Oxidation Protection of Graphite Foams

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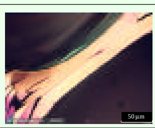
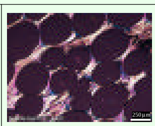
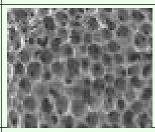
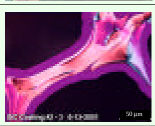
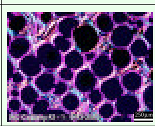
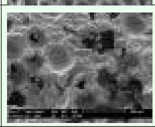
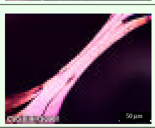
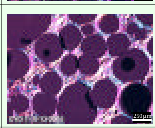
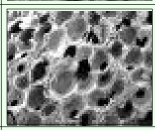
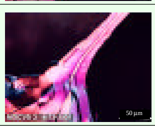
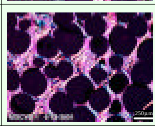
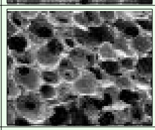
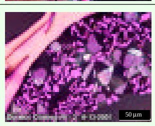
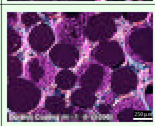
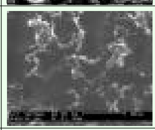
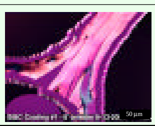
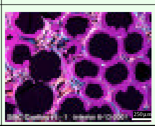
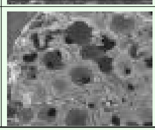
Background

- High-temperature heat exchangers that utilize carbonaceous materials to reduce weight and improve efficiency are currently being explored.
- Graphite foams that exhibit more than an order of magnitude increase in efficiency for electronics cooling and other heat exchangers have been developed.
- Heat exchanger designs based on the graphite foam have been shown to reduce weight by up to 75%.
- The graphite foam must be protected from oxidation at elevated temperatures.
- Methods developed for protecting carbon-carbon composites, i.e. chemically vapor deposited silicon- and boron-containing ceramic layers, have been applied to the graphite foams.

Experimental

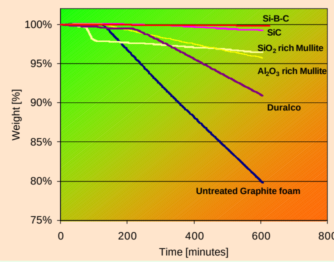
- Ceramic coatings have been applied to graphitic carbon foams to improve high-temperature oxidation resistance.
- Chemically vapor deposited layers; silicon carbide, mullite, and silicon-boron-carbide, and coatings applied using a liquid precursor with particulate fillers, SiC, have been investigated.
- Coating uniformity and integrity (bonding and microcracking) were characterized employing electron (SEM & TEM) and optical microscopy.
- Environmental stability was evaluated using thermogravimetric analysis. Samples were exposed to 1 SCFM of flowing air at 650°C for 8 hours and the weight change per unit mass of carbon was measured.

Results and Discussion

Coating	Optical Analysis	SEM Analysis	Coating Thickness*	Oxidation Rate** [%/hr]
Uncoated Foam	 		--	2.24
CVD SiC	 		~13 μm • very uniform coating • little microcracking	0.27
CVD Mullite (Al_2O_3 rich)	 		~0.6 μm • very uniform coating • Not visible under optical image analysis	0.55
CVD Mullite (SiO_2 rich)	 		~0.6 μm • very uniform coating • Not visible under optical image analysis	0.20
Liquid SiC Precursor "Duralco"	 		~75 μm • very poor coating • Particulates in liquid precursor did not sinter • Coating is not uniform	1.83
CVD Si-B-C	 		10- 50 μm • Coating is mixed between hexagonal and cubic structure • Coating unifromity can be improved	0.10

*Determined with SEM analysis ** Normalized to original carbon foam mass

- The structure of the foam, with large, open and interconnected pores, allows for easy deposition of coatings through out the material.
- This structure is well suited for chemical vapor infiltration as supported by the observation that the CVD coatings infiltrate all microcracks and pores throughout the entire foam samples.
- Although the coatings permeated the entire samples, coating thickness varied thus conditions need to be optimized for the specific layer composition and foam density.
- The CVD coatings provided better protection than the liquid-precursor coating.
- Minimal microcracking of the deposits was found. It is believed that the very high ligament conductivity (>1700 W/m·K) and low bulk modulus (140 MPa) of the foam combine to minimize thermal stresses.
- The CVD Si-B-C layer provided the best protection, however, more detailed characterization of the coating is being conducted to determine composition and better understand its microstructure.



Conclusions

- Ceramic coatings were readily applied to the porous graphite foams.
- The results, although preliminary with single samples and limited exposure data, were promising.
- The ceramic coatings significantly reduced the oxidation rate of the graphite foams at the given conditions.
- The Si-B-C coatings provided the best protection, thus it is hypothesized that as in previous work with carbonaceous materials, the lower-temperature glass former (B_2O_3) would seal microcracks that could form during cyclic operation.
- Coatings may prove to be useful for other applications such as enhanced wetting for infiltration with liquids, for brazing and joining, or for compatibility with other heat transfer medias.