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# Effect of Production Process Parameters on Different Properties of a Nonwoven Spacer Produced on a 3D Web Linker®

## Abstract

*In the field of technical textiles, three-dimensional woven spacer fabrics and knit spacer fabrics are nowadays widely used. Nevertheless, 3D nonwoven structures produced without any threads are still a novel development. Here we examine the possibility of producing nonwoven spacers using 3D Web Linker®, Napco® technology, and study their properties and possible destinations.*

*Two pre-needled monolayers (85% recycled PES 6.88 dtex/97.4 mm, and 15% fusible fibres Co-PES 5 dtex/60 mm) of the same weight were bonded together on a 3D Web Linker® to produce nonwoven spacers, hereafter called Napco structures. A further thermal consolidation process was applied to all the samples, and structures identified as NapcoT were produced. The influence of the monolayers' weight, technological parameters and thermal treatment on different physical and mechanical properties (weight, thickness, thermal properties, tensile properties and sound absorption coefficient) of the nonwoven spacer fabric was studied, and is presented further.*

*It was found that nonwoven spacers can be produced via the Napco® technology if the length of the fibres, the quality of the monolayers and the technological parameters are correctly chosen and correlated. The majority of the tested properties are influenced significantly by the technological parameters, but only slightly by the thermal treatment.*

**Key words:** nonwoven spacer fabrics, 3D Web Linker, Napco, thermal resistance R-value, normal incidence sound absorption (NAC), noise reduction coefficient (NRC).

## Introduction

Web formation mainly produces two-dimensional textile fabrics. However technical textiles, because their fibres are orientated vertically to the material cross-section, are more and more frequently made to be three-dimensional. Three-dimensional textiles provide a perfect structure for car interiors (seat cover replacing polyurethane (PU) foam, door panels, car roof lining, A-B-C pillars, etc.). They completely meet important requirements such as softness, breathability, upholstery-related properties and aesthetic functions. Some other possible fields of application are in medical, hygiene and healthcare fields (as heat and moisture regulators), geotextiles, civil

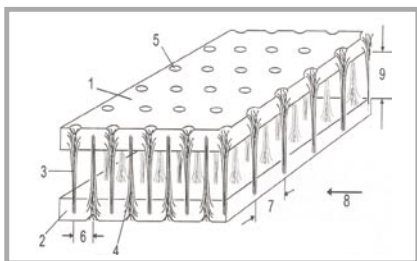
engineering, building, constructions, filtration; sport and leisure; home textiles (upholstery, mattress covers), etc. [1-7].

Nowadays, the application of knit spacer fabrics and woven spacer fabrics is state-of-the-art.

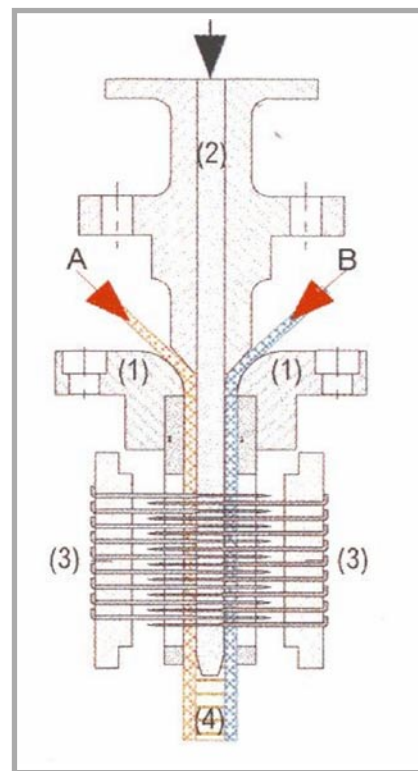
Warp-knitted spacer fabrics are double-layer, warp-knitted constructions in which the two sides of the textiles are joined together. Spacer fabrics with more than 20 mm thickness are under development. A spacer fabric can also be produced on flat weft knitting machines equipped with two needle beds. More recent development work has concentrated on producing spacer fabrics on circular weft knitting machines. In general, spacer fabrics are characterised by high productivity during the manufacturing process. 3D textiles will have an intensified use as textile components for fibre-reinforced plastics as lightweight building units in carrying parts, where nonwovens can only be used in a limited way [8].

The product group of three-dimensional nonwovens or nonwoven spacer fabrics such as Kunit and Multiknit, perpendicular-laid nonwovens (Santex Wavemaker, Struto and Napco) is an advance, not at least for economic reasons. Nonwovens, in general, are highly economical because the chain of manufacturing processes is shorter and costs less, and the equipment is being continuously developed with re-

gard to output and product quality. Currently, more than two-thirds of technical textiles are nonwovens, and nonwovens are growing faster in production than any other textile fabrics, the average annual rate being 6.2% [9]. Other advan-



**Figure 1.** Structure of Napco products: 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.



**Figure 2.** Machine cross-section: A and B - pre-needled nonwoven monolayers; 1- stripper plate; 2- spacer tables; 3- needles' area; 4- fibres' bridges.

