HIGH THERMAL CONDUCTIVITY SIC/SIC COMPOSITES FOR FUSION APPLICATIONS-II

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OBJECTIVE

The objective of this work is to examine SiC composites fabricated by various processing methods designed to improve composite thermal conductivity. Specifically, it is desired to increase the thermal conductivity of these composites to meet requirements for advanced fusion energy systems.

SUMMARY

This report covers material presented at the IEA/Jupiter Joint International Workshop on SiC/SiC Composites for Fusion Structural Applications held in conjunction with ICFRM-8, Sendai, Japan, Oct. 23-24, 1997. An unirradiated SiC/SiC composite made with MER-developed CVR SiC fiber and a hybrid PIP/CVI SiC matrix exhibited room temperature transverse thermal conductivity of 45 W/mK. An unirradiated SiC/SiC composite made from C/C composite totally CVR-converted to a SiC/SiC composite exhibited transverse thermal conductivity values of 75 and 35 W/mK at 25 and 1000°C, respectively. Both types of SiC/SiC composites exhibited non-brittle failure in flexure testing.

PROGRESS AND STATUS

Introduction

This report updates the status of work performed by MER Corporation to develop high thermal conductivity SiC/SiC composites for fusion applications reported initially at the first IEA SiC/SiC Workshop held at Ispra, Italy and in a Fusion Materials Semiannual Progress Report [1,2].

A low-cost, chemical vapor reaction (CVR) process was first developed to directly convert graphite fiber to high-purity, crystalline ß-SiC fiber [3]. Initially Celion 1K, and more recently Amoco T-300 graphite fibers, were used as the precursor graphite fiber. Starting with CVR-converted SiC fiber, two distinct processes (I and II) were developed to fabricate SiC/SiC composite which exhibited high transverse thermal conductivity and non-brittle fracture. Table 1 summarizes the progress-to-date by comparing selected property values for the composites fabricated by the Type I and II processes with those for composites fabricated by the Type I process before it was optimized and by a conventional CVI (chemical vapor infiltration) process using Hi Nicalon™ fiber.

In the hybrid PIP/CVI (Type I) process, the composite matrix was produced by polymer infiltration and pyrolysis (PIP) with a final CVI step. During this reporting period, the Type I process was further optimized to yield composite with increased bulk density (from 2.35 to 2.55 g/cc), increased RT thermal conductivity (from 45 to 55 W/mK in the transverse direction), increased RT 4-pt. flexure strength (from 275 to 320 MPa) and decreased open porosity (from 10 to 8%).

*Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

In the CVR-CVR (Type II) process, a composite preform made from graphite or partially converted CVR-SiC fiber with a pitch-derived carbon matrix was totally converted to crystalline SiC/SiC composite by a CVR process. An initial fabrication run produced a composite that exhibited a relatively high bulk density (2.65 g/cc), much higher thermal conductivity values (75 and 35 W/mK at RT and 1000°C, respectively) and an acceptable flexure strength (250 MPa).

Table 1. Comparison of selected properties for SiC/SiC composites

Type	Density (g/cc)	Ther. Cond. RT (W/mK)	Ther. Cond. 1000°C (W/mK)	Flex. Strength RT (MPa)	Open Porosity (%)
Hi Nicalon/CVI (Ref.)	2.55	13	10	350	15
Type I - Celion 1K (PIP/CVI hybrid)	2.35	45	nm	275	10
Optimized Type I - T300 (PIP/CVI hybrid)	2.55	55	nm	320	8
Type II - T300 (CVR/CVR)	2.65	75	35	250	15

In common, both Type I and II processes require a final high temperature anneal (≥1600°C) to achieve optimized thermal conductivity values. Such an anneal step is inaccessible with current state-of-the-art CVI- or PIP-produced composite made with Hi Nicalon or Nicalon CG fibers because of the thermochemical instability of the fibers when temperatures exceed about 1200°C [4]. The CVR-produced, high purity β-SiC fiber is thermodynamically stable to temperatures exceeding 1600°C; therefore it is amenable to high temperature treatments [5].

In Figure 1, the RT stress-strain curves for composite made by the optimized hybrid PIP/CVI and the CVR-CVR processes are compared to those for composite made by the CVI process with either Hi Nicalon or Nicalon CG fiber. Although the toughness (area under the curve) and strain-to-failure properties are slightly reduced, the ultimate strengths are comparable and the proportional limit stresses are higher. Thus, the composites produced either by the Type I or II processes with a final high temperature anneal exhibit much improved thermal conductivity values as well as density, strength and toughness values comparable to those for conventional CVI-produced composite.

