ABLATIVE RECESSION OF 3D CARBON-CARBON COMPOSITES

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The excellent resistance of graphite to ablative recession in hypersonic environments has long been recognized [1][2]. Carbon-carbon composites appear to provide similar ablative performance with better resistance to brittle fracture [3][4]. This paper describes an experimental study of ablation in turbulent flow of several 3D carbon-carbons all made with the same reinforcement but differing in process details.

Experiments

Materials tested included ATJS graphite and fifteen carbon-carbons all based on the same "223" 3D weave. Fourteen of the composites, densified with pitch, resin, and/or CVD at maximum pyrolysis pressure of 68 atmospheres, have been described by Seibold [5]. One other composite tested (GE223) had been processed with CVD plus five cycles of pitch densification involving pyrolyses at 1000 atmospheres and graphitizations at 2700°C.

Ablation tests were conducted in the MDC-200 plasma-arc heater[6] at MDRL's HIP facility, St. Louis. This Huels-type arc heater uses two hollow cylindrical electrodes. Filtered air, injected tangentially between electrodes, is heated by the arc, flows through the front electrode, and exits via a water-cooled nozzle of 0.375-inch throat diameter, 0.45-inch exit diameter, and an exit Mach number of 1.7. A special cooling technique reduces electrode erosion [7]; no particle impact was observed on any of the models.

The models were 57°-half-angle cones with 0.3-inch diameter afterbodies (Figure 1). The tip was 0.05 inch from the nozzle exit plane and was kept at that fixed position in the stream by a laser-activated recession compensator system [8]. The arc heater was adjusted to give a stagnation pressure of 100 atm at the model. Each model was kept in the stream until 0.25-inch recession occurred. Based on movie films, the cone half-angle stayed fairly constant (between 53° and 67°) during the tests. Model surface temperatures, measured using Thermogage pyrometers (0.9 μm wavelength) aimed about midway between the centerline and the cone circumference, ranged between 3200°C and 4000°C. Typical data is shown in Figure 2.

Run-to-run variations were observed in the bulk enthalpy of the plasma-heated air (between 2200 and 2400 Btu/lb). To place the data on a common basis, recession rate was assumed proportional to the centerline enthalpy of the air stream. As in [2], the centerline enthalpy was estimated higher than the bulk enthalpy by a factor sufficient to account for the discrepancy observed between heat flux measured with calorimeters during facility calibrations and the theoretical heat flux predicted for uniform enthalpy using the theory of Fay and Riddell [9].

Table of Data

Material	HIP Run No.	Bulk Density g/cm^3	Measured Recession in/sec	Normalized Recession in/sec
D	1027	1.91	0.177	0.177
A	1027	1.90	0.179	0.179
DD	1027	1.91	0.167	0.167
R	1027	1.91	0.176	0.176
RR	1028	1.91	0.151	0.151
B	1028	1.87	0.208	0.208
C	1028	1.94	0.153	0.153
DM	1029	1.88	0.246	0.214
BB1	1027	1.88*	0.176	0.176
BB2	1028	1.91*	0.243	0.243
	1029	1.91	0.197	0.171
BB3	1029	1.93*	0.183	0.160
	1028	1.93	0.175	0.175
BC1	1027	1.83*	0.250	0.250
BC2	1028	1.85*	0.215	0.215
	1029	1.88	0.213	0.185
BC3	1029	1.89*	0.206	0.180
	1029	1.89	0.207	0.180
GE223	1027	1.90	0.145	0.145
	1028	1.90	0.141	0.141
ATJS	1025	1.83	0.160	0.150
	1026	1.83	0.167	0.156

1) 7 models per run, all at 100 atm stagnation press.
2) Bulk enthalpies (Btu/lb) were 2200 for runs 1027 and 1028, 2300 for runs 1025 and 1026, and 2400 for run 1029.
3) Bulk density is for representative billets of each material, except * denotes density of ablation model.

