Plastics Research Online
10.2417/spepro.006993

High-modulus biocomposites based on short wood fibers and acrylic resin

Emmanuel Akpan, Bernd Wetzel, and Klaus Friedrich

Replacing natural fiber mats with short wood fibers in acrylic resin biocomposites reduces the associated production cost and cycle time.

In recent years, extensive research efforts have focused on the production of fully biobased composites suitable for the automotive and tribology industries, and for use in windows, doorframes, and outdoor furniture. This area of research is of particular importance because of the environmental problems that are associated with the use of synthetic materials and the depletion of non-renewable resources. Research has shown that composites filled with natural fibers compare favorably with those reinforced with glass fiber mat.[1] However, the use of natural fibers presents a number of problems in the resultant composites. For example, the fibers introduce variability in the mechanical properties, unevenness in the quality of manufactured parts, poor thermal and dimensional stability, and—most significantly—poor adhesion to the polymer matrix.

To overcome these challenges, a heat-curable acrylic resin called Acrodur was produced by BASF, Germany.[2] This resin system overcomes the adhesion problems traditionally associated with natural fibers, and improves the thermal stability of natural-fiber-based composites.[3] Moreover, the resin is fully biobased and is free from formaldehyde and phenols, thus meeting the ecological requirements for use in automotive, tribological, and household applications.[2] Most research and application reports about Acrodur have centered on the use of fiber mats.[4] As yet, however, none of the literature describes the direct use of short wood fibers (SWFs) to produce biocomposites with this resin.

In our study,[5] we therefore investigated the direct use of SWFs and Acrodur 950L for the production of biocomposites. To fabricate our samples, we used a simple mixing technique (with a kneading device) and hot compression molding. Our research is of industrial relevance because of the cost reduction associated with the use of SWFs (in place of glass fiber), and because our approach implements processing techniques based on the use of existing equipment. Moreover, by directly using SWFs—which are known to enhance crosslinking in thermosetting polymers[6]—the cost of pre-processing (e.g., making fiber mats) is eliminated.

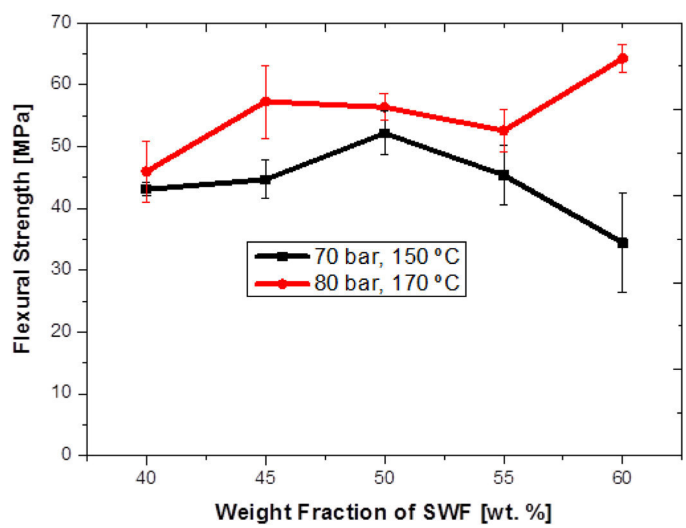

Figure 1. *Flexural strength values of short wood fiber/Acrodur composites with different fiber content and after undergoing treatment (either at 70bar and 150°C, or at 80bar and 170°C). SWF: Short wood fiber.*

To obtain our composites, we mixed Acrodur resin, water, and SWFs (CFF & Co., Germany) at varying ratios. Once the components were homogeneously distributed in the kneading device, we poured the different mixtures into open molds and dried the materials in an oven at a temperature of 120°C. We then cured the dried samples using hot compression molding. To determine the properties of the resultant composites, we evaluated their flexural strength, flexural modulus, and dynamic mechanical behavior.

Our investigations into the flexural strength of the composites revealed that the highest value (64MPa) was achieved for the composite

