EVALUATION OF TRANSTHICKNESS TENSILE STRENGTH OF SiC/SiC COMPOSITES

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ABSTRACT

The transthickness tensile strength (TTS) of 2-D CVI-SiC/SiC composites reinforced with Tyranno SA fibers was evaluated by the diametral compression test. The effect of specimen size and specimen shape on the magnitude of the TTS were studied and the results were analyzed using Weibull statistics.

Specimens failed along an interlaminar plane adjacent to the line of action of the applied load and fractographic analyses revealed that the crack had propagated through matrix pores and along interfaces between the fiber, fiber coating and matrix. The magnitude of the TTS was found to be independent of specimen size or shape for the range of specimen dimensions investigated, although the amount of scatter was largest for the results obtained from the evaluation of the smallest specimens. The characteristic value of the TTS and the Weibull modulus for the distribution of TTS values were 24.9 MPa and 6.48, respectively.

INTRODUCTION

SiC/SiC composites are considered for use in extremely harsh environments primarily due to their excellent thermal, mechanical and chemical stability, and the exceptionally low radioactivity following neutron irradiation [1-2]. In particular, recent improvement in the crystallinity and purity of SiC fibers, the developments and improved composite processing have improved physical and mechanical performance under harsh environments [3-5].

The tensile strength perpendicular to the lay-up planes of 2D laminated composites (transthickness tensile strength: TTS) is typically much lower than the strength of the composite on the lay-up plane. Therefore, it is likely that the design of engineering components utilizing these materials will be limited by strength in this direction. Recently, the American Society for Testing and Materials (ASTM) standardized test method C1468 to evaluate the TTS of continuous fiber-reinforced ceramic matrix composites (CFCCs). Because this test method relies on the use of adhesively-bonded extenders to transfer load to the specimen, its applicability is limited by the properties of the adhesive and can only be used at low temperatures. The diametral compression test [6-9], also known as Brazilian test, overcomes the limitations imposed by the adhesive and, therefore, can be applied at high temperatures. This test method is based on the fact that tensile stresses develop when a circular disk is compressed by two diametrically opposed forces as shown in Figure 1. These tensile stresses exist perpendicularly to the loading direction and are proportional to the applied compressive force. The preparation of test specimens and the actual tests are relatively straightforward, making this test method amenable for use. Because of these reasons, this test method is currently being considered for ASTM standardization.

In this paper we report the TTS results from the evaluation of a 2-D SiC/SiC CFCC by diametral compression. The effects of specimen size and shape on the magnitude of the TTS were investigated and the results were analyzed using Weibull statistics. A discussion regarding the determination of the TTS from the magnitude of the applied load and specimen dimensions is also included.

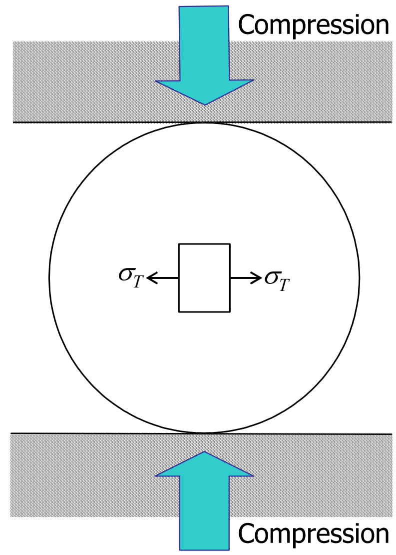

Figure 1. Transthickness tensile strength by diametral compression

EXPERIMENTAL

The material used in this investigation consisted of plain-weave Tyranno™ SA fabric, stacked in [0°/90°] direction, and a SiC matrix synthesized by forced-flow thermal-gradient chemical vapor infiltration [10]. A dual coating of approximately 80 nm-thick SiC and 570 nm-thick C was applied to the fiber prior to matrix infiltration. Pieces with 75 mm diameter and 12.5 mm thick were obtained with 22.6 % porosity. Details of the material and its fabrication can be found elsewhere [6]. Disk specimens of various sizes (diameter: 3.2, 6.4, 9.4 mm, thickness: 1.7, 3.1, 4.5, 6.0 mm) were obtained from the composite piece by core-drilling using a diamond-impregnated tool. Truncated disk specimens (diameter: 6.5 mm, thickness: 3.1 mm, width: 3.2 mm) were also obtained as illustrated in Figure 2.

