments inside the pleated structure.

The results of this campaign have shown interesting properties of the VERTILAP® products in terms of comfort and mechanical behaviour compared with the tested PU foams. At this step, the main drawback of this new 3D nonwoven is its weight and its poor reproducibility. In fact, the obtained results have shown high dispersion values in the case of the VERTILAP® products. A second campaign has been carried out in order to reach the goal of the weight reduction of the VERTILAP® products.

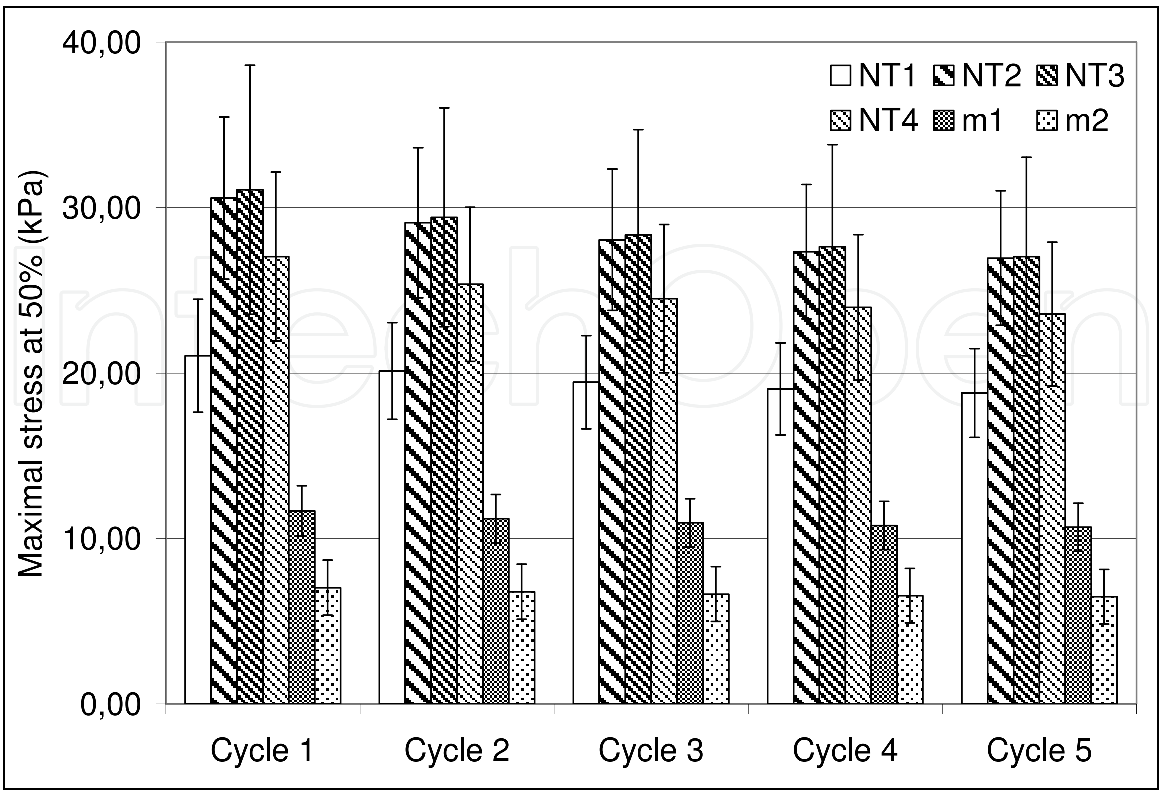


Fig. 26. Maximal stress at 50% deformation of initial thickness of the tested monolayer samples

