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Processing and application of sandwich-structured natural fiber reinforced polymers

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Natural fibers provide low density, and good mechanical properties, are renewable and can be disposed of without any problems. They are therefore a genuine alternative to modern technical reinforcement fibers. Their specific mechanical properties such as stiffness and strength are comparable to those of glass fibers. Natural fibers also offer advantages during processing such as reduced abrasion and no toxicity. An up-scaling to bigger constructions and additionally a wider diversification of natural-fiber-based material is limited by the present "stiffness". Higher-loaded construction parts require higher stiffness, which can be achieved, for example, by sandwich structures. Single-phase sandwich structures were manufactured by foaming the polymer matrix between the outer sheets. The multi-phase systems contain different materials for the core and the surface layer. This article reveals new concepts for natural fibre single-phase sandwich structures as well as for natural fibre multi-phase sandwich structures, their processing technologies and outstanding resulting properties. Consequently, these structures offer a wide range of new applications in natural fibre reinforced polymers.

Key words: Natural Fibers, Polypropylene, Sandwich Structures, Honeycomb Design

1. INTRODUCTION

Properties such as high mechanical strength and stiffness and low weight can be achieved with fiber composite materials. The concept of fiber reinforcement provides materials which meet the requirements of complex mechanical loads. Composite materials, strengthened by synthetic fibers, e.g. glass, carbon or aramid, are currently widely applied in the aircraft industry, railed vehicles, sports equipment and machine tools. Since approx. 1990 natural fibers have enjoyed renaissance as reinforcements for different synthetic materials like polyethylene and polypropylene. High tensile strength and Young's modulus as well as low density and low prices for these raw materials are the outstanding technical advantages of natural fibers like flax, hemp, sisal, etc. .

Unfortunately, natural fibers show non-uniform fiber qualities and therefore non-uniform mechanical properties. Therefore, a desired pre-calculated structure design will be quite complicated to achieve. The greatest attention has to be paid to the finite-dimensional fiber length and the temperature stability of the fibers which result in a degradation of the cellulose molecules causing a reduction of fiber properties.

2. COMPONENTS OF REINFORCED COMPOSITES

Natural fibers are used as reinforcements for thermosetting as well as thermoplastic materials. Because of better wetting and adhesion in the case of thermosetting materials, natural fiber reinforced thermosets reveal a better mechanical profile compared to thermoplastics. However, the required boundary conditions for technical applications will be fulfilled in a better way if thermoplastic polymer matrices are applied.

In comparison with thermosets, the machine processing of thermoplastics (mainly polypropylene (PP)) can easily be carried out as far as safety at work is concerned.. The general advantages of thermoplastics can be seen in an easy primary forming and deformation process. Additionally, the applied fabrication method benefits an efficient processing especially with large quantities. Thermoplastics are re-fusible and they consequently provide a high recycling potential. The storage of semi-finished products at room temperature is nearly unlimited. During processing no contamination by excessive matrix material takes place at the moulding equipment. The interface is very positively influenced by the cleaning and alkalization of the natural fibers, the use of coupling agents and the optimization of the processing procedure for the system natural fiber/PP [1].

The applied matrix materials, strengthened by natural fibers, are mainly petrochemical thermoplastic materials like polyethylene, polypropylene or polycarbonate. So far, it has not been possible to establish thermoplastic matrix materials gained from renewable raw materials. On the one hand this is due to the high prices, on the other hand it can be attributed to the high viscosity and simultaneously to the low thermal stability during the processing procedure. From this follows the high research demand to realize parts with bio-based polymers. In consequence, PP is currently the most advantageous matrix material with regard to economical and technological aspects. In future, the preservation of wood and fossil resources, concepts of sustainability, new environmental regulations and growing global environmental awareness will trigger the search for renewable composites which are compatible with the environment.

3. RECYCLING POTENTIAL

Today, there is an increasing requirement for cradle-to-grave environmental compatibility of materials.

Therefore, glass and natural fiber reinforced polypropylenes were investigated in downgrading experiments regarding the degradation of the mechanical parameters and the fiber length reduction. The granular basic material was processed in the injection molding machine and, after preceding shredding, directly sprayed as splint granular material. As can be seen in the diagram (Fig. 1), a strong decrease of these properties occurs in the case of glass fibers during multiple processing, which correlates with the results of the fiber length measurement. The average length of the glass fibers decreases by 45 % during the course of 5 recycling steps, whereas the average length of the flax fibers only decreases by 25 %. In this case, the advantages of the ductile natural fibers come to the fore. Correspondingly, tensile strength and E-modulus nearly remain at the same level.

