TRANSPORT PROPERTIES OF RIBBON-SHAPED CARBON FIBERS

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Introduction

Previous work conducted at Clemson University has shown that ribbon-shaped carbon fibers represent a potential low-cost alternative to traditional round-shaped carbon fibers for high thermal conductivity applications [1,2]. The as-spun molecular orientation of ribbon fibers is more aligned parallel to the fiber axis, and therefore lower graphitization temperatures are required to achieve properties comparable to those of commercial round fibers.

The thermal conductivity of ribbon-shaped fibers produced at Clemson University and graphitized at 2400°C was measured by two different methods.

Experimental

Several sets of ribbon-shaped fibers were produced at Clemson University using an ARA mesophase pitch produced by Mitsubishi Gas Chemical Company. As-spun fibers were oxidized in air at 280°C for 30 minutes and graphitized in helium at 2400°C. Detailed procedure for the spinning and heat treatment of these fibers can be found elsewhere [3].

Two methods were utilized to evaluate the transport properties of the ribbon fibers. The first instrument, located at BP Amoco in Alpharetta, GA, measures a fiber sample's thermal response to an oscillating heat input [4]. This device was used to measure room-temperature thermal diffusivity of the fibers. A second apparatus, located at the University of Louvain-la-Neuve in Belgium, measures a fiber sample's thermal response to a controlled thermal gradient [5]. This device was used to measure the temperature dependence of the thermal conductivity of selected fiber sets.

Results and Discussion

Figure 1 shows the values of thermal conductivity obtained with the Angstrom's apparatus versus their corresponding electrical resistivities. Two curves representing empirical relations between electrical resistivity and thermal conductivity were added to this plot for comparison. The first curve corresponds to the correlation derived and published by Lavin [6], the second curve represents a proprietary correlation derived by Amoco.

Even though both correlations are based on experimental data obtained for round fibers and spun from different mesophase precursors, they provide a reasonably good fit for the ribbon fiber data, as shown in Figure 1.

Data obtained with the thermal potentiometer and corresponding to the temperature-dependence of both electrical resistivity and thermal conductivity are shown in Figures 2 and 3, respectively. Data previously published for two types of commercial round fibers [7] has been added to these plots for comparison.

The data in both figures show that the temperature-dependence behavior of electrical resistivity and thermal conductivity for ribbon fibers is similar to that for commercial round fibers. Figure 3 also shows that the final properties of ribbon fibers produced at Clemson and graphitized at only 2400°C are comparable to those of commercial round fibers, graphitized at temperatures above 3000°C.

Table 1 summarizes the results obtained for the two sets of fibers that were tested by both methods, as well as their electrical resistivity values and the estimated values of thermal conductivity based on the electrical resistivity.

The results obtained with Angstrom's method appear to be in closer agreement with those estimated by Amoco's proprietary electrical resistivity/thermal conductivity correlation. However, the results obtained with the thermal potentiometer agree more closely with those estimated by Lavin's electrical resistivity/thermal conductivity correlation.

The close agreement of the thermal potentiometer data and the Lavin's correlation should be expected because Lavin's correlation was based on experimental data obtained on commercial round Amoco P-series and DuPont E-series fibers using the same thermal potentiometer employed in the current research. However, the measured values of thermal conductivity of the ribbon fibers were higher than those predicted by Lavin's correlation. This indicates that the internal structure of the ribbon fibers is less disrupted than that of the fibers studied by Lavin. The reason for this may be that better structure is developed in ribbon fibers during extrusion or that the Mitsubishi mesophase can more readily develop an oriented, graphitic structure during fiber processing than other mesophase precursors.

It is very difficult to determine which method for measuring thermal conductivity is more accurate. There are unavoidable sources of error in both. In Angstrom's method the uncertainty in the thermal diffusivity measurement plus uncertainties from the heat capacity and density measurements add to the instrument error. In the thermal potentiometer, the calculation of the cross-sectional area of the fiber bundle appears to be the major source of error.

With the thermal potentiometer, temperature-dependence measurements of both electrical and thermal conductivity can be performed. The Angstrom's apparatus, in its current state, permits only room temperature measurements of both electrical and thermal conductivity. However, it could be modified to allow for temperature-dependence measurements.

Conclusions

Both Angstrom's apparatus and the thermal potentiometer appear to be reliable methods for determining the room-temperature thermal conductivity of carbon fibers. However, the thermal potentiometer offers the advantage of temperature-dependence measurements.