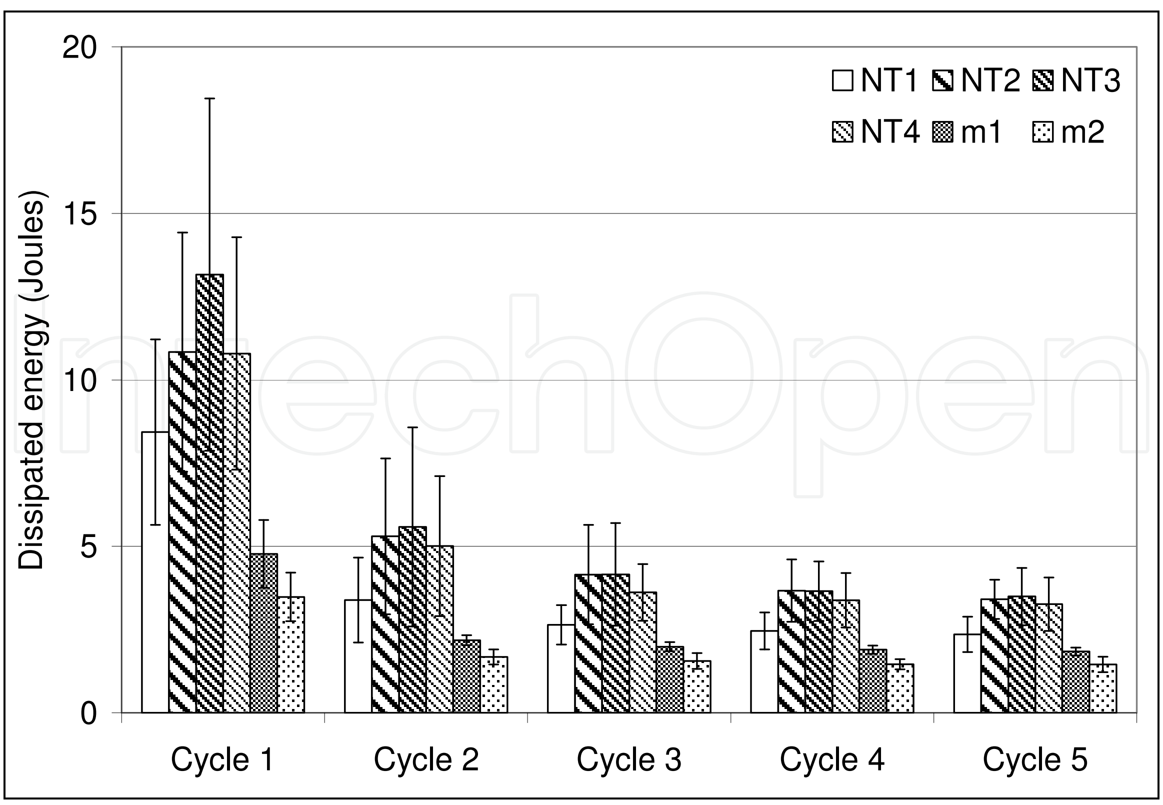


Fig. 27. Dissipated energy of the tested monolayer samples

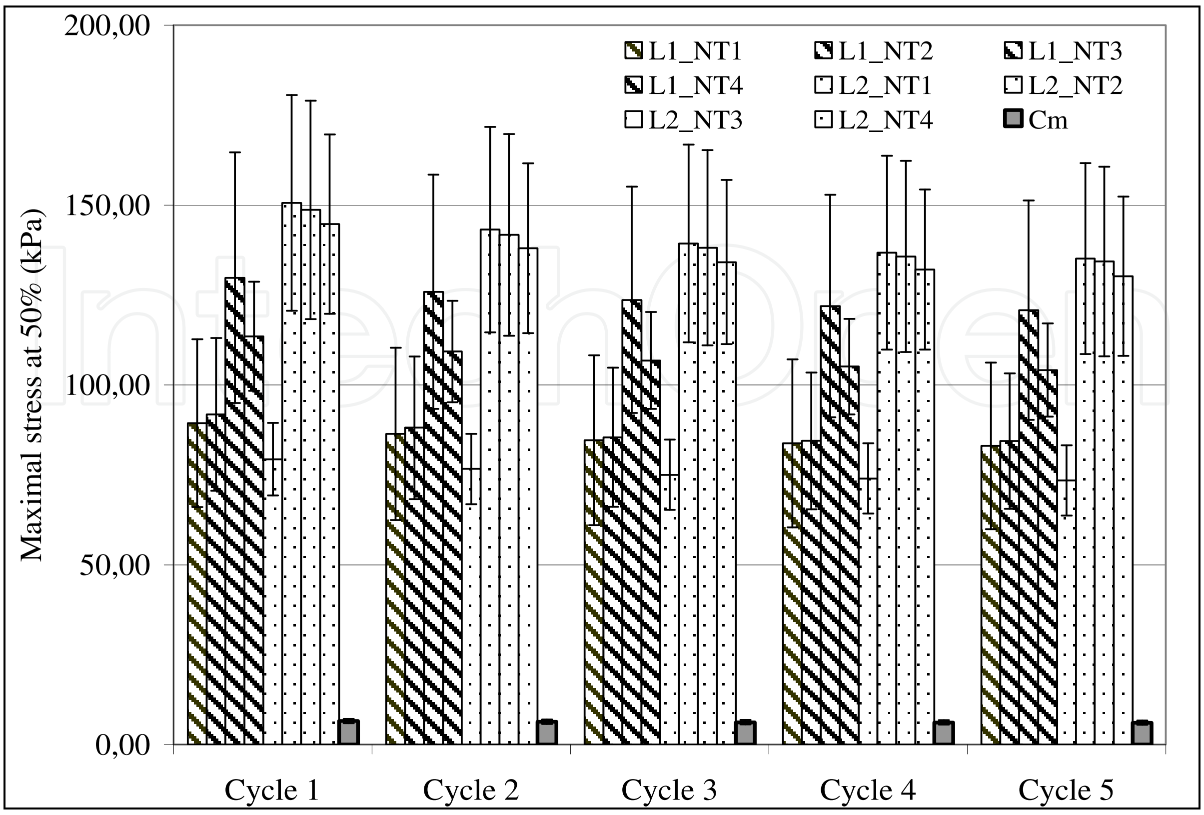


Fig. 28. Maximal stress at 50% deformation of initial thickness of the tested multilayer samples