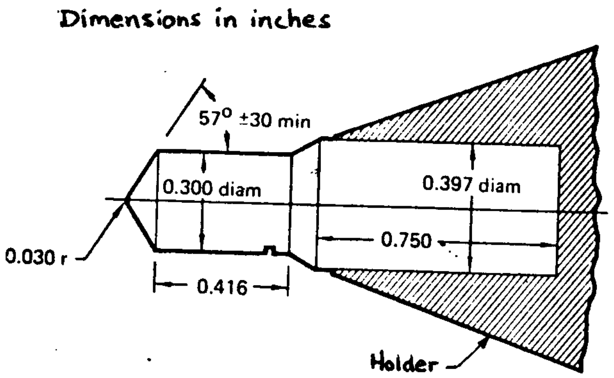

Figure 1. Ablation Test Model

Discussion

Normalized recession rates are shown vs bulk density in Figure 3; where two models of a material were tested, the average is plotted. Two lines are drawn: the solid line is the trend for thirteen of the composites; the dashed line is the expected variation of recession rate with density, assuming mass loss rate is constant for the given environment. The discrepancy between the two trends may result from differences in the heat transfer rate to each model, or from non-thermochemical effects such as mechanical erosion.

Heat transfer augmentation in turbulent flow depends on surface roughness [10]. While the relationship of roughness to microstructure and processing in carbon-carbons is incompletely understood, intuition and available evidence suggest pore size to be of major influence [11]. Matrix pockets of 3D composites densified with pitch at low pressure (68 atm) usually contain one relatively-large pore. The pore size, and therefore the roughness, may be expected to vary with the attained bulk density [12]. For composites densified with pitch at 1000 atm, the matrix pockets contain a dispersion of small pores, similar to the porosity observed in ATJS. In such materials, increases in density might affect the number of pores without necessarily reducing the maximum pore size. Thus the GE223, the ATJS graphite, and the most dense of the low-pressure-processed materials, all lie close to the same dashed trend line in Figure 3. The only other low-pressure-processed material to lie near that line is "RR" which also has small pores by virtue of the impregnations with resin [5].

Conclusions

Plasma-arc testing of 3D carbon-carbons shows recession rate in turbulent ablation to be a strong function of bulk density for materials processed with pitch at low pyrolysis pressures. This suggests that surface roughness developed during ablation is strongly affected by density in such materials. The dependence of roughness on density can probably be reduced by the use of high (1000 atm) pyrolysis pressures, or by the use of thermosetting resin as an impregnant.

Quantitative characterization of the microstructure and the roughness of the models tested would be necessary to substantiate these inferences. The role of aeromechanical erosion should be also investigated as an alternate (or supplementary) hypothesis.

Acknowledgements

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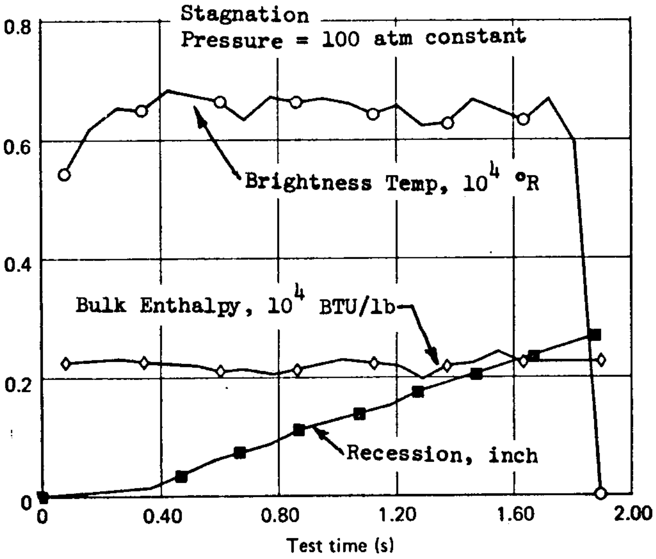

Figure 2. Typical test data

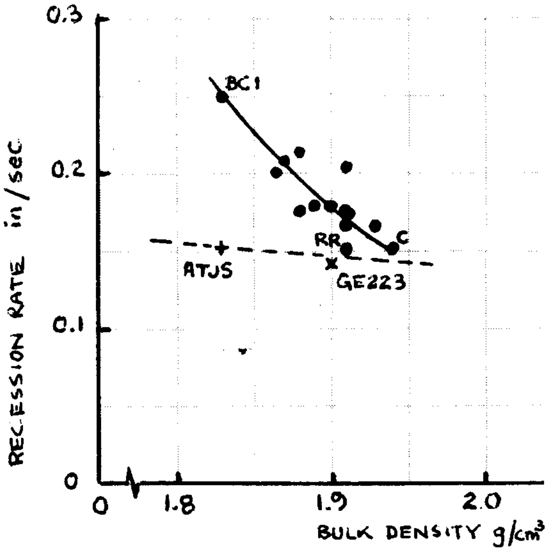

Figure 3. Data Trends