Characterization of High Thermal Conductivity Carbon Materials

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INTRODUCTION

Recently, different grades of carbon materials which have higher thermal conductivity have been manufactured to use for plasma facing components of fusion devices[1,2,3]. Since the plasma facing materials are often subjected to high thermal and mechanical stresses locally, materials having higher thermal conductivity, higher mechanical strength and toughness are desirable. In particular, higher thermal conductivity materials at high temperatures are required because erosion due to high heat loading is smaller. Generally, the thermal conductivity of carbon materials is known to be influenced by higher heat treatment temperature than the final treatment one, graphitization conditions and the kind of carbon fiber used for carbon/carbon(c/c) composites. In addition, it is considered that an addition of metallic elements, such as copper and silver, with high thermal coductivity raises that of carbon materials.

This paper describes an improvement of thermal conductivity of carbon materials due to the treatments stated above. The effects of high temperature heat treatment, an addition of the metallic elements (copper and silver) and pressurized graphitization on the thermal conductivity of carbon materials have been examined.

EXPERIMENTAL

The base materials were a nuclear grade fine-grained isotropic graphite, IG-43, no-pitch impregnated IG-43 and a felt type c/c composite, CX-2002U which were manufactured by Toyo Tanso Co. Ltd.. The felt plane in CX-2002U was denoted as XY-plane. The effects of heat treatment temperature, an addition of metallic elements and pressurized graphitization were examined. The heat treatment temperature was over 3573K higher than the final heat treatment temperature, 2800-3000K. Copper and silver which do not make compounds with carbon even at higher temperatures were chosen as a metallic element to be impregnated into carbon that has higher thermal conductivity. Copper and silver was impregnated to the three base materials, respectively. The materials tested are listed in Table 1. The thermal conductivity measurement was performed using a laser type thermal properties measurement apparatus (Rigaku MJ-800HV) on the specimen of 10mm dia.X(2-4)mm length at 293-1200K.

RESULTS AND DISCUSSION

The thermal conductivity of IG-43 graphite increased slightly at room temperature (RT) and slightly decreased at higher temperature (HT) due to high heat treatment temperature. In the case of CX-2002U c/c composite the thermal conductivity in the fiber axis direction of the felt (XX) increased at RT and changed little at HT. On the other hand, the thermal conductivity in the rectangular direction(ZZ) to the fiber axis (XX or YY) decreased slightly at RT and changed little at HT. The temperature dependence of thermal conductivity of IG-43, Cu-impregnated IG-43 and Ag-impregnated IG-43 are shown in Fig.1 and Fig.2, respectively. The thermal conductivity of the composite materials of IG-43 with copper or silver should exist between that of copper and IG-43 according to the mixing ratio. There are several laws of mixture which might be used for the composite materials. If we express the volume fraction of metal and base material as ϕ_p and ϕ_m, and their thermal conductivities by parallel-slab model as λp and λm, respectively, the thermal conductivity of a composite material is expressed[4,5]by

$$\lambda = \lambda_p \phi_p + \lambda_m \phi_m = \lambda_p \phi_p + \lambda_m (1 - \phi_p).$$

On the other hand, in the case of the Maxwell model which assumes homogeneously diffused sphere particles in the matrix,

$$\lambda = \lambda_m (1 + 2\phi_p A) / (1 - \phi_p A),$$

where $A = (1 - \lambda_m / \lambda_p) / (2\lambda_m / \lambda_p + 1)$.

It seems that both equations do not always give right values for carbon materials containing metallic element which intrudes into the matrix with different shapes. However, it turns out easily that there is no significant difference even if either equation above is used to estimate the thermal conductivity of the composite materials. The Maxwell model was used in the present study. Fig.1 shows that the model does not agree well with the data at RT and agree comparatively well with the data at HT. In contrast to this Fig.2 indicates that the experimental data agree well with the model in the case of IG-43 containing silver. No-pitch impregnated IG-43 graphite indicated the same behavior as IG-43.

CONCLUSIONS

The thermal conductivity of fine-grained isotropic graphite and a c/c composite increased due to impregnation of copper and silver. In particular, it is noted that the thermal conductivity of the copper impregnated graphite indicated smaller temperature dependence than that of the original one. It suggests that copper impregnation into c/c composite materials can raise the thermal conductivity at higher temperature compared with the original materials.

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References

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Table 1 Materials tested.

IG-43	Graphite
IG-43+3573K	
IG-43+9.2vol%Cu	
IG-43+9.3vol%Ag	
CX-2002U	C/C
CX-2002+13.1vol%Cu	
CX-2002+12.2vol%Ag	
CX-2002+491kPa	

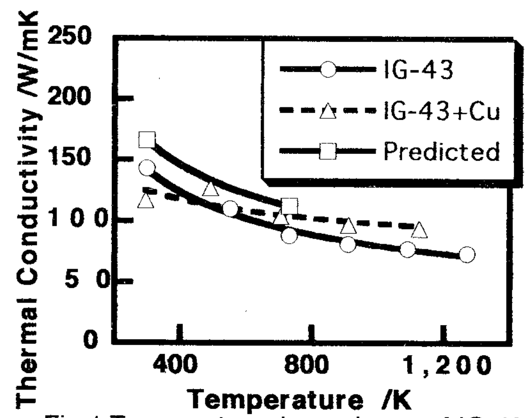

Fig.1 Temperature dependence of IG-43 and IG-43+Cu with the predicted curve.

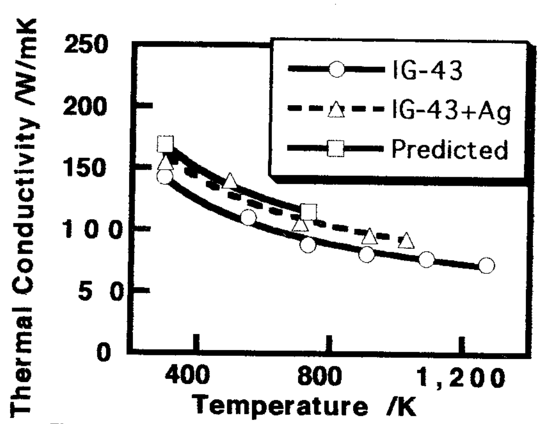

Fig.2 Temperature dependence of IG-43 and IG-43+Ag with the predicted curve.