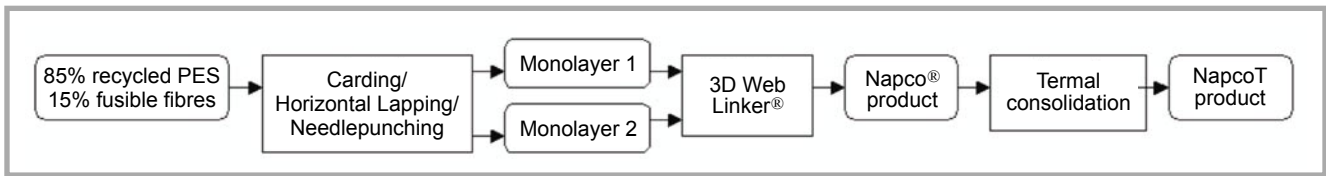


Figure 3. Processing technologies of the Napco and NapcoT samples.

tages that may explain the growth rates of nonwovens are their versatility (there are many ways to design them, using different types of fibres, with different weight, thickness and surface structure) and, to a certain degree, nonwovens may substitute for conventional products such as fabrics, scrims, knits, foams [9, 10].

Karl Mayer [11] has modified the basic Malimo technology to produce three-dimensional fabrics with thicknesses up to 10 mm (Kunit) or 16 mm (Multikunit). Using these techniques, fabrics can be produced with low specific weight, good compressive elasticity and mouldability, and they may be used to replace polyurethane foam in seating uses in cars and other locations. [8] The Kunit three-dimensional fabrics made of staple

fibres are comprised of one stitch side and one pile loop side that has an almost vertical fibre arrangement. The lengthwise-oriented fibrous web is folded and compacted into a pile fibre web at high speed and supported by a brush bar. The fibres are pressed into needle hooks by the brush bar to form a stitch.

Multiknit nonwovens are produced from 100% carded fibres by the stitch-bonding

lapper (Struto), each of which has its own commercial advantages. The mostly used consolidation of the perpendicular-laid web is through-air thermobonding, but Quasi-yarns may also be used to reinforce the 3D nonwoven fleeces [12, 13].

The Santex Wavemaker is a vertical lapping unit that folds nonwovens in a wave form. In this way the fibres acquire a vertical orientation. All kinds of fibre

Table 1. Experimental design.

Sample ID	Factors			
	Needles type ne	Spacers sp, mm	Weight of monolayers we, g/m <sup>2</sup>	Outlet st, mm/stroke
N1	Tetra	5	200	6,8
N2	Fork	5	200	6,8
N3	Tetra	8	200	6,8
N4	Fork	8	200	6,8
N5	Tetra	5	400	6,8
N6	Fork	5	400	6,8
N7	Tetra	8	400	6,8
N8	Fork	8	400	6,8
N9	Tetra	5	200	12,9
N10	Fork	5	200	12,9
N11	Tetra	8	200	12,9
N12	Fork	8	200	12,9
N13	Tetra	5	400	12,9
N14	Fork	5	400	12,9
N15	Tetra	8	400	12,9
N16	Fork	8	400	12,9
N17	Tetra	5	200	6,8
N18	Tetra	5	200	6,8
N19	Tetra	5	200	6,8

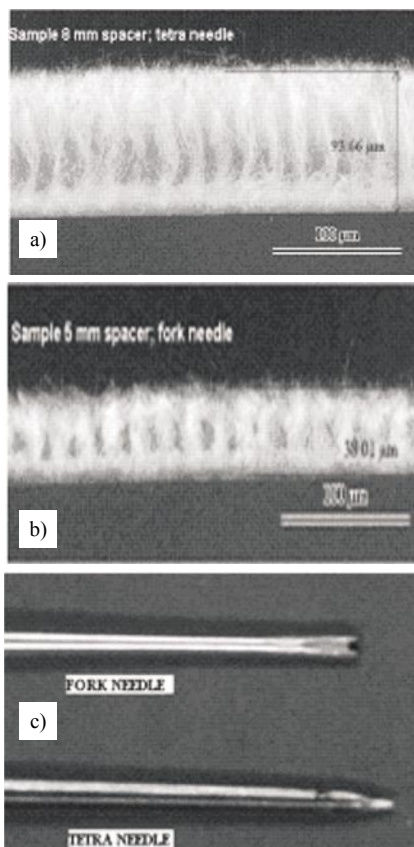


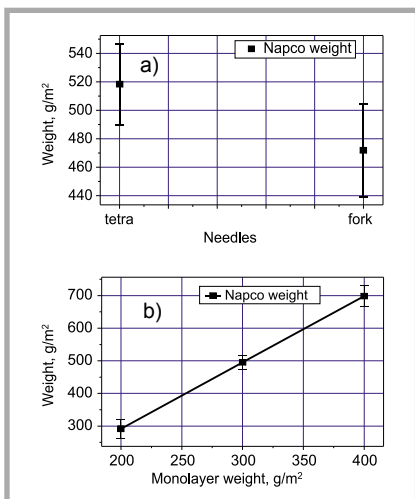
Figure 4. Cross section of the nonwoven spacer fabric: a) sample produced with an 8-mm spacer and tetra-type needles; b) sample produced with a 5-mm spacer and fork-type needles; c) fork and tetra-type needles.

process. The lengthwise-oriented card web is first bonded on the Kunit stitch-bonding machine. In the second stage, the Kunit nonwoven is bonded on the Multiknit stitchbonding machine. The double-sided knit effect of the Multiknit fabric is produced by forming the fibrous content of the pile folds into loops to produce the second knit surface [8]. Thermally-treated Multiknit nonwovens are known under the trade name Caliweb.

