MODELING THE TRANSVERSE THERMAL CONDUCTIVITY OF 2D-SIC$_F$/SIC COMPOSITES MADE WITH WOVEN FABRIC—G. E. Youngblood, D. J. Senor, and R. H. Jones (Pacific Northwest National Laboratory)*

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EXTENDED ABSTRACT

The hierarchical two-layer (H2L) model was developed to describe the effective transverse thermal conductivity (K_{eff}) of a 2D-SiC$_f$/SiC composite plate made from stacked and infiltrated woven fabric layers in terms of constituent properties and microstructural and architectural variables. The model includes the effects of fiber-matrix interfacial conductance, high fiber packing fractions within individual tows and the non-uniform nature of 2D fabric/matrix layers that usually include a significant amount of interlayer porosity. Previously, H2L model K_{eff}-predictions were compared to measured values for two versions of 2D Hi-Nicalon™/PyC/ICVI-SiC composite, one with a "thin" (0.11 μm) and the other with a "thick" (1.04 μm) pyrocarbon (PyC) fiber coating, and for a 2D Tyranno™ SA/"thin" PyC/FCVI-SIC composite. In this study, H2L model K_{eff}-predictions were compared to measured values for a 2D-SiC$_f$/SiC composite made using the ICVI-process with Hi-Nicalon™ type S fabric and a "thin" PyC fiber coating. The values of K_{eff} determined for the latter composite were significantly greater than the K_{eff}-values determined for the composites made with either the Hi-Nicalon™or the Tyranno™ SA fabrics. Differences in K_{eff}-values were expected for the different fiber types, but major differences also were due to observed microstructural and architectural variations between the composite systems, and as predicted by the H2L model.

Based on the results for the four different 2D-SiC$_f$/SiC systems examined, we concluded that the H2L model realistically describes how K_{eff} depends upon constituent, structural, microstructural and architectural variables for typical 2D composites made by chemical vapor infiltration (CVI). Using the H2L model and directly measured K_{eff}- and K_f-values, the fiber PyC coating K_c-values for these four composite systems, when assumed to be the same, were predicted to range from ≈28 W/mK at RT, increase to a maximum 34 W/mK at about 300°C, then continuously decrease to ≈ 28 W/mK at 1000°C. Likewise, the "intrinsic" K_m-values of the ICVI-SiC matrix were predicted to decrease continuously from ≈40 W/mK at RT to 18-20 W/mK at 1000°C. The corresponding K_m-values for the FCVI-SiC matrix were predicted to be somewhat less, ≈28 W/mK at RT decreasing to ≈15 W/mK at 1000°C.

Recent fusion reactor power core design concepts utilizing continuous fiber-reinforced SiC$_f$/SiC composite as a structural material require a K_{eff} ≈15-20 W/mK during operation in the temperature range 600-1000°C [1]. Based on observed degradation limits for irradiated SiC$_f$/SiC composite, to meet current fusion thermal conductivity goals we estimate that candidate SiC$_f$/SiC composites should have unirradiated K_{eff}-values of 43 and 27 W/mK minimum at 600°C and 1000°C, respectively. Current commercially available composites made by CVI-processing with Hi-Nicalon™ SiC fabric exhibit K_{eff}-values at 600°C and 1000°C of only about 11 and 9 W/mK, respectively, values which are much lower than design goals.

In Figure 1, measured K_{eff}-values for a SiC$_f$/SiC composite system made by the CVI-process with near stoichiometric SiC fiber (Hi-Nicalon™ type S) are shown along with H2L model predictions of K_{eff} for a hypothetical and an "optimized" composite both made by the CVI-process, but with Tyranno™ SA fibers. Also shown in this figure are our projected minimum fusion K_{eff}-goals for SiC$_f$/SiC within a 600-1000°C window. Clearly, the K_{eff}-values for currently available 2D-SiC/SiC composite systems and even for a hypothetical "optimized" system fall far short of fusion power core design goals.

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For the following reasons, it does not appear likely that the current minimum fusion K_{eff}-goals can be attained for even an optimized 2D SiC_f/SiC composite system made with woven fabrics with a CVI-SiC fabricated matrix. The Tyranno™ SA fiber has relatively high purity and is crystalline, and has about as high a value of K_f achievable for a SiC-type fiber. The ICVI-SiC matrix is high-purity crystalline SiC with a minimum amount of internal microporosity and a favorable grain crystalline microstructure for producing relatively high K_m-values. A certain amount of macroporosity, both within the fiber bundles and between the fabric layers, is necessary for gas exchange as part of the CVI-process, and likely cannot be reduced beyond that obtained using the isothermal process. Using satin weave fabric with a 0-90 lay-up likely results in the most favorable macroporosity shape factor for a 2D alternating fabric-matrix layer architecture. The f/m interfaces for the examined CVI-processed systems were all well bonded, so the interfacial conductance was already high enough to not have a degrading effect on K_{eff}. Overall, it appears that the margin of improvement in K_{eff} required to meet the minimum fusion K_{eff}-goals is just too large (on the order of doubling even the optimized K_{eff}-values) to be met by any minor improvements potentially possible through CVI-fabrication, structural or architectural methods. Unless design considerations allow adjustment of the minimum fusion K_{eff}-goals downward, it appears prudent for the fusion community to emphasize other methods for continued efforts to develop a SiC_f/SiC composite suitable to meet the fusion thermal conductivity goals.

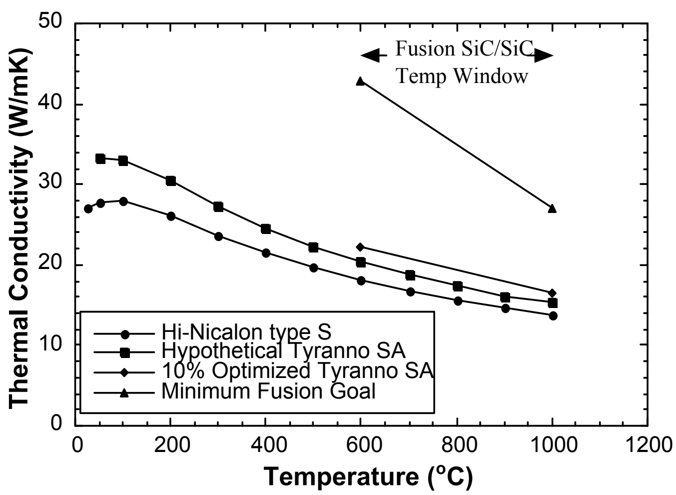

Figure 1. H2L model predictions of K_{eff} for a hypothetical Tyranno™ SA composite system and a 10% optimized Tyranno™ SA system compared to measured K_{eff}-values for the Hi-Nicalon™ type S composite system and to our projected minimum K_{eff} fusion goals for unirradiated SiC_f/SiC, 43 and 27 W/mK at 600 and 1000°C, respectively.

References

[1] A. R. Raffray, R. Jones, G. Aiello, M. Billone, L. Giancarli, H. Golfier, A. Hasegawa, Y. Katoh, A. Kohyama, S. Nishio, B. Riccardi, and M. S. Tillack, Design and material issues for high performance SiC_f/SiC-based fusion power cores, Fusion Eng. and Design 55 (2001) 55.