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# Effects of Layer Thickness and Thermal Bonding on Car Seat Cover Development

**Abstract**

*In this work, composite materials for car seat covers composed of woven fabric + polyurethane foam (PU) + knitted fabric were tested by separation of components of the composite force, which are thermally connected with three different process speeds (30, 34 and 39 m/min) and two thickness PU (2 mm and 4 mm). The thermal bonding of the components into a composite is leading to reduction in thickness and weight of the composite compared to the amount of components before the joining. The force separation decreased as the speed for all samples increased. The smaller thickness of PU had an effect on the larger separation forces of composite components as well as higher abrasion damage. The purpose of this work was to investigate the influence of the thermal bonding speed of the composite components, the effect of PU thickness on the separation force, and abrasion properties.*

**Key words:** *polyurethane foam, thermal bonding speed, woven fabric, knitted fabric, abrasion damage.*

## Introduction

Car seat covers are pretty significant in terms of the vehicle's equipment level and are one of the first parts of the car that a traveller encounters, visually and by touch. In daily life people spend more and more time in cars, thus car seat covers have become important in the comfort area. Prior to the invention of multi-layer composite material, textile and leather products were widely used as single-layer car seat covers, usually in the form of a pad filled with a filling material (feathers, wool, etc.), which have shown to be non-functional due to the low temperature stability. Nowadays composite materials are the most manufactured type of fabric in a group of technical fabrics for this type of application [1, 2].

Components in a composite are thermally fused under a specific temperature and flow rate of material which have a direct impact on the quality of connecting components (*Figure 1*). However, optimising the separation force and quality of bonding of the components depends on other technological conditions. Badly bonded components cannot be visually observed and cause poor composite quality during the end-use [3-7].

Composite fabrics with a polyurethane (PU) foam layer allow better longevity, greater comfort and less deformations in the folded areas. This composite retains the look and shape of the car seat cover without folds longer, especially if the components in the composite are thermally well-bonded. The raw material properties that are selected for the production of composite fabrics have an impact of the properties of the final composite. This means that the properties of composites are inherited from its components and can be changed by selecting components until a composite of the best properties for a given car seat cover is made [8-10]. Currently the properties of materials and composites often change in order to improve quality and produce more durable car seat covers. The outer layer of the composite is the dominant component, usually of woven fabric, and should have an appropriate aesthetic appearance and be reasonably priced. Polyurethane foam, which is in the mid composite layer placed between the woven fabric and knitted fabric, primarily provides comfort during sitting. Therefore it must have a certain elasticity and good adhesion to the woven and knitted fabric at the thermal joining, but at the same time have a certain transparency and porosity, as well as an adequate flexibility. Knitted fabric, as the inside layer, protects the polyurethane foam and improves material properties, such as the hardness, elasticity, high longevity and compactness of the material. The high quality thermal bonding of components (first PU + knitted fabric, and then PU and knitted fabric + woven fabric) requires that a component be bonded well, and that the composite remain elastic. An insufficient bonding temperature or greater speed during thermal bonding will not make PU stick well to woven or knitted fabric, which will result in the separation of components and thus poorer physical and mechanical properties of the composite, mutual displacement of components, tearing in the folded areas and poor appearance. Also higher temperatures or lower speed will allow better bonding of components, but they will also create more melting than PU, which will make a less elastic composite more so during the cooling process [11-18].

The main objective of the study was to determine specific design considerations of adhesive technology for a newly developed three-layer composite in order to achieve the best possible quality of composite material that could be used for the production of car seat fabrics. The aim was first to evaluate the influence of thermal bonding on composite properties and to find a bonding speed that provides the best physical and mechanical properties of the final product, second to investigate the influence of PU foams on the separation force, and finally to test abrasion properties in order to see if the composite meets performance requirements from the automotive sector.

## Materials and methods

### Test procedure

The design of the study guarantees that the results are repeatable with adjusted production conditions that were used for this study. All composite fabrics tested were developed by the Prevent Group from Bosnia and Herzegovina. Thermal bonding of components in a composite with three different bonding speeds (30, 34, 39 m/min) and two thicknesses PU (2 and 4 mm) were examined with respect to the physical and mechanical

properties of a semi-composite (PU + knitted fabric) as well as final composite (woven fabric + PU + knitted fabric) as well as to the impact properties of the components of the composite [19]. The test results are shown in *Figures 2-9* and *Tables 1-3*.