Nowadays, there are two production systems of perpendicular-laid fleeces: the rotational lapper by the Swiss company Santex (Wavemaker) and the vibration

can be transformed into high-resilience and acoustic absorbance nonwovens of up to 50 mm thickness. The products are an excellent substitute for PU-foams, and also suitable for some other applications such as automotive interiors, seat cushions, shoe insoles, etc. [14, 15].

A Struto line consists of a carding machine, a Struto Vertical Lapper and a through-air thermobonding chamber. All kinds of fibres, including recycled fibres as well as natural and synthetic fibres processable by carding, can be used, in fibre blends with a 10 to 100 mass percentage of thermobonding fibres. Vertically



**Figure 5.** Influence of the input parameters on the weight of the nonwoven spacer fabric: a) type of needles; b) weight of the monolayer.

lapped nonwovens can be produced with a thickness between 8 and 35 mm, which due to the vertical position of fibres show bulkiness, heat insulation, filling properties and outstanding compressional rigidity and a high degree of recovery after repeated loading [16 - 18].

Three-dimensional nonwoven structures can also be obtained by means of needle-punching two pre-needled nonwoven layers with a defined space between, realised by mean of a spacer. Napco® is a technology that enables the manufacture of a three-dimensional spacer nonwoven fabric with large hollow spaces, using 3D Web Linker®, a special machine developed by Laroche. In this process, special barb or fork needles arranged in rows penetrate simultaneously from both sides of the two pre-needled nonwovens creating fibre bridges formed by fibre bundles, and so the structure of the layers should contain enough unbounded fibres of sufficiently great fibre length. In Figure 1 (see page 68), a schematic representation of a Napco structure is shown, and a cross-

section of the working zone of a 3D Web Linker® machine that produces 3D structures starting from two pre-needled monolayers A and B can be seen in Figure 2 [20]. This technology allows the production of unfilled 3D-nonwovens, as well as filled products (e.g. granulates, powders, tubes, paste, foam, textile wastes, etc.) for composites. For this study unfilled structures have been produced.

### Experimental design

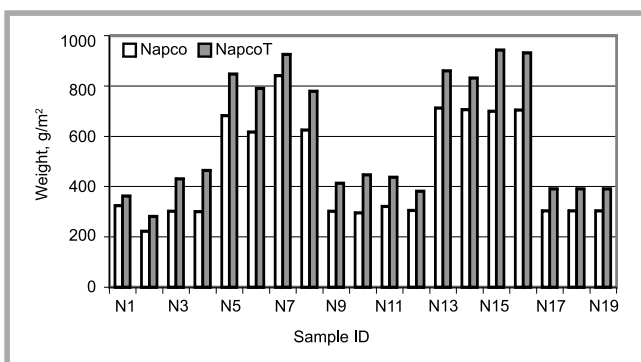
A carded web of 85% recycled PES 6.88 dtex/97.4 mm and 15% fusible copolyester fibres (Co-PES) 5.5 dtex/60 mm (EMS-Griltech) was cross-folded and pre-needled, and nonwovens (monolayers) of 200 g/m² and 400 g/m² were produced. The nonwoven spacers (hereafter called Napco) were produced by bonding two monolayers of the same weight on the 3D Web Linker®. A thermal consolidation process (160 °C) was applied to each Napco structure, and NapcoT structures were produced (Figure 3). The nonwoven Napco spacers were produced according to an experimental plan with 4 factors: the type of needles, the weight of the monolayers, the width of the spacers and the machine outlet. For each factor, 2 quantitative or qualitative levels were considered as follows: weights of 200 and 400 g/m²; spacers of 5 and 8 mm; outlets of 6.8 and 12.9 mm/stroke; fork- and tetra-type needles. A linear model with interactions and a full factorial design (2 levels) with 16 runs and 3 centre points was used. Nineteen nonwoven spacer fabrics type Napco (N1, ..., N19) were produced (Table 1).

In Figure 4 (see page 69) examples are shown of two samples produced with (a) tetra needles, spacer of 8 mm, (b) fork needles, spacer of 5 mm and (c) fork and tetra needles.

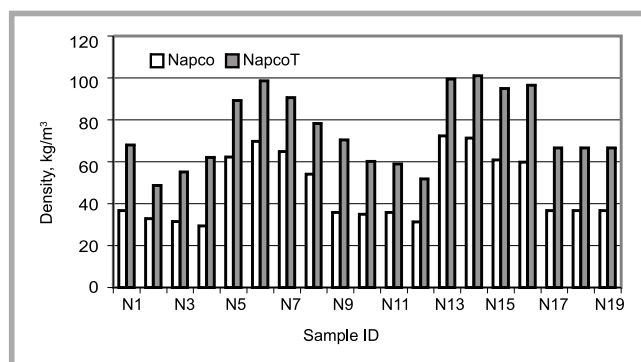
The influence of the input parameters and the thermal treatment on different physical and mechanical properties of the nonwoven spacer has been investigated. The following physical and mechanical properties have been considered as responses: weight (g/m²); thickness (mm); the ratio of machine direction (MD) and cross-direction (CD) breaking force and the MD:CD ratio of the elongation at break; thermal resistance *R*-value, m²·K/W and thermal conductivity *k*, W/(m·K); sound absorption properties (NAC and NRC).

