DEVELOPMENT OF ELECTRICALLY CONDUCTIVE NYLON 6,6 AND HIGH TEMPERATURE NYLON

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Introduction

Most polymer resins are thermally and electrically insulating. Increasing the thermal and electrical conductivity of these resins opens new markets. In this research, Michigan Technological University (MTU) performed compounding runs followed by injection molding and testing (tensile properties, in-plane electrical resistivity, in-plane thermal conductivity, through-plane thermal conductivity, and differential scanning calorimetry) of carbon filled nylon 6,6 and high temperature nylon (HTN). A toughening agent was added to selected HTN formulations. One glass fiber, a 3.2mm chopped E-glass, was used in selected formulations. The carbon fillers investigated included a PAN–based carbon fiber (in 3.2 mm chopped and 200 μm milled form), an electrically conductive carbon black, and Thermocarb. Thermocarb is high quality synthetic, milled (300 μm) graphite that is available from Conoco, Inc.

Experimental Methods

To conduct the extrusions, a Brabender Twin Screw Extruder (42 mm diameter, parallel, counter-rotating, intermeshing twin screw with l/d=6.5, single feed port) was used. An Arburg Model A221-75-350 Allrounder (30 mm diameter, l/d= 14.9) was used to injection mold test specimens. Tensile properties were determined using ASTM D638. The volumetric longitudinal (in-plane) electrical resistivity (ER) was measured using the four-probe technique (1). Through-plane thermal conductivity (TC) was measured using a Holometrix Model TCA-300 Thermal Conductivity Analyzer, which uses ASTM F433 guarded heat flow meter method. In-plane TC was determined using the four-probe method described elsewhere (1). A Shimadzu Model 50 DSC was used to conduct the differential scanning calorimetry tests.

Results and Discussion

As expected, increasing filler content decreases percent strain at failure. To determine which filler had the largest effect on strain, a linear model [$y=\Sigma(a_i x_i)$ where x_i is the weight percent of each constituent, a_i is a constant value, and y is the log % strain] was used. This model showed that carbon black causes the most significant decrease in tensile strain. Figure 1 shows the log (in-plane ER) vs. wt% carbon black. Using the same linear model [$y=\Sigma(a_i x_i)$], one determines that increasing the amount of carbon black causes the most significant decrease in in-plane ER. Figure 2 shows the through-plane TC vs. wt% Thermocarb graphically. Based on the same linear model, one determines that increasing the amount of Thermocarb increases the through-plane thermal conductivity.

As expected due to flow patterns produced in the specimens during injection molding and the anisotropy of the carbon fillers, the in-plane TC is higher than the through-plane TC. For the nylon 6,6 and HTN based conductive resins, the ratio of in-plane TC to through-plane TC is approximately 3.

DSC results for the HTN–based conductive resins show that the melt and recrystallization temperatures are not affected by varying amounts of filler.

Table 1 shows the conductive resins that met the project goals (ER <50 ohm-cm and >1% tensile strain at failure). The ER values obtained in this project were lower than what would be expected by these conductive fillers used alone (2,3). Hence, these results show that there is a synergistic effect on electrical conductivity due to the combination of carbon black, Thermocarb, and in some cases, PAN-based carbon fibers. It is likely that the highly branched, high surface area, electrically conductive carbon black allows pathways to form with Thermocarb and PAN-based carbon fiber which results in enhanced electrical conductivity.

Conclusions

As a result of this study, the following conclusions can be made.

- Carbon black causes the most detrimental effect on strain.
- Increasing the amount of Thermocarb increased the through-plane TC of the composite.

- The in-plane thermal conductivity is 3 times higher than the through-plane TC.
- Carbon black causes the largest decrease in the in-plane ER of the composite.
- Combinations of conducting fillers, which all include Thermocarb and carbon black, produce a conductive resin that meets the targeted specifications.

References

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Acknowledgements

The authors gratefully thank Conoco, Inc. and DuPont, who funded this work, and the project monitor, Kenneth W. Tucker.

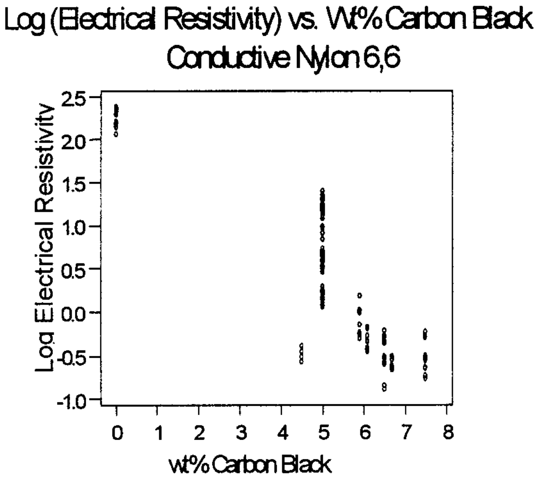
Log (Electrical Resistivity) vs. Wt% Carbon Black
Conductive Nylon 6,6

Figure 1: Log (In-Plane Electrical Resistivity) vs. Wt% Carbon Black for Nylon 6,6 Based Conductive Nylons

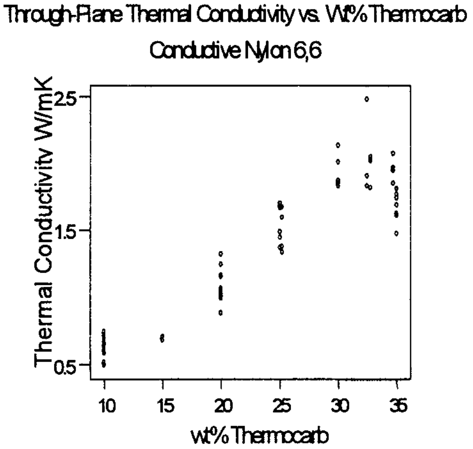
Through-Plane Thermal Conductivity vs. Wt% Thermocarb
Conductive Nylon 6,6

Figure 2: Through-Plane Thermal Conductivity vs. Wt% Thermocarb for Nylon 6,6 Based Formulations

Table 1: Summary of Results for Best Formulations

Material Number	Description	Actual wt%		Tensile Max Stress MPa	Tensile % Strain @ Max Stress	Thru-Plane Therm. Cond. @ 55C W/mK	In-Plane Therm. Cond. @45C W/mK	In-Plane Vol. Elec. Resistivity ohm-cm
17	Nylon 6,6	70	avg	85.02	1.43	0.69	2.46	15
	Glass Fiber 1/8"	10	s	1.91	0.24	0.011	0.42	1.02
	Thermocarb	15	n	5	5	3	2	12
	Carbon Black	5						
	Total	100						
18	Nylon 6,6	75	avg	72.58	1.18	0.69	2.24	17.49
	Glass Fiber 1/8"	5	s	6.78	0.12	0.02	0.37	2.87
	Thermocarb	10	n	5	5	3	2	9
	Carbon Black	5						
	1/8" Chopped PAN Based Carbon Fiber	5						
	Total	100						
HTN-5	High Temperature Nylon	50	avg	30.42	1.22	0.49	1.52	12.76
	Glass Fiber 1/8"	10	s	1.89	0.1	0.01	0.54	1.48
	Toughening Agent	20	n	5	5	2	2	6
	Carbon Particles	15						
	Carbon Black	5						
	Total	100						