Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Acoustical Parameters of Automotive Interiors using Hybrid Fleeces basing on natural fibres

Christian R. Koenig, Dieter Müller and K.-D. Thoben

University of Bremen, Badgasteiner Str. 1, FZB - Room 2140, 28359 Bremen, Germany
chkoenig@uni-bremen.de

Hybrid fleeces are often used to produce composites and layered structures for car interiors. The fleeces consist of reinforcement fibres and polymeric fibres as matrix material. The utilization of natural fibres as a reinforcement for composite may be regarded as an emerging research area in polymer science. An important range of application can be found in the automotive industry. Despite of ecological gains like less environmental impact of the later product within the formation, usage and disposal period further technical and economical advantages result from this strategy. In addition to a reduction of the component's cost and net weight or an improvement of driving safety due to the crash behaviour of the composite material, natural fibre reinforced polymers offer increased recycling capabilities over conventional polymers used in that area. The presentation concentrates on the possibilities by using different materials, different ratios of thermoplastic and natural fibre material and different process parameters. Layers are especially investigated to demonstrate how the fleeces and the techniques to bond the fleeces can influence the acoustical behaviour and mechanical properties. Based on the results of the measurements optimised, multi-layered sandwiches were developed and will be presented.

1 Introduction

The utilization of natural fibers as a reinforcement for composite materials basing on thermoplastic polymers may be regarded as an emerging research area in polymer science. One of their most important field of application can be found in the automotive industry. Despite of ecological gains like less environmental impact of the later product within the formation, usage and disposal period further technical and economical advantages result from this strategy. In addition to a reduction of the component's cost and weight or an improvement of driving safety due to the crash behavior of the composite material, natural fiber reinforced polymers offer increased recycling capabilities over conventional polymers used in that area. Natural plant fibers are incorporated into door trim panels, package trays, trunk trims and other interior parts.

At present time, almost all European automotive producers employ interior parts reinforced by natural plant fibers. Fig. 1 shows the growth in the utilization of natural fiber in the automotive industry for Germany. It is evident that Flax, Hemp and Kenaf are the most applied types of fibers. Particularly in the automotive

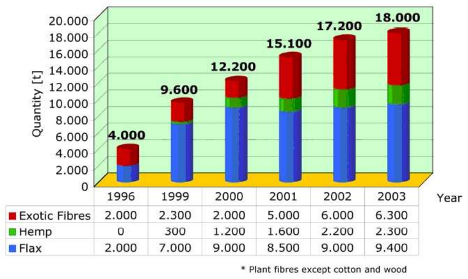

Figure 1: Usage of plant fibers for composite materials in Germany [1]

industry and with respect to driving comfort the acoustical properties of structural parts are considered to be increasingly important. In this context composites and layered compounds basing on natural fibers integrated in a thermoplastic polymer may represent a suitable alternative for a lot of applications. However, both the general compounding of the material and the processing to structural parts have a strong impact on the acoustical features as well as on the mechanical potential of such composite materials.

2 Manufacturing technologies for natural fiber thermoplastic composites

The manufacture of thermoplastic structural parts reinforced by natural fibers in current industrial scales is mainly achieved by compression molding of textile nonwovens.

The required semi-products are produced in a textile carding process with subsequent mechanical needling. Such hybrid fleeces can be described by a maximum of homogeneity and easy handling. However, the limiting factor of this proceeding is the restricted formability of such semi-products, limiting the achievable geometrical complexity of the later structural parts. The generation of highly complex parts would require alternative processing technologies such as injection molding or impact extrusion which are not available for a reinforcement with natural fibers in larger scales yet. This situation is mainly caused by the fundamental difference between synthetic and natural fibers. While synthetic fibers are available as endless filament yarns, natural fibers by nature have a limited structure. Therefore, to enable a transfer of polymer processing technologies established for composites with a reinforcement of synthetic fibers, the provision of a thermoplastic granular material with either a short or long natural fiber reinforcement or even roving of natural fibers would be required.

