SUBCRITICAL CRACK PROPAGATION STUDIES IN HI-NICALON AND HI-NICALON TYPE-S FIBER SiC/SiC COMPOSITES USING COMPACT TENSION SPECIMENS—C. H. Henager, Jr. (Pacific Northwest National Laboratory)

OBJECTIVE

PNNL has performed subcritical crack growth tests under constant applied load at various elevated temperatures in inert environments using subscale compact tension (CT) specimens of two types of SiC-composite materials. The use of CT specimens is preferred over the usual dingle-edge notched beam (SENB) specimens due to more uniform applied stresses over the crack growth region. This study will compare crack growth data taken between two materials as well as specimen geometry types, CT compared to SENB. Plain weave [0/90] Hi-Nicalon CT specimens were tested in argon atmospheres and compared to similar tests of 5-harness satin weave [0/90] Hi-Nicalon Type-S composites. We report here some of the preliminary fractographic examinations of the two materials and an initial assessment of the crack growth data. Additional information on this study will be presented later and also at the 13th International Conference on Fusion Reactor Materials in December.

SUMMARY

The potential use of SiC composites in fusion energy systems is well documented and studied. One of the main issues for the use of this material, other than radiation stability, is the long term crack growth stability problem or static fatigue issue compounded by environmental interactions. In ceramics this requires environmental crack growth studies under constant load and the properties of composites, while improved relative to monolithic ceramics, are nevertheless known to be strongly time and temperature dependent, especially with regard to crack growth. There are strong environmental interactions but also thermally-induced crack propagation rates are not well known. As fiber types evolve and weave structures are modified some of the basic crack growth data is required to understand failure in these materials and to provide design guidelines. Specimen geometry is critical since much data has been obtained using small specimens such as single-edge notched beams due to high materials costs. SENB bars in bending are attractive from a material conservation viewpoint but may not be attractive when geometrical and stress state effects are raised. The need for larger and more uniformly stressed samples is an important consideration. The use of CT specimens, even subscale, is a perceived improvement over SENB tests. This study is designed to show comparisons between data sets of similar materials tested in both geometries.

PROGRESS AND STATUS

Materials

The SiC/SiC materials that were tested included (1) a 5-harness satin weave, 8-ply, [0/90] Hi-Nicalon Type-S fiber composite t from GE Power Systems[1] and (2) a plain weave, 8-ply, [0/90] Hi-Nicalon fiber composite from Dupont Lanxide Corporation (now GE Power Systems[1]). A 150-nm thick pyrocarbon (PyC) interface was applied to the Type-S fibers prior to ICVI processing, while the Hi-Nicalon fibers were coated with 1-μm PyC and similarly processed. Fiber volume fractions were 40% for each material.

Experimental

Subscale CT specimens of each material [1] were tested in an Instron test machine in a high-temperature furnace in argon at the specified test temperature. The initial notch radius was 0.2-mm and the specimens were tested under constant applied loads calculated to provide an initial stress intensity of 10 MPa√m at the notch root. Crack propagation was monitored using a laser extensometer that measured load-line displacements (COD). A plot showing the time-dependent displacements observed during these

[1]http://www.gepower.com

tests for both materials is shown in Fig. 1, where the test temperature is 1373K.

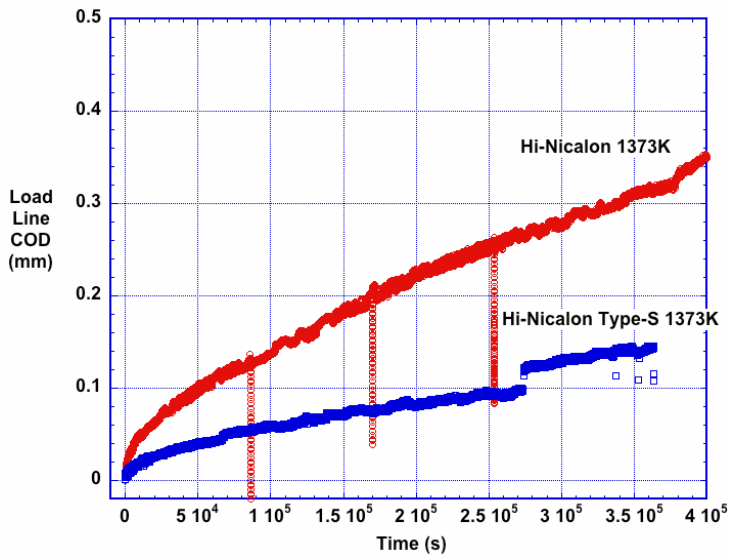

Fig. 1. Load-line crack opening displacements versus time plot of Hi-Nicalon and Hi-Nicalon Type-S fiber composites at 1373K slow crack growth for CT specimens tested in argon.

