Natural Fine-Tuning

Blending Basalt Fibers with Plant Fibers in Thermoplastic and Thermoset Composites

A blend of natural plant and inorganic fibers produces a composite with a very good property profile, without reducing the content of renewable raw materials. In this way, plant fibers such as kenaf or flax hybridized with basalt fibers can compete with glass fiber reinforcement as a low-cost, natural lightweight construction material.

Natural plant (left) and with PP hybridized fiber web (right) after fiber alignment by carding

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Sustainability and environmental compatibility can no longer be ignored in new developments. Renewable resources are gaining in importance and new materials and technologies are being developed to reduce the use of oil-based materials. Plant fibers such as flax, hemp, and kenaf have great potential as reinforcing materials for fiber composites (**Title figure**). They are used particularly, but not exclusively, in the automotive industry [1]. Their main benefit is weight reduction as compared with the use of conventional composites reinforced with glass fibers (GF). An advantage of natural plant fibers (NF) is their low density of about 1.4 to 1.5 g/cm^3 and their excellent lightweight construction properties due to this [2]. By way of comparison, the density of glass fibers (GF) is 2.5 to 2.65 g/cm^3. Besides their good technical properties, NF absorb carbon dioxide (CO_2) from the earth's atmosphere during their natural growth. In addition, energy consumption in the production of NF (9.7 MJ/kg) is 77 % lower than for GF (54,8 MJ/kg) [3].

Despite many positive properties, natural plant fiber-reinforced plastics (NFRP) do not achieve the same level of mechanical properties as glass fiber-reinforced plastics (GFRP). But if the property profile of NFRP were to be improved or extended, they could partially replace conventional GFRP structures. Empirical values in research and industry show that the addition of glass or carbon fibers improves the property profile of the resulting component [4]. However, as a consequence of this, the content of renewable raw materials in the composite – an important advantage – is reduced. The addition of basalt fibers (natural mineral fibers) can improve the property potential of these composites without changing the content of renewable raw materials.

Basalt Fibers for Hybridization of Natural Plant Fibers

Basalt fibers (BF) are natural mineral fibers produced from natural basaltic rock of volcanic origin. Although all the world's raw material resources are, in principle, finite, basalt is virtually inexhaustible since this rock makes up a significant proportion of the earth's crust (about 13 %).

The most important production process for basalt fibers is similar to that for glass fibers. In the first stage of the process, suitable natural rock is melted, »

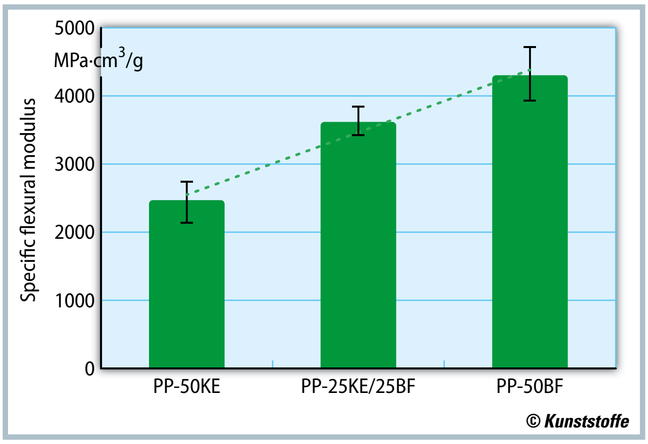

Fig. 1. Comparison of the specific flexural modulus shows that the PP-kenaf composite hybridized with 25 % basalt fibers achieves significantly higher values (source: HS Kaiserslautern)

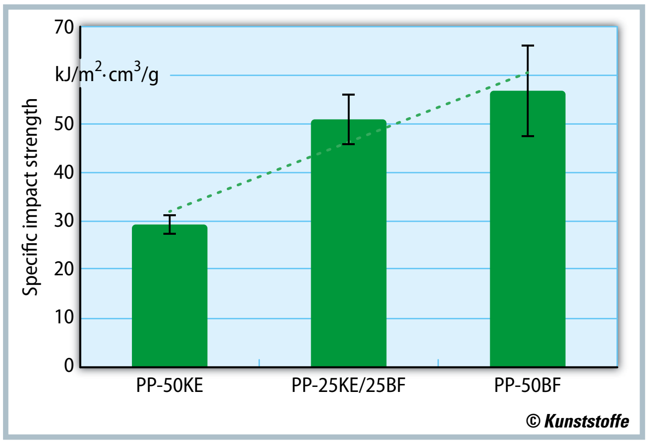

Fig. 2. Specific impact strength of the PP-kenaf composite hybridized with basalt fibers. The addition of 25 % basalt fibers increases energy absorption by 45 % (source: HS Kaiserslautern)