FUTURE WORK

The irradiation behavior of these newly-developed, high thermal conductivity SiC/SiC composites will be examined after several low dose "rabbit" experiments as well as after a relatively high dose, high temperature (10 dpa-SiC, 800°C) experiment which will be carried out as part of the joint Monbusho/US Jupiter P3-4 SiC/SiC fusion materials test program.

ACKNOWLEDGMENTS

This work is being supported by a DOE- SBIR, Phase II Contract No. DE-FG02-94ER81487.

REFERENCES

1. J. C. Withers, W. Kowbel, R. O. Loutfy, G. E. Youngblood and C. Wong, "High Thermal Conductivity SiC/SiC Composites for Fusion Applications," p. 69 in the Proceedings of the IEA International Workshop on SiC/SiC Ceramic Composites for Fusion Structural Applications, 28-29 October 1996, Ispra, Italy.

2. J. C. Withers, W. Kowbel, R. O. Loutfy, G. E. Youngblood and C. Wong, "High Thermal Conductivity SiC/SiC Composites for Fusion Applications," p. 87 in the Fusion Materials Semiannual Progress Report for Period Ending December 31, 1996. DOE/ER-0313/21.

3. W. Kowbel, J. C. Withers, R. O. Loutfy, C. Bruce and C. Kyriacou, "Silicon Carbide Fibers from Graphite Precursors for Fusion Energy Applications," ?????

4. G. E. Youngblood, R. H. Jones, G. N. Morscher and Akira Kohyama, "Creep Behavior for Advanced Polycrystalline SiC Fibers," p. 89 in the Fusion Materials Semiannual Progress Report for Period Ending December 31, 1996. DOE/ER-0313/21.

5. MER reference on the high temperature stability of the MER fiber.

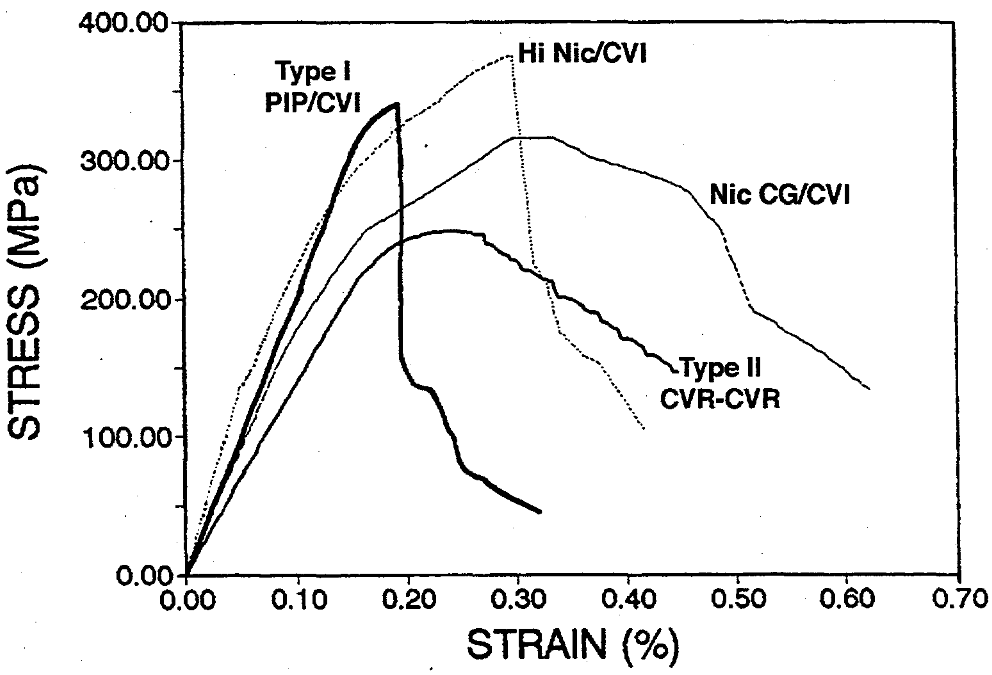

Figure 1. Comparison of 4-point flexure stress-strain curves at RT for SiC/SiC composites