

Understanding the effect of stress on fibres

Aramid fibres are used as reinforcements in high performance composites, e.g. in aerospace applications, but they are also used extensively as reinforcements for rubber, tyres, plastics and concrete. Aramid fibres offer good mechanical properties at low density with the added advantage of toughness or damage/impact resistance. Weight reduction is a key requirement for cost and energy savings, while not impacting on design or performance. Employing aramid fibres as reinforcements has been limited by poor fibre-matrix interfacial adhesion because of the difficulties associated with the aramid fibre surface having insufficient reactive functional groups for covalent bonding with the matrix resin.

Single Fibre Deformation

The study of interfaces in composite systems is essential for the development of an understanding of science and technology of composite materials. An important property of the interface that can greatly affect the mechanical behaviour is the strength of adhesive bonding between the phases. When a load is applied to a fibre-reinforced composite, the load is transferred between the fibre and the matrix through the interface. Analysis of the efficacy of this stress transfer can be attained by observing the stress / strain distribution of the fibre embedded in the composite matrix.

In research conducted by Dr. Austin Coffey of the Department of Engineering at WIT, the technique of Raman spectroscopy has been extended to observe the strains in Twaron fibres embedded in a polymer matrix. Single fibre specimens and fibre polymer composites can be analysed using Raman spectroscopy to measure the stress or strain in the fibre induced by an applied load. In short, the interfacial shear strength of the fibres in the matrix can be monitored such that the interface can be optimised. Optimising the interfacial shear strength in thermoplastic polymers can have significant applications in areas such as the medical device, aeronautical and automobile industries.

Raman Scattering Process

Raman spectroscopy involves the measurement of radiation scattered from a specimen after it is exposed to a light source. The laser beam or electromagnetic radiation used in Raman spectroscopy is considered to be a stream of particles or photons containing energy which can undergo collision and transfer energy to the molecules in the sample [i]. When a molecule is irradiated with the laser, the energy may be transmitted, absorbed, or scattered which is due to vibrational and rotational changes of molecules. The three scattering processes which can occur in the irradiated molecule are shown below (Figure 1).

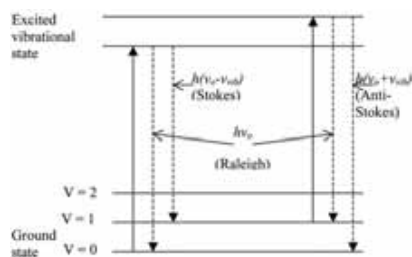


Figure 1 Energy transitions for elastic (Rayleigh) and inelastic (Stokes Raman and anti-Stokes Raman) light scattering [2]

A typical Raman spectrum of the fibre Twaron 2200 is shown in Figure 2. Twaron 2200 fibres give a well defined Raman spectrum. The peaks have been assigned by Kim et al [ii]. Each peak in the Raman spectrum cannot be attributed to a single mode of molecular deformation but is the result of many. The general structure of a Twaron aramid fibre (poly para phenylene terephthalamide - PPTA) is shown in Figure 3. The main peak of interest is that measured at 1610 cm⁻¹, which can be attributed

mainly to the asymmetric deformation of the phenylene ring structure and the stretching of the C-C bonds within the phenylene ring. As the p-phenylene ring makes up a large portion of the backbone of the polymer chain, and the rigid rod polymer chains of Twaron 2200 are aligned along the fibre axis, it would be expected that any stress applied to the fibre would result in molecular deformation of the backbone including the p-phenylene ring.

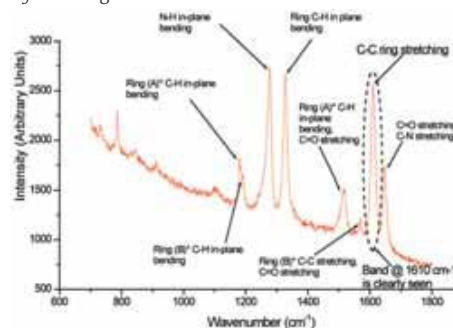


Figure 2 Raman spectrum of a Twaron 2200 fibre obtained using the near IR 785nm laser at an exposure time of 10s, with two accumulations

The shift of the 1610 cm⁻¹ Raman band of a single Twaron 2200 fibre under strain is shown in Figure 3. It is found that the peaks shift to lower wavenumbers under tensile deformation, with the 1610cm⁻¹ peak being the most prominent. This is due to the change of equilibrium bond distance leading to the change of force constant and the wavenumber.

Impact of Research

Mapping of strains in fibres or nanoparticles using Raman spectroscopy has far-reaching consequences in the determination of the best methods for exploitation of tailored composites for specific purposes. With Raman spectroscopy, it is possible to accurately measure the effectiveness of the interface between the fibres and composite matrix. Optimisation of the interface between fibre and matrix can lead to the development of ultra-thin walled catheters for the medical device industry and improved polymer composites for the aeronautical and automobile industries. Dr. Coffey is in the process of publishing his findings in a number of peer reviewed journals including the Journal of Materials Science, and will present his findings at a number of lectures at ANTEC 2007, Cincinnati, USA. Dr. Coffey is a lecturer in Mechanical & Manufacturing Engineering at Waterford Institute of Technology.

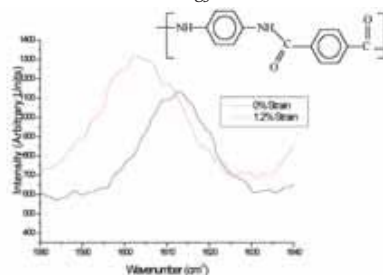


Figure 3 Structure of PPTA Twaron 2200 fibre and the shift of the 1610 cm⁻¹ Raman Band for a Twaron 2200 freestanding single fibre in the 1580 – 1640 cm⁻¹

[i] D.Chambell and J.R. White, Polymer Characterisation, Chapman and Hall, London, 1989

[ii] P.K. Kim, C. Chang, S.L. Hsul, "Normal vibrational analysis of a rigid rod polymer: poly(p-phenylene terephthalamide)", Polymer, 27 34 (1986)

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