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Structure property relation of hybrid biocomposites based on jute, viscose and polypropylene: The effect of the fibre content and the length on the fracture toughness and the fatigue properties

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ABSTRACT

In the present study, the extent of jute and viscose fibre breakage during the extrusion process on the fracture toughness and the fatigue properties was investigated. The composite materials were manufactured using direct long fibre thermoplastic (D-LFT) extrusion, followed by compression moulding. The fracture toughness (K_{IC}) and the fracture energy (G_{IC}) of the PP–J30 composites were significantly improved (133% and 514%, respectively) with the addition of 10 wt% viscose fibres, indicating hindered crack propagation. The addition of viscose fibres resulted in three times higher fatigue life compared with that of the unmodified jute composites. Further, with the addition of (2 wt%) MAPP, the PP–J30–V10 resulted in a higher average viscose fibre length of 8.1 mm, and the fracture toughness and fracture energy increased from 9.1 to 10.0 MPa m$^{1/2}$ and 28.9 to 31.2 kJ/m^2, respectively. Similarly, the fatigue life increased 51% compared with the PP–J30–V10, thus demonstrating the increased work energy due to hindrance of the propagation of cracks.

1. Introduction

In addition to improvement of the strength and stiffness, the use of natural fibre-reinforced thermoplastic composites can also increase the toughness. The measure of resistance to unstable crack growth is termed as fracture toughness (K_{IC}) [1]. K_{IC} represents the critical stress intensity factor, calculated on the basis of the maximum load; the fracture toughness tends to depend on the sample size. Generally, the composites should have high strength together with adequate toughness to resist rapid crack propagation [2]. The crack propagation resistance or fracture toughness of fibre-reinforced composites depends on various factors, such as the toughness of the matrix, additives, the properties of the fibres, the dispersion and distribution of fibres and the orientation and length of the fibres after the manufacturing process. Further, the fracture toughness is greatly affected by applied stress, mode of fracture, matrix cracks, fibre debonding, fibre breakage, fibre frictional pullout and fibre bridging [3,4]. The incorporation of rigid reinforcements in the matrix reduces the ductility and impact toughness, which leads to differences in the crack propagation and the fracture behaviour [5]. The propagation of cracks depends on the debonding of the fibres at the fibre–matrix interface, fibre pullout and fibre and matrix failure [6–8]. In fibre-reinforced composites, the applied stress is transmitted from the matrix to the fibre across the interface; hence, the interfacial adhesion between the fibre and the matrix plays a major role in the crack propagation [9–11]. When the composite is subjected to tensile load, the higher amount of stress will be borne by fibres, which causes the weak fibres to fail first. Further, application of the load on the composite causes failure of the intact fibres; this fibre fracture increases the stress concentration in the matrix, thus leading to matrix cracking [12]. In the case of a weak fibre/matrix interface, the matrix crack defects along the fibre–matrix interface tends to have crack bridging along the fracture path and pullout of the fibres. As a result, the fibres provide higher resistance to crack growth by arresting and bridging the cracks. However, in the case of a strong fibre–matrix interface, the matrix crack propagates into fibres without leaving intact fibres to produce pullout, resulting in the lack of fracture toughening [13]. The fibre pullout process requires additional energy, and it increases with mean fibre length [14]. Therefore, the current study adopted the direct long fibre thermoplastic (D-LFT) compounding process to maintain the

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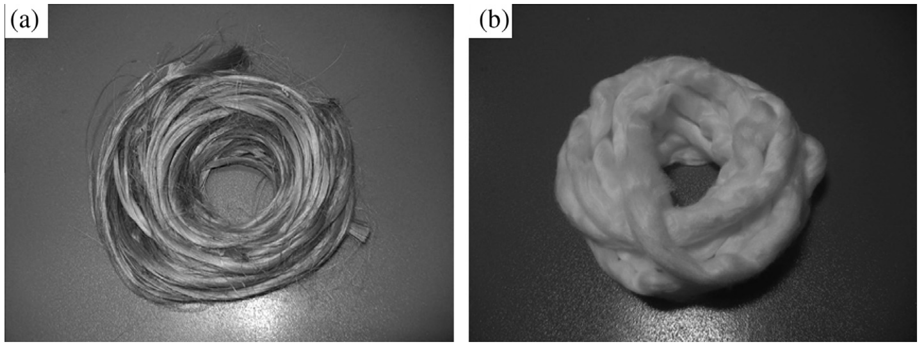

Fig. 1. The appearance of (a) jute fibres and (b) viscose fibres.