extruded through nozzles into filaments, coated, and wound up on reels. For use in nonwoven manufacture, the continuous filaments are cut to the desired length [5, 6]. Basalt fibers are often used as an alternative to glass fibers for reinforcing composites [7]. They have approximately a 5 % higher density than standard glass fibers but about 15 to 20 % higher tensile strength, compressive strength, and elastic modulus values. In addition, they have very high fire resistance, heat resistance in excess of 500 °C (the fiber itself melts at 1450 °C), high chemical resistance, and low moisture and water absorption. BF also offer ecological and health advantages over GF. The specific enthalpy of fusion of basalt is lower than that of GF. Furthermore, BF cause less environmental pollution during production and disposal [5].

BF pose a lower health risk in processing and use because they are 100 % natural and inert. This means that they are classified as non-toxic and non-carcinogenic. BF also have natural protection from UV radiation, biological effects, and corrosion. Melting and filament drawing are purely physical processes in which no other components or additives are used. Consequently, no authorization is required under the EU Reach regulations. Furthermore, BF can be re-used and the production process has a CO_2 balance close to that for natural plant fibers [6].

Since March 2018, the Textile Engineering Department of Kaiserslautern University of Applied Sciences (Pirmasens campus), Germany, has been engaged in a project on "Bast/basalt hybrid structures for the reinforcement of composites". The project has investigated processing these hybrid structures both with polypropylene (PP) as the thermoplastic matrix and with an acrylic-based thermosetting binder system (AC).

Mechanical Characterization of the Fibers

For these investigations, only materials available on the market were used. In a first step, all the selected fiber types were mechanically characterized with a single-fiber tester (type: Favigraph, manufacturer: Textechno GmbH, Mönchengladbach, Germany). The characteristic values determined were fiber linear density (DIN EN ISO 1973, vibroscope method) and fiber breaking force and elongation at break (DIN EN ISO 5079). From the results obtained, it is clear that NF, with linear density values of about 80 dtex to 140 dtex and high standard deviations of ±30 %, have a much coarser structure than BF (6 ± 1 dtex). This is due to the fact that natural plant fibers are separated as technical fiber bundles (irregular bundles consisting generally of 10 to 40 individual fibers), while BF are obtained as individual filaments. This is reflected in the maximum tensile force at break, which for the natural plant fibers is about 300 to 400 cN ± 100 to 200 cN, while BF have a maximum tensile force at break of about 55 ± 12 cN. Because of their finer diameter, however, BF have twice the strength (8 cN/dtex) of NF (3 to 4 cN/dtex). BF also have twice the elongation at break value (4 %) of NF (2 %).

Production of Semi-Finished Products and Mechanical Characterization of the Hybrid

Initially, two fundamental questions were considered: firstly, whether the hybrid semi-finished products could be manufactured and processed by established methods (carding, needle punching, hot pressing, etc.); secondly, whether homogeneous distribution of the very different fibers could be achieved.

For the production of natural plant fiber-reinforced thermoplastics, PP is admixed at the beginning of the process in the form of melt-bonding fibers in a weight ratio of 50 % and processed into a nonwoven with an areal density of 1800 g/m² (PP-NF). For use with the thermosetting resin, pure natural plant-fiber nonwovens with an areal density of about 1000 g/m² were produced and then impregnated with 30 wt. % of the acrylic resin system (aqueous dispersion) on a padder (AC-NF). The aim of incrementally replacing the plant fibers with basalt fibers was successfully accomplished in both processes.

For the mechanical characterization, test plates of both semi-finished products (PP-NF and AC-NF) were press molded with a thickness of about 2.0 mm and their tensile strength (DIN EN ISO 527-4), three-point bending (DIN EN 178), and impact strength properties (DIN EN ISO 179-1) determined. As a result of the manufacturing process, differences of ±10 % in the areal density of the semi-finished product and consequently in the density of the component (also in serial production)