Continued on next page

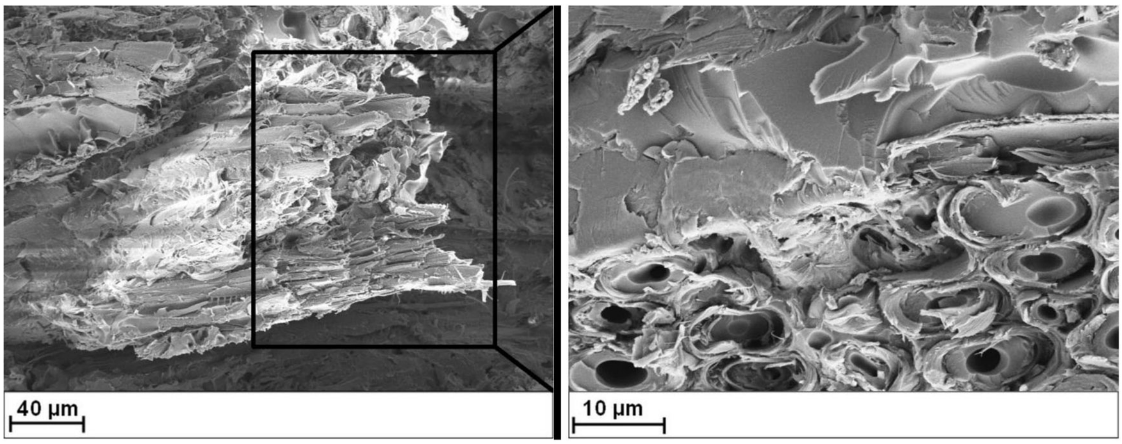

Figure 2. *Scanning electron micrographs showing the fracture surfaces of 60wt% SWF-filled composites prepared at a temperature of 170°C and under a pressure of 80bar.*

with 60wt% of SWFs, processed under a pressure of 80bar and at a temperature of 170°C (see Figure 1). This value is comparable to that achieved with long wood fibers (natural fibers).[4] We attribute this result to the good interfacial bonding—i.e., between the fiber and the matrix—in the SWF composite material (see Figure 2), which leads to good flexural strength.

In terms of the flexural modulus of the composites (see Figure 3), we found that samples with 45wt% of SWFs processed at a temperature of 170°C and under a pressure of 80bar achieved the highest flexural modulus (8.01GPa). However, the composite with 60wt% of fibers cured at 170°C and 80bar achieved the best combination of flexural strength and modulus. Additionally, the flexural modulus of this composite was higher than that exhibited by non-woven fiber-filled Acrodur composites.[2,4,7,8] There are a number of factors that could contribute to these improvements. First, SWFs may enable a better, more uniform dispersion in the Acrodur matrix. Due to their aspect ratio, SWFs are also known to better aid crosslinking in thermosetting resins. It is also likely that the fibers become a major contributor to the composite properties. As such, the SWFs are expected to possess better bending properties (compared with long wood fibers). Finally, we believe that the hemicellulose and cellulose contained within SWFs react with the

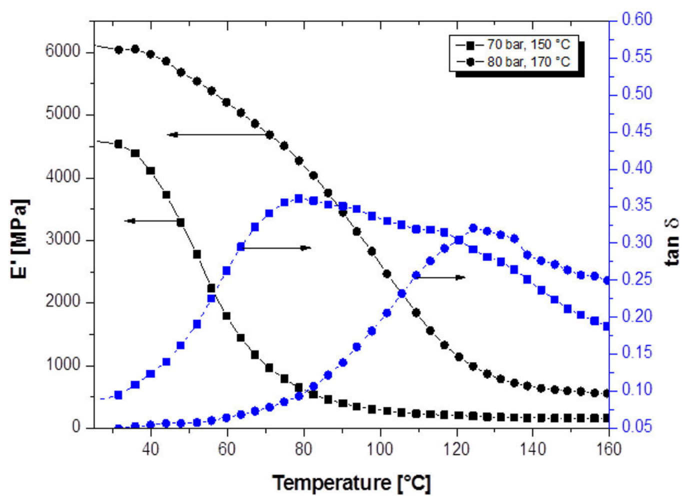

Figure 4. *Effect of processing on the thermomechanical properties of the SWF/Acrodur composites with 60wt% of SWFs. E': Storage modulus. tan δ: Damping factor.*

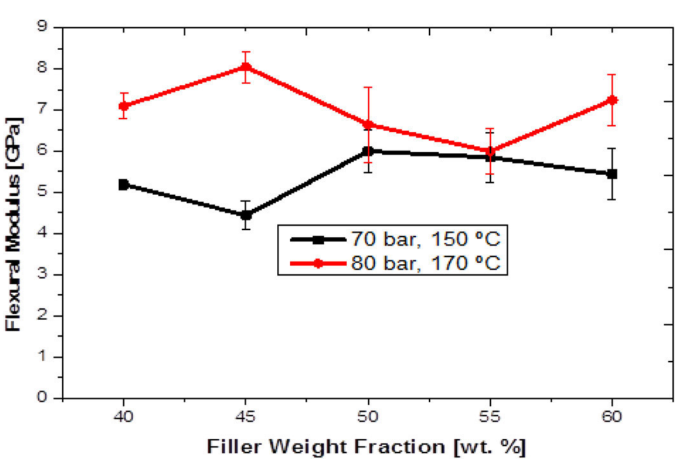

Figure 3. *Flexural modulus values of the SWF/Acrodur composites.*

Continued on next page

resin at high temperatures to form a more complex network, thus making the material stiffer. Our results indicate that the SWF composites could be a suitable replacement for long-wood-fiber-filled composites in applications where good flexural modulus is required.