Table 1
Material formulations and denotations.

Materials	PP (wt.%)	Jute fiber (wt.%)	Viscose fiber (wt.%)	MAPP (wt.%)
PP–J30	70	30	0	0
PP–J30–M2	68	30	0	2
PP–J30–V5	65	30	5	0
PP–J30–V10	60	30	10	0
PP–J30–V15	55	30	15	0
PP–J30–V10–M2	58	30	10	2

length of the fibres during processing. The length of fibres is controlled by reduced shear, which also inclines the fibres to orient along the flow direction.

The main objective of the present study was to investigate the effect of jute and viscose fibres and the extent of their breakage on the fracture toughness and fatigue properties of PP composites manufactured via the D-LFT process. The effect of fibre length on mode I type fracture toughness of the composites was experimentally evaluated. The failure mechanism with the addition of viscose fibres in PP/Jute composites was identified and discussed.

2. Experimental

2.1. Materials and compounding

Homopolymer polypropylene (PP) Propel 1350YG, extrusion grade, with a melt flow index (MFI) of 35-g/10-min (230 °C, 2.16 kg) was purchased from Indian Oil Corporation Ltd., India and was used as the matrix. Maleic anhydride grafted polypropylene, Epolene E-43, Sigma Aldrich, USA was used as the coupling agent. The jute fibres were procured from Chandra Prakash & Co. Pvt. Ltd., Jaipur, India. The fibres were in the form of long fibre bundles of 1–2-m length, and the fibres were connected manually to form continuous fibre rovings. In this study, the jute fibres were used in the form of long hand-made rovings, as shown in Fig. 1(a).

The viscose fibres were supplied from Cheran Spinning Mills, Erode, India. Viscose is a derivative of wood pulp (also called as regenerated cellulose) processed via a spinning method. The fibres are staples or filaments of size ranging from 36 to 40 mm; the filament fibres are infinite in length, as shown in Fig. 1(b). The density of the used viscose fibres was 1.3 g/cm^3.

A co-rotating twin-screw extruder with a side feeder ZE-25 model Berstorff Maschinenbau GmbH, D-3000 (Hannover, Germany) was used to perform the Direct-Long Fibre Thermoplastics (D-LFT) process. The extruder was equipped with a gravimetric feeder, two atmospheric vents and a vacuum vent, as described in our earlier study [15]. Prior to compounding, the jute fibres were washed and dried at 60 °C for 48 h until a uniform weight was achieved. Similarly, the viscose fibres were dried at 60 °C for at least 2 h. Hand-made roving of viscose and jute fibres was incorporated into side feeder of the extruder, which feeds it directly into the polymer melt. The fibre weight fractions was controlled by the screw speed, and it was calculated using targeted fibre content, the weight of the fibre roving per meter, the length per screw revolution and time. The compositions used for the comparison are shown in Table 1.

2.2. Scanning electron microscopy

The morphology of the jute and viscose fibres was analyzed using scanning electron microscopy (SEM) with an instrument of Zeiss EVO-MA15, Germany. An acceleration voltage of 15 kV was used, and the sample surfaces were sputter coated with gold prior to SEM observation to avoid charging.

2.3. Fibre content and length measurements

PP matrix was removed after boiling in xylene using a Soxhlet extraction apparatus to study the actual fibre content and determine how the extrusion process affected the fibre length. After extraction, the fibres were manually separated in water and then observed using an optical microscope M/s. OPUS with a magnification in the range of 0.75 × –4.5×.

The actual fibre content (A_{fc}) was calculated based on the targeted rate, and the fibre length was measured automatically from the images using image analysis software. At least 200 fibres were measured of both fibres to calculate the average fibre length (A_{fl}).

2.4. Fracture toughness and fracture energy

The plane strain fracture toughness (K_{IC}) of the composites was measured from the single edge notch tensile (SENT) test. The SENT tests were performed using an Instron 3382 tensile testing machine in compact tension (CT) method using a cross-head speed of 1.5 mm/min. The CT specimens were cut from the compression moulded composite sheets. The dimensions of the specimens were

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