Furthermore, experimental investigations in laboratory scales found a distinctive fiber shortening for injection molding and extrusion processes with natural fiber reinforced thermoplastics. Resulting from that is a significant decrease of mechanical properties, limiting the application possibilities of the later product (Fig. 2). The manufacture of structural parts by compression molding can be subdivided into two different main process steps, the production of a semi-product and the molding process itself. The generation of semi-products can primarily be assigned to textile processes. At first, polymeric and natural fibers are blended to ensure a homogenous compounding. Following, this fiber blend transfers a carding process to generate a fibrous web or felt. Applying mechanical carding technology results in oriented fleece properties with higher strength in machine direction whereas aerodynamic carding generates semi-products with homogenous properties. Subsequent bonding usually is carried out by mechanical needling. Fol-

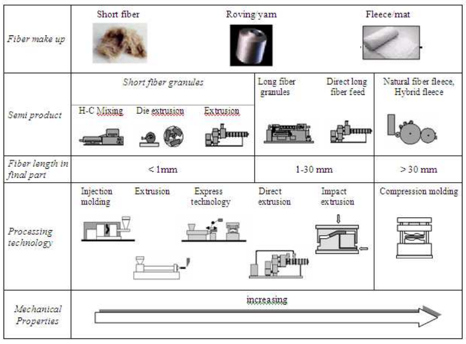

Figure 2: Processing technologies for natural fiber reinforced composite materials [2, modified and extended illustration]

lowing, the semi-product traverses a thermal compression molding process in which the thermoplastic polymeric component is molten and embeds the natural fibers when cooling down.

3 Materials and Methods

3.1 Applied materials

The subsequently described investigations were carried out employing composites with polypropylene as thermoplastic binder. Due to its favorable processing and flow properties it can be regarded as state of the art in natural fiber composite applications. For reinforcement the following types of natural fibers were applied:

- Flax tow (retted and cut, Source: AGRO-Dienst GmbH, 2001)
- Hemp R1 (retting degree 1, slightly retted, cut, Source: AGRO-Dienst GmbH, 2001)
- Hemp R4 (retting degree 4, strongly retted, cut, Source: AGRO-Dienst GmbH, 2001)

The raw components were processed to hybrid fleeces with variations in mechanical consolidation (needling density range: 10 to 200 $\frac{E}{cm^2}$), blending ratio (natural fiber- binder fiber 30/70 to 70/30). Furthermore, a commercial type of hybrid fleece with a blending ratio of natural fiber/polymeric fiber 60/40 was employed, displaying a share of the natural fiber compound as followed: Flax 50

3.2 Generation of composites

The generation of composite samples followed the process cycle shown in Fig. 3 and took place within two steps. In the first step the semi-product was heated up to plasticize the thermoplastic binder. Following in the second step, the heated and plasticized semi-product was consolidated in a cooling process to generate a composite sample.

3.3 Generation of layered composites

Sandwich composites were built up as follows:

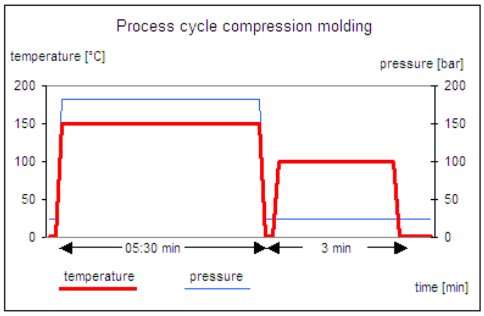

Figure 3: Process cycle for generation of composites

- Surface layers, Flax/PP 70/30, thermal compressed to a thickness of 2,5mm
- Center layer, Flax/PP 30/70, non-compressed.

3.4 Mechanical investigations

Referring to their mechanical properties the composites were characterized by their bending strength, tensile strength and impact strength. Tests were carried out in accordance with German DIN EN 63 for bending tests, DIN/EN ISO 527-4 for tensile tests and ISO 179 for impact tests.

3.5 Acoustical investigations

Two different means of measurement were applied to investigate the absorbance characteristics of the materials. Absorption coefficients can be determined by impedance tubes and a so-called Alpha cabin. The impedance tube primarily measures material properties by perpendicular sound while the Alpha cabins determines geometrical and surface influences by applying a diffuse sound field.

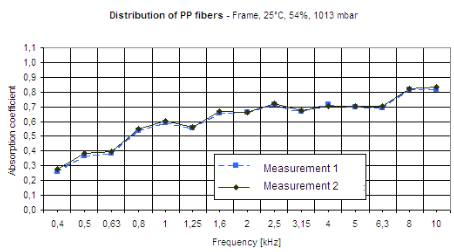

Figure 4: Reproducibility of measurements

4 Results and discussion

During the arrangement of the investigations, previous interest focused on a deeper understanding of the general acoustical behavior of the materials. Extensive measurements were carried out to acquire the reproducibility of acoustical measurements. Analyzing unconsolidated distributions of fiber material and hybrid fleeces with different levels of needling was also used to determine and design multi-layered composites.

4.1 Reproducibility of measurements

To determine the reliability of absorption measurements, Fig. 4 shows an example of an unconsolidated distribution of PP fibers in the Alpha-cabin. After finishing a single measurement the fiber distribution was completely removed from the measuring device so that every measurement represents a unique distribution of fibers. However, the results reveal a very good correspondence between the single measurements.