### Results and discussions

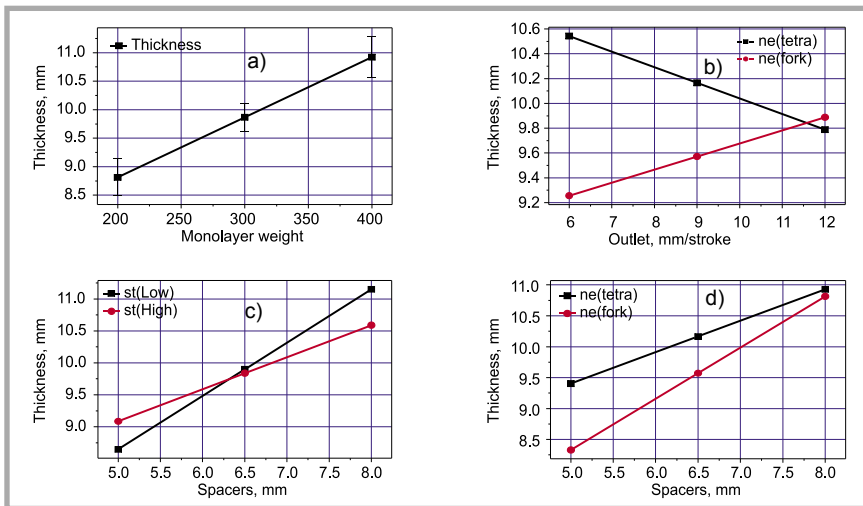
Using graphic software, models were created between the input parameters and a given response. The quality of a model is described by R2 (the fraction of the variation of the response explained by the model) and Q2 (the fraction of the variation of the response that can be predicted by the model). R2 is an overestimated measure and Q2 is an underestimated measure of how well the model fits. Generally values of R2 and Q2 close to 1 indicate an excellent model. In every case, the scaled and centred coefficients were plotted and compared, the default model was refitted, and only the factors with the main influence on a given response, as well as their interactions, were kept in the model. The model has a hierarchy, and a case appeared when a factor itself had no great influence on the response, but was involved in interactions with other factors and so was retained in the model. Every time it was checked if the residuals were normally distributed and the (non)existence of outliers was also verified. The unscaled coefficients were listed (with a confidence level of 0.95), and the regression equations were written in every case. The main influences of the factors, as well as the interactions between



**Figure 6.** Influence of the thermal treatment on the weight of the nonwoven spacer fabric.



**Figure 7.** Influence of thermal treatment on the density of the nonwoven spacer fabric.



**Figure 8.** Influence of the input parameters on the thickness of the nonwoven spacer fabric: a) monolayer weight; b) interaction outlet and needle type; c) interaction spacers and outlet; d) interaction spacer and needle type.

en factors on the selected responses, are discussed next.

### Weight of the two-layer Napco samples

The weight of the Napco samples was measured according to ISO 8543/6 (1998) and the average value of ten measurements was used in the model. The model was refined and those factors with no significant influence on weight were eliminated. A good model was found ( $R^2=0.96$  and  $Q^2=0.94$ ) with the weight of the monolayers ( $w_e$ ) having the greatest influence on the weight of the Napco structures; needles ( $n_e$ ) also had a lower effect. No other significant influences or interactions were noted. The main influences are given in Figure 5. As can be seen, a high-weight Napco product can be obtained using type 1 needles (tetra) and the maximum weight of the monolayers ( $400 \text{ g/m}^2$ ). The weight of the samples was also measured after thermo-consolidation. An increase in weight after the thermal treatment was noticed for all the samples (Figure 6). The lowest relative increase (9.1%) was noticed for sample N7 and the highest (35.33%) for N4. The increase of the samples' weight is explained by the increase of their density due to shrinkage during the thermal treatment, e.g. an increase with values between 37.42% (N13) and 110.92% (N4) (see Figure 7).

### Thickness of the two-layer Napco samples

The thickness of the samples was measured using the image analysis method, a Nikon Optiphot microscope and a

Lucia System for Image Processing and Analysis (version 4.51). A good model was found ( $R^2=0.94$ ,  $Q^2=0.82$ ) with the weight of the monolayer having the main influence on the thickness, followed by the spacers. The outlet ( $st$ ) does not have a great influence, but there are other significant interactions between the outlet and the type of needles ( $st*n_e$ ), spacers and needles ( $sp*n_e$ ) as well as outlet and spacers ( $st*sp$ ) (Figure 8) explanation of the designations see Table 1. A spacer with a high thickness can be achieved by starting from a high weight monolayer ( $400 \text{ g/m}^2$ ) and using maximum spacers (8 mm), a low outlet of the machine (6.8 mm/stroke) and tetra needles. After the thermal consolidation, a decrease in the thickness with values between 9% (N6) and 40% (N1) was noted for all the samples (Figure 9 - see page 72).

