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Thermal Anisotropy of Hollow Carbon Fiber-Carbon Composite Materials

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Abstract : Carbon composites were prepared with pitch-based round, C, hollow-type carbon fibers and pitch matrix. The thermal conductivities parallel and perpendicular to the fiber axis were measured by steady-state method. It was found that the thermal conductivities depended on the cross-sectional forms of the reinforcing fibers as well as the reinforcing orientation and carbon fiber precusors. Especially, mesophase pitch-based hollow carbon fiber-carbon composites had the most excellent thermal anisotropy, which was above 100.

Keywords : hollow-type carbon fiber, thermal anisotropy, isotropic reinforcingfibers.

1. Introduction

A field of aerospace application such as rocket nozzle or nose cone utilizes the highly directional thermal conductivity of quasi-crystalline pyrolytic carbon to distribute heat and to insulate, because heat loads must be managed, that is, transferred or dissipated[1~6].

Recently, the fibrous composites have been on the rise as the materials for the thermal management because of their outstanding properties and of the wide range of fabrication processes[6-10]. Mesophase pitch-based carbon fibers offer an ideal structure for heat conduction. This is due to their ability to develop graphitic crystallinity and a high degree of basal-planes orientation in the axial direction[5]. Non-circular carbon fibers including hollow cross-section prepared by mesophase-based pitch lead tobetter orientation than that of the ordinary cross-sectional carbon fiber along the fiber axis[11~13]. Therefore, with appropriate combination of selected matrices and reinforcement, it is now possible to tailor composite materials with almost the desired thermal conductivity as to the fiber types[5].

In this research, it was investigated how thermal transfer characteristics of the fibrous composite are effected by fiber cross-sectional shapes.

2. Materials and Experiment

Isotropic and anisotropic carbon fibers were

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produced from petroleum and coal tar pitch, respectively[14]. The prepregs for producing C/C composites were prepared by mesophase pitch powder and isotropic/anisotropic carbon fiber balanced as the same weight in the electric oven remaining about 280 ℃. And then these were molded by hot-press to the size of 5x8 cm. The green-body samples were carbonized up to 1000 ℃ at 5 ℃/min, and then resulting pores were impregnated by the same pitch under a vacuum. These procedures were repeated 3-4 times. The principle of the measurement is based on the heat transfer of Fourier's law. The instrumentation for measuring the thermal conductivity provides accurate measurement of temperature and power supply as a steady-state method. Fast response temperature probes(thermocouples), with a resolution of 0.1 ℃, give direct digital readout in ℃. The power control circuit provides a continuously variable electrical output of 0-100 Watts with direct readout [15]. The measurements of the thermal conductivity are made on a cylindrical sample of 2.5 cm in diameter and 2 mm in thickness at the temperature range of 100 to 250 ℃. The calculation of thermal conductivity values follows the equations below:

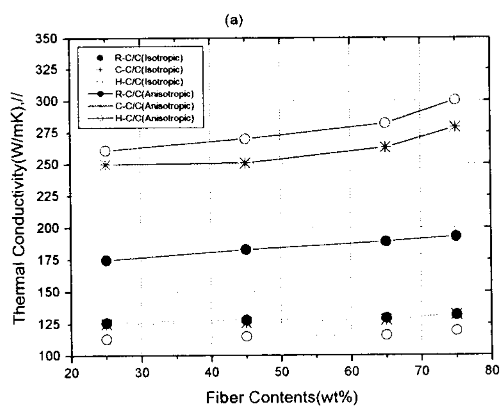
$$K = q*t/[A(T2-T1)]$$

where,
k : thermal conductivity,
A : Area of heat conduction,
T2-T1 : Temperature differences between heating and cooling part,
t : Sample thickness,
q : Watts applied.

3. Results and Discussion

The fibrous composite has anisotropic characteristics in heat transfer as well as in mechanical property. The thermal conductivities for isotropic and anisotropic carbon fibers-reinforced carbon composites were compared as functions of fiber cross-sectional forms(round, hollow and C-type), contents(wt%) of them(Fig. 1) and measuring temperature(Fig.2).