## Test materials

A three-layer composite was made by the Prevent Group from Bosnia and Herzegovina and consisted of an external fabric, middle fabric and inside layer:

- *Woven fabric (fabric outside):* 100% polyester (PES) multifilament, dobby weave, density of warp/weft: 29/20.5 (yarn/10 cm), fineness of warp/weft: 620 dtex f 144/f 167 48 × 3 dtex
- *Knitted fabric (inside layer):* 100% polyester (PES) multifilament, Locknit (Charmeuse), density of arrays/rows: 13/11 (cm), fineness of the yarn: 75-f 36 dtex.
- *Polyurethane foam – PU (mid fabric):* 2 mm and 4 mm were used to make the composites. Basic PU data are as follows: colour: white; weight per unit area (DIN 12127): 46.342 g/m²; maximum tensile strength (DIN 13934-1): parallel: 101.7 N, vertical: 105.8N; elongation at break (DIN 13934-1): parallel: 54.3%, vertical: 49.6%; static elongation 25N (DIN 53360): longitudinal: 56.98%, vertical: 99.21%; permanent elongation (DIN 53360): longitudinal: 6.85%, vertical: 36.85%; burning behaviour (DIN 75200, FMVSS 302): L:NBR, T:NBR, ≤ 100 mm/min; smell 80°C/2 h and smell 40°C/24 h (PV 3900): 3.

## Machines for weaving, knitting and bonding of composite components

- *Looms:* Rapier weaving machine, Dornier (Germany): width 220 cm
- *Knitting machines:* Terrot (Germany): S296-1, E28 30 ``.
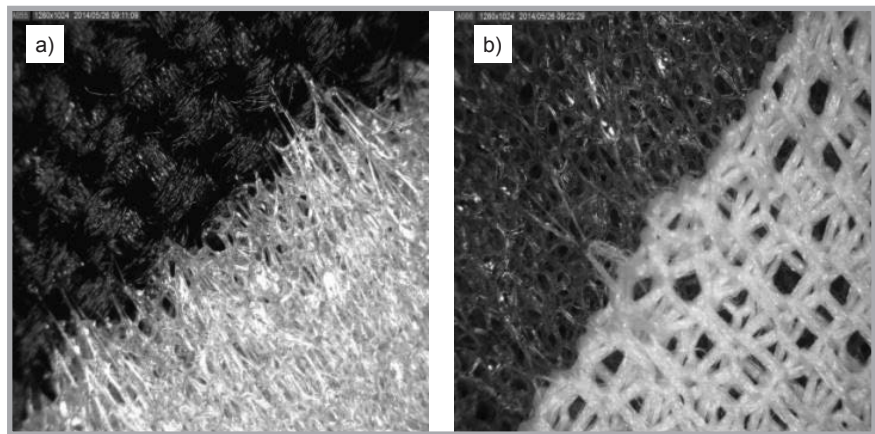- *Composite machinery with a gas flame:* Schmid, Model: 128/2200 (Germany)



**Figure 1.** *Separation of components: a) Woven fabric and PU, b) Knited fabric and PU.*
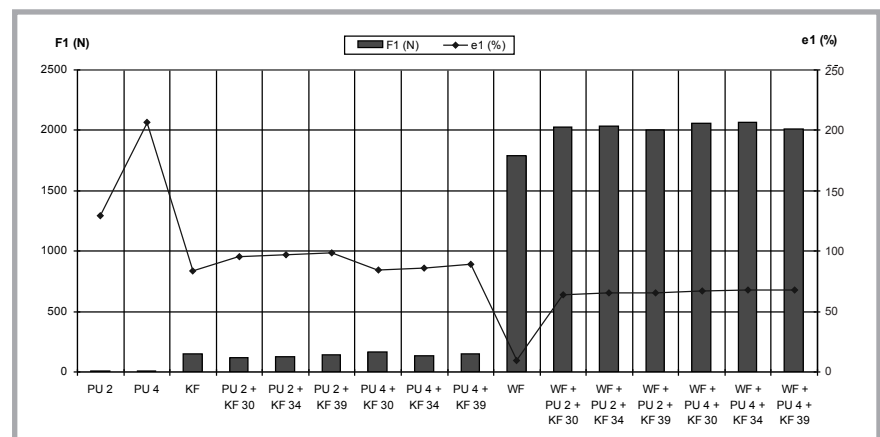


**Figure 2.** *Breaking force and elongation at break in the longitudinal direction.*
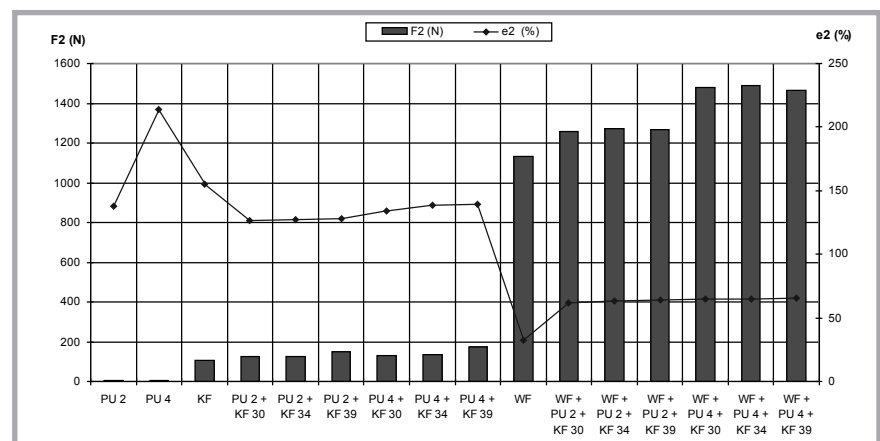