### Thermal properties

The insulation of a material is rated in terms of thermal resistance, called the  $R$ -value, which indicates the resistance to heat flow. The higher the  $R$ -value, the greater the insulating effectiveness.

$$R = \Delta t \cdot A \cdot P, \text{ m}^2\text{K/W}$$

where:

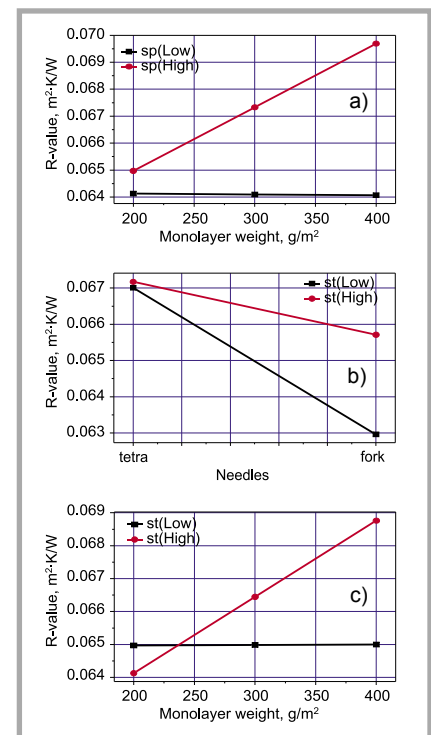
- $R$  –  $R$ -value,
- $\Delta t$  – temperature difference,
- $A$  – area,
- $P$  – time/heat loss.

The thermal resistance  $R$ -value ( $\text{m}^2\text{K/W}$ ) for the given samples was measured [21] using TECOSY, an apparatus with a guarded hot plate and one sample. Each sample was tested three times, according to the temperatures  $T_1$  and  $T_2$  of the

two plates: a)  $T_1 = 35 \text{ }^\circ\text{C}$ ,  $T_2 = 25 \text{ }^\circ\text{C}$ ; b)  $T_1 = 40 \text{ }^\circ\text{C}$ ,  $T_2 = 30 \text{ }^\circ\text{C}$ ; c)  $T_1 = 45 \text{ }^\circ\text{C}$ ,  $T_2 = 35 \text{ }^\circ\text{C}$  and the average of the three individual measurements has been calculated. This has been repeated for two different samples (for each of 19 experiments), the average was calculated and used in the model.

### Thermal resistance $R$ -value, $\text{m}^2\text{K/W}$

A model with many interactions and  $R^2=0.83$  and  $Q^2=0.48$  was found. The spacers have the greatest influence, followed by weight and the type of needles. The outlet  $st$  (mm/strokes) has a small influence, but there are significant interactions between the outlet and the weight of the monolayers ( $st*w_e$ ), needles and outlet ( $st*n_e$ ) as well as between the spacers and weight ( $sp*w_e$ ). The main influence and the interactions between the factors are given in Figure 10. Maximum thermal resistance can be obtained for maximum weight ( $400 \text{ g/m}^2$ ), maximum spacers (8 mm) and outlet (12.9 mm/stroke) and using tetra-type needles; the high weight and distance (filled with air) between layers may lead to a high  $R$ -value. No significant, unidirectional influence of the thermal treatment on thermal resistance could be noted (Figure 11): for some samples an in-



**Figure 10.** Influence of the input parameters on the  $R$ -value of the nonwoven spacer fabric: a) interaction monolayer weight and spacer; b) interaction needle and outlet; c) interaction spacers and outlet; d) interaction monolayer weight and outlet.

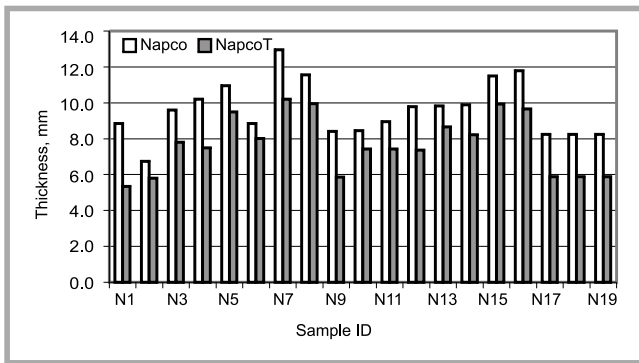


Figure 9. Influence of the thermal treatment on the thickness of the nonwoven spacer fabric.