RESULTS AND DISCUSSION OF ONGOING WORK

One of the main findings has been reported before, namely, that Hi-Nicalon Type-S fiber is more creep resistant than Hi-Nicalon fiber and this is clearly observed in the data shown in Fig. 1. Under identical loading conditions the Type-S fiber has a lower crack growth rate as reflected in the load-line COD data. This is illustrated in Fig. 2 showing displacement-time data for Hi-Nicalon at 1373K compared to that for Type-S at 1473K. The fiber creep data of DiCarlo et al. indicates that Type-S fiber provides about 100K of additional temperature utility compared to Hi-Nicalon fibers [2-4], which the CT data demonstrates.

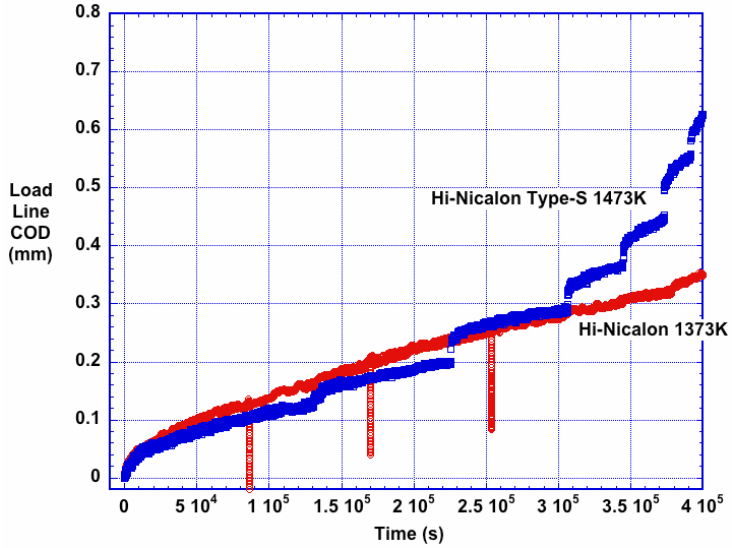

Fig. 2. Load-line crack opening displacement versus time plot of Hi-Nicalon at 1373K and Hi-Nicalon Type-S fiber composite at 1473K slow crack growth for CT specimens tested in argon.

Compared to an SENB bar, the CT specimen geometry offers much larger crack growth volumes and more uniform stresses during the crack growth test as the crack extends from the notch. For the SENB bars tested previously at PNNL and elsewhere previously [5], the distance from the notch tip to the end of the specimen is 4.5-mm versus 22-mm for the CT specimen. In terms of fiber bundles and weave patterns this translates into approximately 3 fiber weave bundles for the SENB bar compared to 14 for the CT specimen, which is significant difference. However, for the CT specimen once the crack has grown about 10-mm the system becomes unstable with respect to fast fracture and, under constant load, the sample will fail. Thus, the difference in usable crack extension is not as great as indicated above. The SENB bar is stable until the crack reaches the far end. Further work will compare SENB data with CT data in terms of absolute crack velocities and the measure temperature dependence of crack growth in the Type-S fiber composite. Both the CT and SENB specimens are able to sustain stable crack growth over 6 x 10^5 seconds. Figure 3 shows representative curves for CT and SENB tests with the Type-S composite material in each case at 1373K.

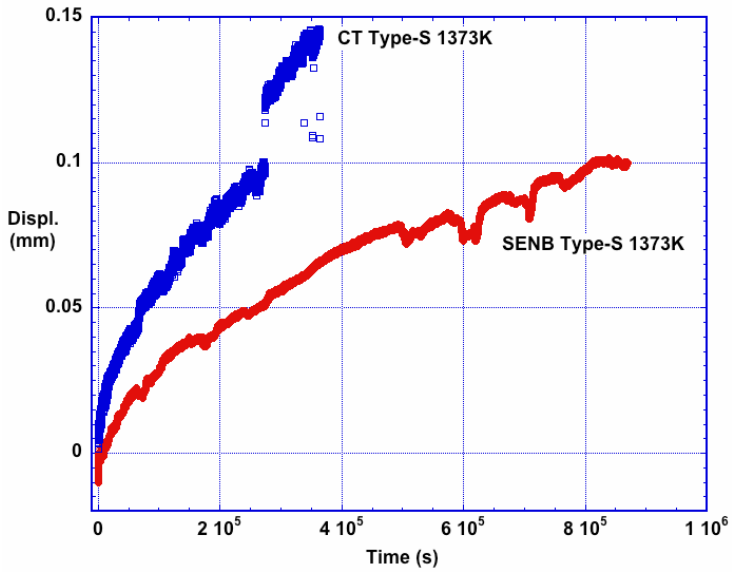

Fig. 3. Displacement-time data for Type-S fiber composites tested at 3173K in argon for CT and SENB specimens. The displacement curves cannot be directly compared due to geometry effects. However, the curve shapes are similar and can be fit using log functions as discussed previously [6].

