CELLULAR SILICON CARBIDE CERAMICS AT HIGH TEMPERATURE

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ABSTRACT

Because of high thermal conductivity, low coefficient of thermal expansion and good thermal shock and corrosion resistance cellular silicon carbide ceramics are of particular interest for applications at high temperatures, e.g. in volumetric burners or CSP plants. Out of different typical high temperature materials like silicon infiltrated silicon carbide, Alumina and a FeCrAl-alloy, especially pressureless sintered silicon carbide (SSiC) has been identified as the most promising material for such applications. A durability of the material over a long period of time, up to 10.000 hours or even more is essential. In order to assess durability, the behavior of SSiC cellular ceramic foams at temperatures up to 1550 °C for short and 1250 °C for long operation times, at medium and high gas velocities and under the influence of various amounts of oxygen, water vapor and impurities has been investigated. In comparison to SiSiC material a significant higher oxidation resistance of our recently new developed SSiC was obtained. Based on identified degradation mechanisms the durability of SSiC foams can be estimated.

SUMMARY AND CONCLUSIONS

Cellular Ceramics made of Sintered Silicon Carbide (SSiC) are especially suited for high temperature appliances. But degradation may occur because of oxidation effects and crack evolution in abrupt temperature gradients. Oxidation effects depend mainly on temperature, gas composition and gas velocity. The demonstrably parabolic oxidation behavior under typical gas combustion conditions make degradation effects predictable. E.g. a 30 µm degradation of SSiC struts in typical cellular burner inserts will be reached after 80,000 hours of isothermal operation at 1200 °C. This will decrease strength by simply reducing the cross section, but after very long time measurements only (not shown here). In contrast, higher gas velocities (>5 m/s) and high water content (> 20 %) result in para-linear degradation and limits stability significantly.
Strength degradation by cracks caused by high thermal gradients depends on burner design and are therefore hard to predict. On that account start-stop experiments and stress simulations of cellular components in temperature gradients should be used to predict their lifetime.

SAMPLE PREPARATION

Open celled ceramic foam samples (fig. 1) were made by replication technique (fig. 2). Focused on cell size 10 ppi (pores per inch acc. to ASTM D 3576-77) with a total porosity of 87 %, different sample sizes and numbers appropriate for the four test rigs have been investigated. B-doped SSiC ceramics with 3 levels of microstructural porosity in the struts (fig. 3) have been developed and compared.

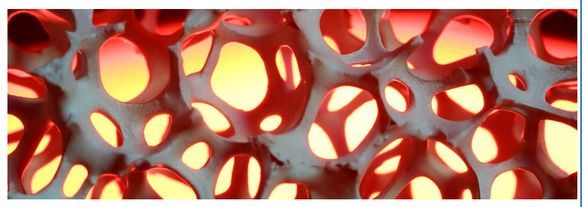

Figure 1: Open celled ceramic foam made of SSiC.

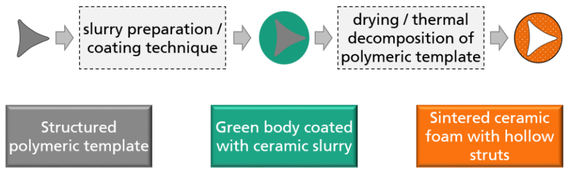

Figure 2: Preparation method by template method (acc. to Schwarztwalder 1963).

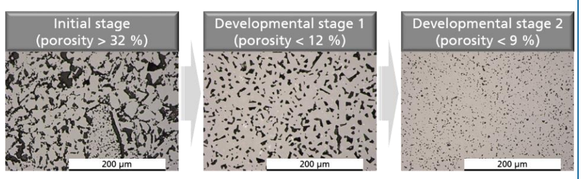

Figure 3: Stages of development of SSiC (struts with different levels of microstructural porosity).

EXPERIMENTAL

Four different types of test rigs varying in gas composition and temperature gradients were used to describe the degeneration behavior at high temperature (table 1). Only real burner test rigs (fig. 4) deliver typical burner conditions (gradients, atmosphere), but not enough samples for statistical evaluation of strength degradation. Therefore a special tube furnace test rig was developed to realize a larger volume at constant temperature in a combustion atmosphere (fig. 5).

Table 1: Test rigs and conditions for sample treatment.

