Mechanisms of Load Transfer in Tension to Estimate Interfacial Behaviour of Kevlar 29 / Epoxy Composites by Laser Raman Spectroscopy

A Chennakesava Reddy
Professor, Department of Mechanical Engineering
Vasavi College of Engineering, Hyderabad, India

Abstract: In this paper Laser Raman Spectroscopy (LRS) was used to estimate interfacial strength of single Kevlar 29/ Epoxy composite system under tension. The debonding was due to local stress concentration and matrix yielding giving rise to exponential increase of the transfer length. At 1.5% matrix strain the fibre is debonded from the matrix.

Keywords: Kevlar 29, epoxy, single fibre, Raman spectroscopy

1. Introduction

In fibre-reinforced composites, good interfacial bonding is a primary requirement to ensure load transfer from matrix to reinforcement. A large number of techniques [1] have been developed for understanding interfacial adhesion of glass fibre reinforced polymers (figure 1). In the pull-out method, the fibre is embedded in a solid matrix material and pulled with an increasing force [2]. The microtension test was developed by Miller et al. [3] to prepare pull-out samples with very small embedded fibre length. In this method, the fibre is embedded in a small axi-symmertrical drop of resin and pulled out. In the microcompression test, a composite specimen is sectioned perpendicular to the fibre axis, the end of a single fibre is compressively loaded with a very fine diamond tip, and the fibre is pushed down from the composite [4]. One of the most widely used tests is the fragmentation test [5]. Each test specimen for the fragmentation test consists of one fibre embedded in a chosen polymer matrix. The specimen normally has a dog-bone shape. Elongating the specimens in a tensile tester results in fibre breakage. This experiment is done under a light microscope so that the fragmentation process can be observed in-situ.

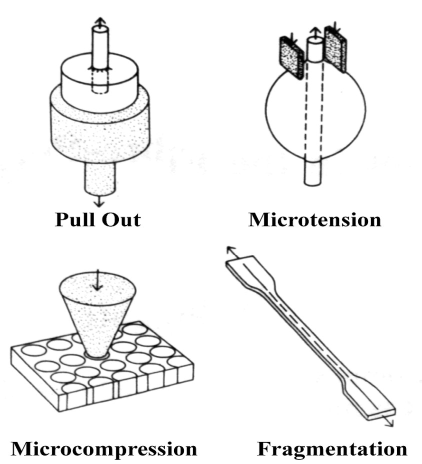

Figure 1. Four methods currently used for measuring interfacial properties [1].

The fibre inside the resin breaks into increasingly smaller fragments at locations where the fibre's axial stress reaches its tensile strength. The shear stress at the fibre/matrix interface is given by

$$\tau = 0.5\,\sigma_f d/l_c \qquad (1)$$

where, d is the fibre diameter, l_c is the limiting fragment size and σ_f is fibre fracture strength.

The value of shear stress is usually lower than that obtained from interlaminar shear strength [2]. But, full fragmentation occurs only when the matrix strain is at least three times greater than that of the fibre. hence, the fragmentation test is not suitable for tough polymer fibres such as Kevlar.

The objective of this paper was to estimate interfacial strength of single Kevlar/ Epoxy composite system under tension using Laser Raman Spectroscopy (LRS).

