THE MECHANICAL PROPERTIES OF C/C COMPOSITES AS RELATED TO ITS RESISTANCE TO HIGH TEMPERATURE EROSION

Haya Weisshaus*, Yaacov Haimovitch, Israel Engelberg
RAFAEL, Materials & Processes Department (27),
P.O.Box 2250, Haifa 31021, ISRAEL

Introduction

Most high temperature aerospace applications of Carbon/Carbon (C/C) composites are implicated by erosion. The implementation of new C/C composites in these systems is often not considered due to the lack of their erosion resistance information. Evaluation of this property needs either field testing, which is very expensive and not always accessible, or a proper simulation. The arc tunnel facility provides combined high temperature / jet stream conditions, in which comparative erosion results are obtained. However this testing is quite expensive as well and hence should be used following a cost effective planning. A better use of the arc tunnel would be to establish a correlation between any of the C/C composites room temperature properties and its resistance to erosion. The present research was planned with this prospective, choosing the mechanical properties as a preliminary selection method of suitable aerospace C/C composites.
Many articles discuss the effects of various types of raw materials and the processing parameters on the mechanical properties of C/C materials [1-3] but only very few deal also with the erosion resistance [4]. No correlation between the composites' mechanical properties and its erosion resistance is reported, though the architecture (weave type, number of directions, volume fraction of fibers) and the processing (final graphitization, number of densications) effects on the erosion itself are discussed. As for the mechanical properties of the C/C composites, its variations as related to the fibers type and the matrix precursor type are mentioned in few sources. The fiber/matrix bonding and the fibers surface treatment are believed to have a major effect on the flexure and the interlaminar shear results tested in 1D composites [1-3]. The authors claim that the composite with the PAN-based, high tenacity HTA fibers is much weaker than the PAN-based high modulus fibers composite. It is also mentioned that the role of the matrix / fiber bonding is far more important in the carbonized stage, than in the graphitized. However, the major differences in the composites' strength are a result of the heat treatment, rather than the fibers type.

Experimental

Materials
C/C composite specimens from three types, as related to the fibers, were fabricated. All PAN-based fiber type, two high modulus and one high tenacity fibers with various surface treatments. The single filament properties of each fiber are summarized in Table 1. Multidirectional C/C composites were fabricated with each one of these fibers. Six cycles of coal tar pitch impregnation and carbonization under high pressure (HiPIC), followed by about 2600°C graphitizations between each cycle, were used for the densification of a phenolic resin stabilized grid.

Specimens Preparation and Testing
Specimens for mechanical testing were prepared based on standard ASTM methods : ASTM D-638 type 4 or double sized type 5 specimens for tension, ASTM D-695 for compression, ASTM C-651 for testing in 4 points flexure mode [5]. Both the strength and the moduli were evaluated.
Rectangular specimens were prepared for the erosion resistance test in the arc tunnel facility. Measurements during the test included the power supply, the air jet fluxes and pressures, the enthalpy, the backside temperatures at few points and the total time. Measurements before and following the test included weight, size changes at few points, Computed Tomography (CT) nondestructive evaluation and microstructure analysis Scanning Electron Microscopy (SEM and Semquant), on Jeol JSM-84.

Results

The following Table 2 summarizes the densities and the average mechanical properties of the C/C composites specimens. The erosion resistance results in the x and z directions are summarized in Table 3. CT results are given in Table 4.

Discussion and conclusions

Minor differences in the mechanical properties, as well as the erosion resistances are observed with all the three compared C/C composites, though significant differences are reported in the single filament properties of each

fiber. According to these results it seems that, unlike the behavior in polymeric matrix composites, the initial filament properties are less indicative to the C/C composites properties, at least when all the fibers are PAN-based. Even the different surface treatments do not seem to significantly change all the tested properties.
A somewhat lower erosion rate is observed in the z direction of the HT reinforced fibers composite, probably as a result of a higher resin-based, glass-like carbon existing in this material, as observed by the initial CT evaluations. CT results following the arc tunnel testing prevail mechanisms of erosion otherwise not detected, i.e. a depletion of material under the surface of the HT fibers composite, while the surface itself is densified, probably due to carbon vapors deposition.
The results obtained so far, fail to distinguish between the composites according to the fiber's mechanical properties, hence conclusions couldn't be drawn as to the relationship between them and the erosion resistance. Further research in this direction is planned.

References

1. Fitzer E, Geigl KH, Huettner W. The influence of carbon fiber surface treatment on the mechanical properties of C/C composites. Carbon 1980 ; 18(4):.265-270.
2. Manocha LM, Yasuda E, Tanabe Y, Kimura S. Carbon 1988 ; 26(3):333.
3. Jain PK, Bahl OP, Manocha LM. Effect of carbon fiber type on the mechanical performance of C/C composites. SAMPE QUARTERLY, April 1992; 43.
4. Baker CF, Dunn DR, .Mills ER. Low cost, low erosion throat material for solid rocket motors. 30th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Indianapolis,(IN. USA): 1994 ; AIAA-94 -3187.
5. Weisshaus H, Kenig S, Siegmann A. Effect of materials and processing on the mechanical properties of C/C composites. Carbon 1991; 29(8):1203.

Table 1. The single filament properties of the PAN-based fibers used to reinforce the C/C composites.

Fiber Type	Tensile Strength MPa	Tensile Modulus GPa	Elongation %	Density gr./cc	Diameter μm
HM A	3240	355	0.9	1.76	7
HM B	2400	343	0.9	1.8	6.7
HT	3000	235	1.3	1.77	7

Table 2 : The average mechanical results of 3 types of C/C composites, each containing a different fiber, all identically processed and tested in direction x.

Fiber Type	C/C Density gr./cc	Tension	Compression	Bending	Tension	Compression	Bending
		Strength MPa			Modulus GPa		
HM A	1.942	86	72	92	52	46	60
HM B	1.965	105	85	110	52	40	52
HT	1.91	108	79	115	48	49	58

Table 3 : The average erosion resistance results of 3 types of C/C composites, tested in x/z direction.

Direction	Fiber Type	C/C Density gr./cc	Erosion Rate A mm/sec	Erosion Rate B mm/sec	Erosion Rate C mm/sec	Total Wt. Loss %
x	HM A	1.942	0.264	0.221	0.071	15.30
x	HM B	1.965	0.233	0.225	0.086	12.70
x	HT	1.91	0.266	0.226	0.072	13.44
z	HM A	1.942	0.283	0.220	0.080	14.52
z	HT	1.91	0.255	0.215	0.070	14.10

Table 4 : The CT scanning results of 2 C/C composites following erosion tests.

Fiber Type	Initial Density	CT based Density*	CT value				
			Average	Surface	Top	Center	Bottom
HM A	1.942	1.915	630 ± 27	754	672	579	626
HT	1.91	1.795	557 ± 29		559	515	543

* The average CT values are translated to density units using a calibration graph.