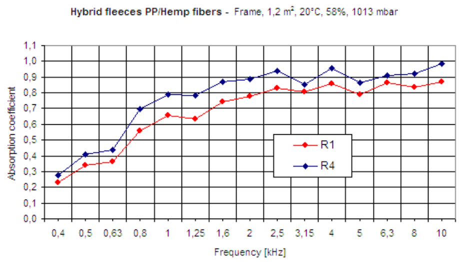

Figure 5: Influence of the retting degree on absorption for hybrid fleeces

4.2 Influence of retting degree of hemp fibers on absorption

The influence of fiber retting on the acoustical properties was investigated by extensive series of measurements using fiber distributions, hybrid fleeces and composites. Fig. 5 shows the results for hybrid fleeces. With reference to Muessig [3], the duration and type of retting has a strong influence on the fiber properties. Therefore, a strong influence on the absorption properties can be expected as well. Fig. 7 testifies this assumption. A higher retting degree leads to lower absorption properties of the hybrid fleece as increased retting results in a smoothed fiber surface and higher fineness. The results agree with investigations of Watanabe, who found higher absorption coefficients by an increasing fineness of PP fibers.

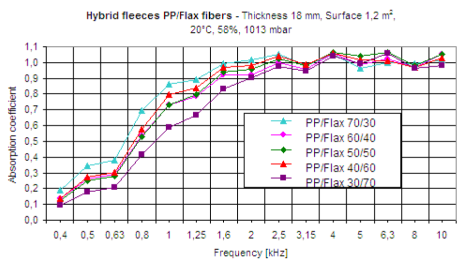

Figure 6: Absorption coefficients of Flax/PP hybrid fleeces

4.3 Influence of blending ratio of binder and polymer fibers

The influence of different blending ratios was determined by varying the contents of natural fibers in hybrid fleeces and compressed composites. Fig. 6 shows the absorption for hybrid fleeces made of flax and PP fibers. Fig. 7

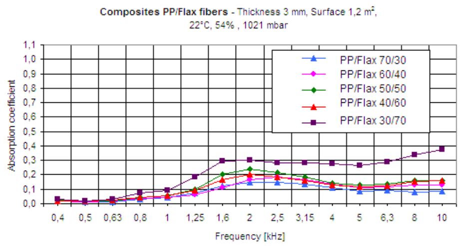

Figure 7: Absorption coefficients of Flax/PP composites

shows the influence of the blending ratio on compressed composites. For uncompressed fleeces the absorption

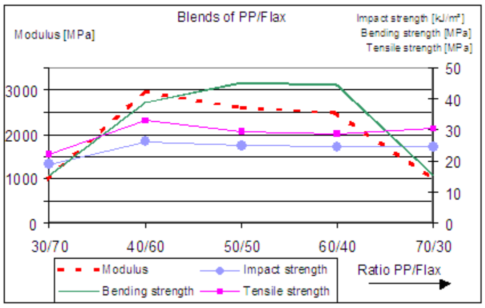

Figure 8: Mechanical properties of composites (Processing temperature: 180°C), Thickness of samples: 2,5mm

improves with an increase of the PP share, especially in the lower frequency range from 0,4 to 2,5 kHz. In opposite, for compressed composites a higher share of binder material results in a decrease of absorption capabilities. Fig. 8 displays the results of mechanical testing

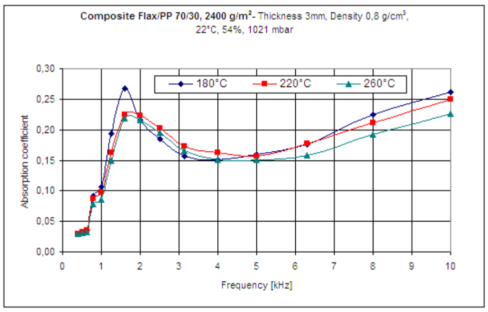

Figure 9: Absorption coefficient for different processing temperatures

of these composites. In contrast to the results of the acoustical characterization, a maximum of mechanical properties was found for comparatively low contents of natural fiber. Mechanical stress imposes both the polymeric matrix and the reinforcing fiber. With regard to the experimental data and considering the later application, a compromise between stiffness and strength has to be the aim when designing a structural part. With reference to the described results, fiber contents lower than 40% and higher than 60% lead to a distinctive decline in mechanical properties. In this context the considerable