	Muffle furnace	Burner	Hot gas burner	Burner-tube-furnace
Parameter				
Atmosphere	dry air	combustion	combustion	combustion
v (m/s)	0	< 5	50 – 100	< 10
T (°C)	RT – 1550	600 – 1250	600 – 1450	1000 – 1200
Test time (h)	100 – 500	100 – 3250	100 – 200	100 – 500
Investigation of				
Weight change	✓	✓	✓	✓
Microstructure	✓	✓	✓	✓
Mech. Strength	✓			✓

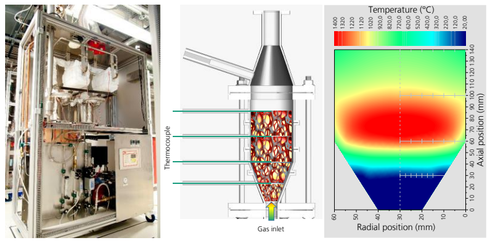

Figure 4: Burner test rig and simulated temperature field (3.5 kW, Lambda 1.67).

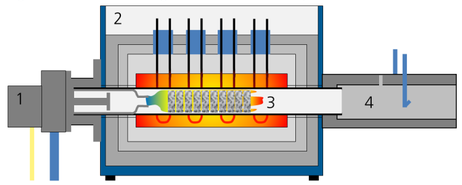

Figure 5: Tube furnace test rig: gas burner (1), tube furnace with electrical heaters (2), samples (3), exhaust (4).

RESULTS I (INVESTIGATION OF OXIDATION BEHAVIOR)

Most samples showed parabolic oxidation behavior, and therefore parabolic oxidation rate k can be determined (fig. 6). Measurements revealed a large impact of both temperature and microstructural porosity, inducing inner oxidation. Samples at stage 2 (< 9 % porosity in the struts) showed equal behavior as typical, dense SSiC ceramics.
Para-linear oxidation effects were detected only at high gas velocity + increased water vapour (fig. 7). Under typical combustion conditions only a slight effect of burners' lambda was detected (not shown here).

Figure 6: Par. Oxidation rates dependent on temperature, atmosphere (dry, burner = combustion). Color represents different development stages (decreased strut porosity).

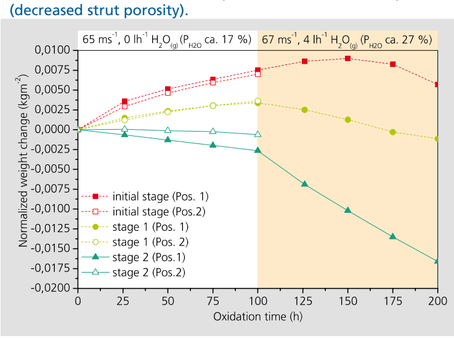

Figure 7: Mass change at 1400 °C at high gas velocities without 17 % (white background left) and 27 % H_2O (orange background right), indicating additional mass loss by SiO_2 instability (para-linear behavior).

RESULTS II (EVALUATION OF STRENGTH DEGRADATION)

Strength was not affected by oxidation in the burner-tube-furnace test within 500 h (fig. 8). However, cracks occurred in burner test rig samples, resulting from steep temperature gradients (fig. 9). This will cause strength degradation after long-time application.

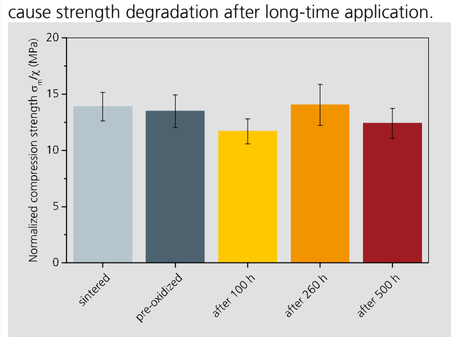

Figure 9: Strength of samples after oxidation in tube furnace test rig at 1200 °C.

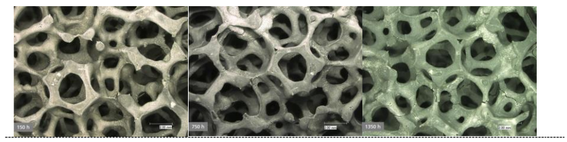

Figure 10: Crack appearance after long time testing at 1200°C in burner rig.

COMPARISON TO OTHER MATERIALS (BURNER RIG)

SiSiC, Alumina and FeCrAl-Alloy were tested in the same burner rig at constant power load (3.5 kW, λ= 1.67) resulting in different temperatures and failure modes. Alumina failed because of fast crack evolution, FeCrAl alloy because of extremely fast oxidation, both after 100h. SiSiC is stable, as long as temperatures are low enough to avoid Si-(alloy) melting (< 1300 °C).

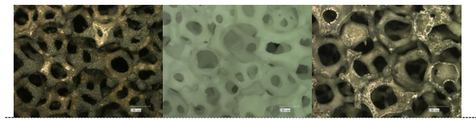

Figure 11: Samples after burner rig test (left FeCrAl, middle Al_2O_3, right SiSiC).

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