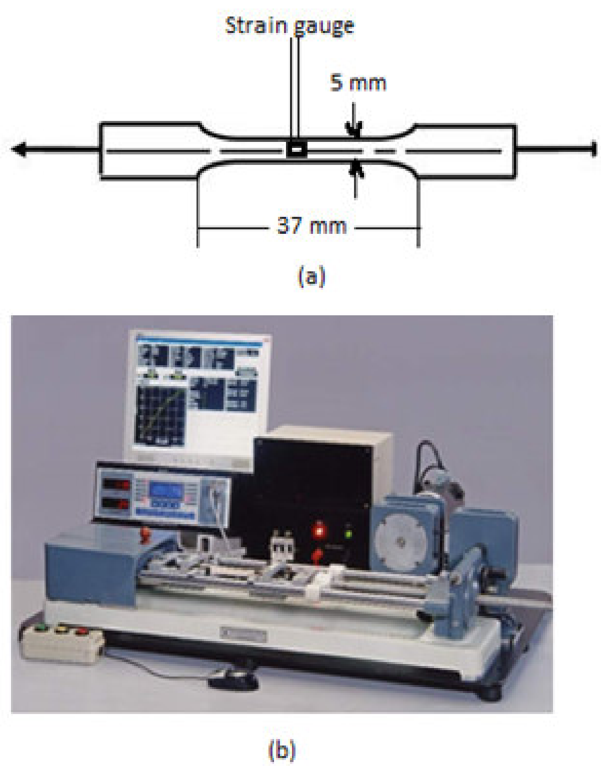

Figure 1: Dog-bode tensile specimen (a) and Tensometer (b)

2. Materials and Methods

The fibre material was the short-untreated Kevlar 29 fibres. The length of the fibre was 1.5 mm. The matrix material epoxy. The single filament was embedded in the matrix consisting of 100 parts (by weight) of resin to 36 parts of hardener. The dog-boned tensile specimens were prepared. Dog-bonded graphite moulds were half filled with the resin/hardener mixer and allowed to set partially before the fibre and the remain amount of resin/hardener mixture were added. After curing for one day at ambient temperature, thin film resistance strain gauge was attached with adhesive to the surface of the tensile specimen. The tensile specimens were allowed to cure at ambient temperature for one week to avoid thermal stresses inducing in the fibre on account of matrix shrinkage. the tensometer was used to apply tensile load in the fibre direction. the tested specimens are shown in figure 2.

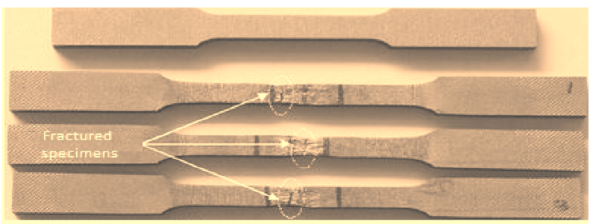

Figure 2. Tested specimens

For the Raman spectroscopy the intensity of the light was kept below 8μm on the tensile sample to avoid damaging the fibre or the matrix. A CCD imaging detector was used for recording of the Raman spectra (figure 3).

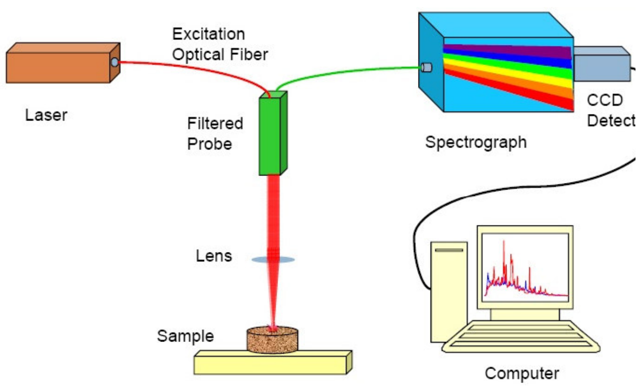

Figure 3. Raman spectroscopy

Fibre axial stress (-*l*/2, +*l*/2) is obtained from the following relation [6]

$$\sigma_f = E_{f-m}\varepsilon\left[1 - \frac{\cosh\beta_{cox}z}{\cosh\beta_{cox}l/2}\right] \quad (2)$$

The matrix interfacial shear stress is given by

$$\tau = \frac{1}{2}r_f E_{f-m}\varepsilon\beta_{cox}\left[\frac{\sinh\beta_{cox}z}{\cosh\beta_{cox}l/2}\right] \quad (3)$$

3. Results and Discussion

The fibre-strain distribution along the fibre was recorded till the matrix failure. The fibre strain profiles for 0.5%, 1.0%, 1.5 and 2.0% of strain were recorded during experimentation to estimate load transfer from matrix to fibre.

3.1 Tensile strain distribution

Figure 4 shows the continuous change of load transfer profiles till debonding and interface failure (figure 4c). Up to 0.7% strain the well-bonded fibres with matrix was observed. From 0.7% matrix strain up to 1.5%, a gradual decrease of the initial slope of the stress transfer is observed. No load is transferred through the ends of the fibre.

