Molecular Strain in High Performance Cellulose Fibres via an Environmentally Benign Processing Route

Nandula D. Wanasekara[1], Stephen J. Eichhorn[1], Sameer Rahatekar[2], Thomas Welton[3], Alexander Bismarck[4], Herbert Sixta[5], Kevin Potter[2]

[1]College of Engineering, Maths and Physical Sciences, University of Exeter, UK, [2]Faculty of Engineering, University of Bristol, UK [3]Faculty of Natural Sciences, Imperial College of London, [4]Institute of Materials Chemistry & Research, Polymer & Composite Engineering (PaCE), University of Vienna, Austria, [5] Department of Forest Products Technology, Aalto University, Finland

s.j.eichhorn@exeter.ac.uk

Abstract. A new class of environmentally benign solvents, known as ionic liquids (ILs) are utilized to produce high performance cellulose fibres with improved mechanical properties. The liquid crystalline nematic phase of cellulose solutions will be utilized to spin cellulose fibres with high stiffness and strength. A comprehensive characterization of manufactured fibres will be carried out to understand the relationships between fibre manufacturing parameters (e.g. draw ratio) and the degree of alignment of cellulose chains on mechanical properties. Raman spectroscopy and X-ray diffraction will be utilized to characterize the orientation and molecular deformation of cellulose fibres. Initial studies on pre-drawn cellulosic fibres that have been produced this way show promising results and potential to increase the stiffness and strength using higher draw ratios during production. These results were compared to other regenerated cellulose fibres such as Bocell (a high modulus cellulose fibre spun from anisotropic phosphoric acid solution) and Ioncell (a fibre produced by dry-jet wet spinning using IL as the solvent). We envision that these sustainable and high performance cellulose fibres will find applications as a replacement for glass fibres and as a precursor for carbon fibres for aerospace, sports and auto industries.

Introduction

Cellulose is of the most abundant biopolymers on earth. Cellulose is an attractive alternative to synthetic polymers due to its eco-friendly characteristics such as biodegradability, renewability and sustainability. However, the insolubility of cellulose in conventional solvents due to its strong inter- and intra-molecular hydrogen boding, has limited its industrial applications. Ionic liquids have recently attracted attention as an eco-friendly solvent for cellulose due to its ability to be fully recycled and for their use in low energy processing environments. [1] The availability of ionic liquids have opened up new opportunities to explore environmentally friendly manufacturing of high performance cellulose fibres for applications in polymer and composite industries. The current methods of cellulose fibre manufacturing, such as the viscose process, are not considered to be sustainable due to the generation of waste and the use of toxic solvents. Therefore, there is a need for manufacturing of high performance cellulose fibres using environmentally benign processes. These fibres could replace glass fibres and be used for sustainable precursors for manufacturing high stiffness/strength carbon fibres. These fibres will achieve higher stiffness to weight ratios when compared to glass fibres, which consume high energy during manufacturing. [2]

Characterization of Cellulose Fibres

Single fibre filaments will be deformed in tension using a customized loading rig and the local micromechanics of the fibres will be studied using Raman spectroscopy. This technique involves following a shift in the peak position of a characteristic Raman band for cellulose. These shifts can be used as an indication of molecular deformation in the fibres, and can be related to their structure. [3, 4] Through the mapping of side groups, we can also gain insight into the influence of hydrogen bonding on the mechanics of fibres. [5] The level of hydrogen bonding in the structure will determine the initial stiffness of the fibres. Further, Raman spectroscopy will be utilized to map the interface between cellulose nanocrystals dispersed within the spun cellulose fibres. A previously established method will be used to study the local stress state between the cellulose dissolved in ILs and cellulose nanocrystals. [6] Preliminary studies on pre-drawn spun cellulosic fibres have shown interesting results and potential to increase the stiffness and strength with higher draw ratios (Figure 1). Raman shifts with deformation have been compared to other regenerated cellulose fibres such as Ioncell [7] (dry-jet wet spun fibre using cellulose dissolved in IL) and Bocell (a high performance cellulose fibre spun from phosphoric acid solution).

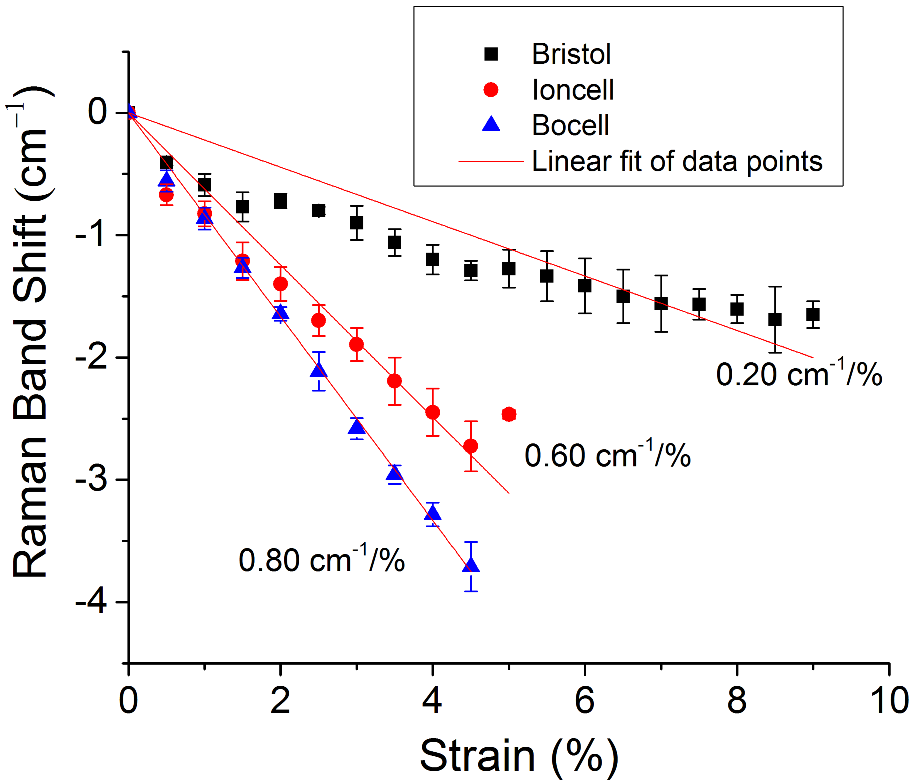

Fig. 1. Shift in the position of a Raman band (1095 cm^{-1}) as a function of deformation for three cellulose fibres

References

[1] F. Hermanutz, F. Gähr, E. Uerdingen, F. Meister, B. Kosan, *Macromolecular Symposia*, 2008, 262, 23-27

[2] S.V. Joshi, L. T. Drzal, A. K. Mohanty, S. Arora, *Composites Part A*, 2004, 35, 371-376.

[3] K. Kong, S. J. Eichhorn, *Polymer*, 2005, 46, 6380-6390.

[4] S. J. Eichhorn, R. J. Young, G. R. Davies, *Biomacromolecules*, 2005, 6, 507-513.

[5] K. Kong, S. J. Eichhorn, *Journal of Macromolecular Science, Part B Physics*, 2005, 44, 1123.

[6] T. Pullawan, A. N. Wilkinson, S. J. Eichhorn, *Composite Science and Technology*, 2010, 70, 2325-2330.

[7] M. Hummel, A. Michud, M. Tanttu, S. Asaadi, Y. Ma, L. K. J Hauru, A. Parviainen, A. W. T. King, I. Kilpelainen and H. Sixta, Advances in Polymer Science, 2015, accepted.