**Figure 3.** *Breaking force and elongation at break in the transversal direction.*

**Table 1.** *Weight and thickness of samples tested.*

| Samples | Weight, g/m² | | | Thickness, mm | | |
|---|---|---|---|---|---|---|
| | Values measured | Sum of components | The difference (reduction, %) | Values measured | Sum of components | The difference (reduction, %) |
| Woven fabric (WF) | 316.1 | – | – | 0.70 | – | – |
| Knitted fabric (KF) | 51.4 | – | – | 0.22 | – | – |
| Polyurethane foam (PU) 2 mm | 76.5 | – | – | 0.70 | – | – |
| Polyurethane foam (PU) 4 mm | 144 | – | – | 1.40 | – | – |
| PU 2 mm + KF | 124.5 | 127.9 | 2.73 | 0.88 | 0.92 | 4.55 |
| PU 4 mm + KF | 192.2 | 195.4 | 1.66 | 1.60 | 1.62 | 1.25 |
| WF + PU 2 mm + KF | 438.2 | 444 | 1.31 | 1.44 | 1.62 | 12.50 |
| WF + PU 4 mm + KF | 506.5 | 511.5 | 0.99 | 2.18 | 2.32 | 6.42 |

**Testing methods and devices**

Testing was conducted by using particular methods under strictly defined temperature and humidity of the material being tested. The moisture conditions were defined as 65 ± 2% and temperature 20 ± 2°C as standard atmosphere conditions for testing.

*Testing of samples:*
- Breaking force and elongation at break were performed on all samples in the longitudinal and transversal directions with a dynamometer – Pellizzato/Tinius Olsen type H5KS (USA), according to the DIN EN ISO 13934-1 standard.
- Testing the separation force of components with two thickness PU (semi-composite: knitted fabric + PU and composites: woven fabric + PU + knitted fabric) was conducted with a dynamometer – Pellizzato/Tinius Olsen type H5KS, according to the DIN 53 357 standard.

- The durability of the upholstery was tested according to the ASTM D 4966-98 Standard Test Method for Abrasion Resistance of Textile Fabrics – Martindale Abrasion Tester Method [20, 21]. The weight for upholstery required was 12 kPa. The abrasion resistance was tested based on the two PU foam thickness. The samples were first ckecked after every 3000 cycles, then after 4000 and finaly after 5000 cycles till the number of abrasion cycles reached 100000 cycles.

## ■ Results

The weight and thickness of each sample with different bonding process speeds was measured, the values of which are shown in *Table 1*. By bonding components into a composite, the weight and thickness of the composite were reduced. The weight of the composite is less than the sum of the components' weight be-

fore bonding, the difference of which is more evident with a low PU thickness (PU reduction of 2 mm to 1.31%, PU 4 mm to 0.99%). Also the thickness of the composite was reduced by thermal bounding of the components (PU 2 mm to 12.50%, PU 4 mm to 6.42%).

The breaking force of the components (woven fabric, knitted fabric and PU), semi-composite (knitted fabric + PU) and composites (woven fabric + PU + knitted fabric) are shown in *Table 2* and *Figures 2-4*. The breaking forces of the semi-composite and composites were changed by changing the speed of thermal bonding. First the thermal joining of knitted fabric with PU of 2 mm in the semi-composite led to a decrease in the breaking force in the longitudinal direction from 12.14% at a speed of 39 m/min to 27.98% at a speed of 30 m/min, while in the transversal direction the breaking force increased from 11.98% at a speed of 30 m/min

*Table 2. Breaking force, elongation at break and hardness of samples . Note: KF: knitted fabric; WF: woven fabric; 30, 34, 39: speed 30, 34, 39 (m/min), F – breaking force (N), I – elongation at break (%), σ – hardness (F/mm²), X – arithmetic mean (N), CV – coefficient of variation (%).*