Fig. 1(a) shows the thermal conductivity parallel to the fiber axis of the composites reinforced with three different cross-sectional types of carbon fibers measured at 200 ℃. Heat transfer of mesophase pitch-based carbon fibers reinforced composites was higher than those of isotropic pitch-based ones. Also, C and hollow types carbon fibers reinforced composites were higher than the ordinary cross-sectional (round) type ones. Whereas, as Fig.1(b) show, thermal conductivities perpendicular to the fibers showed the opposite trend. Especially, hollow-fibers composite have the lowest conductivities. So, we can expect great thermal anisotropy(means the ratio of conductivity parallel(//) and perpendicular(+) to the fiber direction), which may be required in aerospace application such as rocket nozzle or nose cone. The thermal anisotropiccharacteristics are in Fig.1(c). Mesophase pitch-based hollow and C-type carbon fibers composites were superior to the ordinary cross-sectional (round) type ones.



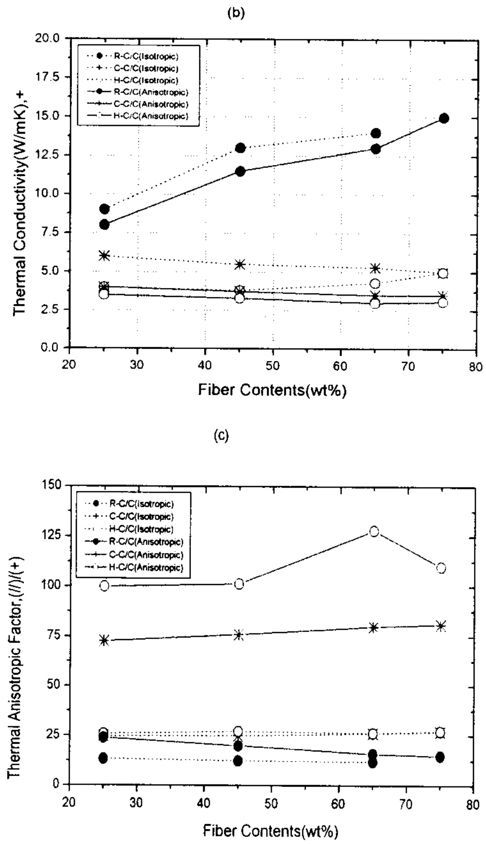


Fig. 1. Changes in thermal conductivity parallel(a)/perpendicular(b) to the fiber axis and anisotropy factor(c) with measuring temperature.(with thickness = 2mm, density =isotropy(1.58), anisotropy(1.65)).
Note that R-C/C(Isotropic) means carbon composites reinforced with round cross-section isotropic carbon fibers. And H, C means carbon fibers with hollow, C-type cross-section.(see Fig. 3, 4)

On the other hand, in Fig.2(a,b,c) are plotted values as to temperatures. The results were similar to these as to fiber contents mentioned above.

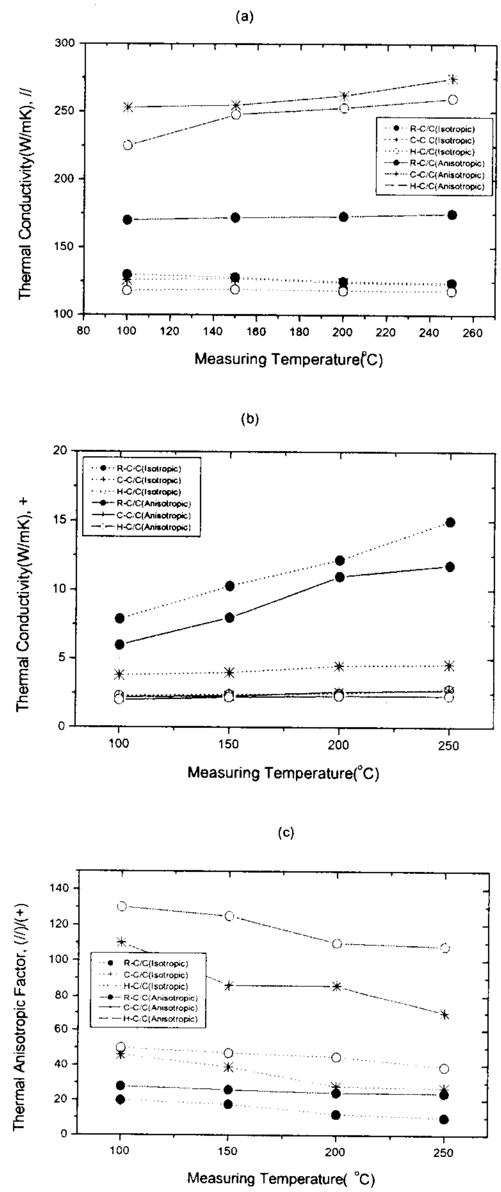
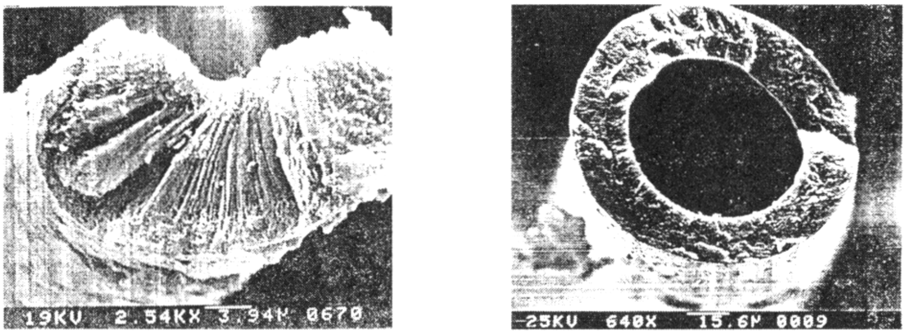
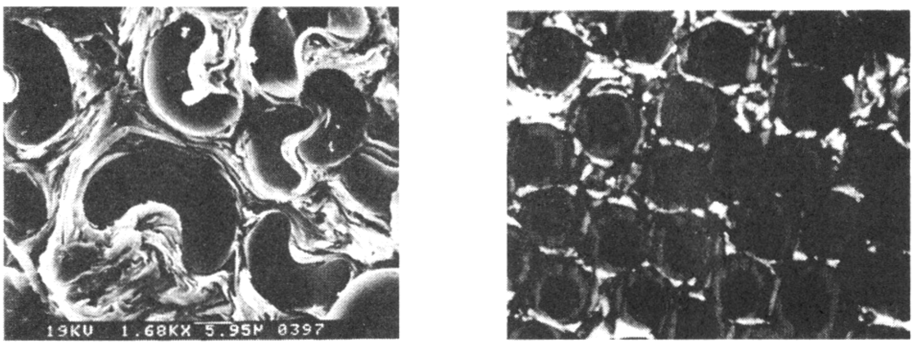


