EFFECT OF SUBSTRATE FIBER ORIENTATION ON CHEMICAL VAPOR DEPOSITED (CVD) NEEDLED FELT CARBON-CARBON COMPOSITES*

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Introduction

Previous material development conducted by Sandia with chemical vapor deposited (CVD) composites has resulted in successful atmospheric reentry of carbonized felt/carbon matrix heatshields.[1,2] CVD/felt conical shapes are made by first fabricating a needled rayon felt substrate, which is subsequently carbonized and CVD infiltrated to the desired density.

Conical shapes had previously been fabricated in two separate rayon fiber orientations as illustrated in Figure 1. The two configurations were placed for cutting conical batts with or across the fiber orientation as shown in the figure. The preferential alignment of short rayon fibers in the two different fiber orientations resulted in strength differences as noted in Table I. The type 2 configuration has been used for all later reentry testing.

Thermal stresses produced during reentry are a critical parameter for CVD/felt materials. The factors of safety of the type 2 cone during a typical reentry are shown in Figure 2. As noted, the factor of safety for the circumferential direction is lower than the longitudinal direction. If the circumferential strength of the type 2 cone could be improved by combining the fiber orientations shown in Figure 1, it was theorized that the circumferential factor of safety could be increased. This paper describes an experimental study that was accomplished to investigate the effect of different fiber orientations on the carbon-carbon composite properties.

Experimental

Conical shapes were fabricated for this study because it had been found from previous studies [3] that CVD/felt flat plates do not produce representative properties of conical shapes. The seamless rayon felt cones were produced by applying batts of carded felt material over a mandrel and needling each applied batt until the desired thickness and density were obtained. The felt cones having an average bulk density of 208 to 240 kg/m^3 (.208 to .240 gm/cc) were fabricated from 5.5 denier, 0.038 meter (1.5 inch) long viscose rayon fibers. Conical rayon shapes were fabricated to represent types 1 and 2 of Figure 1, and a combination of these two types using alternate plies of types 1 and 2. The cones were subsequently carbonized and infiltrated to an approximate density of 1810 kg/m^3 (1.81 gm/cc) by the isothermal CVD technique. Heat treatment to 3273°K for two hours followed the infiltration. One each of the type 1 and type 2 cones and two of the combination types were used in this evaluation.

Samples were cut from the finished shapes for evaluation and destructive tests. In addition to non-destructive evaluation (NDE) of the cones, evaluation and testing included metalurgical examination of the CVD matrix, x-ray diffraction, ablation testing, tensile and compressive testing, and thermal conductivity and thermal expansion measurements. Mechanical properties and thermal expansion measurements for the longitudinal and circumferential directions and thermal conductivity for the perpendicular (radial) direction were obtained at room and elevated temperatures.

Results and Discussion

The three different types of cones had similar physical properties (metallurgical, x-ray diffraction density, NDE).

Figure 3 shows the tensile strength in the longitudinal direction for the cones as a function of temperature. The longitudinal strengths of the combination type cones are approximately equal to the strength of the type 2 cone. The type 1 cone, although having a lower longitudinal strength than the other two cone types evaluated in this study, had approximately seventy percent greater strength than cones made previously as type 1 (Table I). The reason for this anomaly is being studied. The room temperature circumferential strengths of type 1 and the two combination cones were approximately the same (28.6-29.4 MN/m^2), and the type 2 strength was, as expected, lower (24.8 MN/m^2).

Figure 4 shows the thermal expansion of types 1 and 2 construction and one of the combination type cones for the longitudinal and circumferential directions. The types 1 and 2 construction have thermal expansions in the longitudinal and circumferential directions which are the reverse of each other, whereas the thermal expansion for the combination type of construction is between these values.

Ablation results from arc plasma tests indicated that all materials were similar in ablation performance. No significant differences in thermal conductivity were noted.

While detailed thermal stress calculations (as accomplished for the data presented in Figure 2) must be performed to fully assess the thermal stress capability of the CVD/felt material, a thermal stress figure of merit value is a useful technique for comparing different types of the same material. This figure of merit can be defined as:

$$\text{FOM} = \frac{(\text{Tensile Strength})(\text{Thermal Conductivity})}{(\text{Modulus})(\text{Coef. of Thermal Expansion})}$$

Increasing values of this parameter are a measure of increasing thermal stress resistance. The figure of merit values shown in Figure 5 for the longitudinal and circumferential directions were obtained for properties at 2200°K. The figures of merit in each direction for the combination type of cone construction are more equal than for the type 2 construction and are higher than for either the type 1 or type 2 cones. The higher figures of merit for the combination type cones indicate that the higher circumferential stress would be lowered without raising the stress in the other direction.

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Conclusion

CVD/felt cones were successfully fabricated with two different fiber orientations (types 1 and 2) and with a combination of types 1 and 2. Similar physical properties were obtained for all infiltrated cones. The properties obtained from the combination type of cone construction indicate that the calculated thermal stresses were lower than in the types 1 and 2.

