Multiwall Carbon Nanotubes / Polymer Composite Fibers

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Abstract

The broad objective of this study was to determine whether the introduction of carbon nanotubes into a polymer matrix would have a significant effect upon its physical properties. The study was carried out by intimately mixing varying concentrations of multiwall carbon nanotubes with polypropylene. These materials were then extruded through a capillary die and drawn down to form composite fibers. Their mechanical properties were measured and compared to virgin polypropylene filament.

Introduction

The addition of conductive fillers is commonly used to induce conductivity into otherwise insulating polymers. Carbon black at concentrations of between 15 and 20wt% is often used for this purpose. However, the inclusion of fillers may diminish the other desirable properties of the polymer matrix. Thus, the filler content must be minimized otherwise processing the composite by extrusion or injection molding may be difficult, the mechanical properties reduced and cost increased. The remarkable properties of carbon nanotubes offer the potential for enhancing the properties of polymer matrices at very low nanotube concentrations. This could enable high performance lightweight materials to be developed that could be used in a wide range of advanced engineering applications.

Experimental

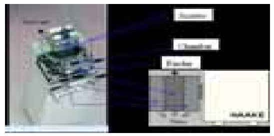

Figure 1 Haake Polylab Reomixer

Mixing: Polypropylene and multiwall nanotubes (MWNT) were blended in a HAAKE Polylab Rheomixer, (Figure1). Dispersion of the MWNTs is crucial to the production of both a homogenous product and to composite performance that would be impaired by inhomogeneity in composition. The optimum conditions for mixing were investigated by varying the three controlling parameters temperature, residence time and rotor speed. Temperature was maximized, typically around 200°C, to provide a fluid matrix but without risking degradation of the polypropylene, while time and rotor speed were minimized for similar reasons. At the completion of the test the composite material was recovered and then embrittled by cooling with dry ice and crushed to -5mm in a laboratory mill.

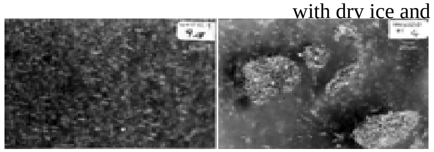

Figure 2 Illustration of Good & Poor Dispersion

Dispersion: Dispersion was determined quantitatively by optical microscopy of polished sections of the samples set in resin (Figure 2). At any given temperature, the dispersion efficiency can be related to the mechanical energy input into the mix, approximating to a logarithmic function, Figure 3.

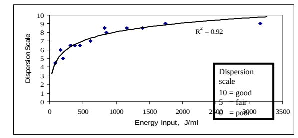

Figure 3 Fiber Dispersion as a Function of Energy Input

Figure 4 Haake Twin Screw Extruder

Spinning: The Polypropylene/MWNT composite material was transferred to a Haake Twin Screw Extruder operating at 200ºC, Figure 4. The melt was extruded through a 1 x 20mm capillary die to produce a composite thread, 1mm in diameter. This was attached to a wind-up drum rotating at speeds of up to 1700rpm to draw filament in the range 20 to 75µm. The shear fields generated in the spinning process produce composite fibers with the MWNT aligned with the axis of the fiber, Figure 5.

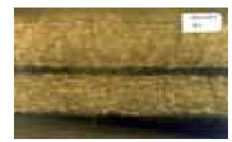

Figure 5 Polypropylene Fiber with Aligned MWNTs

Testing: The tensile properties of the fibers were measured using a MTS QTest instrument. Ten fibers from each test were mounted on cards and their diameter measured by optical microscopy along the 19mm gauge length. The fibers were tested to failure in tensile mode with a crosshead speed of 50mm/minute, (ASTM D2101).

Conclusions

Multiwall carbon nanotubes have been successfully dispersed in a polypropylene matrix by high shear mixing. The product composite materials containing up to 2.5vol% MWNTs were melt spun to yield continuous filament. There was a substantial increase in the elastic modulus, (by ~100%) of the composite fibers in comparison to the virgin polypropylene fibers. Alignment of the nanotubes within the fiber offers a practical route to the production of composites with controlled nanotube architecture.

Results and Discussion

There is a significant increase in the elastic modulus as the concentration of MWNTs in the polymer is increased, Figure 6. In contrast, there is no apparent improvement in the tensile strength of the fibers, Table 1. Tensile strength is controlled by the distribution of flaws in the fiber and it would thus appear that some of the MWNTs are contributing to these weaknesses. However, improvement to the interfacial bonding between the MWNTs and the polymer matrix could have a major influence on the tensile strength. Surface treatment of the MWNTs to make them more compatible with the matrix, or using a matrix with different characteristics could prove to be informative areas of investigation. The electrical properties

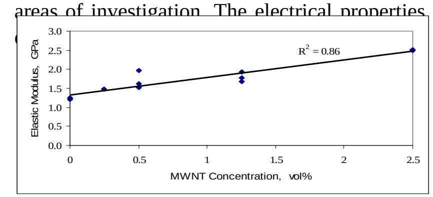

Figure 6 Modulus of Polypropylene/MWNT Fiber

Sample	MWNT conc^n (vol%)	Screw feed rate (rpm)	Take-up spool speed (rpm)	Fiber Properties: Diameter (µm)	Yield strength (MPa)	Yield strain (%)	Elastic modulus (GPa)	Break strength (MPa)	Break strain (%)
Virgin PP	0	0.5	1700	54	61 ± 3	8.5 ± 1.2	1.20 ± .15	n/m	n/m
Mixed PP	0	0.25	1700	29	54 ± 5	8.5 ± 1.2	1.25 ± .14	n/m	n/m
4069	0.25*	0.25	1700	30	52 ± 4	10.1 ± 1.7	1.48 ± .16	n/m	n/m
Hext 1a	0.5	0.25	1700	36	42 ± 8	8.9 ± 2.6	1.62 ± .54	66 ± 20	620 ± 210
Hext 1d	0.5	0.25	530	49	46 ± 12	6.5 ± 1.7	1.96 ± .72	58 ± 16	720 ± 170
Hext 1f	0.5	2.0	1700	66	36 ± 13	7.4 ± 2.8	1.51 ± .43	43 ± 10	590 ± 210
Hext 2b	1.25	n/m	370	28	45 ± 4	6.2 ± 0.6	1.67 ± .24	70 ± 3	800 ± 110
Hext 2c	1.25	1.0	880	58	44 ± 26	3.9 ± 1.0	1.77 ± .59	61 ± 28	890 ± 170
Hext 2g	1.25	1.0	1700	35	50 ± 32	6.8 ± 3.2	1.93 ± .62	78 ± 52	600 ± 220
Hext 3b	2.5	1.0	530	76	52 ± 9	3.1 ± 0.5	2.51 ± .44	51 ± 9	400 ± 170
Hext 3d	2.5	1.0	530	54	48 ± 19	2.9 ± 0.8	2.50 ± 1.05	51 ± 18	540 ± 290

Table 1 Polypropylene/MWNT Fiber Properties

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