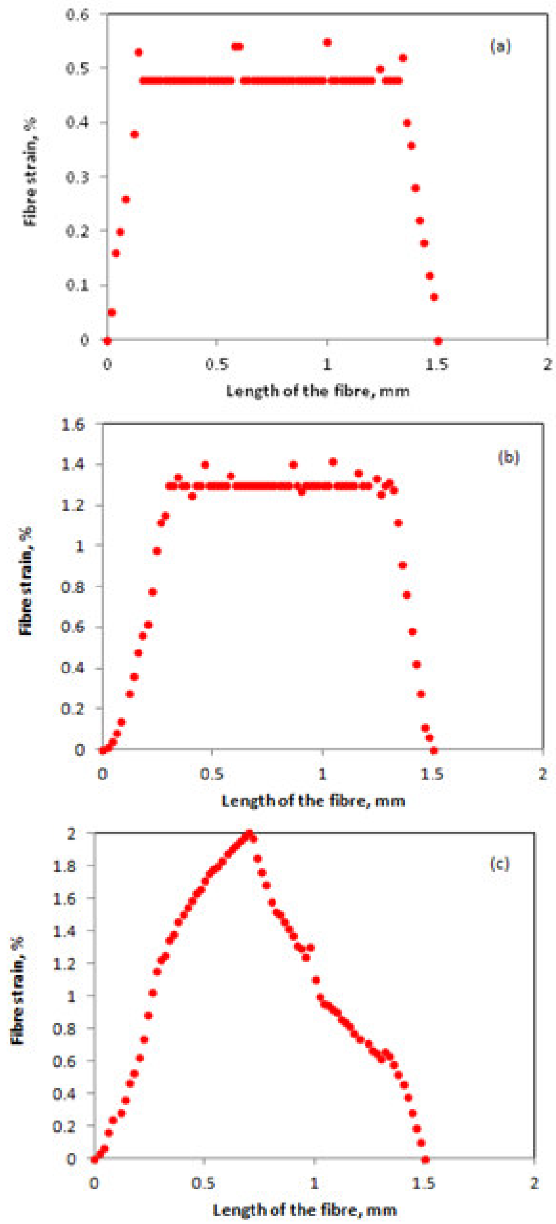

Figure 4. Axial tensile strain in the fibre as a function of fibre length

3.2 Mechanisms of tensile load transfer

The composite strength is very much dependent on the interface strength since the load transfer requires a strong interfacial bonds. the interfacial bonds include chemical bonding, mechanical interlocking and friction generated between the fibres and the matrix during load transfer. If the frictional force remains constant, the load on the fibre increases linearly from the fibre ends. a decrease in adhesion between the fibre and matrix results in debonding at the fibre-matrix interface.

Up to 0.45% of matrix strain the Cox model [6] presents an accurate mechanism of load transfer in a single fibre (figure 4a). Beyond 0.5% matrix strain, debonding initiates from the fibre ends due to local yielding of the matrix. At about 1.5% of matrix strain the whole fibre appears to be debonded (figure 5a) although the maximum matrix strain can be still reached (figure 4c) due to friction. At 2.0% of matrix strain, the fibre breakage at middle is seen from figure 5b. Using cross-polarised light, the region around the fibre breaks exhibits a coloured pattern. The phenomenon in the case of single fibre composites is caused by the interfacial shear and frictional stresses and strains at the interface [7]. It can be seen that these stresses occur symmetrically around a given fibre break. Upon saturation, the ends of these patterns almost touch each other (figure 6b and 6c); thereby indicating that shear stress transfer takes place over the whole fragment length. The actual interfacial shear strength is the sum of the value due to friction and chemical bonding (figure 7).

