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Development of long-basalt-fiber-reinforced thermoplastic matrix composites

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Long-fiber-reinforced compounds are particularly advantageous with respect to their dynamic mechanical properties.

Fiber fragmentation is one of the most significant problems affecting injection-molded composites. Since increased residual fiber length can significantly enhance mechanical and physical properties, numerous industrial technologies have been developed to produce parts in which the residual fiber length exceeds the usual values of a few tenths of millimeters.[1–7]

Our aim was to study the usability of continuous basalt fibers for injection molding of long-fiber thermoplastic (LFT)-matrix composites and compare their properties with conventionally compounded short-fiber-reinforced materials. For our tests, composites were manufactured by Kamenny Vek (Russia) using one matrix and one type of reinforcement but employing two different technologies.

The manufacturer treated the fibers with a sizing containing a silane coupling agent optimized for epoxy resins. They employed 6mm-long chopped fibers for compounding, while long-fiber-reinforced composites were made using roving with a linear density of 1200tex. As matrix material, they used polyamide 6 (PA6), produced by FACT GmbH (Germany). They also made the PA6-LFT (P-LFT) compound based on their patented technology in which the molten matrix resin is placed in an extruder, and the melt impregnates the roving (driven through a special extrusion tool). After solidification, the product (which resembles a pultruded rod) is cut into pieces of the required length. The length of the pellet grains used for our tests (and, therefore, the length of fibers inside the grains) was 11mm. The short-fiber-reinforced composite was made using a conventional compounding and injection-molding method. The reinforcement and matrix were mixed in a Brabender Plasticorder PL 2100 twin-screw extruder. Following extrusion (at a temperature of 290°C), the composite was granulated. For mechanical tests, standard dumbbell specimens were made through injection molding with a cross section of 4×10mm^2. We tested PA6 matrix resin with 30% by weight of conventional, short basalt fiber (SBF) and LFT

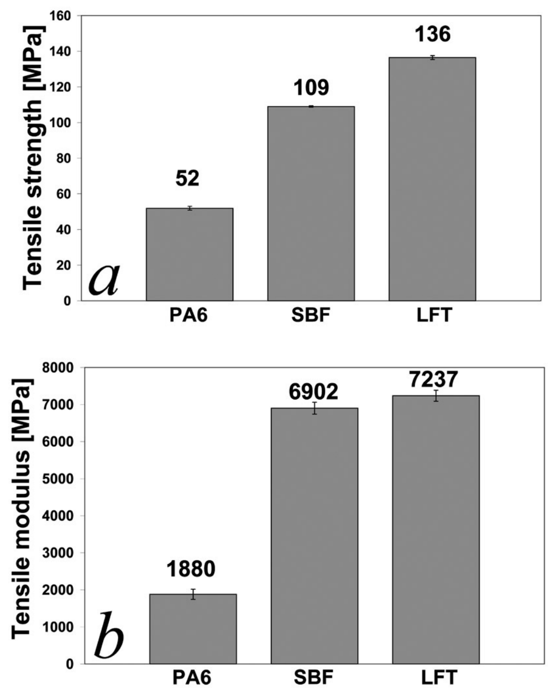

Figure 1. *(a) Tensile strength and (b) modulus. PA6: Polyamide 6. SBF: Short basalt fiber. LFT: Long-fiber thermoplastic matrix.*

in our short- and long-fiber-reinforced composites, respectively, at an injection-molding temperature of 290°C.

We carried out three-point bending and tensile tests according to the International Organization for Standardization (ISO) 178 and 527 standards, respectively. We also conducted Charpy impact tests on a CEAST® Resil impactor according to the EN ISO 179 standard, with both notched and unnotched specimens. The energy of the hammer was 15J, with an impact speed of 3.3m/s. We recorded the energy absorbed by the specimen and calculated the Charpy impact strength. We determined the residual fiber length in the injection-molded specimens

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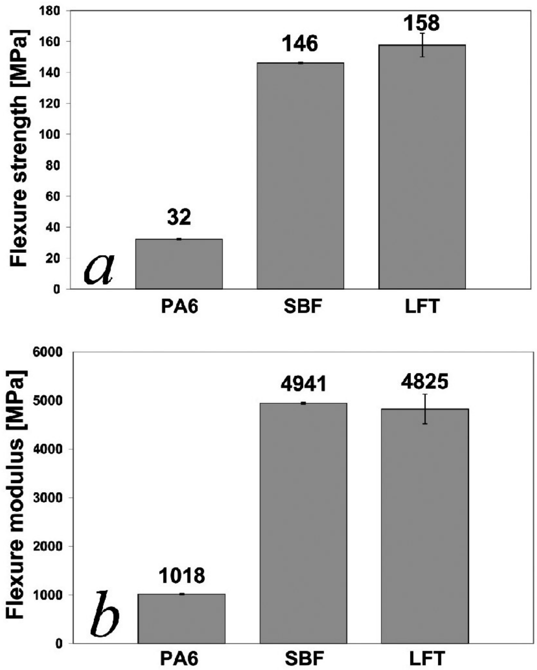

