Microtomographic Characterization of Paper

C. A. Bronkhorst, K. A. Bennett
Weyerhaeuser Technology Center, Federal Way, WA, U.S.A.

Introduction

From a mechanical or microstructural perspective, paper is a multiscale stochastic composite material. It is constructed from discrete tubular fibers that are bound to each other primarily through hydrogen bonds. Some of these fibers are collapsed, and some are not. The fibers themselves are also a composite material; three significant layers make up the material's wall, and each layer contains largely crystalline cellulose microfibrils embedded in an amorphous cellulosic polymer matrix. In each wall layer, the microfibrils align themselves differently with respect to the global fiber axis.

Generally, paper has a porosity of greater than 0.5. Therefore it can be considered a high-density cellular solid material of distinctly orthotropic character. Until recent years, paper has only been quantitatively considered a planar material. A complete microstructural characterization is important, however, for understanding the development of the mechanical and transport properties of this class of material.

Methods and Materials

All experiments reported on here were performed at the Pacific Northwest Consortium Collaborative Access Team (PNC-CAT) insertion device beamline 20-ID. The procedures employed were those developed by Seidler et al. [1, 2] and are not discussed further here.

Our most successful measurements were taken by using a photon energy of 8.0 keV and a detector distance of 25 mm. Using them resulted in a corresponding resolution of 1.6 μm/pixel.

Measurements were made on several different types of wood-pulp-fiber-based materials ranging in porosity from 0.1 to 0.6. Both manufactured orthotropic and laboratory in-plane isotropic materials were examined.

Results

Planar and transverse cuts through the 3-D tomogram of a laboratory in-plane isotropic material are given in Figs. 1 and 2, respectively. Note that the image in Fig. 1 demonstrates an hour-glass profile. This was observed on most of the samples and is a result of dimensional change that occurs during exposure to the beam during absorption measurements. This profile shape remains after measurement, suggesting that it is the result of a mechanism such as ozone degradation of the polymeric materials within the fibers rather than hygroscopic dimensional change.

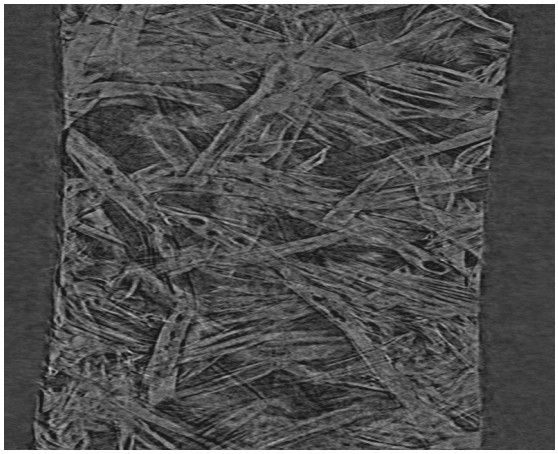

FIG. 1. Planar image of an in-plane isotropic paper material of porosity 0.55. The widths of collapsed fibers are on the order of 30-40 μm.

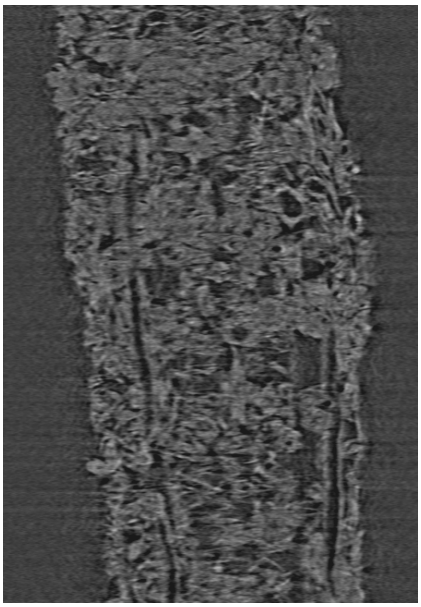

FIG. 2. Transverse image of the sample in Fig. 1. Uncollapsed fibers parallel and perpendicular to their axis are very clear. Fiber wall thicknesses are on the order of 5-10 μm. Sample thickness is 290 μm.

Work is now underway to begin quantifying the mesoscale microstructural characteristics of this class of stochastic material.

Acknowledgments

Use of the APS was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38. Direct access to sector 20 was granted by PNC-CAT, University of Washington. Generous assistance from Dr. G. Seidler is gratefully acknowledged.

References

[1] G. T. Seidler, L. J. Atkins, E. A. Behne, U. Noomnarm, S. A. Koehler, R. R. Gustafson, and W. T. McKean, *Proceedings of the 2001 Trieste Workshop on Granular Materials.*

[2] G. T. Seidler, G. Martinez, L. H. Seeley, K. H. Kim, E. A. Behne, S. Zaranek, K. H. Kim, B. D. Chapman, S. M. Heald, and D. L. Brewe, Phys. Rev. E **62**, 8175 (2000).