References

1. Schmitt, H. W., Paper FC-57A, Tenth Biennial Conference on Carbon, Lehigh University (1971)
2. Stoller, H. M., Irwin, J. L., Wright, G. F., Granoff, B., and Gieske, J. H., Paper FC-57, Tenth Biennial Conference on Carbon, Lehigh University (1971)
3. Irwin, J. L., Proceedings of the 16th National SAMPE Symposium, Los Angeles (1971)

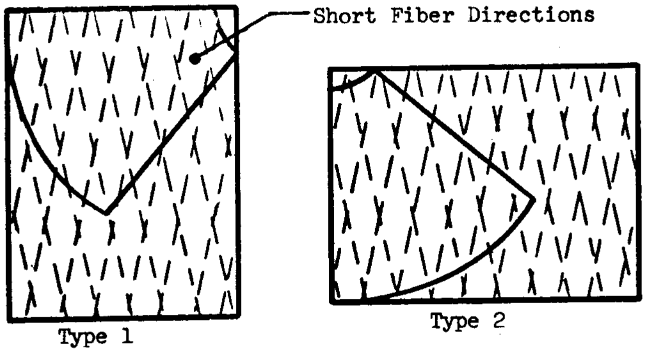

FIGURE 1. RAYON FIBER ORIENTATION

TABLE I. STRENGTH OF TYPES 1 & 2 CVD/FELT CONES

Cone	Long. Strength, MN/m^2	Circum. Strength, MN/m^2
Type 1	16.9	32.6
Type 2	34.5	23.4

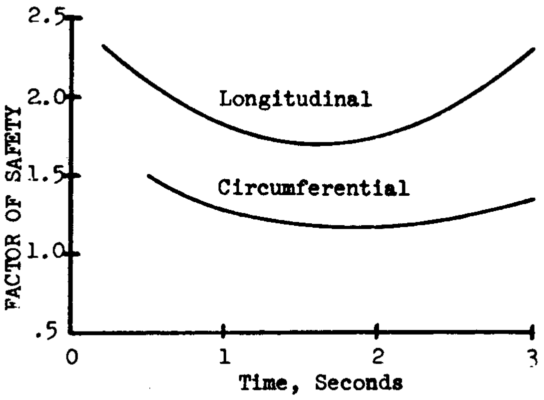

FIGURE 2. FACTOR OF SAFETY TYPE 2 CVD/FELT CONE

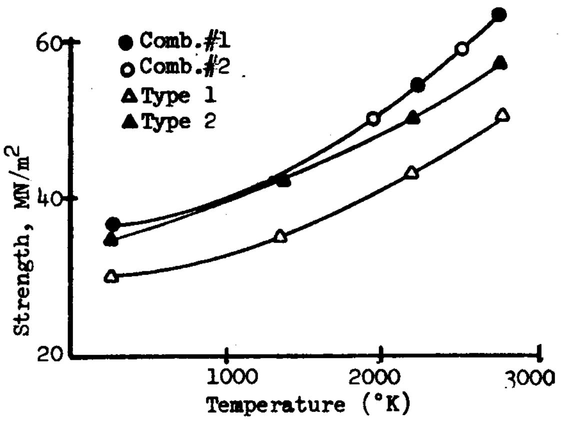

FIGURE 3. LONGITUDINAL TENSILE STRENGTH OF CVD/FELT CONES

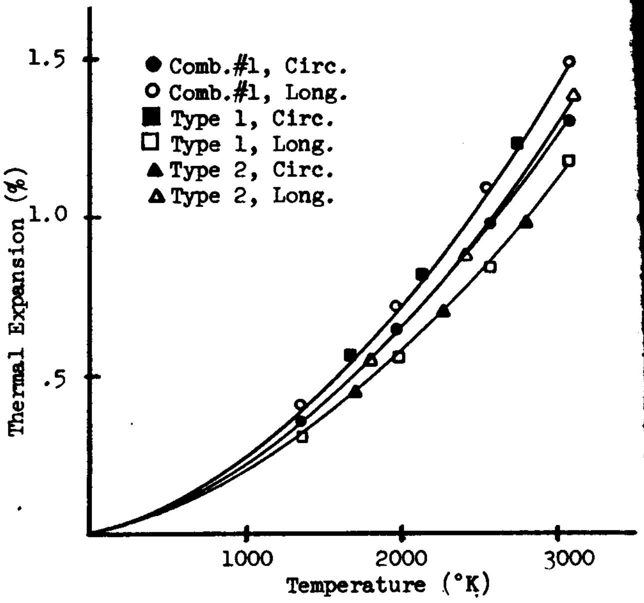

FIGURE 4. THERMAL EXPANSION OF CVD/FELT CONES

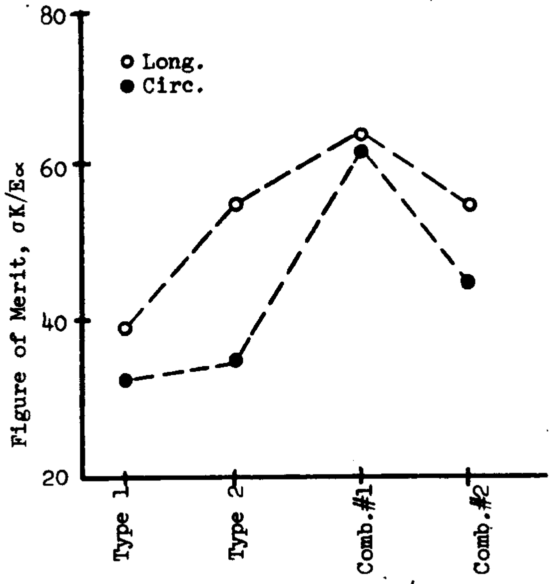

FIGURE 5. FIGURE OF MERIT FOR CVD/FELT CONES