Our investigations into the thermal properties of the composites show that they exhibit very good thermomechanical behavior at temperatures of up to 100°C (see Figure 4). For example, composites with 60wt% of fibers that were processed at a temperature of 170°C and under a pressure of 80bar exhibit a storage modulus of up to 2.5GPa at 100°C. The samples with lower SWF content exhibit a lower storage modulus. Typically, increasing the weight fraction of the filler leads to an increase in the storage modulus across the whole temperature range.[5] We attribute the high storage modulus of our composites to the increased stiffness of the matrix (i.e., as a result of the reinforcing effect imparted by the fibers, and because of the strong fiber–matrix adhesion).

In summary, we have demonstrated that direct use of short wood fibers in an acrylic resin matrix can result in composites with flexural properties and thermal stability comparable to those of composites fabricated with long wood fibers. We found that the composite with 60wt% of SWFs that was processed under a pressure of 80bar and at a temperature of 170° exhibited the highest flexural strength (64MPa) and flexural modulus (7.2GPa). Our results therefore suggest that the composite would be suitable for use in the interior trims of automobiles, furniture, office partitions, and ceiling tiles. For example, in terms of the flexural strength and modulus, our composite compares favorably with FlexForm and SuperLite (currently used in automotive applications). In our future work, we aim to gain a deeper understanding of the evolution of the flexural and thermomechanical behavior of the SWF-filled acrylic resin biocomposites using different sizes and types of wood fibers. Specifically, we hope to gain an understanding of the mechanisms and interactions at the fiber–matrix interface. We are also carrying out experiments into the specific use of these materials in tribological applications.

The authors gratefully acknowledge support from BASF, CFF & Co. GmbH, and the Alexander von Humboldt Foundation.

Author Information

Emmanuel Akpan, Bernd Wetzel, and Klaus Friedrich
Institute for Composite Materials (IVW GmbH)
University of Kaiserslautern
Kaiserslautern, Germany

Emmanuel Akpan is currently a postdoctoral research fellow under the Alexander von Humboldt Foundation. He is interested in the scientific understanding of biobased and environmentally friendly polymer composite systems, and in the development of high-performance polymer biocomposites for automotive and biomedical applications.

Bernd Wetzel is research director for the Materials Science Department. His research interests focus on high-performance polymers, nanocomposites, coatings, and biomimetic materials, including tribology, fracture mechanics, and processing–structure–property relationships. His research projects cover topics from the fundamentals up to industrial application.

Klaus Friedrich graduated in manufacturing technology from Dortmund University of Applied Sciences, Germany, and in mechanical engineering from Ruhr-University Bochum, Germany. Here, he earned his PhD in materials science. He later became research director for materials science at the IVW, University of Kaiserslautern, Germany. Together with his co-workers, he has published more than 800 papers in refereed journals, books, and conference proceedings. He is also the editor of six books. He continues to act as a research consultant for various institutes and industrial companies.

References

1. P. Wambua, J. Ivens, and I. Verpoest, *Natural fibres: can they replace glass in fibre reinforced plastics?*, **Compos. Sci. Technol. 63**, pp. 1259–1264, 2003.
2. B. Reck and J. Türk, *Thermally curable aqueous acrylic resins—a new class of duroplastic binders for wood and natural fibers*, **Angew. Makromol. Chem. 272**, pp. 5–10, 1999.
3. M. S. Islam and M. Miao, *Optimising processing conditions of flax fabric reinforced Acrodur biocomposites*, **J. Compos. Mater. 48**, pp. 3281–3292, 2014.
4. K. Liang, Q. Gao, and S. Q. Shi, *Kenaf fiber/soy protein based biocomposites modified with poly(carboxylic acid) resin*, **J. Appl. Polym. Sci. 128**, pp. 1213–1218, 2013.
5. E. I. Akpan, B. Wetzel, and K. Friedrich, *Processing and properties of short wood fiber/acrylate resin composites*, **Polym. Compos.**, 2017. doi:10.1002/pc.24604
6. N. S. M. El-Tayeb, *A study on the potential of sugarcane fibers/polyester composite for tribological applications*, **Wear 265**, pp. 223–235, 2008. doi:10.1016/j.wear.2007.10.006
7. L. Medina, R. Schledjewski, and A. K. Schlarb, *Process related mechanical properties of press molded natural fiber reinforced polymers*, **Compos. Sci. Technol. 69**, pp. 1404–1411, 2009.
8. M. A. Rasyid, M. S. Salim, H. M. Akil, and Z. Ishak, *Optimization of processing conditions via response surface methodology (RSM) of nonwoven flax fibre reinforced acrodur biocomposites*, **Procedia Chem. 19**, pp. 469–476, 2016.