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DURABILITY OF CERAMIC MATRIX COMPOSITES IN COMBUSTION ENVIRONMENTS

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Si-based ceramic matrix composites (CMCs) continue to draw attention as materials for high temperature components in aircraft turbine engines. To date, no burner rig recession data has been published for SiC-based composites. The purpose here is to report SiC recession of CMCs compared to that reported previously for monolithic materials.

Background

SiO_2 scale volatility and the resulting recession of SiC has been previously identified for CVD, as well as sintered, SiC and Si_3N_4 materials [1-2]. Linear weight loss and surface recession of SiC was observed as a result of SiO_2 volatility for both fuel-lean and fuel-rich gas mixtures. A strong Arrhenius temperature dependence exists, and parametric studies using multiple linear regression were used to develop recession relationships as a function of $e^{-Q/RT} \cdot P^X v^Y$ for both lean and rich combustion conditions. Recession of 0.2-2.0 µm/hr is predicted for typical combustion conditions at 1200-1400°C, with a somewhat higher absolute recession rate and activation energy for rich combustion versus lean.

Experimental

NASA GRC's high pressure burner rig (HPBR) was used to expose both commercially available SiC/SiC composites, as well as those developed under NASA's Enabling Propulsion Materials (EPM) program, to realistic gas turbine combustion conditions. Samples (3"x0.5"x0.125") were exposed to both fuel-lean ($10\%O_2$-$8\%H_2O$-$7\%CO_2$-bal.$\%N_2$ @ $\phi=0.5$) and fuel-rich ($6\%H_2$-$12\%H_2O$-$12\%CO$-$5\%CO_2$-bal.$\%N_2$ @ $\phi=1.5$) jet fuel gas mixtures. The primary test parameters included a pressure of 6 atm., temperatures of 1100°-1300°C, and resulting gas velocities of 16-24 m/s. Exposures ranged between 50-250 hrs.

Results

Fuel-Lean mixtures Weight change was plotted as a function of time for a series of test temperatures for both AlliedSignal Composites, Inc. (ACI) chemical vapor infiltrated and EPM melt infiltrated SiC/SiC composite materials. As with the monolithic SiC materials, linear weight loss was observed as shown in Figure 1, and the resulting loss rates also exhibited an Arrhenius temperature dependence. Here, no differences between the two materials were noted, and a single equation was developed for CMC material loss:

$$K_l\,(\mu m/hr)=2.6036\times10^{5}[e^{-188kJ/mol\cdot RT}] \quad (1)$$

where Equation 1 predicts surface recession (µm) converted from weight change (mg/cm^2) using the density of SiC.

Fuel-Rich mixtures. Rich-burn tests were also conducted on BF Goodrich and ACI materials over the test conditions. Once again, linear weight loss and an Arrhenius temperature dependence were noted. Equations were developed for CMC material loss:

$$K_l\,(\mu m/hr)=6.296\times10^{6}[e^{-230kJ/mol\cdot RT}] \quad (2)$$

$$K_l\,(\mu m/hr)=4.629\times10^{6}[e^{-219kJ/mol\cdot RT}] \quad (3)$$

where Equations 2 and 3 predict surface recession for the BFG and ACI materials, respectively. Figure 2 shows the Arrhenius plots compared to the monolithic CVD SiC results. The slope of each curve is used to determine the activation energy (Q) of the thermally activated process, also given in Figure 2.

A summary of all results is given in Table I. In both fuel-rich and fuel-lean cases, the activation energy (Q) is higher for the CMCs when compared to the monolithic material, while rich-burn is consistently higher than lean-burn for a given material. Although there is slight differences in the absolute recession, the temperature dependency of both the BFG (Q=230 kJ/mol·K) and DuPont (Q=219 kJ/mol·K) CMCs were similar. Using Equations 1-3, long-term recession has been predicted under standard (6 atm, 16-24 m/s) conditions and compared to monolithic CVD SiC. For example at 1300°C, rich-burn exposure could typically predict nearly 10 mils of recession in only 1000 hrs, while lean-burn, although still very significant, would be nearly half that of rich-burn.

These results clearly indicate the concern for SiC recession extends to composite structures as well. Microstructure and protective coating concepts are secondary topics also planned for discussion.

References

[1] R.C. Robinson and J.S. Smialek, "SiC Recession due to SiO_2 Scale Volatility Under Combustor Conditions, Part I: Experimental Results and Empirical Model," J. Am. Ceram. Soc., in press, 1999.

[2] E.J. Opila, et. al., "SiC Recession Due to SiO_2 Scale Volatility Under Combustor Conditions. Part II: Thermodynamics and Gaseous Diffusion Model," J. Am. Ceram. Soc., in press 1999.

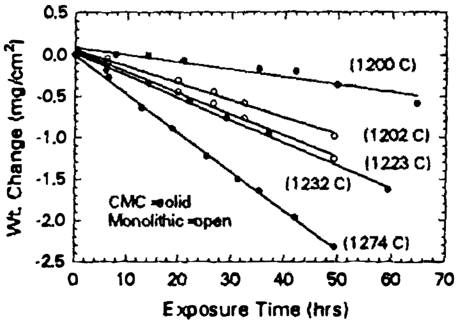

Figure 1. Linear weight loss of SiC-based materials under standard fuel-lean conditions (P=6 atm.).

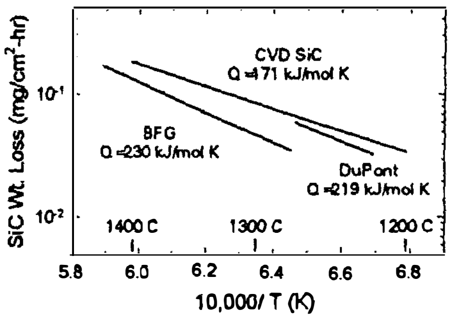

Figure 2. SiC/SiC CMC weight loss (kl=mg/cm2-hr) under standard rich-burn conditions compared to monolithic SiC.

Table I. Results for rich and lean (6 atm, 1300°C, 1000 hr)

	RICH-BURN		LEAN-BURN	
	CVD	CMC	CVD	CMC
Q (kJ/mol K)	171	219-230	111	188
Recession (µm)	259	143-245	110	155