Volatile Reaction Products From Silicon-Based Ceramics in Combustion Environments Identified

Silicon-based ceramics and composites are prime candidates for use as components in the hot sections of advanced aircraft engines. These materials must have long-term durability in the combustion environment. Because water vapor is always present as a major product of combustion in the engine environment, its effect on the durability of silicon-based ceramics must be understood. In combustion environments, silicon-based ceramics react with water vapor to form a surface silica (SiO$_2$) scale. This SiO$_2$ scale, in turn, has been found to react with water vapor to form volatile hydroxides. Studies to date have focused on how water vapor reacts with high-purity silicon carbide (SiC) and SiO$_2$ in model combustion environments.

Because the combustion environment in advanced aircraft engines is expected to contain about 10-percent water vapor at 10-atm total pressure, the durability of SiC and SiO$_2$ in gas mixtures containing 0.1- to 1-atm water vapor is of interest. The reactions of SiC and SiO$_2$ with water vapor were monitored by measuring weight changes of sample coupons in a 0.5-atm water vapor/0.5-atm oxygen gas mixture with thermogravimetric analysis (ref. 1). SiC initially exhibited a weight gain due to SiO$_2$ formation:

$$\text{SiC}(s) + 3\text{H}_2\text{O}(g) = \text{SiO}_2(s) + 3\text{H}_2(g) + \text{CO}(g)$$

At longer durations, a weight loss attributed to the volatility of SiO$_2$ in water vapor became apparent:

$$\text{SiO}_2(s) + 2\text{H}_2\text{O}(g) = \text{Si(OH)}_4(g)$$

$$\text{SiO}_2(s) + \text{H}_2\text{O}(g) = \text{SiO(OH)}_2(g)$$

By testing SiO$_2$ (rather than SiC) in water vapor, a linear weight loss uncomplicated by the oxidation reaction (1) can be observed by thermogravimetric analysis.
Weight change kinetics for SiC and SiO\textsubscript{2} in 0.5 atm H\textsubscript{2}O/0.5 atm O\textsubscript{2} at a temperature of 1200 °C and a velocity of 4.4 cm/sec.

The identities of the volatile species were established by using a specialized mass spectrometer that samples reactions at 1-atm total pressure (ref. 2). SiO\textsubscript{2} samples with large surface areas were exposed to water vapor/oxygen mixtures at high temperatures. Molecules with masses corresponding to both Si(OH)\textsubscript{4} and SiO(OH)\textsubscript{2} were identified.

Because SiO\textsubscript{2} is volatile in combustion environments, it no longer provides protection for SiC. Consumption of SiC thus occurs at more rapid rates in water-vapor-containing environments. The consumption rate of SiC increases with water vapor pressure as well as gas velocity. This is a concern when SiC is applied in the high-pressure, high-velocity aircraft engine environment. Current efforts are focused on coatings for SiC that prevent volatility of the surface SiO\textsubscript{2}.

References


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