ANALYSIS OF DIMENSIONAL CHANGES AND FIBER-MATRIX INTERACTIONS DURING PROCESSING OF 3D CARBON-CARBON COMPOSITES

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Introduction

The 3-D carbon-carbon composites undergo dimensional changes [1] during the multiple carbondization/graphitization cycles, as shown in Fig. 1a. For the particular material shown, all dimensions decrease initially. Subsequent processing cycles cause little change in the Z dimension and significant increases in X, Y dimensions. Other pertinent changes that occur in the material and are related to the growth phenomena are shown in Fig. 1b.

Analysis and Results

To establish the mechanism that causes dimensional changes during processing, an approximate analysis was conducted using a mathematical model shown in Fig. 2. Starting with the temperature-dependent properties of constituents (fibers and matrix), the elastic and thermal properties in the axial and transverse directions of yarn bundles were calculated using equations (modified to account for fiber orthotropy) of [2 and 3]. The matrix within the yarn bundles and matrix pockets was assumed to have temperature-dependent mechanical and thermal properties similar to ATJS graphite. The fibers were assumed to be orthotropic. The ambient in situ Thornel 50 fiber Young's modulus in the axial direction was determined using the results of [4]. Variations of fiber axial modulus and axial coefficient of thermal expansion with temperature were taken as shown in [5]. The room-temperature Young's modulus and coefficient of thermal expansion of the fibers in the transverse direction were calculated using equations of [2 and 3] in combination with test data on transverse Young's modulus and transverse thermal expansion data for graphite/epoxy composites. Once the room-temperature properties of the fibers in the transverse direction were determined, the variation of these properties with temperature was assumed to be similar to pyrolytic graphite in the c-direction. The final results for the typical properties of unidirectional carbon-carbon yarn bundles are given in [1].

To determine the elastic and thermal properties and the internal stress state in the 3-D carbon-carbon composites as the latter undergo exposure to elevated temperatures, analytical techniques similar to those described in [2], were used. The nominal void content of 3-D material was assumed to be 8%, of which 2% of the voids were estimated to be within the yarn bundles. The effective fiber content (including sheath of highly oriented material) within the yarn bundle was taken as 68%, which is representative of the values observed in various composites. The dimensions of the yarn bundles in the X, Y, and Z directions were taken as shown later in Fig. 5. Typical theoretical results as well as limited experimental data on the mechanical and thermal properties of 3-D carbon-carbon composites are shown in Figs. 3 and 4, whereas Fig. 5 shows the final results on the stress state of various locations within the 3-D carbon-carbon composites. The stresses shown were based on elastic analysis. If the influence of plasticity (both fibers and matrix undergo elastic deformations at high temperatures) were taken into account, the stresses would be somewhat lower than shown in Fig. 5. It is these stresses that cause the changes in the dimensions of the 3-D carbon-carbon blocks as well as internal cracks within the yarn bundles and at the bundle crossovers. The compressive stresses at locations shown in Fig. 5 cause the yarn bundles to undergo necking and billowing, as well as cracking within the yarns as shown in Fig. 6. As the yarns undergo necking and cracking due to compressive stresses, the tensile stresses in the direction of yarn axis are relieved. The net result is that during the initial processing cycles, only necking and interyarn cracking takes place. Such deformations would cause initial decrease in the dimensions of 3-D carbon-carbon composites blocks. Upon exposure to additional processing cycles, the necking ceases when the fiber compaction at the yarn crossovers is stablized. High tensile stresses then arise in the direction of yarns (see Fig. 5). The tensile stresses would be somewhat lower than shown in Fig. 5 because of relief due to plastic fiber deformations at high temperatures. On cooldown, the high tensile stresses would be relieved; however, a permanent set and cracking at theyarn crossovers would take place because of the plastic deformations noted above. It is this permanent set which causes the increase in the dimensions of 3-D carbon-carbon blocks. Because the stresses are higher in the X and Y directions than in the Z direction, the increase in X and Y dimensions should be higher than the increase in the Z dimension. The experimental results shown in Fig. 1 and [1] confirm the behavior postulated on the basis of theoretical results. As is readily seen, the various blocks initially undergo decrease in dimensions and on subsequent carbonization/graphitization cycles the dimensions of the blocks increase, the increases being greater in the X and Y directions than in the Z direction. Work is now underway to obtain quantitative results on the dimensional changes of 3D C-C composites during the multiple processing cycles.

Acknowledgements

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References

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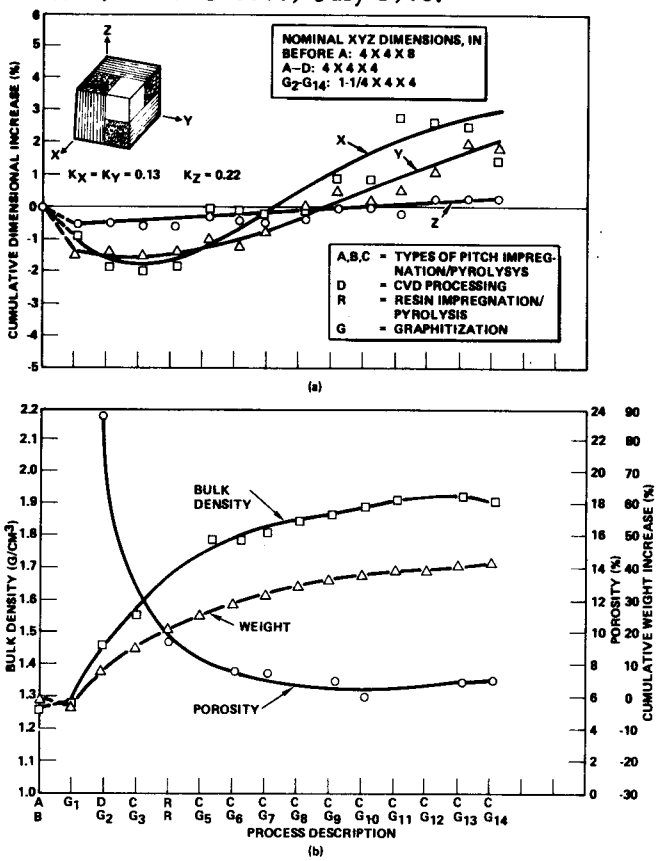