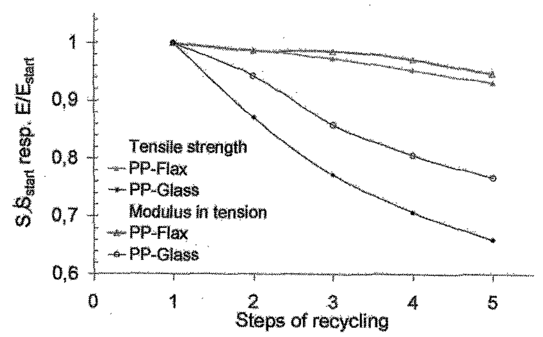

Fig. 1: Relative mechanical properties depending on the steps of recycling

4. NFC LIGHTWEIGHT CONSTRUCTION

The natural fiber composites have to be designed adequately in order to extensively use the potential of lightweight constructions. It can be stated that especially the pressing technology is appropriate to manufacture the above-mentioned design because it realizes high fiber volume contents.

Hybrid nonwovens, containing natural fibers and polymer fibers, are often used as semi-finished parts. They realize a homogeneous distribution of the strengthening fibers in the final product as well as a homogeneous wetting and penetration during the consolidation process [2]. The processing of the hybrid nonwovens to semi-finished parts involves two consecutively aligned presses. The process consists of the following steps: Press 1: Heating the mold to pressing temperature, insertion of the blanks, application of low pressure to transfer the pressing temperature, short ventilation, transfer of heated blanks into the cold press 2, maintenance of processing pressure during the cooling phase. Depending on the chosen materials, the heating phase (main part of the cycle time) takes between 1.5 and 4 minutes. Applying this processing technology the following designs can easily be achieved.

4.1 SANDWICH COMPOSITES

The dimensioning of natural fiber composites including sandwich structures to improve the stiffness is state of the art. Sandwich structures can be classified into single or multi-phase composites.

Single-phase composites can be realized, for example, by foaming the polymer material in the core region and an additional compact compressing of the outer parts. Multi-phase composites include classical sandwich structures using different materials for the core and the outer parts [3].

Especially in the case of natural fibers adequate materials for the core have to be developed. The outstanding recycling properties of the natural fibers have to be maintained. Additionally, the economical advantages should not be affected negatively. In consequence, besides thermoplastic foams mainly paper or cardboard-based honeycomb structures are applied (Fig. 2).

At the Katholic University of Leuven (Departement MTM and Devision PMA), Belgium, a very cost-effective product was developed by slitting corrugated boards and their subsequent distortion and folding to TorHex honeycomb structures [3].

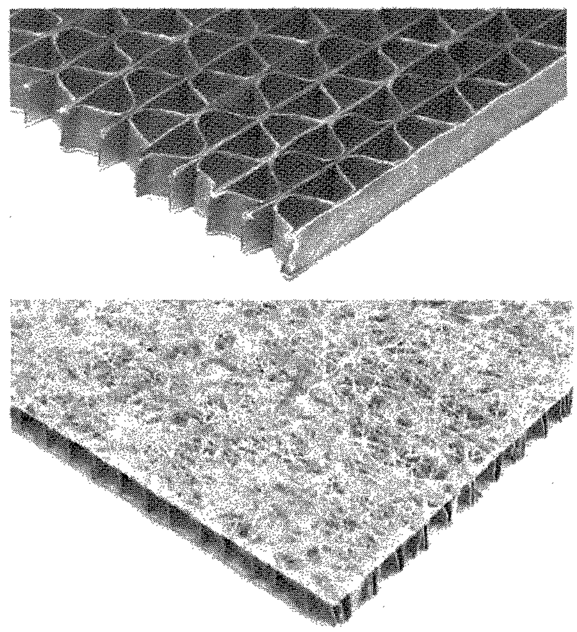

Fig. 2: Paper honeycomb and layers of NFC combined to a natural fiber sandwich structure, K.U. Leuven

4.2 RIB STRUCTURES

Furthermore, it is possible to create integrated sandwich structures during the processing of hybrid nonwovens into parts. Within certain limits well-defined semi-finished structures can flow during the casting process. Ribs can be generated by means of impact extrusion, provided that the tool geometry is well-designed. These ribs show a high thickness ratio (Fig. 3). The process requires a loose structure of the basis material as well as reinforced thermoplastics in the case of glass fiber mats. Thus the processed nonwovens need to contain a low fiber content and should provide less consolidation. The high stiffness of the final part results from the nearly optimal fiber orientation adapted to the progress of stress inside the ribs. Unfortunately, the ribs reveal an extensive shrinkage.

