CERAMIC RELIABILITY FOR MICROTURBINE HOT-SECTION COMPONENTS

Technical Progress

Studies of dynamic fatigue properties for SiAlON ceramics (Kennametal Inc., PA) were continued during this reporting period. Kennametal was awarded by DOE under Microturbine Materials Program to develop SiAlON ceramics for hot-section components for advanced microturbines. The SiAlON ceramics due to their superior wear resistance have been developed for metal cutting tool applications, and might have great potential for structural applications in microturbine systems. The purpose of this study is to generate a database for down-selecting the candidate composition(s) and also for probabilistic component design and life prediction efforts carried out by microturbine companies. All of the materials, sintered with different chemical compositions, i.e., rare earth oxide content, contain a mixture of α- and β-SiAlON grain microstructure. The SiAlON ceramics were fabricated under the Phase I contract, and MOR bars were longitudinally machined per the revised ASTM C116 standard with 600 grit surface finish. The dynamic fatigue tests were carried out at 20 and 1204°C and at stressing rate of 30 and 0.003 MPa/s in air per ASTM C1465. The 30 MPa/s is used to evaluate the inert characteristic strength as a function of temperature, and 0.003 MPa/s is applied to measure the slow crack growth (SCG) susceptibility at high temperatures.

Test results at 20°C and 30 MPa/s showed that all of the SiAlON materials exhibited comparable relatively low Weibull modulus with respect to commercially available silicon nitride ceramics evaluated and reported previously (Table 1 and Fig. 2-7). Preliminary fractography examinations indicated the low Weibull moduli obtained for all of the SiAlON materials evaluated might result from the metal contamination during processing. Also, results showed that the values of the inert characteristic strength of SiAlON strongly depended on the size and content of elongated β-SiAlON grains. For instance, the material contained fine α-SiAlON matrix plus a relative high content of β-SiAlON grains (e.g., AB832 and AB832) exhibited higher characteristic strengths than those with more equiaxed microstructure (e.g., AB582 and AB532). The effect of β-SiAlON elongated grain size and content on the measured mechanical strength is consistent with those previously reported for silicon nitride ceramics. On the other hand, results showed there was minor change in inert characteristic strength accompanied with a high fatigue exponent for 2308E material when tested at 20°C and 0.003 MPa/s (Fig. 8 and 9). Note that the 2308E material showed a 20% degradation in strength with a low fatigue exponent (~36) when tested at 1204°C (Table 1), indicative of high susceptibility to SCG at temperature. Dynamic fatigue tests at 1204°C will be carried out for these SiAlON materials and results will be discussed in the next quarterly report.

Table 1. Summary of uncensored Weibull and strength distributions for Kennametal SiAlON ceramic specimens with as-machined surface (longitudinally machined per the revised ASTM C1161 standard).

Material	# of Spmns. Tested	Stressing Rate (MPa/s)	Temp. (°C)	Uncens. Weibull Modulus	± 95% Uncens. Weibull Modulus	Uncens. Chrctstic Strength (MPa)	± 95% Uncens. Chrctstic Strength (MPa)
2308A	15	30	20	5.92	3.80, 8.55	651	589, 715
2308E	15	30	20	6.06	3.91, 8.73	783	710, 858
2308E	12	0.003	20	6.62	4.06, 9.90	807	729, 887
AB132	15	30	20	6.39	4.16, 9.14	878	801, 958
AB531	15	30	20	10.65	6.75, 15.55	801	757, 844
AB532	15	30	20	8.47	5.27, 12.65	721	673, 771
AB582	15	30	20	7.21	4.65, 10.34	567	523, 613
AB831	15	30	20	8.45	5.42, 12.29	960	894, 1025
AB832	15	30	20	10.70	6.83, 15.57	1029	973, 1084
2308A	15	30	1204	9.79	6.52, 13.62	393	370, 415
2308E	15	30	1204	7.45	4.67, 11.05	540	489, 582
2308A	15	0.003	1204	10.68	6.87, 15.38	415	392, 437
2308E	14	0.003	1204	3.37	2.29, 4.55	440	369, 522