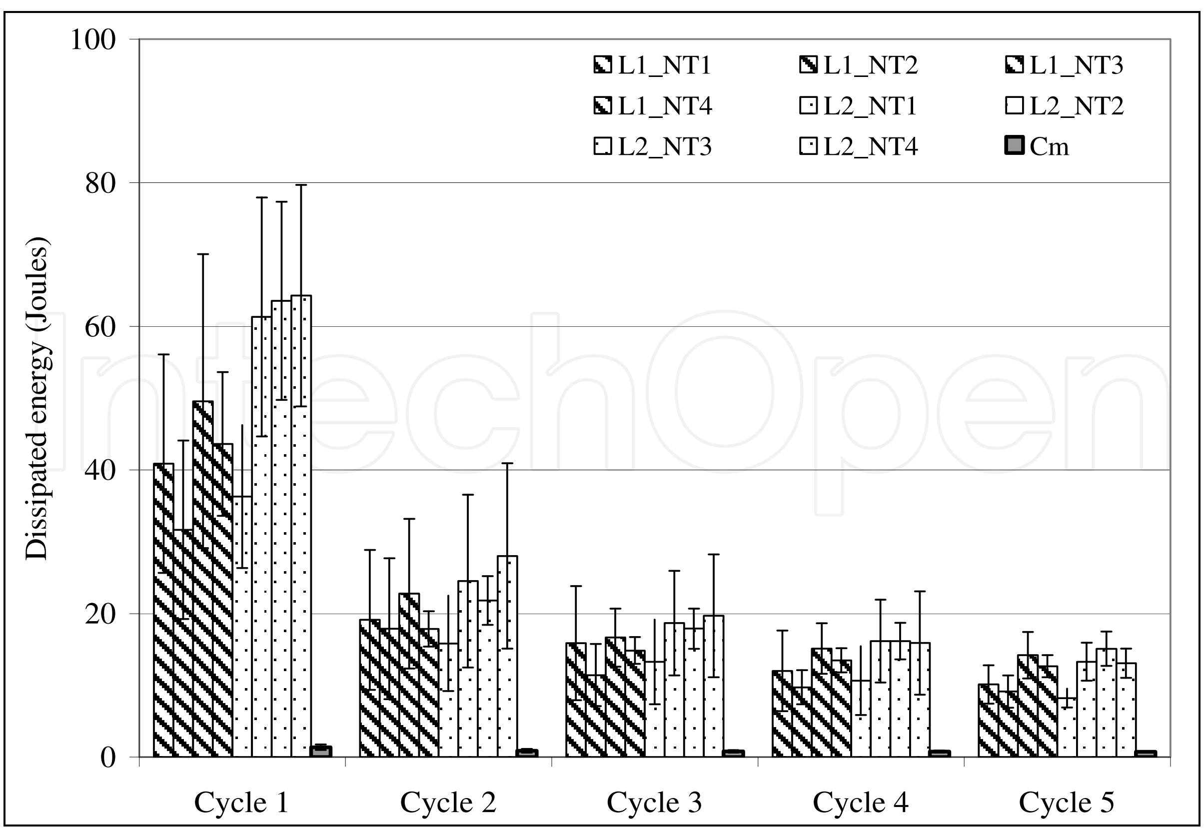


Fig. 29. Dissipated energy of the tested multilayer samples

4.3.2 Campaign B

In this experiment, the previous production procedure has been applied to manufacture the VERTILAP® products of this campaign but the technique to divide the initial tow of 90 ktex has been improved by spreading the tow between two beams in order to apply a minimal tension necessary for the filaments separation. Tows presenting a count from 7 ktex to 10 ktex have been pleated. During the manufacturing process, the speed before the verticalisation zone has been varied. The obtained single 3D nonwovens have been laminated at a speed of 5 m/ min at 120°C. The hot melt adhesive was a 20 g/ m² co-polyester web with a melting temperature of 60/ 75°C. It is also important to note an increase of 60% of the laminating speed compared to the previous samples (NT1, NT2, NT3 and NT4). This result enables to validate the products/ process procedure.

The results of characterisation have shown a decrease of the weight of the 3D nonwovens compared to the previous samples. Indeed, the single 3D nonwovens present a mass per unit area of 164 g/ m² while the mass per unit area of the laminated ones is 484 g/ m². Structure's irregularity has been observed on the manufactured 3D nonwovens. This irregularity is mainly due to the irregularity in the tow. In fact, finer the tow, the more irregular the structure is as expressed in the Martindale's law (Martindale, 1945).