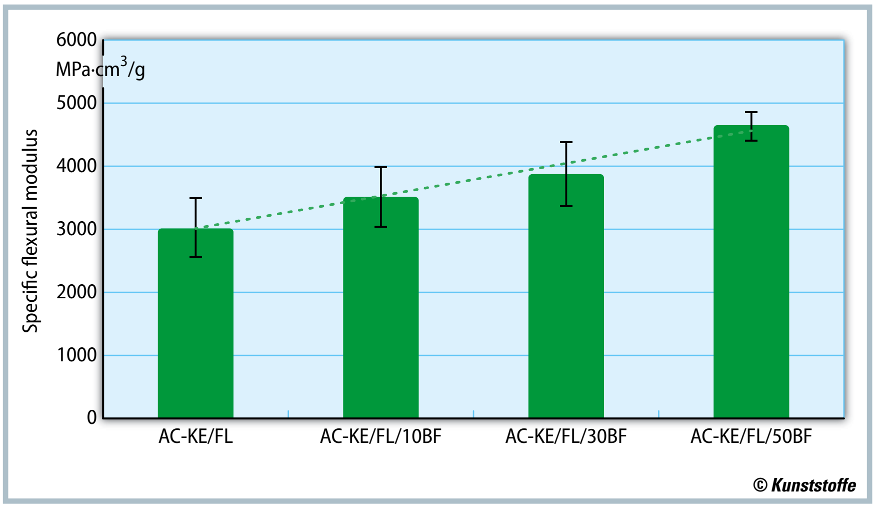

Fig. 3. Continuous improvement of the specific flexural modulus (stiffness) of the acrylic resin-kenaf/flax composite hybridized with basalt fibers was found with increasing addition of basalt fibers (source: HS Kaiserslautern)

were not uncommon. Since density plays a key role in component properties [2], the specific properties were determined for the sake of a meaningful comparison.

Shown here, by way of example, are the specific flexural modulus and impact strength of the PP-NF variant with kenaf (50 % PP + 50 % kenaf (PP/KE)), a hybrid mixture of kenaf and basalt (50 % PP + 50 % kenaf/basalt (ratio 25 : 25) (PP/KE/BF)), and a 100 % basalt/PP composite (50 % PP + 50 % basalt (PP/BF)).

The addition of 25 % BF to a kenaf-reinforced PP resulted in an improvement in elastic modulus of approx. 45 % (**Fig. 1**), while flexural strength was increased by about 25 %. The tensile property results for the hybrid composite (PP-KE/BF) were even more positive, with an improvement of some 70 % in tensile strength and some 50 % in tensile modulus. It was also pleasing to find that, through the addition of BF, not only were the strength and stiffness of the composites significantly improved, but energy absorption (Charpy) had also increased by between 50 % and 75 %, depending on the composite (**Fig. 2**).

For the impregnation with the acrylic-based binder system, 100 % natural plant-fiber nonwovens were produced from a blend of kenaf and flax fibers for reference purposes and the NF were then incrementally replaced with BF. **Figure 3** shows the results for the specific flexural modulus by way of example. The results show that, with an addition of only 10 % BF to the 100 % NF nonwo- »

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References & Digital Version

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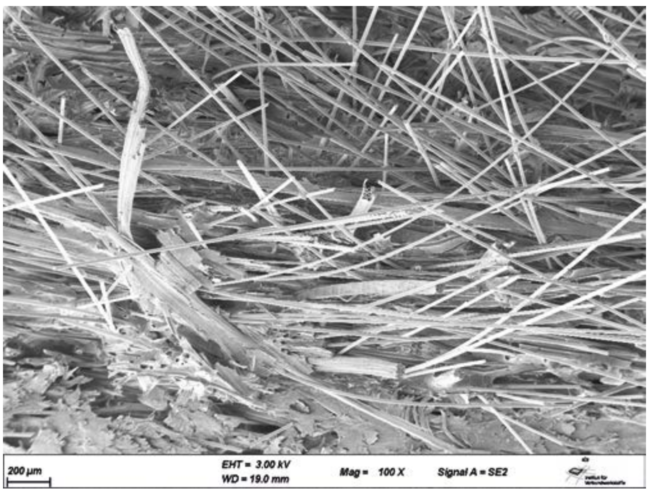

Fig. 4. The scanning electron micrograph of the fracture surface of the PP-KE/BF composite shows pronounced fiber pull-out attributable to a poor fiber-matrix bond (© HS Kaiserslautern)

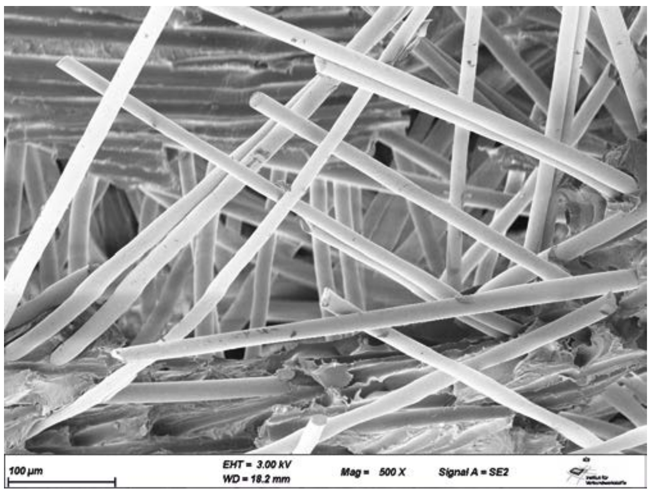

Fig. 5. The smooth fibers apparent in the scanning electron micrograph of the fracture surface of the 100 % PP-BF composite show that the basalt fiber size used is unsuitable for PP (© HS Kaiserslautern)

