8.2 Thermal Conductivity of SiC/SiC Composites – Porting PNNL EMTA Code for Fusion Analyses — C. H. Henager, Jr. and Ba Nghiep Nguyen (Pacific Northwest National Laboratory,[1] Richland, WA 99336, USA)

OBJECTIVE

An existing modeling method, the EMTA (Eshelby-Mori-Tanaka approach) modeling approach [1], is applied to the study of SiC/SiC 2D woven composites for fusion reactor applications for the first time, to the best of our knowledge, with excellent results. We compare EMTA model results to existing thermal conductivity data for these materials and suggest that in the future this approach can be beneficial by providing us with tools to further optimize these composite materials for fusion energy applications since the EMTA method and code can address both thermal and mechanical properties with the same framework.

SUMMARY

The study, measurement, prediction, and control of thermal conductivity of SiC/SiC composites is a critical issue for Fusion. Both high conductivity (first wall) and reduced conductivity (flow channel insert) materials appear to be required for specific fusion reactor applications so that low-activation goals are achieved. This study has applied an Eshelby-Mori-Tanaka approach (EMTA) implemented in PNNL EMTA software to predict thermal conductivities of SiC/SiC composites. The EMTA homogenization procedure is structured in three steps to capture the effects of the constituent materials including the fiber-coating layer on the thermal conductivities of the as-formed composites. The results show that when perfectly bonded to the fibers a thicker fiber coating layer with higher thermal conductivity than that of the fibers leads to increased thermal conductivities for the composite. EMTA can be effectively used to identify the interfacial thermal conductance by correlating the EMTA predicted thermal conductivities with the measured values. A reverse engineering procedure in EMTA is useful to determine the thermal conductivities of the constituents if the actual measured values are not available or are unknown.

PROGRESS AND STATUS

Introduction

SiC/SiC continuous fiber composites are under consideration as structural materials for first wall or breeder blanket applications in advanced fusion power plants and advanced nuclear fission reactors. In such applications the materials in a high-temperature neutron radiation environment or non-radiation environment are subjected to a high heat flux that imposes extremely stringent requirements on the thermal conductivity of the components. These requirements must be satisfied concurrently with other thermomechanical requirements. The focus of this paper is on the prediction of the thermal conductivities of two-dimensional (2D) woven SiC/SiC and unidirectional (UD) SiC/SiC composites for fusion reactor applications. To this end, a Mori-Tanaka type model combined with the Eshelby's equivalent inclusion method has been explored to predict the thermal conductivities of these composites as a function of temperature and the constituent parameters such as thermal properties of the fiber and matrix phases, fiber volume fraction, fiber orientation, and fiber/matrix interfacial thermal conductance

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[2-5]. A computational tool named EMTA (Eshelby-Mori-Tanaka approach) was developed to implement the EMTA models for the computation of thermal conductivities of fiber-reinforced composites [1].

Computational Procedures

Figure 1 provides a schematic of the multiscale computational procedure that is adopted in this paper. The computation considers the UD composite containing aligned coated fibers from which the first EMTA homogenization is performed to obtain the homogenized thermal conductivity of the fiber/coating layer system. Next, the second EMTA homogenization is carried out to determine the thermal conductivity of the UD composite containing aligned equivalent fibers and embedded in a matrix material. Finally, a fiber orientation averaging technique [6] is applied to compute the thermal conductivity of the as-formed composite having a fiber orientation distribution. The computational procedure assumes perfect bonding between the fibers, the fiber coating layer and the matrix material. Thus, it does not include explicit modeling of the physical debonding that affects the thermal conduction from the fibers and their surrounding materials. If debonding occurs, this will be accounted for by an equivalent layer with associated thermal properties. A computer code named EMTA was developed that implements the Eshelby-Mori-Tanaka approach to predict the thermoelastic properties and thermal conductivities of fiber-reinforced composites [1].