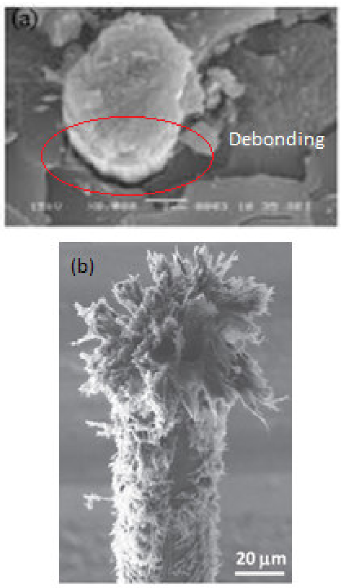

Figure 6. Debonding between Kevlar 29 fibre and matrix (a) and Kevlar 29 Fibre breakage (b).

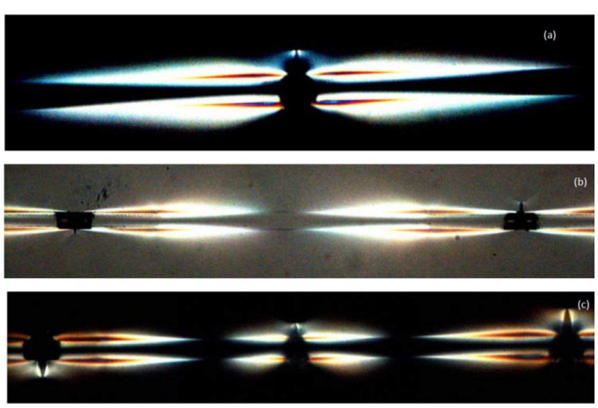

Figure 7: Interface patterns seen by using cross-polarized light for an epoxy resin. a) One crack with a deformation into the epoxy on the top around which the plane polarized light is visible. b) Two neighbouring cracks. c) Three neighbouring cracks.

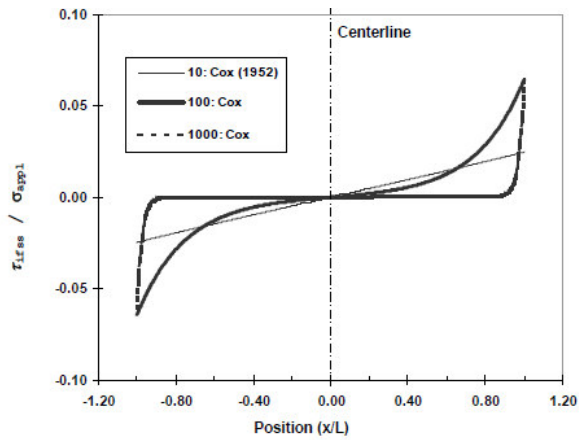

Figure 6. Cox interfacial shear stress predictions against fibre axial position for several fibre aspect ratios (AR=10, 100, and 1000).

4. Conclusions

As the load increased debonding started propagating from the ends of the Kevlar 29 fibre due to local stress concentration and matrix yielding giving rise to exponential increase of the transfer length. At 1.5% matrix strain the fibre is debonded from the matrix.

References

1. M. R. Piggott in Interfacial Phenomena in Composite Materials, edited by I. Verpoest and F. Jones, Butterworth-Heinemann, Oxford, 3 (1991).

2. Kelly, A. and Tyson, W.R. Tensile properties of fibre-reinforced metals: copper/tungsten and copper/molybdenum. Journal of the Mechanics and Physics of Solids, 13, 329-350, 1965.

3. B. Miller, P. Muri and L. Rebenfeld, Microbond Method for Determination of the shear Strength of a Fibre/Resin Interface, Composites science and Technology, 28, 17 (1987).

4. H. F. Wu and M. K. Ferber, interfacial mechanical characterization of nicalon sic fibre alumina-based composites, Journal of Adhesion, 45, 89 (1994).

5. N. J. Wadsworth and I. Spilling, Load transfer from broken fibres in composite materials, British Journal of Applied Physics, 1, 1049 (1968).

6. H. L. Cox, The elasticity and strength of paper and other fibrous materials, British Journal of Applied Physics, 3 (1952) 72.

7. B. Kotiveerachari and A. Chennakesava Reddy, Interfacial effect on the fracture mechanism in GFRP composites, CEMILAC Conference, Ministry of Defence, India, 20-21st August, 1999, Vol.1, no.B, pp.85-87.