Regarding the physical characteristics (Fig. 30) in the case of the monolayer products, the objective of lightness has been reached and the 3D nonwoven, NT5, is also more comfortable in term of air permeability compared with the tested foams (m1, m2). NT5 also presents a better thermal insulation property compared with m1 sample. In the case of the multilayer products, the foam (Cm) present better physical characteristics compared with the laminated 3D nonwoven (L3 sample).

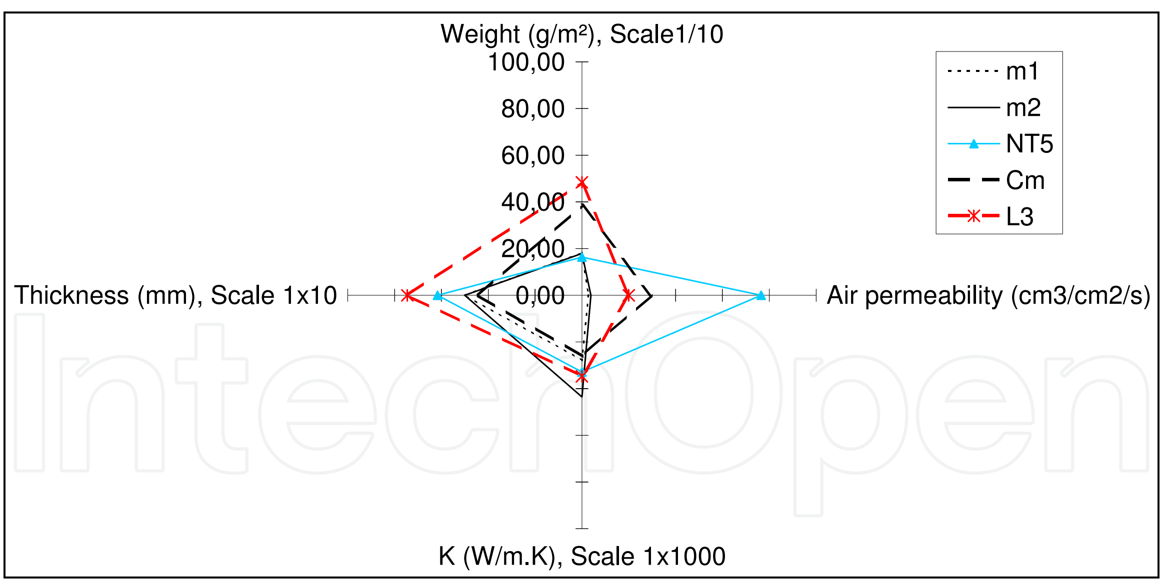


Fig. 30. Physical characteristics of the tested samples

Regarding the compression properties on one cycle (Fig. 31), a balance has been observed between the resilience and the dissipated energy in the case of single and laminated 3D nonwovens. This result shows that this new product presents, simultaneously, good resilient property and suitable comfort (soft touch). Except the problem of structure's irregularity, the characteristics of the obtained 3D nonwovens have been significantly improved. In both cases of monolayer and multilayer products, it has been observed that the

VERTILAP® products and the foam present globally the same resilient property but the foams dissipated less energy. It can be said that, the VERTILAP® products present better characteristic in term of comfort (soft touch).