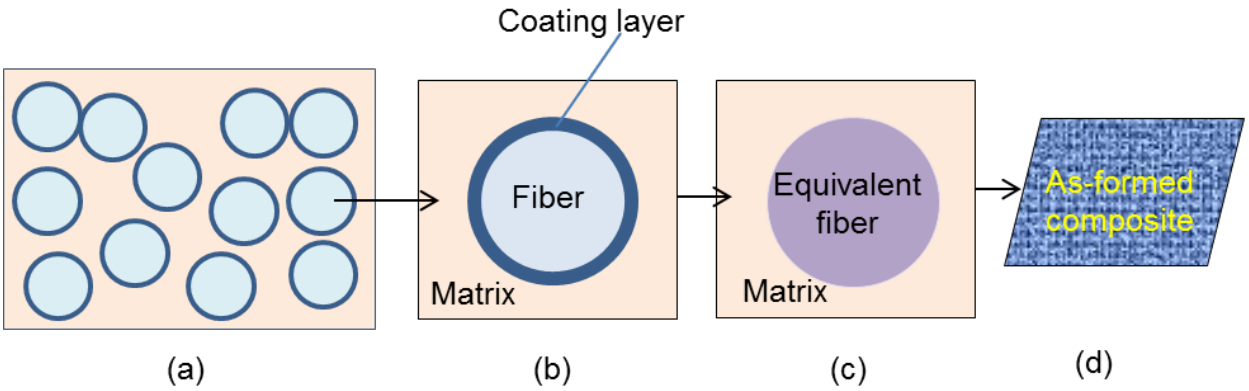

Figure 1. Schematic of the EMTA computational procedure for composite homogenization.

RESULTS

Figure 2 shows a typical computation using EMTA for the in-plane and transverse thermal conductivities of DuPont 2D woven SiC/SiC composites made using Hi-Nicalon Type-S fibers and isothermal CVI SiC matrix infiltration. The EMTA results match the measurements with excellent agreement when the matrix and fiber thermal conductivities are known but the interfacial, or coating, thermal conductivity is not known and must be determined from the experimental data via a fitting procedure. In this case, Youngblood et al. measured the matrix and fibers individually and used typical analytical models of composite conductivity for their results [7]. Here EMTA is used to duplicate this research but with the added benefit of being a

robust code that can handle any composite layup and also can be used to model mechanical properties.

EMTA also has a reverse engineering feature that can be used to predict individual constituent properties given some knowledge or understanding of the other conductivities. These will be demonstrated in a separate publication.

Future work will involve 1) addition of radiation damage mechanics into EMTA so that thermal conductivity as a function of dose can be predicted and 2) demonstrating the simultaneous modeling of mechanical and thermal properties so that composite design can be integrated and tailored for specific applications in a more general and robust manner.

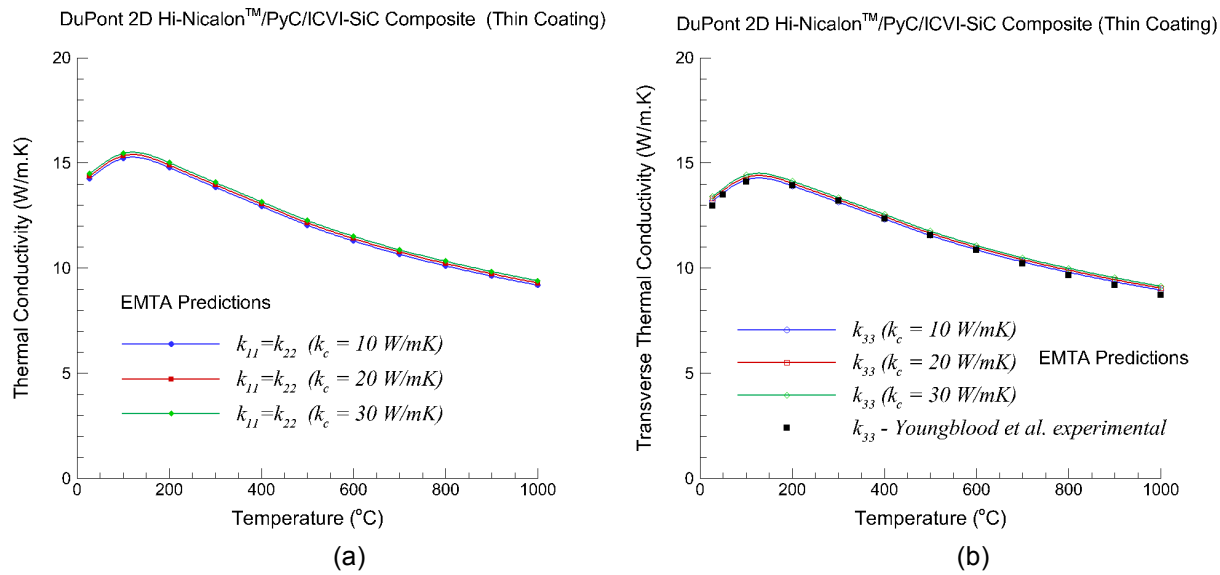

Figure 2. Thermal conductivities predicted by EMTA for the DuPont 2D SiC/SiC woven composite with the thin fiber coating layer: (a) In-plane thermal conductivities, k_{11} and k_{22}, and (b) transverse thermal conductivity k_{33} compared to Youngblood et al.'s experimental results [7].

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