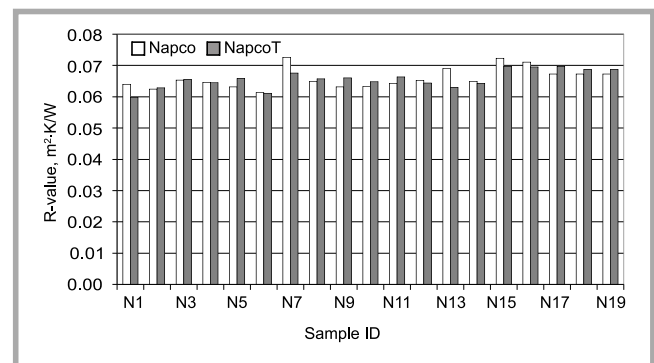


Figure 11. Influence of the thermal treatment on the R-value of the nonwovens spacer fabric.

crease (between 0.31% for N3 and 4.43% for N9) could be noted, and for others a decrease, the highest relative decrease being noted in experiment N7 (6.89%).

### Thermal conductivity coefficient $k$ , W/mK

The thermal conductivity coefficient  $k$  was calculated as  $k = d/R\text{-value}$ , W/mK, where  $d$  is the thickness of the samples in m and  $R\text{-value}$  is the thermal resistance,  $m^2K/W$ . Four large interactions were found (Figure 12): outlet / type of needles (a); monolayer weight / outlet (b); spacer / needles (c); spacers / outlet (d). A sample with a low thermal conductivity coefficient  $k$  can be obtained with low weight monolayers, minimum mm/strokes, minimum spacers and fork-type needles. A decrease in values between 3 (N13) and 35% (N1) of the thermal conductivity coefficient could be noted for all the experiments, after the thermal treatment (Figure 13); the thermal treatment favourably influences the thermal isolation capacity of all experiments.

### Tensile properties

The Statimat M tensile tester ISO 1421 [22] was used to test the elongation at break and breaking force of the samples, before and after the thermal treatment. The speed of the drawing frame head was 100 mm/min, and the specimen was 200 mm in length & 50 mm in width. The breaking force in N and elongation at break in % was measured in machine-(MD) and cross-direction (CD), and then the MD : CD ratio (both for breaking force and elongation at break) was calculated and used in the model.

The individual models for the nonwoven spacer were rather poor. No significant correlation was found between the input factors and elongation at break & breaking force, or between the input factors and the MD:CD ratio of breaking force or elongation at break. As Napco is a friendly needling process and the needle density is much lower than in a normal needle-punching process, the tensile properties of multi-layer products mostly

depend on the strength of the monolayer and not on the technological parameters of the bonding machine considered here. The clear influence of the thermal treatment was noted, however. In the case of the Napco samples, a breaking force ratio MD : CD < 1 (min. 0.37 and max. 0.86) was noted in all the cases, which means that the samples have a higher breaking force in cross-direction. The monolayers were produced via the cross-lapping operation, and they therefore have a higher breaking force in the cross-direction. This seems to have been maintained after the Napco process as well. After the thermal treatment, a breaking force ratio MD : CD between 0.47 and 1.17 was noted for the NapcoT samples, Figure 14. In all the cases, an increase in the MD : CD breaking force was noted after the thermal treatment with values between 5% and 160%. For all the samples, a more equilibrated MD : CD ratio (close to 1) was found after the thermal treatment.

In the case of elongation at break, a ratio MD:CD > 1 (min. 1.03 and max. 1.68) was noted in all the cases, which means that the Napco samples have a higher elongation in the machine direction. After the thermal treatment, an MD:CD elongation ratio with values between 0.7 and 1.49 was noted (Figure 15), and thus a decrease with values between 39% and 0%.

### Sound absorption properties

Investigations to determine the normal incidence sound absorption (NAC) of the given samples were conducted using the standing wave-tube method, ASTM C384 [23]. A single-tone plane wave travelling in one direction down a rigid tube is reflected by the test specimen to produce a standing wave. Measurement of this standing wave produces a normal absorption coefficient for the single tone. The measurements were done within the

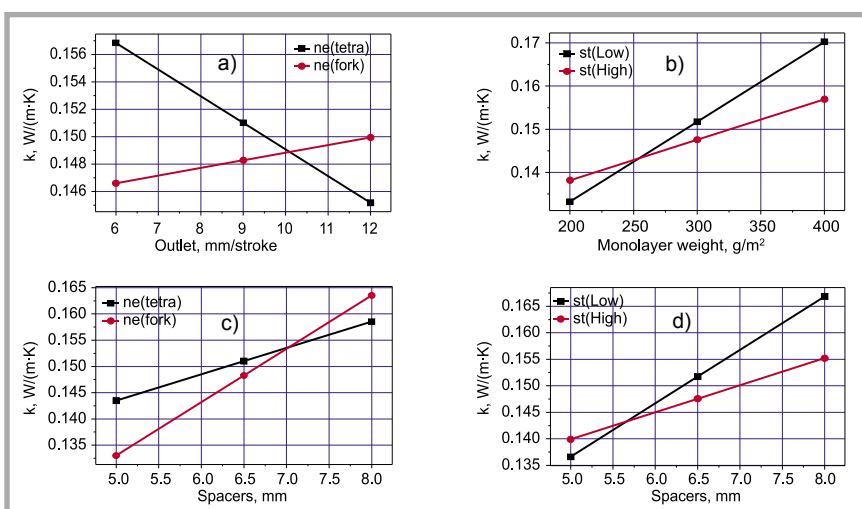


Figure 12. Influence of the input parameters on thermal conductivity of the nonwoven spacer fabric: a) outlet and needles; b) monolayer weight and outlet; c) spacer and needles; d) spacer and outlet.