| | | Longitudinal direction (L) | | | | Transversal direction (T) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F, N | Force difference, % | I, % | σ, F/mm² | F, N | Force difference, % | I, % | σ, F/mm² |
| WF | $\overline{X}$ | 1786.67 | | 9.5 | 51.05 | 1133.33 | | 32.33 | 32.23 |
| | CV | 6.14 | | 5.19 | 5.81 | 6.24 | | 0.89 | 6.22 |
| KF | $\overline{X}$ | 146.67 | | 83.33 | 13.33 | 106 | | 155 | 9.64 |
| | CV | 11.97 | | 3.47 | 10.22 | 6.12 | | 8.54 | 5.54 |
| PU 2 mm | $\overline{X}$ | 4.35 | | 129.04 | 0.12 | 4.31 | | 137.99 | 0.12 |
| | CV | 0.06 | | 0.14 | 0.01 | 0.02 | | 0.04 | 0.06 |
| PU 4 mm | $\overline{X}$ | 9.09 | | 206.79 | 0.13 | 6.67 | | 213.68 | 0.09 |
| | CV | 0.02 | | 0.03 | 0.10 | 0.74 | | 0.03 | 0.02 |
| PU 2 mm + KF (30 m/min) | $\overline{X}$ | 118 | -27.98 | 95.67 | 2.68 | 125.33 | +11.98 | 126.67 | 2.85 |
| | CV | 5.56 | 5.11 | 6.03 | 4.58 | 9.54 | 7.98 | 6.91 | 7.06 |
| PU 2 mm + KF (34 m/min) | $\overline{X}$ | 127.67 | -18.29 | 97 | 2.90 | 127 | +13.14 | 127.33 | 2.89 |
| | CV | 2.39 | 4.18 | 1.78 | 3.81 | 4.79 | 3.70 | 3.17 | 3.58 |
| PU 2 mm + KF (39 m/min) | $\overline{X}$ | 134.67 | -12.14 | 98.33 | 3.29 | 147.67 | +25.30 | 127.88 | 3.36 |
| | CV | 7.62 | 6.55 | 2.94 | 7.33 | 6.52 | 6.48 | 2.72 | 7.44 |
| PU 4 mm + KF (30 m/min) | $\overline{X}$ | 153.33 | -1.56 | 84.33 | 2.04 | 130 | +13.33 | 134 | 1.63 |
| | CV | 3.69 | 3.89 | 2.21 | 2.54 | 7.69 | 6.66 | 1.97 | 6.77 |
| PU 4 mm + KF (34 m/min) | $\overline{X}$ | 153 | -1.77 | 85.67 | 1.66 | 137.33 | +17.96 | 138.67 | 1.72 |
| | CV | 5.68 | 5.10 | 0.67 | 4.77 | 9.67 | 8.90 | 1.67 | 5.77 |
| PU 4 mm + KF (39 m/min) | $\overline{X}$ | 148.33 | -5.01 | 89.33 | 1.85 | 175 | +35.62 | 138.33 | 2.19 |
| | CV | 12.87 | 10.44 | 5.52 | 6.88 | 5.96 | 5.52 | 4.17 | 4.78 |
| WF + PU 2 mm + KF (30 m/min) | $\overline{X}$ | 2030 | +4.55 | 63.67 | 28.19 | 1256 | +0.98 | 62 | 17.44 |
| | CV | 2.55 | 3.10 | 0.79 | 3.01 | 7.99 | 7.87 | 3.07 | 6.99 |
| WF + PU 2 mm + KF (34 m/min) | $\overline{X}$ | 2036 | +4.83 | 65.5 | 28.28 | 1270 | +2.08 | 63.5 | 17.64 |
| | CV | 1.22 | 2.01 | 0.89 | 4.22 | 2.72 | 3.57 | 9.5 | 3.77 |
| WF + PU 2 mm + KF (39 m/min) | $\overline{X}$ | 2007 | +3.45 | 65.67 | 27.87 | 1268 | +1.92 | 63.9 | 17.61 |
| | CV | 2.04 | 2.35 | 2.07 | 3.20 | 3.97 | 3.50 | 14.15 | 3.79 |
| WF + PU 4 mm + KF (30 m/min) | $\overline{X}$ | 2060 | +5.71 | 67.11 | 18.90 | 1480 | +15.81 | 64.66 | 13.58 |
| | CV | 0.97 | 1.48 | 0.76 | 3.41 | 3.57 | 3.44 | 5.23 | 3.27 |
| WF + PU 4 mm + KF (34 m/min) | $\overline{X}$ | 2063 | +5.84 | 67.5 | 18.93 | 1487 | +16.21 | 64.67 | 13.64 |
| | CV | 2.1 | 2.11 | 0 | 3.22 | 5.39 | 5.01 | 3.75 | 4.20 |
| WF+ PU 4 mm + KF (39 m/min) | $\overline{X}$ | 2011 | +3.41 | 67.84 | 18.45 | 1465 | +14.95 | 65.17 | 13.44 |
| | CV | 2.72 | 2.98 | 4.38 | 6.59 | 0.7 | 2.44 | 2.18 | 3.77 |

to 25.30% at a speed of 39 m/min. Thermal bonding of knitted fabric and PU of 4 mm caused an decrease in the breaking force in the longitudinal direction from 1.77% at a speed of 34 m/min to 5.01% at the speed of 39 m/min, which is significantly less than with thinner PU. The breaking force increased significantly in the transversal direction compared to the thinner polyurethane, from 13.33% at a speed of 30 m/min to 35.62% at a speed of 39 m/min.