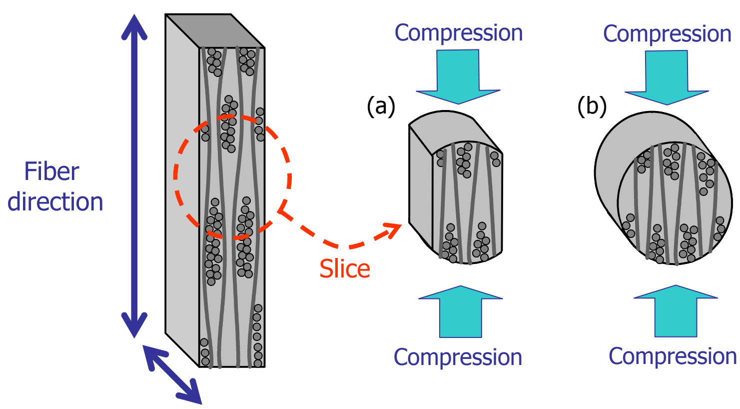

Figure 2. Specimen types for diametral compression tests, (a) truncated disk, (b) disk

Transthickness tensile tests were carried-out at ambient conditions (20°C/35% RH) using an electromechanical testing machine at a constant cross-head displacement rate of 10 μm/s. The test specimens were subjected to diametral compression using two parallel plates of Hexoloy® SA SiC. This material was selected due to its low Poisson's ratio (0.14) and high elastic modulus (390 GPa) to minimize radial expansion at the contact area. The specimens were aligned and fixed with double-sided tape on the bottom plate. Figure 2 illustrates the relation between the fabric orientation and the loading direction. At the end of the tests, the fracture surfaces were examined by scanning electron microscopy.

RESULTS AND DISCUSSION

Figure 3 shows typical stress-displacement curves for specimens of various sizes. In every case the load increased monotonically to a peak value, which was followed by an abrupt drop and an audible indication that the sample had failed. Every specimen failed by a crack that propagated along the loaded diameter, along an interlaminar region through large pores in the matrix, and along the fiber/fiber coating/matrix interfaces. Figure 4 is an SEM micrograph of a typical fracture surface. Debonded fibers and CVI coated fiber-bundle surfaces without matrix infiltration were evident on the fracture surfaces.

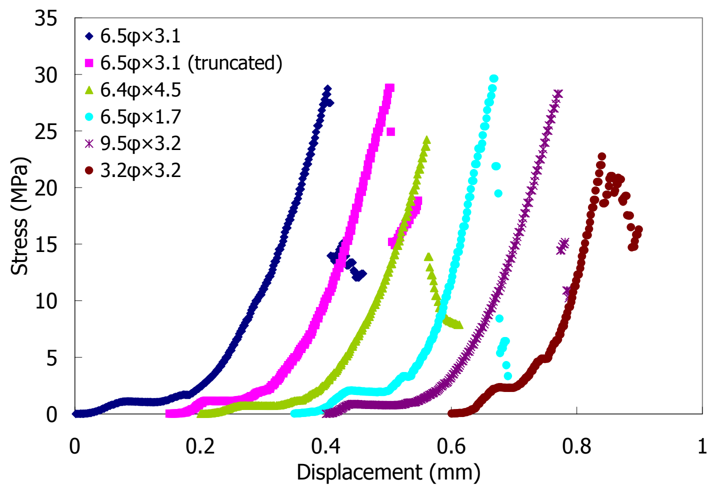

Figure 3. Typical loading curves of various size specimens

The TTS (σ_T) was determined according to Eq. (1).

$$\sigma_T = \frac{2P}{\pi dt} \tag{1}$$

where P is the load at failure, d is the diameter, and t is the thickness of the specimen [7,8]. However, this relationship between the TTS and the failure load is only valid for isotropic materials and, therefore, it needs to be corrected to account for the transverse isotropy of the material evaluated. This work is in progress and will be reported in the future.