Fig. 2. Changes in thermal conductivity parallel(a)/perpendicular(b) to the fiber axis and anisotropy factor(c) with measuring temperature.(with thickness = 2mm, density =isotropy(1.58), anisotropy(1.65)).
I : isotropic carbon fibers reinforced composites, A : anisotropic carbon fibers reinforced composites.



(a) Anisotropic C-type carbon fiber (b) Anisotropic Hollow type carbon fiber

Fig. 3. Micro-structures of mesophase pitch-based carbon fibers.



(a) Isotropic C-type carbon fiber reinforced carbon composites (b) Isotropic hollow-type carbon fiber reinforced carbon composites

Fig. 4. Micro-structures of composites.

In this research, it was found that the fiber cross-sectional forms and their different molecular structures have an effect on the thermal anisotropy characteristics of the fibrous composites. Especially, the thermal conductivity perpendicular to the fiber axis in mesophase pitch-based H-C/C composites was the lowest. These results can be expected from the micro-structures show in Fig.3 and 4. In spite of its actualheat transfer area is smaller, the parallel conductivities of H-C/C composites were also similar to that of R-C/C. These phenomena indicate that when the fibers of the same contents were reinforced the molecular orientation within hollow carbon fibers is more dominant than the effect of matrix of R-C/C composites in the conductivity. Mesophase pitch-based C-C/C composites were also somewhat excellent in the thermal conductivity parallel to thefiber axis and in the thermal insulation effect perpendicular to the fiber axis. These facts are due to the micro-structure(prefer molecular orientation) of the C-type, hollow carbon fibers, and thermal resistance wall induced by the macro-structure(enlargement surface area).

4. Conclusions

The cross-sectional shapes like C-and

hollow-shape carbon fibers can be designed to maximize mechanical and other properties. The applications for hollow-shape fibers include composite reinforcement, micro-hear exchanger, insulation, hear flow control and so on. In the research, it was found the hollow and C-type carbon fiber-carbon composites had a high directional thermal conductivity to distribute and to insulate heat such as structures rocket nozzle, nose cones an so on comparing with that of round carbon fibers. The results for non-circular carbon fibers are inferred from the reasons following as:

(1) inducing higher molecular orientation due to wider shear stresses during the spinning, (2) hindering the hear conduction from matrix to fibers by skin structures, where graphite sheets lie parallel to the surface, (3) possessing the wider surface area, which offer greater heat flux along the fiber axis, and (4) forming the tunnels by hollow fibers and the ability for insulating and exchanging heat.

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