The separation forces of components in the composite are shown in **Table 3** and **Figures 5-9**. The results show differences depending on various thermal bonding speeds as well as the directions of testing.

The separation force of knitted fabric in the composite and PU of 2 mm is from 6.45 N (speed at 39 m/min) to 8.69 N (speed at 30 m/min) in the longitudinal direction, and 6.21 N (at a speed of 39 m/min) to 8.59 N (at a speed of 30 m/min) in the transversal direction. The forces of separating knitted fabric from PU of 2 mm and woven fabric in the longitudinal direction were from 6.48 N (speed at 39 m/min) to 7.94 N (speed – 30 m/min), while in the transversal direction they were from 6.70 N (at a speed of 39 m/min) to 8.37 N (at a speed of 30 m/min). Composites with thicker PU do not show any significant difference in the forces of separation, varying from 6.03 N (speed – 34 m/min) to 8.11 N (speed – 30 m/min) in the longitudinal direction and from 6.24 N (speed – 39 m/min) to 8.62 N (speed – 30 m/min) in the transversal direction. The force of separating knitted fabric from 4 mm PU and woven fabric in the longitudinal direction is from 5.83 N (speed – 39 m/min) to 8.5 N (at a speed of 30 m/min), and in the transversal direction it is from 5.94 N (at a speed of 39 m/min) to 8.67 N (at a speed of 30 m/min).

The correlation coefficient between the longitudinal and transversal forces of separation is very high, ranging from $r = 0.9487$ (force separation of knitted fabric, 2 mm PU and woven fabric) to $r = 0.9934$ (force separation of knitted fabric, 4 mm PU and woven fabric). A higher correlation coefficient between the longitudinal and transversal directions of the separation forces pertains to a thicker PU.

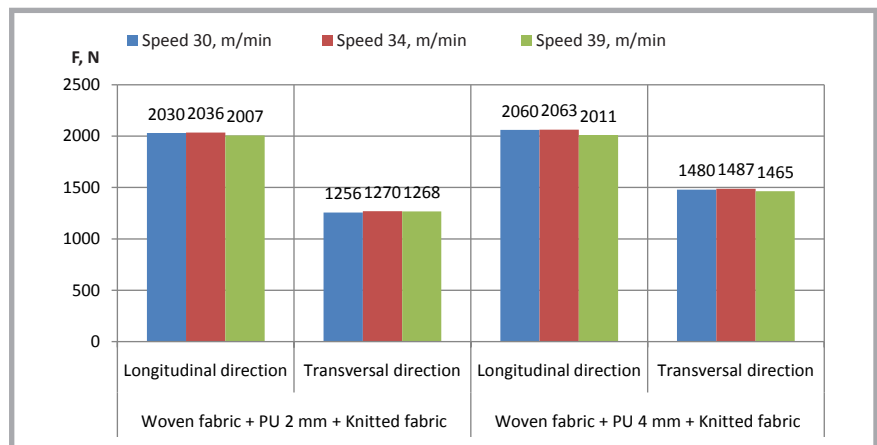Abrasion damage is presented as the percentge of mass loss of the abraded composite fabrics on the outside layer.



*Figure 4. Breaking force of the composites (WF + PU + KF) in the longitudinal and transversal directions at three bonding speeds.*
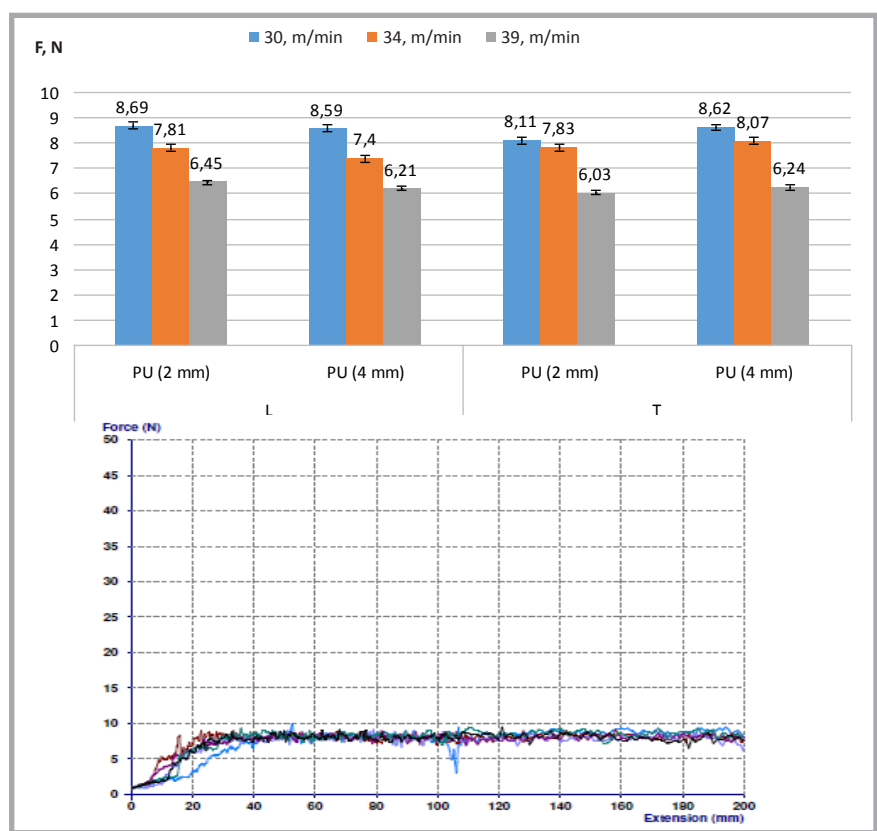