range of 250-5000 Hz using a Bruel & Kjaer 2144 frequency analyser, a Bruel & Kjaer 4002 standing wave tube (a 10-cm diameter tube for the range of 250 Hz to 2000 Hz, a 3-cm diameter tube for the range of 2500 Hz to 5000 Hz), and a Bruel & Kjaer 1024 sine generator. To globally evaluate the sound absorption properties of the samples, the Noise Reduction Coefficient (NRC) was calculated. NRC represents the percentage of acoustic energy absorbed, calculated as an average of laboratory test data at the frequencies of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz adjusted to the nearest 0.05; this is only used to express the effectiveness of the materials tested.

No significant influence of the input parameters on the sound absorption coefficient NAC of the Napco samples was noted for the tested frequencies; the models were rather poor. After the thermal treatment, no significant modifications of the NRC of the tested samples could be noted (Figure 16). Nevertheless, there were variations in the NAC with the temperature for all the samples; globally, however, the samples showed the same NRC after thermal consolidation, with the exception of samples N1, N3 and N7. From the tech-

nological point of view, all three samples were produced with tetra needles and at the same outlet of 6.8 mm/stroke. In Figure 17 (see page 74), examples are given of NAC variation with frequency and temperature for two sets of samples: Napco 1 and Napco 2, both processed with monolayers of 200 g/m<sup>2</sup>, spacers of 5 mm and outlet of 6.8 mm/stroke but with different types of needles. Napco 15 and Napco 16 are processed with monolayers of 400 g/m<sup>2</sup>, spacers of 8 mm and an outlet of 12.9 mm/stroke, but with different types of needles.

### Conclusions

Nonwoven spacer fabrics can be produced on 3D Web Linker® if the length of the fibres, the quality of the monolayers and the technological parameters are correctly chosen and correlated. In order to allow the creation of fibre bridges, it is important that the monolayers contain sufficient unbounded fibres and sufficient long fibres (e.g. according to the size/width of the spacer). The fibres should be able to migrate from one monolayer to another, create fibre bridges and link the two monolayers.

- Some of the experimental problems (e.g. broken needles or uneven surface appearance) which occurred during processing suggest the need for a good correlation between the needle type, weight of the monolayers, outlet and the size of the spacers. For example, in the case of spacers of 8 mm, low weight monolayers of 200 g/m<sup>2</sup>, slow delivery of the material (outlet of 6.8 mm/stroke) and fork-type needles (sample ID N4), a decrease in the quality of the delivered material could be noted. In the case of dense, high-weight monolayers (400 g/m<sup>2</sup>) and slow delivery of the material (outlet 6.8 mm/stroke), some (fork) needles were broken (sample ID N8).
- Influence of the technological parameters (input factors):
  - A summary of the input parameters on the tested responses is given in Table 2 (see page 74). For each response the main influences are given, as well as the value of the factors that should be adopted to obtain the minimum (-) or maximum (+) value of that response. For example, in order to obtain a nonwoven spacer with a high weight, one should use tetra needles and maximum weight monolayers (400 g/m<sup>2</sup>). On the

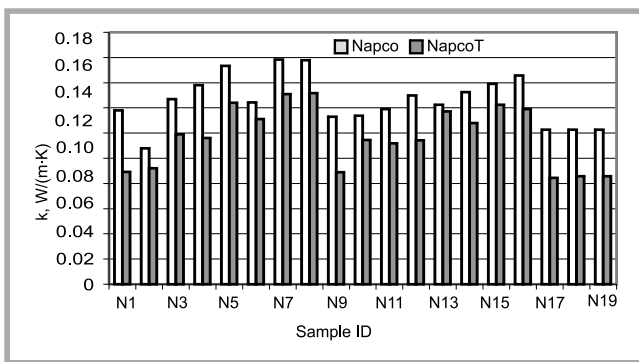


Figure 13. Influence of the thermal treatment on the thermal conductivity of the nonwoven spacer fabric.

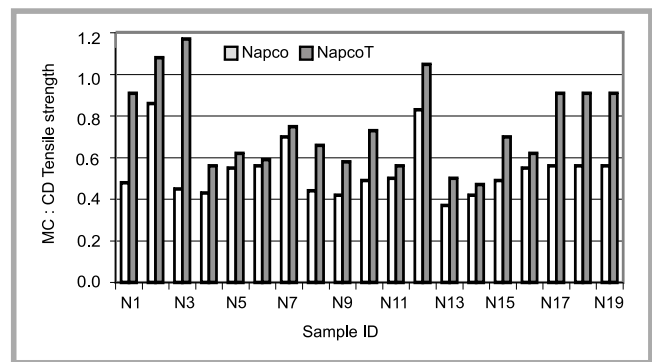


Figure 14. Influence of thermal treatment on MD:CD breaking force of the nonwoven spacer fabric.