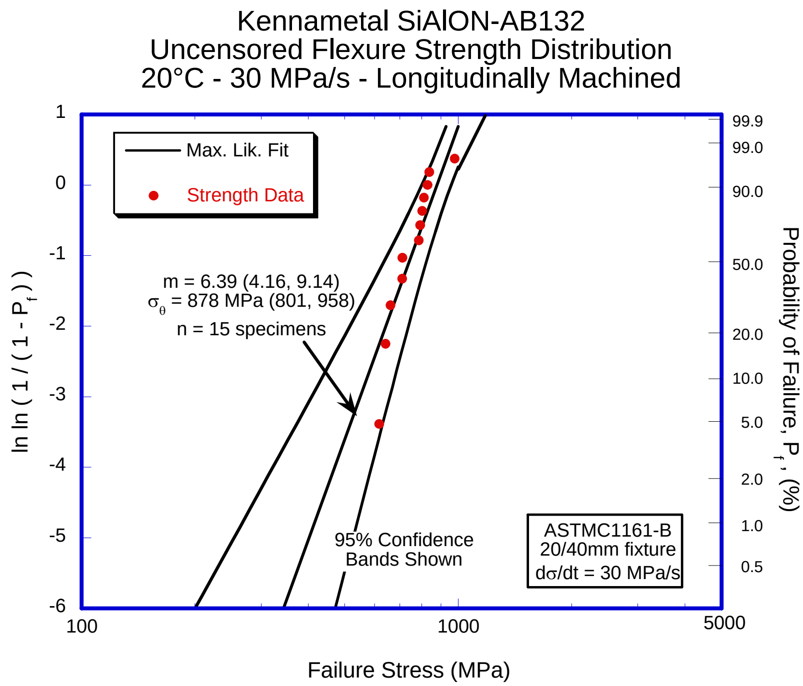

Figure 2. Uncensored flexure strength distribution at 20°C and 30 MPa/s of SiAlON-AB132 ceramic with as-machined surface (bulk material).

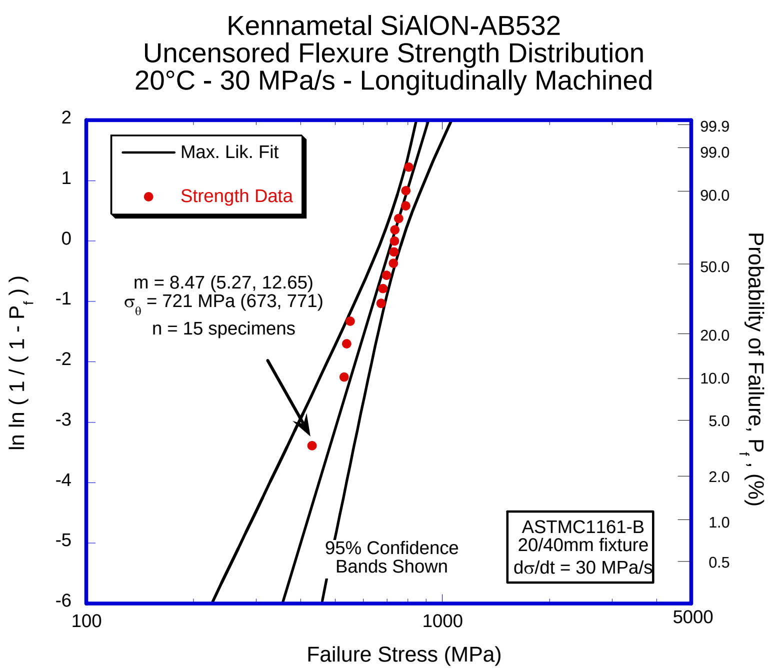

Figure 3. Uncensored flexure strength distribution at 20°C and 30 MPa/s of SiAlON-AB531 ceramic with as-machined surface (bulk material).

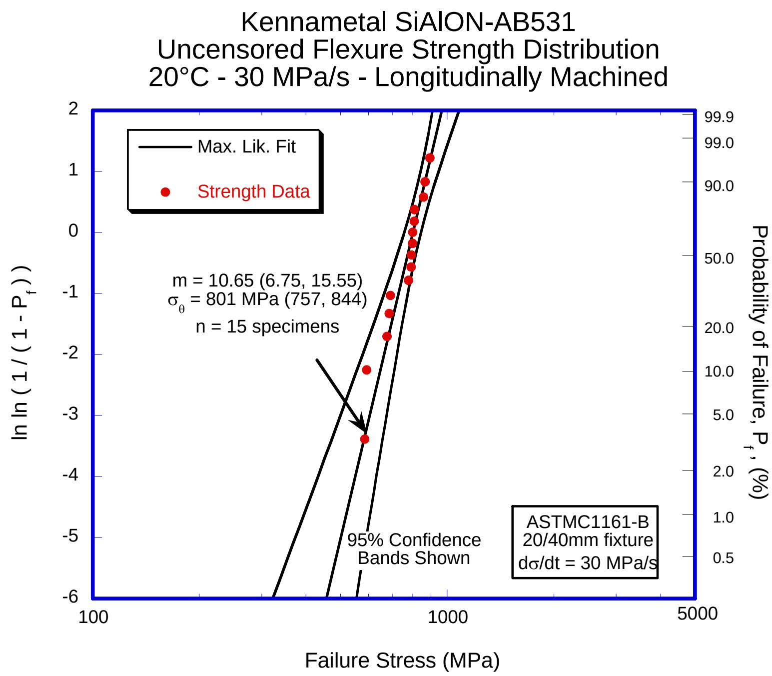

Figure 4. Uncensored flexure strength distribution at 20°C and 30 MPa/s of SiAlON-AB532 ceramic with as-machined surface (bulk material).

