Role of the Interface and Matrix Structure in the Mechanical and Thermal Properties of C/C Composites

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Introduction

Carbon-carbon composites have received considerable attention in the aeronautic and space industries due to their resistance to thermal ablation and good strength retention under extreme thermal shock conditions [1]. Most commercial C/C composites are fabricated from (graphitized or non-graphitized) fibers infiltrated and densified by either gas- or liquid-phase impregnation.. The infiltrated composites are then carbonized and graphitized to achieve the desired structural and physical properties. To obtain a *dense matrix structure*, the impregnation/ carbonization/graphitization cycle is usually repeated several times.

A great deal of work has been done to investigate the effect of matrix structure on the mechanical properties [3-6]. Whittaker *et al.*[7,8] have attempted to model the thermal transport properties of C/C composites. But no obvious correlation has been determined between these properties. However, a fundamental understanding of mechanical and thermal properties of carbon materials is both suitable and crucial because of the development of aircraft brake materials which serve both as structural materials and as the heat sink to absorb the kinetic energy of the aircraft. The objectives of this study are to investigate the *relationships* between thermal and mechanical properties of C/C composites and matrix structure and to examine the role of *the interface* between fiber and matrix utilizing a textural approach to explain the performance of these physical properties.

Experimental Setup and Results

All samples are made from pre-impregnated carbon fiber layers (prepreg based on polyimide matrix). This prepreg was cured and hot-pressed. The samples were then carbonized and subsequently densified by repeated infiltration/carbonization cycles. Mechanical property testing included only the flexural bending test. The thermal Diffusivity is measured by the flash diffusivity technique; and the final density and porosity of the samples were carefully measured using the mineral spirit method. All samples were characterized by transmission electron microscopy, scanning electron microscopy, and optical microscopy. All sample characteristics are represented in the table below.

Figure 1 shows the relationship between flexural modulus and the transverse (orthogonal to the fiber direction) thermal diffusivity measured at room temperature. It is obvious that we can divide this graph into regions. The first region, which covers the flexural modulus range from 0 to 20 GPa, shows slightly constant or roughly increasing behavior. The variation in the results shown for different samples is attributed to the differences in their graphitizability. While in the second region, above 25 GPa, the thermal diffusivity increases dramatically. Similiar results are observed for the longitudinal thermal diffusivity. This increase is the result of the formation of the interface between fiber and matrix.

The table shows that no correlation between physical properties and porosity exists; only a scatter of data is shown. In comparison with other parameters, porosity seems to be the minor factor. However, if we choose density as a parameter of the process and we consider only samples A through F, it seems that the results are more clear.

As shown in the table below, the physical properties depend on the density, but the mechanism and the behavior are unclear. The results suggest that beside these two parameters, other factors may be important. In our data, one obviously important parameter is the quality of the inter (see Figure 1). When the samples are devoided of the interface (gap between fiber and matrix), the physical properties are diminished; and when the interface is present, the physical properties are improved.

Discussion - Conclusion

Optimization of C/C composite processing has been a hodge podge of components developed to

achieve a maximum density and a minimum porosity. From this study, it is possible to assess that these parameters have no real physical sense if they are not related to the structure of the materials. However, they can have physical meaning if the structure of the fiber, matrix, and the connection between them are held constant.

In considering carbonaceous materials for use in high temperature structures, it should be noted that most of the properties (mechanical, thermal and chemical) very sensitively depend on the texture. In this study, It seems that the mechanical and thermal properties of C/C composites are partially influenced by the matrix and fiber structures and, more precisely, by the aptitude of the carbon component to graphitize. A small grain size, smaller crystallite and lower graphitizability diminishes the physical properties; and a large grain size, larger crystallite, and higher graphitizability improves physical properties. However, the major and determining factor is the connection between fiber and matrix. This interface and its structural quality can enhance, reduce, and/or modify the mechanical and thermal properties. In fact, the presence of the interface is essential for good transverse thermal conductivity and heat transfer and also for increasing the flexural modulus.

At this point in the study of these C/C composites, consisting of three components (fibers, matrix and interface), the transverse thermal and mechanical properties can be attributed primarily to the interface; and secondly, to the graphitizability of the fiber and matrix; and finally, to the porosity.

References

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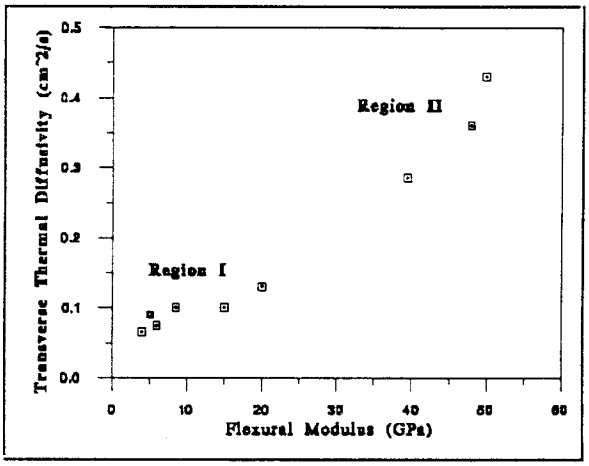

Figure 1. Transverse Thermal Diffusivity vs. Flexural Modulus

	Flexural E (GPa)	*Transverse α (cm^2/s)*	*Longitidinal α (cm^2/s)*	*Porosity (%)*	*Density (g/cc)*	*Interface*
A	4.02	0.065	0.264	14.76	1.61	Gap
B	5.14	0.073	0.47	15	1.6	Gap
C	6.01	0.074	0.55	9.68	1.64	Gap
D	8.56	0.127	0.59	10	1.63	Gap
E	15.04	0.1	0.64	13	1.71	Gap
G	20.01	0.13	0.92	15.3	1.65	Gap
H	39.53	0.285	0.8	12	1.85	Yes
I	48.01	0.36	1.36	12.8	1.86	Yes
J	50	0.43	1.4	12	1.87	Yes