Figure 2. *(a) Flexural strength and (b) modulus.*

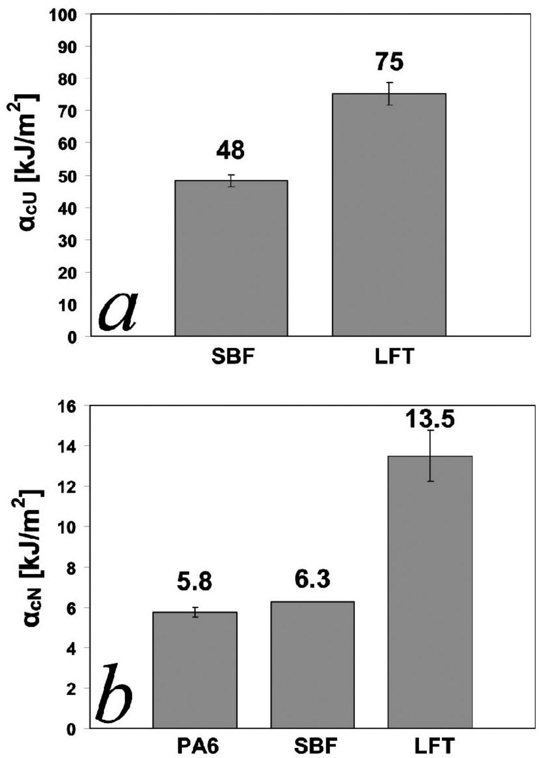

Figure 3. *Charpy impact strength of (a) unnotched (α_{cU}) and (b) notched (α_{cN}) specimens.*

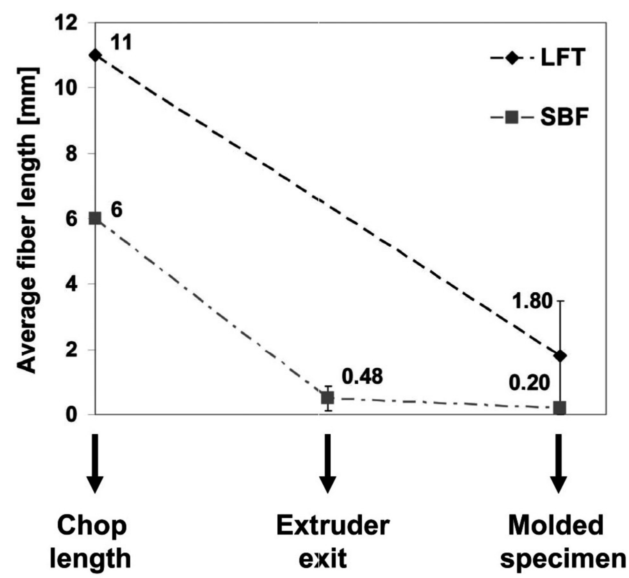

Figure 4. *Average residual fiber length at different phases during processing.*

by calcinating pieces cut from the middle section of dumbbell specimens in ceramic pots (using both a gas flame and an electric oven). We measured the lengths of 500 fibers from each sample using an optical microscope. We also fabricated samples from the short-fiber granulate (SBF) compounded in a twin-screw extruder. Figures 1 and 2 show the results of our tensile and flexural tests.

Basalt-fiber reinforcing significantly increased the strength and stiffness of the matrix material. The LFT surpassed the tensile strength of SBF by 25%, while its flexural strength was 8% higher. Figure 3 shows the results of our Charpy impact tests. Unnotched specimens of the neat matrix material did not break. We concluded that increased fiber length has a much stronger effect on the composites' dynamic than on their static mechanical properties. The Charpy impact strength of unnotched specimens increased by 56%, while the gain for notched specimens—where the difference between PA6 and SBF is negligible—was 100%.

Figure 4 shows the average residual fiber lengths as a function of processing stage. For SBF, the starting value is the length of chopped fibers, while for LFT it is the length of fibers in long-fiber pellet grains. (LFT processing does not include extrusion.) During extrusion and grinding, the length of chopped basalt fibers decreased to an average of 0.48mm. These fibers suffered from further fragmentation to 0.20mm. Despite our use of conservative injection-molding parameters, the originally 11mm-long LFT fibers fragmented to an average length of 1.8mm, which is an order of magnitude longer than the

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residual length of SBF fibers. Since the nominal fiber diameter is 14μm, the LFT length-to-diameter ratio is 130, while it is only 14 for SBF fiber.

The dynamic mechanical properties of long-basalt-fiber-reinforced thermoplastic composites are more than twice improved compared to short-fiber materials. We conclude that continuous basalt fibers are suitable for application in P-LFT technologies, and that long-fiber-reinforced composites have much better dynamic mechanical and shrinkage properties than short-fiber-reinforced materials. We will continue our research on the development of basalt and glass-fiber-reinforced, injection-molded composites, focusing mainly on the relationships among the processing parameters, fiber lengths, and mechanical properties (particularly temperature resistance and high-temperature behavior).

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