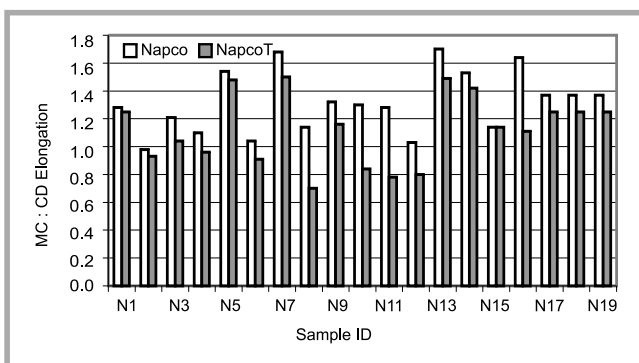


Figure 15. Influence of thermal treatment on MD:CD elongation at break of the nonwoven spacer fabric.

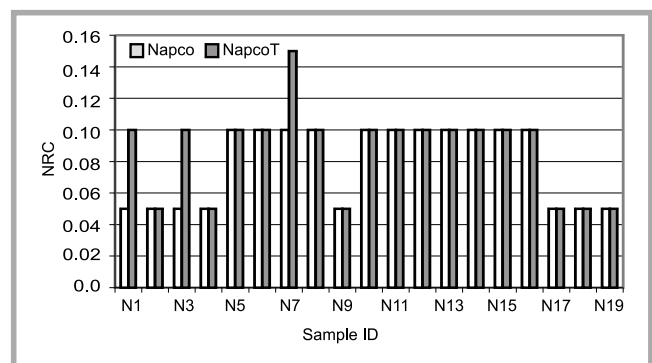


Figure 16. Influence of the thermal treatment on NRC.

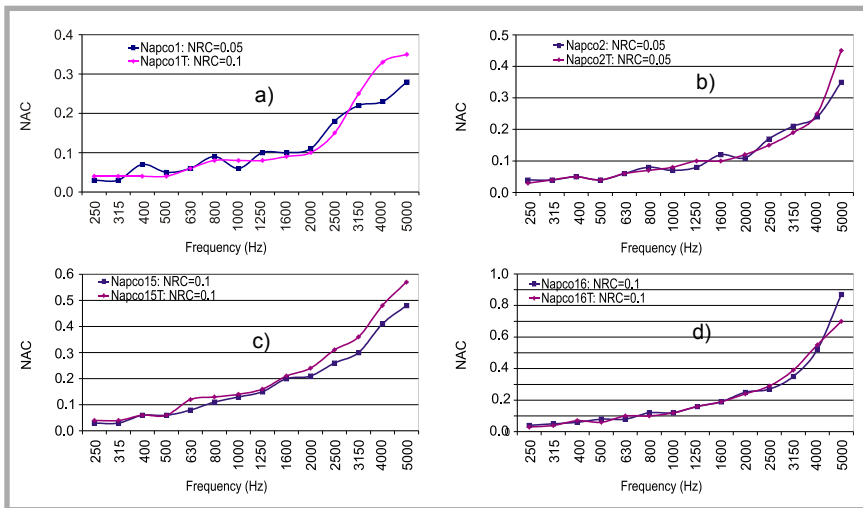


Figure 17. Influence of thermal treatment on NAC: a) sample N1; b) sample N2; c) sample N15; d) sample N16.

Table 2. Influence of the technological factors on the tested properties of the nonwovens spacer fabric.

	Factors					Remarks
	Needles type (ne)		Spacers (sp)	Weight of monolayer (we)	Outlet (st)	
	Tetra	Fork				
Weight, g/m <sup>2</sup>	+			+		For maximum weight: max. we; needles have low effect
Thickness, mm	+		+	+	-	For maximum thickness: max. we and sp, min. st
R-value, m <sup>2</sup> ·K/W	+		+	+	+	For maximum R-value: max. we, sp, st; many interactions
K, W/m·K	-		-	-	-	For minimum k: min. we, sp and st

other hand, a nonwoven spacer with a high *R*-value can be obtained with tetra needles, spacers of 8 mm, monolayers of 400 g/m<sup>2</sup> and an outlet of 6.8 mm/stroke.

- Rather low NACs were measured in almost all the samples at the tested frequencies. The open structure of the Napco products, with low thickness monolayers and an air gap in-between, does not lead to good sound absorption. No significant influence of the input parameters on the sound absorption coefficient of the samples was noted.
- Influence of the thermal treatment:
  - It was noted that the thermal treatment increases the weight, density and the MD : CD tensile strength of the samples, and decreases the thickness and MD : CD elongation. A slight increase in the *R*-value after the thermal treatment was noted for most of the samples.
  - In the case of the thermal conductivity coefficient *K*, W/(m·K), a decrease (with values between 3 and 35%) could be noted after the thermal treatment for all the exper-

iments. Thus the thermal treatment favourably influences the samples' thermal isolation capacity.

- An equal NRC (or slightly higher for some of the samples) has been noted after the thermal treatment.
- To summarise the influence of the thermal treatment on the selected properties, it can be said that the given fibrous mixture with 15% fusible fibres does not significantly improve the properties of the samples, but it might be possible that another (higher) ratio of regular/fusible fibres may have a greater influence on the samples' properties.

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