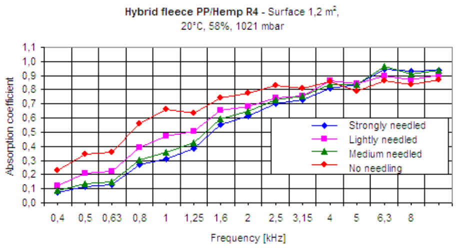

Figure 10: Absorption coefficients for hybrid fleeces and different degrees of needling, PP/Hemp R4 (50/50)

impact of the processing temperature on the properties of natural fiber reinforced thermoplastics has to be pointed out. Mueller and Krobjilowski [4] proved that maximum mechanical properties can only be achieved in a narrow and specific range of processing temperatures. Higher or lower processing temperatures result in a decline of mechanical properties. Fig. 9 clarifies that the processing temperature also affects the absorption of a composite directly.

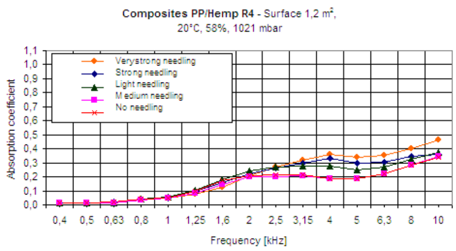

Figure 11: Absorption coefficients for composites and different degrees of needling, PP/Hemp R4 (50/50)

4.4 Influence of mechanical bonding on semi-product and composite

The influence of bonding by mechanical needling on the mechanical and acoustical properties was investigated for hybrid fleeces and composites. Fig. 10 shows the results for hybrid fleeces while Fig. 11 displays the influence for composites. The basic results can be summarized by a deterioration of absorption properties especially in the low frequency range when increasing the needling density. As displayed in Fig. 11, no difference occurs for composites in the low frequency range beneath 1 kHz. In the frequency range between 1 and 2 kHz, strongly compacted composites show the lowest absorption. However, for higher frequencies this influence inverses as above a frequency of 2 kHz highly compacted composites show the best absorption values. The so-called needling density captures the degree of bonding and is defined as the number of punctures per area. The influence of the needling density on the mechanical properties is shown in Fig. 12.

4.5 Influence of density and thickness

Fig. 13 shows the influence of the composite's thickness on the absorption of the specimen. A change in

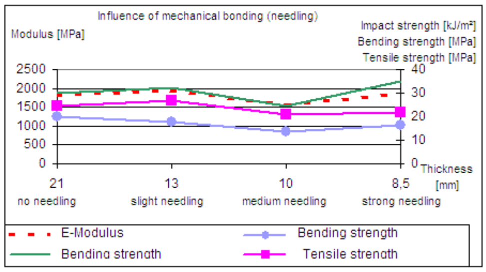

Figure 12: Influence of needling on mechanical properties of composites PP/Hemp R4

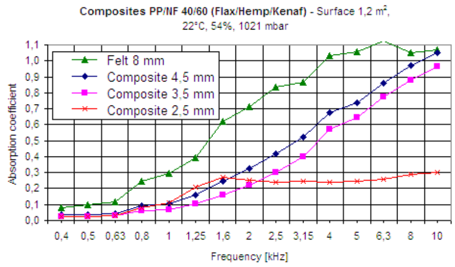

Figure 13: Influence of composite density on absorption coefficient (Alpha-cabin)

thickness is equivalent to a variation of the specimen's density. As obvious the density of the composite has a strong impact on the absorption properties. To verify these results measurements using the impedance tube were carried out. Fig. 14 shows the results. Both figures allow the same conclusions. As expected the best absorption capabilities can be found for the unconsolidated felt. An increase of density by consolidating the hybrid fleece to a composite results in a decrease of absorption coefficients. Regarding the three analyzed different thicknesses, a higher degree of consolidation leads to a further decrease in absorption. In this context it has to be pointed out that the decrease in absorption by reducing the composite's thickness from 3,5 to 2,5 mm is by far more distinctive than the one when reducing the thickness from 4,5 and 3,5 mm. The impact of the density on the mechanical properties is contrary to it's influence on absorbance. A reduction of the density can be expected to go along with a reduction of porosity and an increase of contact areas between fiber and polymeric component. Thus an incline of mechanical properties should occur with an increasing density of the sample. Fig. 15 shows the experimental data,

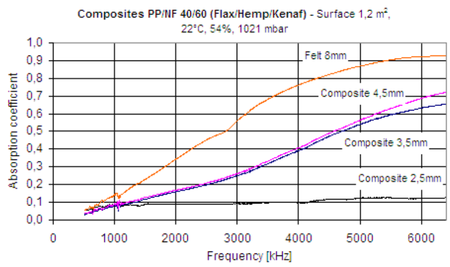

Figure 14: Influence of composite density on absorption coefficient (Impedance tube)

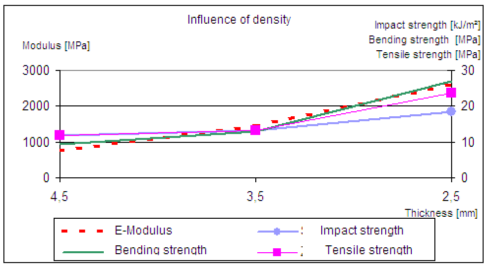

Figure 15: Influence of density on the mechanical properties of composites

confirming this assumption.