Figure 1

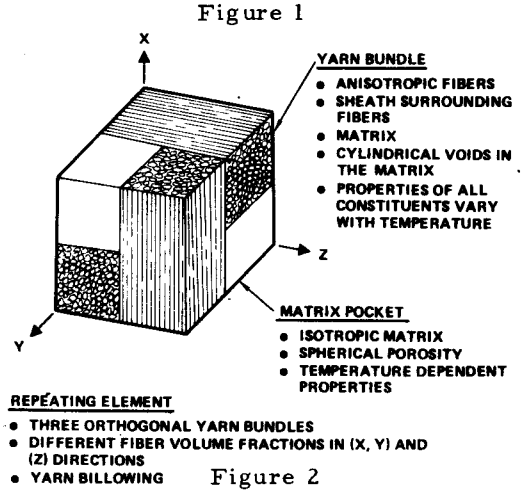

Figure 2

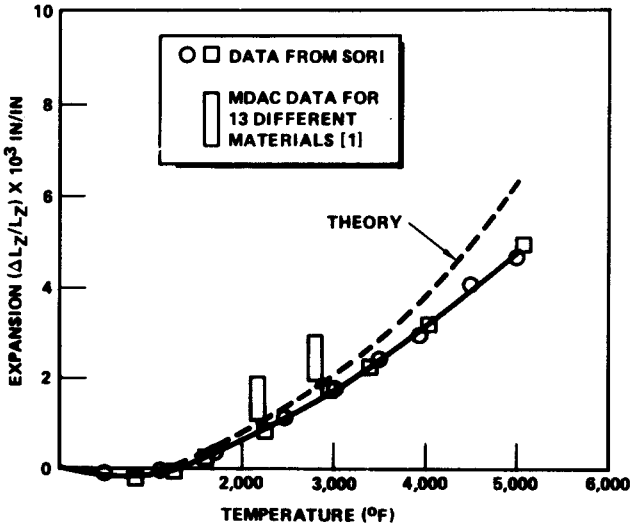

Figure 3

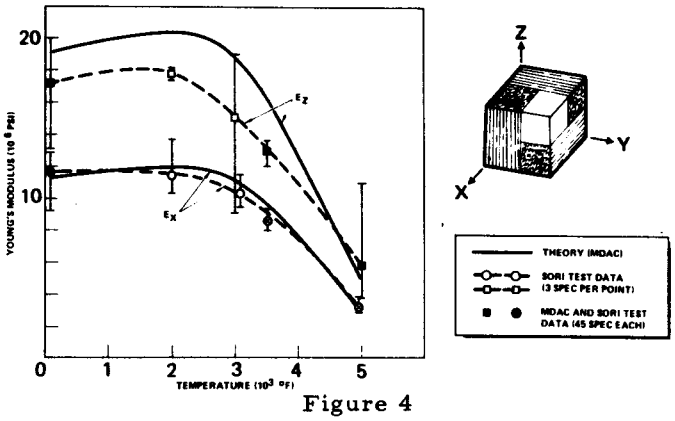

Figure 4

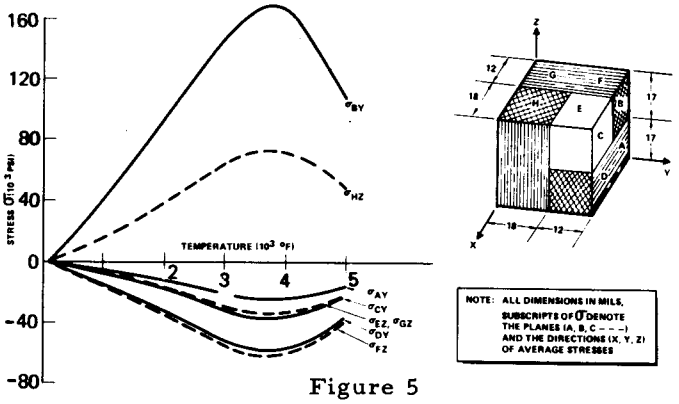

Figure 5

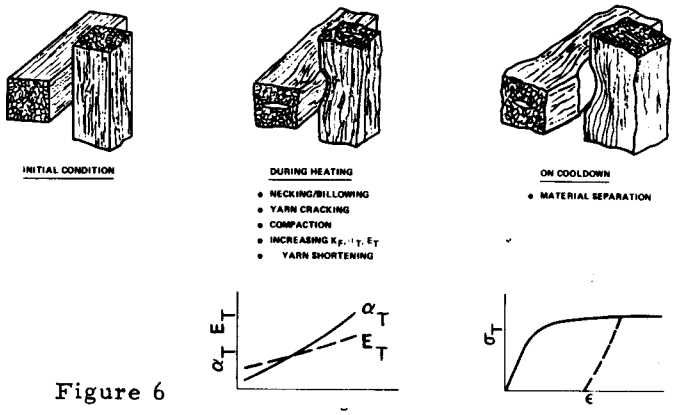

Figure 6