*Figure 5. Separation forces of woven fabric from PU and knitted fabric. F: separation force (N).*
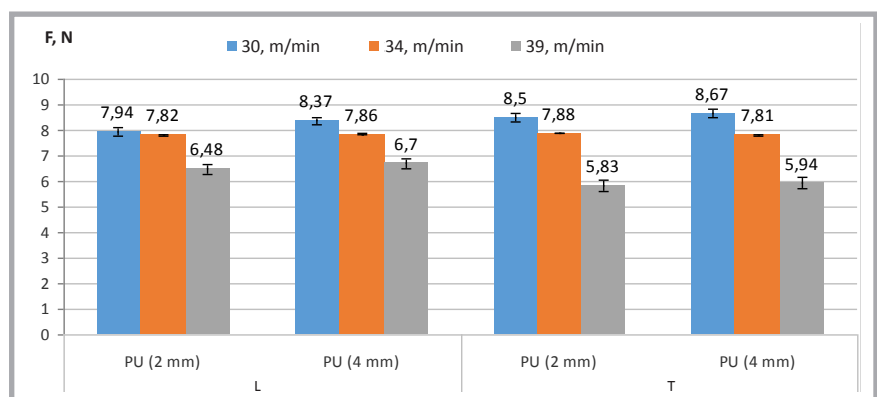


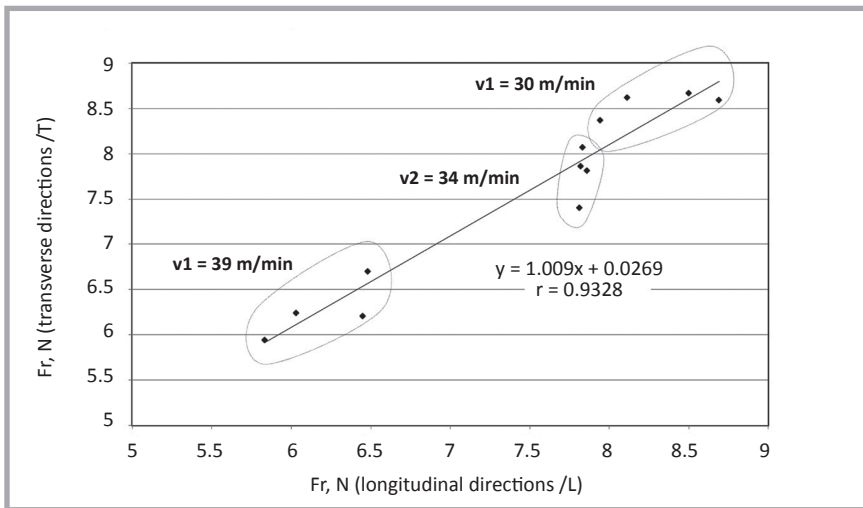*Figure 6. Separation forces of knitted fabric from PU and woven fabric.*

**Figure 7.** *Correlation coefficient between the forces of separation patterns of longitudinal and transversal directions*

**Table 3.** *Separation forces of components through the thickness of PU and speed bonding.* **Note:** *$r_1$: the coefficient of correlation of the force separation of woven fabric from PU and knitted fabric between the longitudinal and transversal directions, $r_2$: the coefficient of correlation of forces separating knitted fabric from PU and woven fabric between the longitudinal and transversal directions, $r_3$: the coefficient of correlation of forces separating samples with 2 mm PU/PU 4 mm thickness between the longitudinal and transversal directions, $r_4$: correlation coefficient of the separation force between the sample longitudinal (L) and transversal (T) directions.*