Figure 5(a) shows the effect of diameter on the TTS of SiC/SiC test specimens 3.1 mm-thick, while Figure 5(b) shows the effect of thickness on the TTS of SiC/SiC 6.5 mm-diameter test specimens. The error bars represent one standard deviation about the

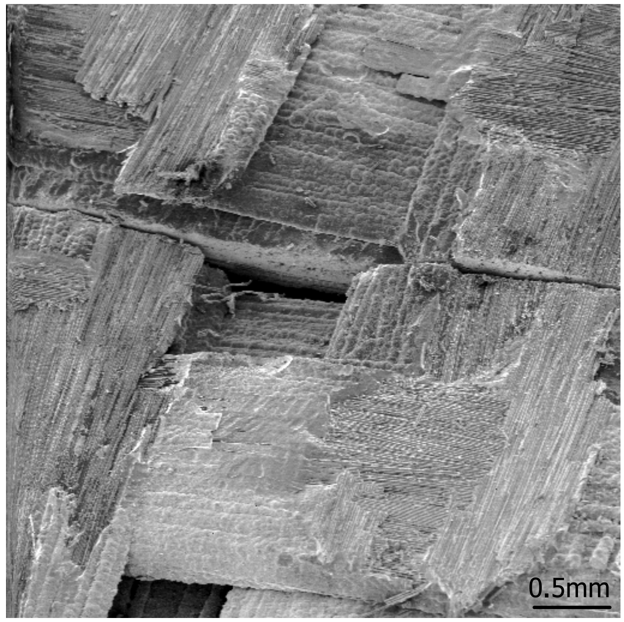

Figure 4. Fracture surface after the diametral compression test

mean value. In the thickest specimens, it was difficult to identify the magnitude of the load at which failure ocurred, since the curves showed multiple load drops. Two values of TTSs were obtained for these specimens from two critical loads in the curves. An analysis of variance (ANOVA) [11] of all the test results revealed that there are no significant differences among these mean values at the 95 % confidence level. Therefore, for the range of values examined, there are no apparent size effects on the magnitude of the TTS of the material evaluated. It was found, however, that scatter was largest for the TTS values obtained with small-diameter (3.2 mm) specimens, which can be attributed to lack of precision in the alignment of the test specimen during the test, and the reduced number of fabric unit cells in the gauge section of the test specimen.

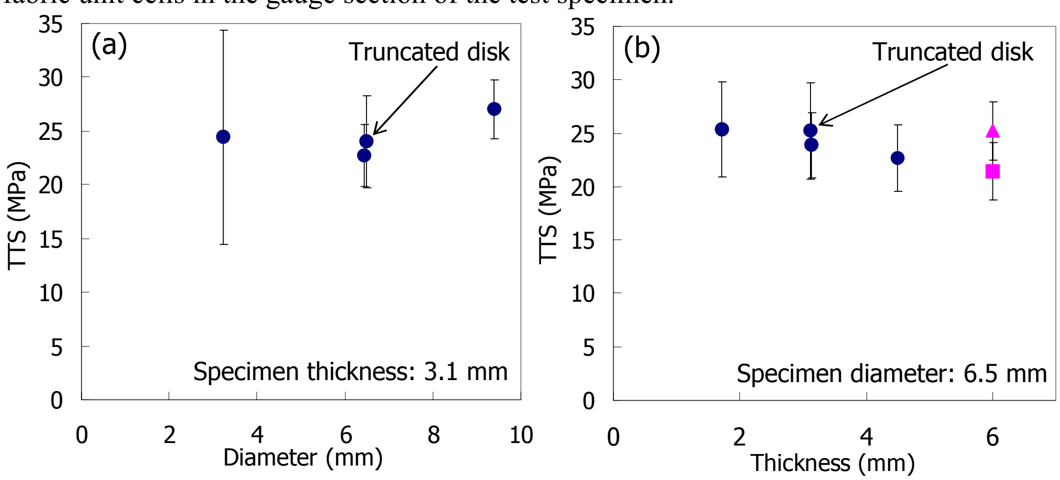

Figure 5. Size effects on transthickness tensile strength, (a): effect of diameter, (b): effect of thickness

