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Short- and long-glass fibre reinforced polyamide 6,6 composites: Tensile properties of injection moulded specimens

Aziz Hassan[1], A. Hamid Yahaya[1], Z. Abidin Ibrahim[2] and Peter R. Hornsby[3]

[1]Dept. of Chemistry and [2]Dept. of Physics, University of Malaya, 50603 Kuala Lumpur, Malaysia
[3]Wolfson Centre for Materials Processing, Brunel University, Uxbridge, Middlesex UB8 3PH, UK

ABSTRACT Injection moulding of fibre reinforced polymer composites is associated with the problem of fibre breakage. If fibre length retained in the finish product is too short, this will limit the expected improvement in property and defeat the purpose of reinforcement. Extrusion and pultrusion are two methods normally employed for the melt compounding of polymer composite feed stock for the injection moulding, produced short- and long-fibre composites, respectively. In this work, these composites were injection moulded at different fibre loading and tested for the tensile properties. Both tensile strength and tensile modulus of long fibre composites improved compared to the short composites counterpart despite reduction in fracture strain.

ABSTRAK Pengacuan suntikan komposit polimer diperkuat dengan gentian adalah menyebabkan pemutusan gentian. Jika panjang gentian dalam bahan siap terlalu pendek, ianya akan menghadkan peningkatan sifat-sifat yang diharapkan dan menggagalkan tujuan pengkuatan. Ektrusi dan pultrusi adalah dua kaedah yang biasanya digunakan untuk mengkompoun komposit polimer untuk acuan suntikan, menghasilkan masing-masingnya komposit gentian-pendek dan -panjang. Dalam kerja ini, pengacuan suntikan dilakukan terhadap komposit pada kandungan gentian yang berbagai dan dilakukan ujian regangan. kedua-duan kekuatan regangan dan modulus regangan komposit gentian panjang adalah meningkat dibandingkan dengan komposit gentian pendek yang setara walaupun pemanjangan pemutusan berkurang.

(extrusion, pultrusion, injection moulding, tensile properties)

INTRODUCTION

Fibre reinforced polymer composite (FRPC) materials are being increasingly used in a wide range of technology and engineering applications. FRPC materials offer a number of distinct advantages over more conventional engineering materials, such as high value of specific modulus and specific strength, superior corrosion resistance, improved fatigue properties, low manufacturing cost, etc [1].

Conventional short fibre compounds are manufactured by incorporating chopped strand/fibres with the initial length in the range of 3-6 mm into the plastics melt on the compounding extruder to produce homogeneous and well wetted granules of compounds for injection moulding. In the injection moulded product, the average fibre length is in the range of 0.2 to 0.4 mm [2]. Due to the relatively small fibre length retained in the final product, the improvement achievable in the properties of the finished article is limited. The pultrusion process [3,4] however, enables the production of fibre reinforced thermoplastic composites, where continuous fibre bundles/tows are separated and the individual filaments are coated with the polymer matrix. The pultruded product/composites are then pelletised to a required length for injection moulding, and are called long fibre composites, LFC [5].

EXPERIMENTAL

Commercial materials used for the characterisation were Maranyl® A100 (unreinforced polyamide 6,6), Maranyl® A190 (short glass fibre reinforced polyamide 6,6 composite, 18% fibre volume fraction) and Verton® RF7007 (long glass fibre reinforced polyamide 6,6 composite, 19% fibre volume fraction).

A single gated double cavity, impact and tensile standard test bar mould was used in the moulding of the test specimens. The dimensions of dumb-bell shaped tensile test pieces are in accordance with the ASTM Standard D638-80, type 1 [6]. The list and the abbreviation of specimens prepared are given in Table 1.

For the determination of fibre volume fraction, V_f, samples from the central portion of injection moulded tensile test piece were cut and the polymer matrix was removed by heating a composite specimen in a muffle furnace at a temperature of up to 600°C for a period of between six to seven hours. Fibres were then weighted.

Tensile tests were carried out using an Instron Universal Testing Machine with a cross-head speed of 1.0 mm/min at room temperature of about 23°C. The composite modulus was recorded at 0.5 % strain. ASTM standard D638–80 [6] was used as a standard in calculating the tensile properties.

Table 1. Specimens abbreviation and formulation.