| Testing parameters | | | PU thickness 2 mm | | PU thickness 4 mm | |
|---|---|---|---|---|---|---|
| | | | L | T | L | T |
| Speed 30, m/min | Separation of woven fabric from PU and knitted fabric | $\overline{X}$, N | 8.69 | 8.59 | 8.11 | 8.62 |
| | | CV, % | 5.19 | 6.05 | 13.9 | 10.32 |
| Speed 34, m/min | | $\overline{X}$, N | 7.81 | 7.40 | 7.83 | 8.07 |
| | | CV, % | 10.51 | 7.81 | 8.56 | 11.95 |
| Speed 39, m/min | | $\overline{X}$, N | 6.45 | 6.21 | 6.03 | 6.24 |
| | | CV, % | 7.29 | 6.21 | 4.66 | 5.61 |
| | | $r_1$ | 0.9849 | | 0.9904 | |
| Speed 30, m/min | Separation of knitted fabric from PU and woven fabric | $\overline{X}$, N | 7.94 | 8.37 | 8.50 | 8.67 |
| | | CV, % | 6.55 | 7.17 | 4.24 | 3.22 |
| Speed 34, m/min | | $\overline{X}$, N | 7.82 | 7.86 | 7.88 | 7.81 |
| | | CV, % | 5.63 | 14.84 | 5.85 | 3.77 |
| Speed 39, m/min | | $\overline{X}$, N | 6.48 | 6.70 | 5.83 | 5.94 |
| | | CV, % | 5.93 | 5.3 | 4.12 | 4.04 |
| | | $r_2$ | 0.9487 | | 0.9934 | |
| | | $r_3$ | 0.8929 | | 0.977 | |
| | | $r_4$ | L : T = 0.9328 | | | |



**Figure 8.** *Breaking force (F) of composite and separation force (Fr) of woven fabric with PU 2 mm.*
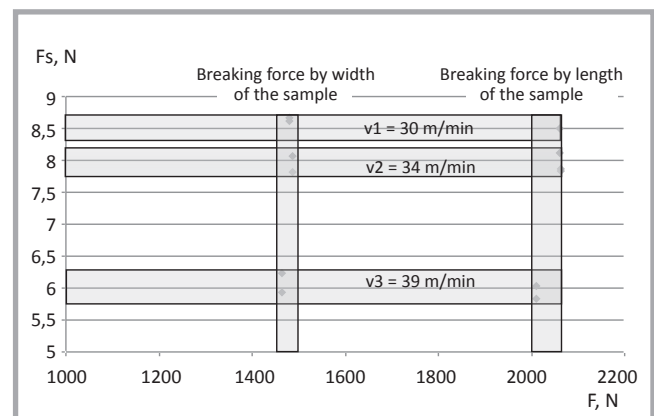


**Figure 9.** *Breaking force (F) of composite and separation force (Fr) of woven fabric with PU 4 mm.*

Samples were weighted (in grams) at the initial stage and after a certain number of cycles (see **Figure 10**). The mass loss values in % were determined as:

$$Mass\ loss = \left( \frac{Mass_{initial} - Mass_{certain\ cycle}}{Mass_{initial}} \right) * 100 \quad (1)$$

The results showed that the composite fabric with thicker PU foam (PU 4 mm) had a lower effect on mass loss (1.49%) when compared with the composite fabric with thinner (PU 2 mm) PU foam (2.28%).

■ **Discussion**

The thermal bonding of the components affects the weight reduction (0.99% to 1.31%) and composite thickness (6.42% to 12.5%), especially in low thickness PU.

By comparing the breaking force of the final composite and breaking forces of composite components prior to thermal bonding, it can be observed that the breaking forces increased in both the longitudinal and transversal direction. Thermal bonding between the composite and PU of 2 mm in the longitudinal direction caused an increase in breaking forces from 3.45% at a speed of 39 m/min to 4.83% at a speed of 34 m/min, which is not a huge difference between the speeds. The transversal direction of the same composite shows an increase in breaking forces from 0.98% at a speed of 30 m/min to 2.08% at a speed of 34 m/min.

The elongation at break increased with an increase in the thermal bonding speed, which can be explained by the fact that the greater speed of bonding caused a lower amount of PU melt, less stiffness of the material, and therefore high-
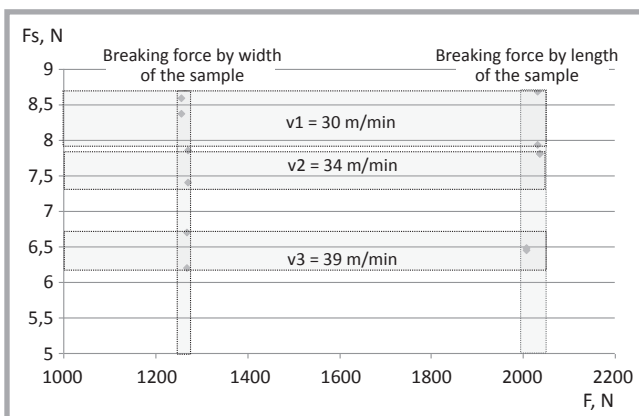
er elongation as well. Semi-composites (knitted fabric + PU) have higher elongation at break than the final composite (knitted fabric + PU + woven fabric), which difference is especially apparent in transversal directions. These results are logical because knitted fabric is more elastic and flexible than fabric. Material exertion during thermal bonding in the transversal direction decreased, which later influenced higher elongation.