ven (about 8 % in the composite), flexural rigidity was increased by some 16 %. The addition of 30 and 50 % BF to the NF nonwoven (about 23 % and 38% in the composite) resulted in an improvement in flexural rigidity of 28 % and 54 % respectively. The specific impact strength was increased from about 25 kJ/m² • cm³/g with AC-KE/FL to about 30 kJ/m² • cm³/g with AC-KE/FL/50BF (17 %). The remaining composites showed an improvement of about 6 % to 13 %.

Morphological Characterization

Scanning electron microscopic analysis of the composites showed homogeneous distribution of the bast and basalt fibers, without agglomerates, in both the thermoplastic and thermoset composites. However, on the fracture surface of the PP-NF composites (**Fig. 4**), greater fiber pull-out was observed with the BF. This indicates a poor fiber-matrix bond, as confirmed by the clean, smooth surface of the basalt fibers without any matrix residue (**Fig. 5**), and leads to the assumption that the size was unsuitable for PP. For new trials, BF suitably sized for PP will be used. In this way, an even greater improvement in composite properties is expected.

The scanning electron micrograph of the thermoset composite (**Fig. 6**), on the other hand, showed a smoother, more homogeneous fracture surface with less fiber pull-out. In addition, matrix residues were observed on the basalt fiber surface, which is attributable to good wetting of the fiber surface by the matrix. Furthermore, the resin residues on the BF surface indicate that the size used was suitable for the thermoset matrix.

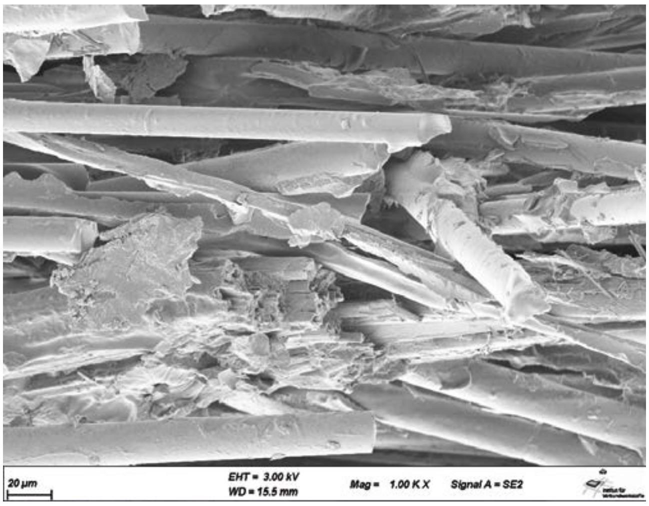

Fig. 6. The scanning electron micrograph of the fracture surface of the acrylic-NF/BF composite shows a homogeneous fracture surface without individually pulled-out fibers (© HS Kaiserslautern)

Processing into Components

Besides component properties, processing parameters such as cycle times and drapability, in particular, are of crucial importance for serial production. To analyze drapability, the semi-finished products were processed into small components (**Fig. 7**). These showed no thinning or wrinkling at the edges. In press molding, no differences from the usual serial production materials were noted. In subsequent trials, larger components, including serially produced automotive parts, will be made. ■

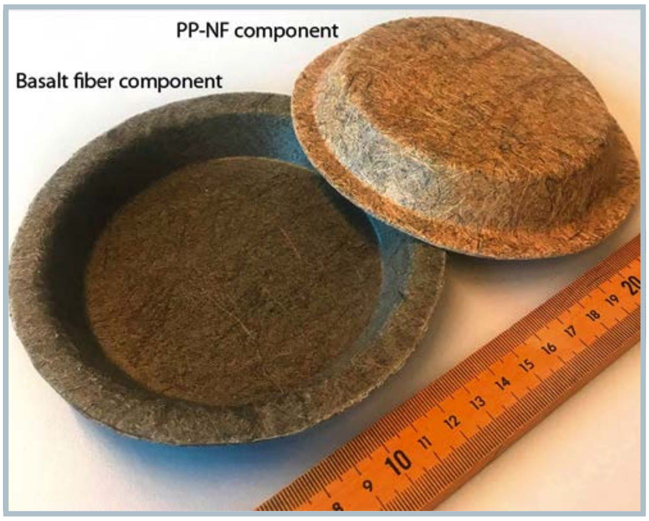

Fig. 7. Press molded components made from PP-NF (right) and PP-basalt fibers (left) (© HS Kaiserslautern)