Sample	V_f	Fibre	Description
S05	0.05	short	Maranyl® A190, diluted with Maranyl® A100
S10	0.10	short	Maranyl® A190, diluted with Maranyl® A100
S15	0.15	short	Maranyl® A190, diluted with Maranyl® A100
S18	0.18	short	Maranyl® A190, used as received
L05	0.05	long	Verton® RF7007, diluted with Maranyl® A100
L10	0.10	long	Verton® RF7007, diluted with Maranyl® A100
L15	0.15	long	Verton® RF7007, diluted with Maranyl® A100
L18	0.18	long	Verton® RF7007, diluted with Maranyl® A100

Table 2. Tensile properties.

Sample	Tensile strength (MPa)	Tensile modulus (GPa)	Fracture strain (%)	Property index		
				Tensile strength	Tensile modulus	Fracture strain
S05	52	6.0	4.2	std	std	std
L05	60	6.6	3.5	1.15	1.10	0.83
S10	82	6.6	3.5	std	std	std
L10	96	8.0	3.0	1.17	1.21	0.86
S15	105	6.8	3.1	std	std	std
L15	125	9.0	2.8	1.19	1.32	0.90
S18	113	6.9	3.0	std	Std	std
L18	138	9.5	2.7	1.22	1.38	0.90

RESULTS AND DISCUSSION

Fibre volume fraction, V_f was calculated using the following equation:-

$$V_f = (M_f/\delta_f) / [(M_f/\delta_f) + (M_m/\delta_m)] \quad (1)$$

where M and δ are weight and density respectively; and subscripts f and m referred to fibre and matrix, respectively.

As shown in Table 1, the experimental value of V_f are as expected, despite physical blending approach which had been adopted in mixing the compounded materials with the virgin matrix in order to reduce V_f. This is believed to happened since the following precaution had been taken, i.e. at an intended fibre loading, the blends were prepared in batches with a total weight of 500 g each and fed into the injection moulding machine batch by batch. During the trial run, blends were prepared only in one batch with a quantity of about 4 kg. Compounded materials tends to settle down in the feed hopper of the injection moulding machine, leaving unfilled polymer matrix at the top. This results in moulded specimen with variable V_f, higher at the beginning and lower at the end of the run.

In tensile tests, all specimens break in a brittle manner, except some indication of ductility showed by sample S05, short fibre composite (SFC) with the lowest V_f. However, this behaviour is not observed in sample L05, LFC with the same V_f. This is believed to be due to the existence of longer fibre which restricts the matrix movement even at low V_f.

Tensile properties of these composites are given in Table 2 together with the plots of properties against V_f given in Figures 1-3. The calculation of property index, PI was carried out using the following equation:-

$$PI = (P_c/V_f)/(P_{c,r}/V_{f,r}) \quad (2)$$

where, $P_{c,r}$ and $V_{f,r}$ are respectively the property and fibre volume fraction of a reference composite, and; P_c and V_f are the corresponding property and fibre volume fraction of the composite from which a comparison is to be made.

Fracture strain of LFC is reduced between 10-17%, with property index between 0.83-0.90. This is expected to be due to the existence of longer fibres, which further restricts matrix ductility. In order to fully utilise the contribution from the fibre to the composite strength, the composite should be able to fail only at the longest possible extension. Therefore, the reduction of fracture strain of LFC is a disadvantage for the composites.

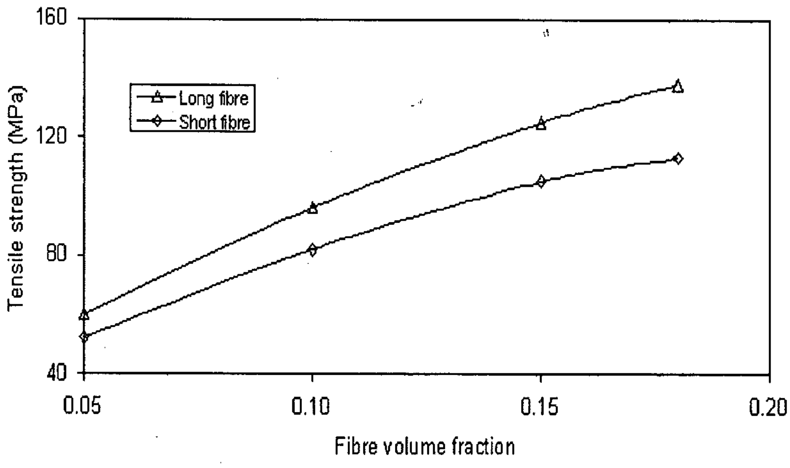

Figure 1. Tensile strength of short and long fibre composites.