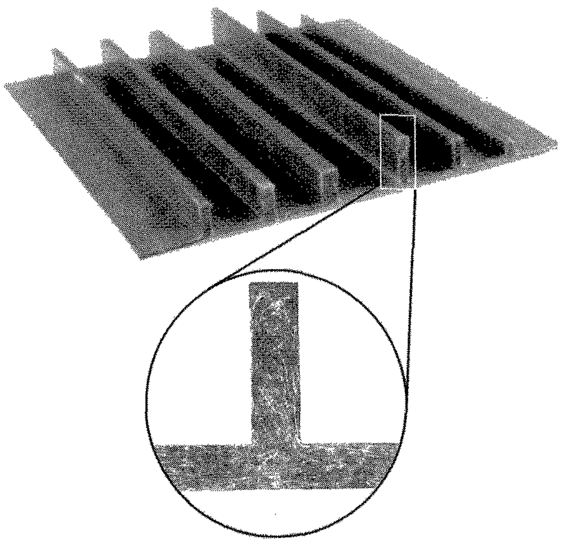

Fig. 3: Single-phase design, extrusion of ribs

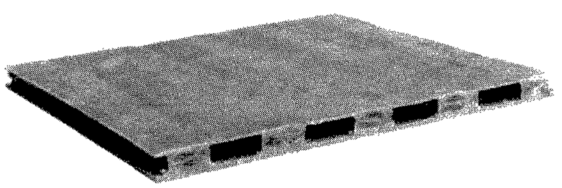

Fig. 4: Single-phase design, integrated rib structures

5. APPLICATIONS

5.1 INTERIOR LININGS (AUTOMOTIVE)

More and more different functions are integrated into the interior door linings used in the automotive industry. The processing concepts also require the integration of switcher, handle bars, stackers, lighting, etc. into the linings. Ideally, the interior door linings have to be designed working-resistant. Consequently, this leads to a reduced assembly complexity and is less material and cost consuming. The usage of thermoplastic natural fiber sandwich composites fulfill the technical requirements and lead to a reduced mass of the final part (Fig. 5).

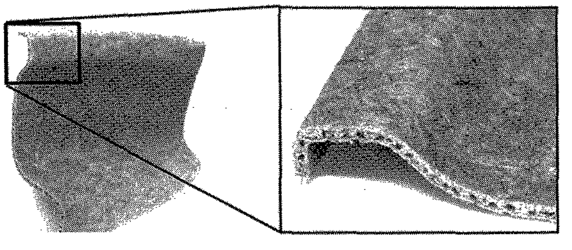

Fig. 5: Complexly deformed sandwich components, interior door lining.

5.2 HARD COVERS FOR MUSICAL INSTRUMENTS

Innovative natural-fiber-based hard covers for different musical instruments have to meet the following requirements: mechanical reliability, design options, economical processing and environmental friendliness. Hard covers built up from natural fiber sandwich composites provide high stiffness and strength in bending. They withstand pressure and impact load on the surface as well as pointed transmission of force at the handle bar and the hinges. The inside instrument is protected against penetrating humidity and extensive variation in temperature. The materials used stabilize the scale of the stringed instrument by balancing the humidity inside the cover.

To gain maximal design options the material should provide a good malleability and a high deformation degree. A very efficient production can be achieved by means of a one-step process which implies a subsequent forming of the base and the pattern material.. The short cycle time and the low costs of the used materials benefit an attractive marketing of these hard covers. Last but not least, the ecological aspects are convincing factors for the customers compared with competing products. Figure 6 reveals a section of a violin hard cover built up from natural fiber sandwich composites, whereas Figure 7 shows the entire product.

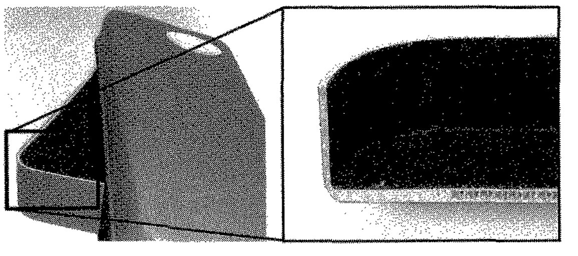

Fig. 6: Sandwich composite, section of a hard cover

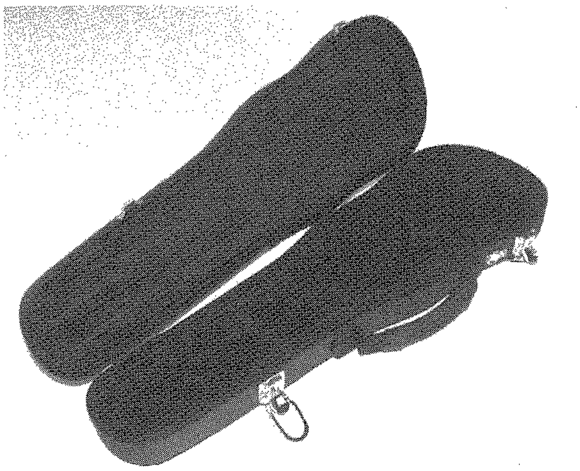

Fig. 7: Hard cover for a violin, Jakob Winter Ltd.

6 SUMMARY

Plant fibers like flax and hemp are suitable as reinforcements for thermoplastic matrices. Current developments in materials combination keep the advantages of NFC, e.g. the recyclability. By means of specific designs (single or multi-phase) the performance of NFC can be improved. The materials combination paper honeycombs with outer layers of NFC leads to a significant increase in stiffness with an additional weight reduction. The sandwich design facilitates an extensive deformation which enables complexly shaped parts.

Natural fiber composites reveal a high process reliability and reproducible materials properties.

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