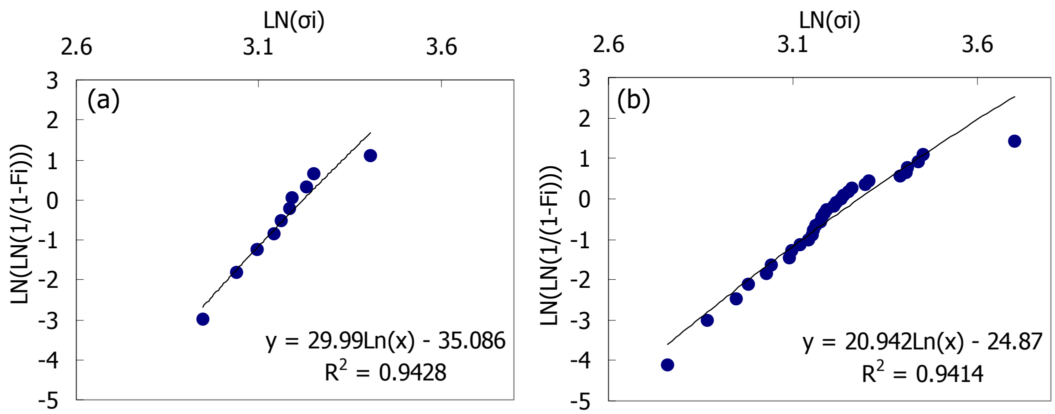

Figure 6. Weibull plots of transthickness tensile strength of (a): standard size specimens and (b): all specimens

The TTS results were analyzed using Weibull statistics. Figure 6 shows Weibull plots for (a) TTS of standard size specimens (diamter: 6.4 mm, thickness: 3.1 mm); (b) TTS of all specimens without the thickest specimens (thickness: 6.0 mm). The Weibull modulus and scale parameter for the standard specimens are 9.41 and 25.1 MPa, respectively, while those for the entire data set are 6.48 and 26.7 MPa, respectively. The Weibull modulus of the strength data set that includes all specimens is smaller than that of standard size specimens, and this is attributed to the large scatter of the data obtained from the evaluation of small diameter specimens. The Weibull modulus for a data set that excludes the small diameter specimens is 8.15. This relatively large value of the Weibull modulus is consistent with materials that contain large-sized defects that are responsible for failure.

It was also found that the TTS of the material evaluated was independent of specimen geometry, i.e.- disk-shaped versus truncated disk-shaped specimens. This is important because for the range of dimensions investigated in this work, these results validate the use of truncated-disks specimen geometries when the material is available only as a thin plate and the diameter of the disk is larger than the thickness of the plate. Therefore, these results support the validity of this test method for the evaluation of the transthickness tensile strength of 1-D and 2-D CFCCs.

SUMMARY

The TTS of CVI-SiC reinforced with Tyranno™ SA fibers was evaluated by diametral compression using specimens of various sizes (diameter and thickness) and shapes (disks vs. truncated disks). All specimens failed along an interlaminar plane adjacent to the diametral plane of the applied load. Analysis of the fracture surfaces revealed that the dominating crack grew along large pores in the matrix and along the fiber/fiber coating/matrix interfaces. It was found that for the range of specimen dimensions investigated, the magnitude of the TTS was independent of size or specimen geometry (disk vs. truncated disk). It was also found that there was considerable scatter in the TTS results obtained from the evaluation of the smallest disk specimens, and this could be attributed to reduced precision in the alignment of the specimen during the test, and the

reduced number of fabric unit cells in the gauge section. The average TTS, the one standard deviation, the Weibull modulus and the scale parameter for the entire data set were 24.9 MPa, 4.77, 6.48 and 26.7 MPa, respectively. Although the magnitude of TTS was determined from the peak load using the elastic solution for isotropic materials and, therefore, needs to be corrected to account for the transverse isotropy of the material, these results demonstrate the applicability of this test method to determine the TTS of CFCCs. On-going work is focused on the determination of correction factors to account for anisotropy and the implementation of this test method at elevated temperatures.

ACKNOWLEDGEMENTS

The material used in this work was fabricated under the collaboration program of Oak Ridge National Laboratory, Japan Atomic Energy Research Institute, and Kyoto University. This work was supported by the office of Fusion Energy Science, US DOE under contract DE-AC-05-00OR22725 with UT-Battelle, LLC.

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