Fractography on the CT specimen has begun and is one aspect of comparing specimen geometry types. Longer crack growth distances and larger interaction volumes provide more crack-fiber interactions for study. Figure 4 is a composite image spanning about 1.2-mm in distance from the notch tip showing the cracking pattern present in the CT specimen tested at 1373K in argon. Broken fibers near the tip of the notch where the crack opening is largest gradually transition to bridged fibers at about 0.5-mm from the notch tip. Further study of such images is required before comparison to SENB cracking patterns can be made.

RESULTS

CT and SENB crack growth data for SiC/SiC composites provide needed data for time-dependent deformation in these materials. CT specimens are larger, require more material, provide more uniform stresses during crack propagation, and have larger cracked volumes for study. SENB specimens are much less expensive to prepare and conserve materials but lack uniform stress fields and have shorter crack propagation distances. However, the crack distances may be long enough provided that the fundamental process is the interaction of the crack with single bridged fibers since each fiber bundle

includes several hundred fibers. The CT specimen may provide better characterization of crack growth rate and mechanisms if composite architecture dominates.

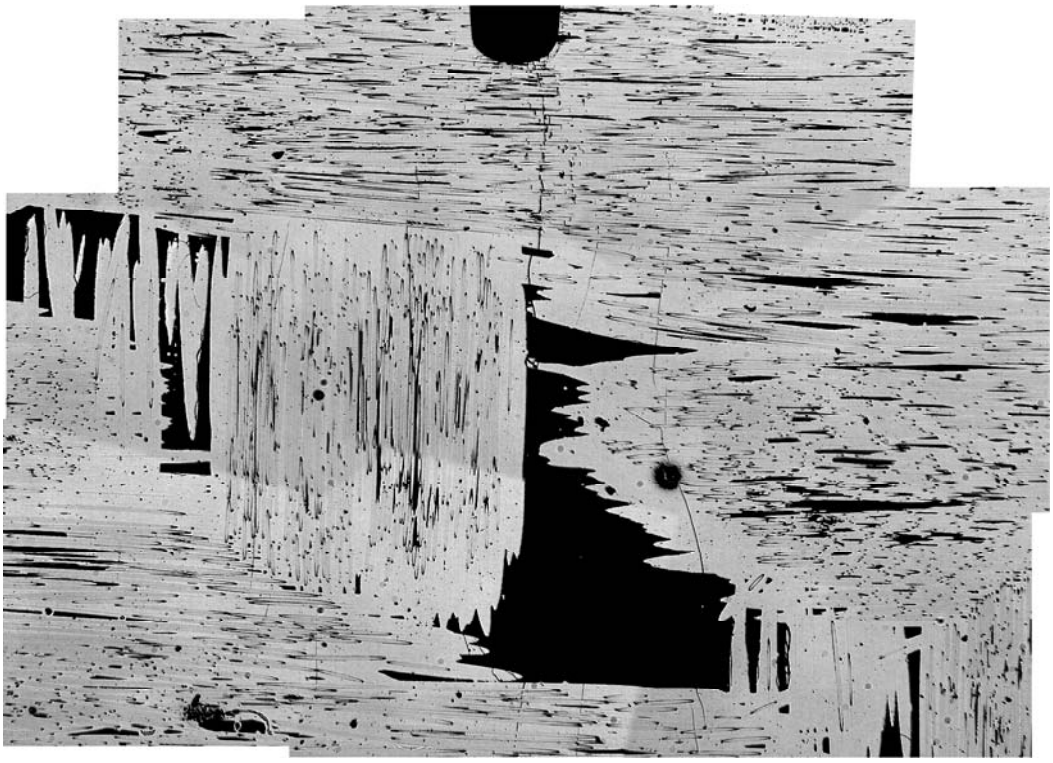

Fig. 4. Composite image of optical micrographs showing cracks grown in Type-S composite material tested at 1373K in argon over 4 x 10^5 seconds of slow crack growth.

References

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