The lowest separation force was measured for the component heat welded at 39 m/min, while the highest values of separation force were measured at 30 m/min.

The correlation coefficient between the forces of separation of the longitudinal and transversal directions with respect to the thickness of the PU is also very high and amounts to 2 mm PU r = 0.8929, the composite with PU 4 has r = 0.977 mm, and with the inclusion in all samples (L:T) r = 0.9328.

The abrasion resistance of the composite was determined for the outer layer. According to the low average mass loss values (1.49% – 2.28%), the composite fabrics have high abrasion resistance properties. The mass loss of the composite fabric made from thinner PU foam (2 mm) at 100000 abrasion cycles showed a greater mass loss when compared to the composite made from thicker foam (4 mm).

## ■ Conclusions

Car seats are the prime interface in the car interior and should last the life of the vehicle. Our research tested the best possible combination of components for a newly designed composite in order to get the best possible mechanical properties. The experimental results gave evidence that the composites have a lower weight and thickness when compared to the thickness and weight of the three components that were used in the thermal bonding process. This indicates that during surface PU melting, the woven fabric and knitted fabric, merged in the resulting melt and thus formed a good bond. During the thermal bonding process, the longitudinal tension of woven fabric, knitted fabric and PU affects the elongation and specific deformation of composites.

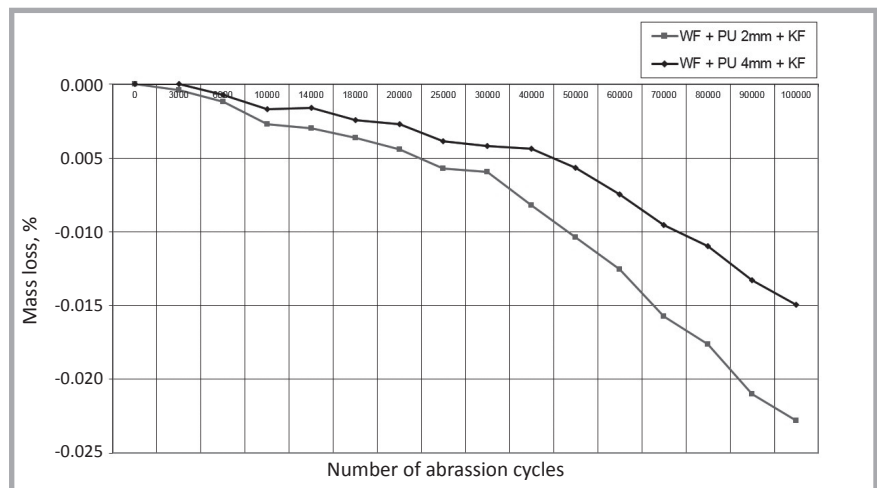Our results provide evidence that the greater thickness of PU had an impact on the increase in the breaking forces of



**Figure 10.** *Effect of abrasion treatment on mass loss values for two composite fabrics with different PU thickness.*

composites, especially in the transversal direction.

By analysing the results of breaking forces of the final composite in comparison with the sum of breaking forces of all components before thermal bonding, it was observed that the breaking forces of the composites in the longitudinal and transversal directions at all speeds of thermal coupling with both thickness of PU were increased.

The separation force of PU and knitted fabric is greater than that of knitted fabric from PU in all samples in both directions and for both thicknesses. Smaller PU thickness and a lower thermal bonding speed cause stronger separation forces.

According to the results obtained, it can be concluded that the tearing force increases with speed bonding reduction.

The correlation coefficient between the longitudinal and transversal forces of separation is very high per sample, as they are when all samples are included.

The composite fabrics tested showed high abrasion properties, thus they meet strict the performance requirements of car upholstery. The values of abrasion damage in terms of mass loss are higher when the composite fabric is made with a thinner PU foam.

In this study we tried to find what would be the optimal speed for bonding components in order to achieve a high quality and high-strength composite material for seat production.

This research examined the influence of the thermal bonding speed of individual components in a composite (woven fabric, PU and knitted fabric) on the properties of the final composite, and presented the correlation between parameters in the longitudinal and lateral directions of the composite.

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**The Scientific Department of Unconventional Technologies and Textiles** specialises in interdisciplinary research on innovative techniques, functional textiles and textile composites including nanotechnologies and surface modification.

Research are performed on modern apparatus, *inter alia*:

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- Thermogravimetric analyser TG 209 F1 Libra, Netzsch with FT-IR gas cuvette
- Sigma 701 tensiometer, KSV
- Automatic drop shape analyser DSA 100, Krüss
- PGX goniometer, Fibro Systems
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