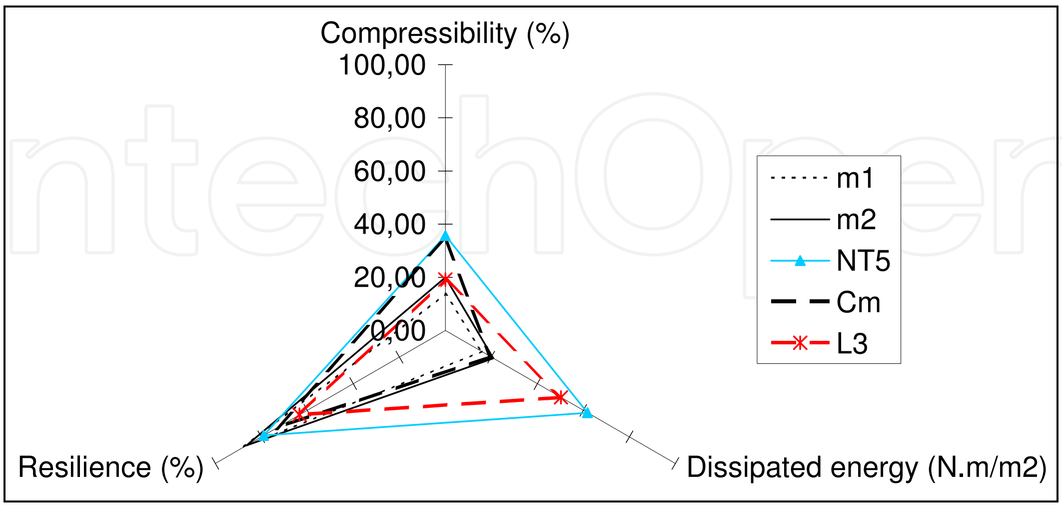


Fig. 31. Compressional characteristics of the tested samples

The compression curves of the tested samples are presented on Fig. 32.