Ribbon-shaped fibers produced at Clemson University and graphitized at only 2400°C exhibited transport properties comparable to those of commercial round-shaped fibers and graphitized at temperatures above 3000°C.

References

[1] Edie, DD, Fain CC, Robinson KE, Harper AM, Rogers, DK. Ribbon-shape carbon fibers for thermal management. Carbon 1993;31(6):941-949.

[2] Edie, DD, Robinson KE, Fleurot O, Jones SP, Fain CC. High thermal conductivity ribbon fibers from naphthalene-based mesophase. Carbon 1994;32(6):1045-1054.

[3] Cato AD, Gallego NC, Edie DD, Deshpande GV. Rectangular carbon fibers for thermal management applications. Proceedings of the 22nd annual conference on Composites, materials and structures. Cocoa Beach (Florida. USA): Society, 1998.

[4] Gallego NC, Edie DD, Treleaven JW, Deshpande GV. The thermal conductivity of ribbon-shaped carbon fibers. Proceedings of the 23rd annual conference on Composites, materials and structures. Cocoa Beach (Florida. USA): Society, 1999.

[5] Piraux L, Issi JP, Coopmans P. Apparatus for thermal conductivity measurements on thin fibres. Measurement 1987;5(1):2-5.

[6] Lavin JG, Boyington DR, Lahijani J, Nysten B, Issi JP. The correlation of thermal conductivity with electrical resistivity in mesophase pitch-based carbon fiber. Carbon 1993;31(6):1001-1002.

[7] Nysten B. Microstructure et proprietes de transport: Les fibres de carbone. Universite Catholique de Louvain, Belgium, PhD thesis, 1991.

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Table 1. Room-temperature electrical resistivity and thermal conductivity of selected fiber sets.

		Thermal Conductivity (W/m·K)			
		Estimated		Measured	
Ribbon Fiber Set	Electrical Resistivity (μΩ·m)	Amoco's Correlation	Lavin et al.'s Correlation	Angstrom's Method	Thermal Potentiometer
S1	2.94 ± 0.10	452	502	442	567
S9	2.15 ± 0.07	600	635	544	696

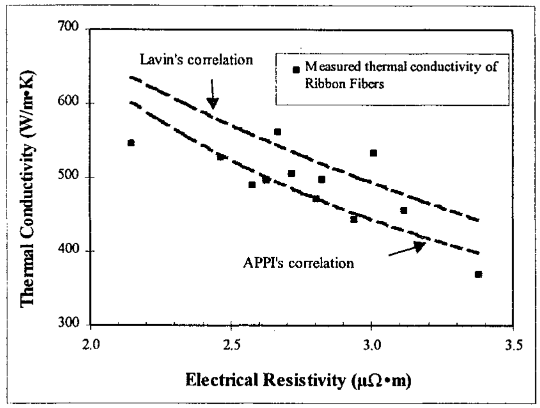

Figure 1. Values of thermal conductivity, measured with Angstrom's apparatus, versus the measured room-temperature electrical resistivity for ribbon fibers.

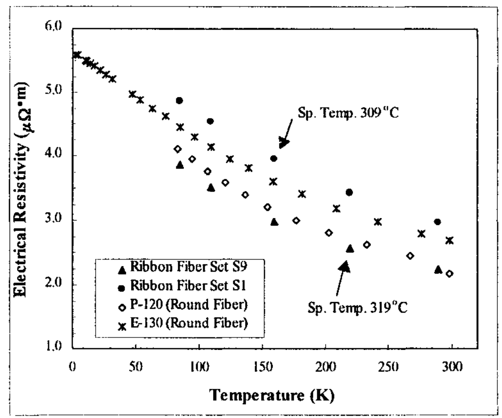

Figure 2. Temperature-dependence electrical resistivity of two sets or ribbon fibers and two types of commercial round fibers.

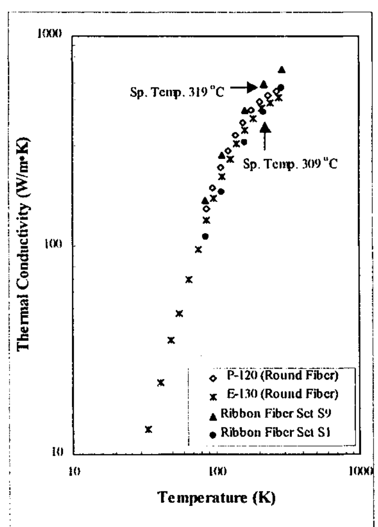

Figure 3. Temperature-dependence thermal conductivity of two sets or ribbon fibers and two types of commercial round fibers.