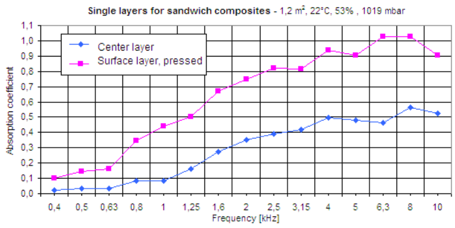

Figure 16: Absorption coefficient of single layers for optimized sandwich structure (Alpha cabin)

4.6 Acoustically optimized layered structures

The previously described results elucidate that an optimization of acoustical composite capabilities may go at the expense of mechanical strength or stiffness. Thus, combining both high absorbance and good mechanical properties obviously requires new strategies in material design. Such a strategy can be found in the generation of multi-layered composites. The material parameters

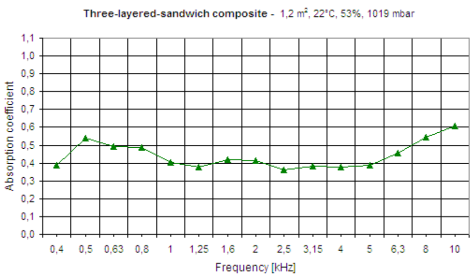

Figure 17: Absorption coefficients for 3-layered-sandwich composite (Alpha cabin)

for the single layers can be deduced from the experimental data. The non-compressed center layer should display a low needling density, employ natural fibers with a low retting degree and high quality and offer a high content of polymeric fibers. In the framework of the following experiments a hybrid fleece of PP and Flax with a blending ratio of 70/30 was used for this purpose. The molded and consolidated surface layers should show a high content of natural fibers and a high degree of needling. For this purpose a PP/Flax fleece with a blending ratio of 30/70 and a needling density of 100 punctures per cm^2 was employed. Fig. 16 represents measurements in the Alpha cabin for these single layers. Basing on these single layers, a sandwich structure was generated by stapling the layers as described in chapter 3.3. This sandwich structure again was measured by means of the Alpha cabin. Fig. 17 shows the results. The figure displays a distinct improvement in absorbance by the investigated sandwich structure. Future work will focus on an opening of the surface to enable a better utilization of the absorbance capabilities of the center layer.

5 Conclusions

The paper presented investigations on the mechanical and acoustical properties of composites basing on natural fibers and polypropylene as binder material. The investigations covered the influence of several material and processing parameters on the bending, impact and tensile strength as well as on the absorption capabilities. It was demonstrated that hybrid fleeces made of PP and natural fibers have excellent characteristics regarding the acoustical behavior. Varying the type of fiber or the degree of mechanical pre-compacting has a direct impact on the acoustical properties of the fleece. Furthermore it was shown that the degree of pre-compacting also has a direct influence even on the later composite part. However, it has to be pointed out that an optimization of the composite's acoustical capabilities can go at the expense of mechanical strength or stiffness. Thus, combining both high absorbance and mechanical properties obviously requires new strategies in material design. Basing on the results an acoustical optimized 3-layered-sandwich structure was developed. It was proved that the acoustical behavior can be improved distinctively by such a strategy.

References

[1] Market Study, Use of natural fibres in the German automotive production 1996 till 2003; nova-Institute Hürth, September 2004.

[2] Mieck, K. P., Stand und Entwicklung des Einsatzes von Naturfasern und umweltfreundlich hergestellten Cellulosefasern für Composites - Eine werkstoffliche Betrachtung, 2. Internationales Symposium Werkstoffe, Erfurt/Germany,1999

[3] Muessig, J., Untersuchung der Eignung heimischer Pflanzenfasern für die Herstellung von naturfaserverstärkten Duroplasten - Vom Anbau zum Verbundwerkstoff, VDI Verlag GmbH, Düsseldorf/Germany, 2001

[4] Mueller, D. H., Krobjilowski, A. Effects of thermal impact during the manufacturing process on the properties of natural fiber reinforced thermoplastics, 4. International AVK-TV Conference, Baden-Baden/Germany, 2001