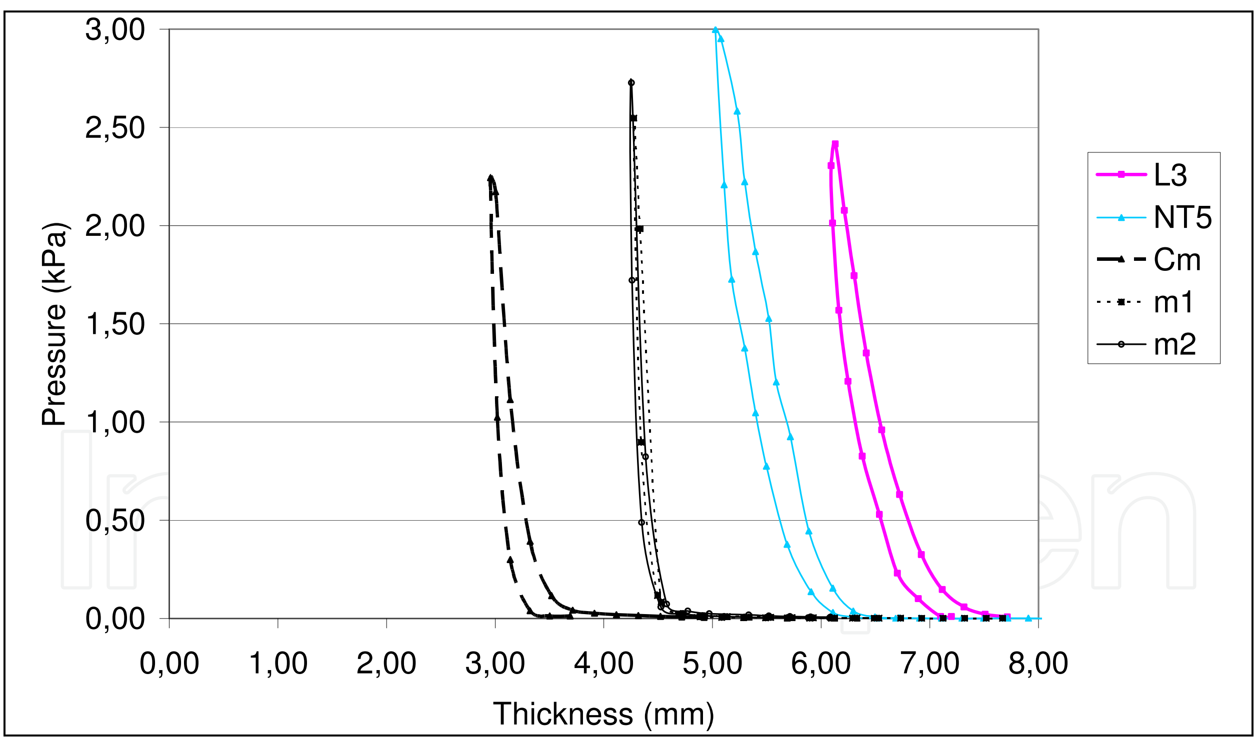


Fig. 32. Compression curves on one cycle (KES-FB3) of the tested samples

In addition to the previous characterization, the study of the tailorability of these new products has been carried out. The tailorability of the VERTILAP® 3D nonwoven has been positively validated through the execution of upholsteries for a headrest and door panels (Fig. 33). These automotive prototypes have been visually and tactically assessed thanks to sensory panelists (Philippe et al., 2004) and textile industrialists.

Fig. 33. Automotive prototypes with VERTILAP® products

At the end of this campaign, the initial question of PU foam replacement has found a positive answer. Indeed, the development of the experimental prototype has allowed improving the quality of the final product especially in terms of weight and comfort in the case of the monolayer products. Nevertheless, the feeding material presents the problem of the structure's irregularity. The final results show that the developed products/ process procedure has been successfully implemented and has permitted to improve the process and the expected products.

5. Conclusions and outlook

One original point of the VERTILAP project is the cluster that has been built for it (scientists, textile companies and competitiveness clusters). This cluster has made possible the development of an innovative 3D nonwoven. This work has contributed to increase know-how on the VERTILAP® process and knowledge on the obtained pleated 3D nonwoven in terms of methods and tools of characterisations. This study has shown that the new 3D nonwoven present good qualities, in terms of compressional behaviour and comfort (soft touch, air permeability and thermal insulation), compared to the current automotive PU foam. The realisation of the automotive parts (headrest and door panel) with this new product has shown that the VERTILAP® products present good suitable taylorability properties. At this step of the work, the question initially asked "can the PU foam be replaced by the VERTILAP® 3D nonwoven?" has found a positive answer and the recyclability problem has been solved. It can be said that the VERTILAP® 3D nonwoven could be a good candidate to replace certain PU foam in automotive trim applications.
Moreover, the obtained results during this work have generated data that will be used to develop a new VERTILAP® prototype of 1m width. This new prototype will be manufactured by the new subsidiary company NSC Environnement of the NSC Group. This new machine will allow conducting industrial testing campaign at high speeds of production. Different feeding materials such as nonwoven web or carded web will be used in order to obtain a good homogeneity of the product. The obtained 3D nonwovens thanks to this new prototype will be characterised through more investigations. In fact, characteristics such as the behaviour modelling, the acoustic insulation, the comfort through sensory analysis and the taylorability could be realised.
The forthcoming of the VERTILAP project has been initiated in order to extend the development of the new 3D nonwoven beyond automotive applications. This second phase has been labelled, in 2009, by the French competitiveness "Fibres Innovative Cluster". New

industrial partners (Freudenberg Politex, Paul Hartmann, DIROY, Jacob Holm Industries, Albany International, Steelcase) have joined the project VERTILAP for this industrial phase.

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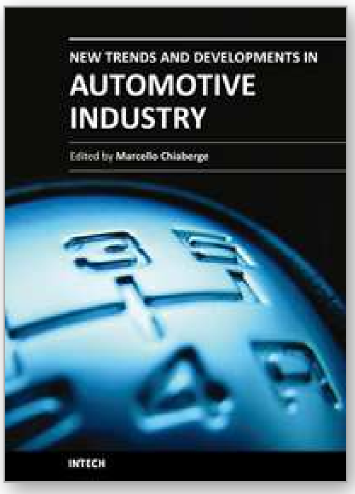

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This book is divided in five main parts (production technology, system production, machinery, design and materials) and tries to show emerging solutions in automotive industry fields related to OEMs and no-OEMs sectors in order to show the vitality of this leading industry for worldwide economies and related important impacts on other industrial sectors and their environmental sub-products.