Despite the reduction in fracture strain, tensile strength and tensile modulus of LFC increased between 16-22% and 10-38% with property index between 1.15-1.22 and 1.10-1.38 respectively, compared to their SFC counterpart. This behaviour further proved the effectiveness in reinforcement of LFCs. Curtis [7] and Curtis *et al.* [8] have also reported that the reduction of fracture strain of composites were associated with a longer fibre and higher fibre volume fraction in composites.

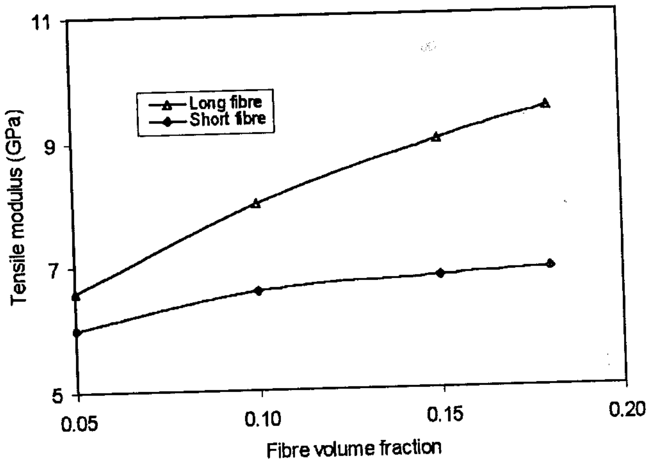

Figure 2. Tensile modulus of short and long fibre composite.

The microstructure investigation of the fractured specimens revealed that the fibre diameter of SFC and LFC are 10 μm and 17 μm respectively. Calculation showed that fibres in LFC with diameter of 17 μm have total length and total surface area of only 35% and 59% respectively, compared to fibres in SFC with 10 μm diameter. This is a clear advantage of SFC with smaller fibre diameter. However, tensile strength and tensile modulus still indicates the superiority of LFC despite their lower value of total fibre length and total fibre surface area. This means that total fibre length and total fibre surface area alone are not the sole parameter in determining the composite property, but the length of the individual fibre itself.

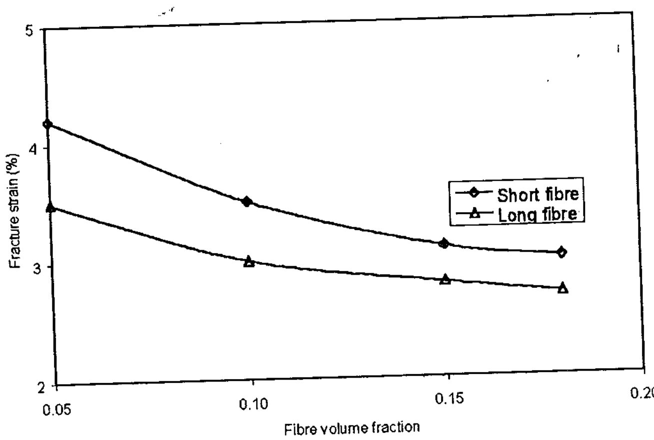

Figure 3. Tensile fracture strain of short and long fibre composite.

In tensile test, fibre matrix interfacial shear strength, τ_i is very important in determining the final properties and this parameter is very much dependent on the length of the individual fibre. Upon fracture during testing or service life, fibre length, L is the determining factor whether that particular fibre will break and contribute its full strength to the composites or pull-out instead and only contribute partially to the composite strength [9].

Since SFC exist with much shorter average fibre length [10] and much higher total fibre length, total number of fibres will be much more than that of LFC. This will certainly produce more fibre end and notching effect. During testing or service life, this area will be the weakest point and become the stress concentration area.

Finally, it can be concluded that LFC, despite the reduction in their fracture strain of 10-17% and having lower values of total fibre length (35%)and total fibre length (59%) as compared to those of SFC, still show improvement in tensile strength (16-22%) and tensile modulus between (10-38%).

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