EFFECTS OF FIBER CHOICE AND WEAVE GEOMETRY UPON CYLINDRICAL WEAVE CARBON/CARBON

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Summary

A material synthesis study is described herein, which has had the goal of providing guidance to the experimental carbon/carbon materials development programs for cylindrical weave integral throat and entrance section carbon/carbon nozzles.

A wide range of weave geometries and fiber choices were evaluated to determine both the thermomechanical properties and processing- and service-induced stress levels for cylindrical weave materials. The results of this study indicate that weave geometries which favor reduced axial and radial fiber content and increased hoop fiber content result in a reduction of hoop fiber stress levels.

For many weaves, the billet I.D./O.D. ratio has been shown to have a significant effect upon the processing stresses. Radial fiber pullout due to free surface effects has been shown to significantly increase the predicted hoop fiber stresses over cases where the radial fibers are assumed to act to their fullest capability.

Discussion

This study has been restricted to cylindrical weave materials. For cylindrical weaves, it can be shown that the thermal stress states developed in the hoop fibers during processing are the critical ones. It can also be shown that the thermal stresses in service, for the kinds of geometries being considered, are relatively of secondary importance. However, a screening for service-induced thermal stresses was made on the basis of a very simple temperature gradient to be sure that no serious discrepancies among the behavior of the various materials were being overlooked. A true evaluation of service performance requires consideration of at least two-dimensional stress states, rather than the one-dimensional ones considered herein, so that the shear stresses can be included. The shear stresses are a possible source of weakness of these materials during service.

The analytical screening required first determining the available fiber properties for the ten fibers to be considered. The unavailable properties were estimated and the range of geometries and loading conditions were defined. Next, the composite properties were computed and combined with the loading conditions and nozzle geometry to define the fiber stress levels. Composite strengths were predicted, and the resulting stress ratios (fiber strength/fiber stress) for each loading condition were determined. The materials with the least chance of experiencing damage during processing and the best chance of surviving firing gradients could thus be defined and identified as the best candidates for future evaluation.

Fiber Properties

The fibers which were considered for nozzle application included several commercially available fibers, T50, T300, HM1000, Pitch fiber (VS0022), along with several experimental fibers. At the time of the analysis, some preliminary test data on the axial properties of all of these fibers were available, and those properties were used in the analyses.

The available property data for most of the fibers considered included axial moduli and dry yarn strength versus length at room temperature, modulus and strength at several elevated temperatures, and axial thermal expansion of the yarns. Various estimating procedures were utilized to obtain the required fiber properties for those cases where the absence of good test methods or test data or both resulted in fiber properties being unavailable.

Test results provided "as received" yarn strength versus length data such that the room temperature Weibull strength parameters could be defined. For the fibers where no strength data at elevated temperatures existed, the moduli and strengths were assumed constant with temperature. This assumption is reasonable for most graphite fibers for temperatures up to near 4000F. For fibers where some elevated temperature properties were available, the elevated temperature moduli and strengths were utilized.

Weave Geometries

With all multidimensional composites, significant variations in properties can be obtained through variations in weave geometries. With cylindrical weaves, the manufacturers have a reasonable degree of latitude in weaving the preforms. Therefore, a study of the weave geometry effects was undertaken to define the factors which are most desirable for a cylindrical weave relative to processing- and service-induced thermal stress levels.

Fiber packing within the fiber bundles was assumed to be 58%. Axial prism volume fractions were considered from 25 to 45%. Radial prism volume fractions were considered from 5 to 35%, while the hoop prism volume fraction was varied between 15 and 45%. Thus a wide range of weave geometries were considered to identify the trends apparent due to weave configuration.

Loading Conditions

Two basic loading conditions were considered: processing-induced stresses due to the graphitization cycle and service-induced stresses due to temperature gradients within the nozzle.

Prior to the last graphitization cycle during processing, it is assumed that a high pressure pitch impregnation cycle has resulted in filling all of the cracks and voids within the unit cell. Thus, no cracks exist at the start of graphitization. As the temperature is increased to 1000F, the pitch will carbonize, resulting in some cracking. The amount of cracking at 1000F is assumed to be small, such that assuming an uncracked unit cell at 4000F is slightly conservative.

A nozzle billet subjected to a uniform temperature rise develops thermal stresses due to property mismatches at several levels: between the fiber and matrix within the fiber bundle, between the subcell regions within the unit cell, and due to the cylindrical anisotropy of the nozzle billet.

The service-induced stresses occur on a processed material. Hence, subcell cracking will exist and it is appropriate to use post-processing properties. Service stresses arise from temperature gradients, cylindrical anisotropy, nozzle geometry, and internal nozzle pressures. For screening purposes, a slice of the nozzle was analyzed. Internal pressures were not applied. A linear temperature gradient was assumed.

Results

The variables addressed during this study have been aimed at determining the best potential fibers and weave configurations for a cylindrical weave rocket nozzle material. Each of the major areas considered is discussed below.

Changing radial and circumferential volume fractions while holding the axial prism volume fraction at 25% was found to result in increasing stress ratios with increasing hoop fiber content.

The effects of geometry changes and the differences between processing-induced stresses and a linear temperature gradient were investigated for the T50 PAN fiber system. The hoop fiber stresses decrease with decreasing axial fiber content and increasing hoop fiber content. In all cases, the stress ratios resulting from a temperature gradient on a fully processed material are higher than the processing-induced stress ratios. This indicates that processing induces the most severe thermal environment for a cylindrical weave. The limiting case is an all hoop wrap material. However, an all hoop wrap material may not be desirable due to low resistance to cracking between hoop fibers and possible poor recession performance. In other words, failure modes other than hoop fiber failure will dominate if the geometry is varied to an extreme. The limits to which one might change the geometry without involving other detrimental effects were not fully explored in this study.

If one assumes that the radial fibers are intact and carrying their full load in the composite, then very large radial fiber stresses are predicted. Since the radial fibers are short and intersect two free surfaces, the fiber bundles can crack away from the surrounding composite. If the radial fiber bundles crack away from the composite at the surface, then some finite distance along the fiber bundle is required before the fiber bundle stresses can be built up to their full level. It is this phenomenon which is believed to prevent large numbers of yarns being fractured during graphitization of a 3-D cartesian billet. In cylindrical weaves, radial fiber unbonding results in a significant increase in the radial expansion coefficient of the billet and a very large increase (40-70%) in the hoop fiber stress levels.

The effect of changing billet geometry on processing stress levels is of concern since the goal of the material development is to apply carbon/carbon to larger diameter nozzles. As an initial step in evaluating the effects of billet geometry upon processing-induced stress levels, several T50 PAN materials were modeled in billets with a fixed 10" O.D. and a variable I.D. The effect of billet geometry (R/t) upon the hoop fiber stresses depends upon the cylindrical anisotropy of the material. If the weave is balanced, such that radial and hoop moduli and thermal expansions are equal, then there are no macroscopic stresses developed for a uniform temperature rise and the billet R/t will not affect the hoop fiber stress levels during processing. If, however, the weave is not balanced or if radial fibers pull out, then increasing billet R/t results in increasing hoop fiber stress levels.