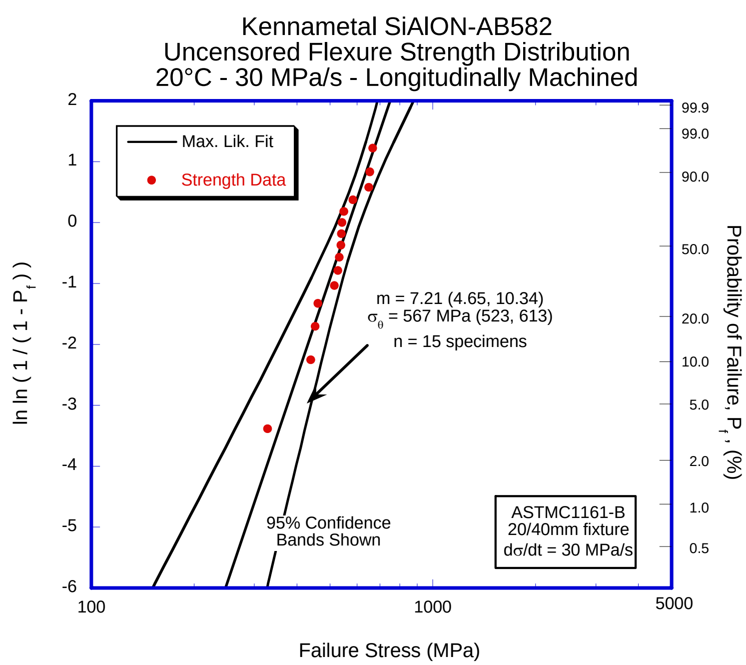

Figure 5. Uncensored flexure strength distribution at 1204°C and 30 MPa/s of SiAlON-AB582 ceramic with as-machined surface (bulk material).

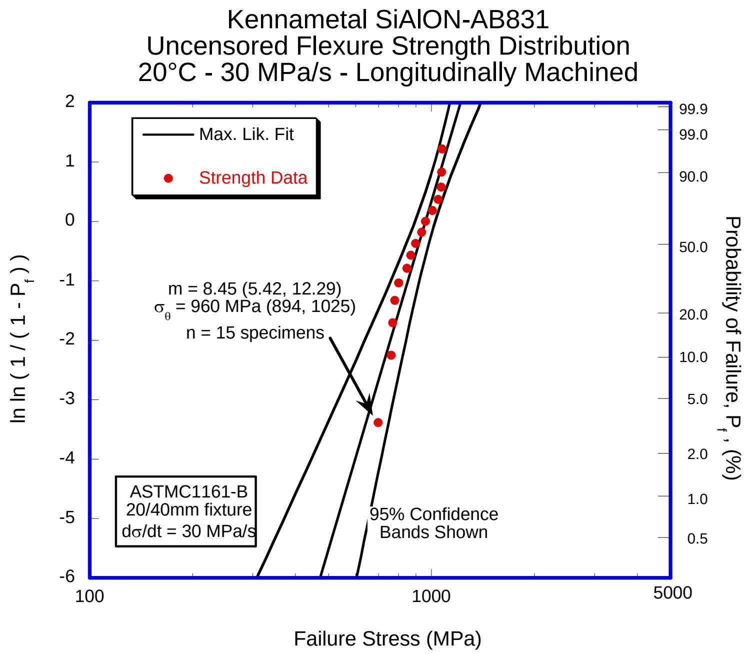

Figure 6. Uncensored flexure strength distribution at 1204°C and 30 MPa/s of SiAlON-AB831 ceramic with as-machined surface (bulk material).

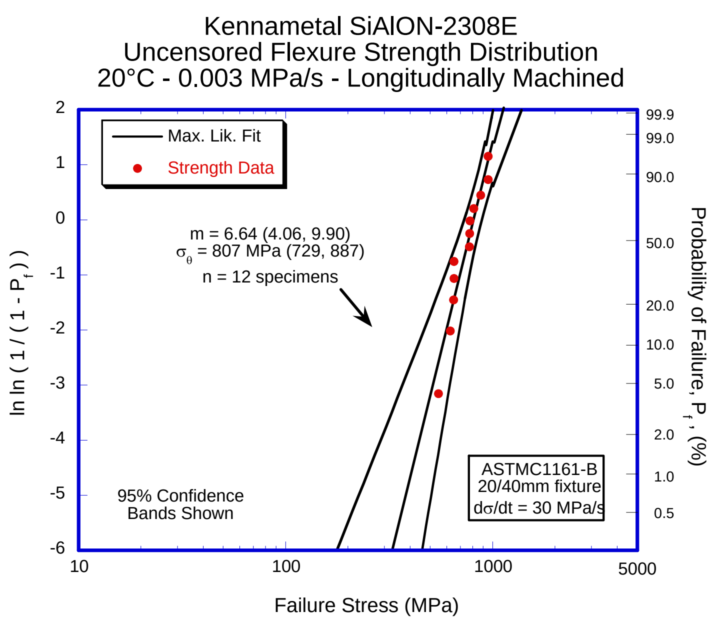

Figure 7. Uncensored flexure strength distribution at 20°C and 30 MPa/s of SiAlON-AB832 ceramic with as-machined surface (bulk material).

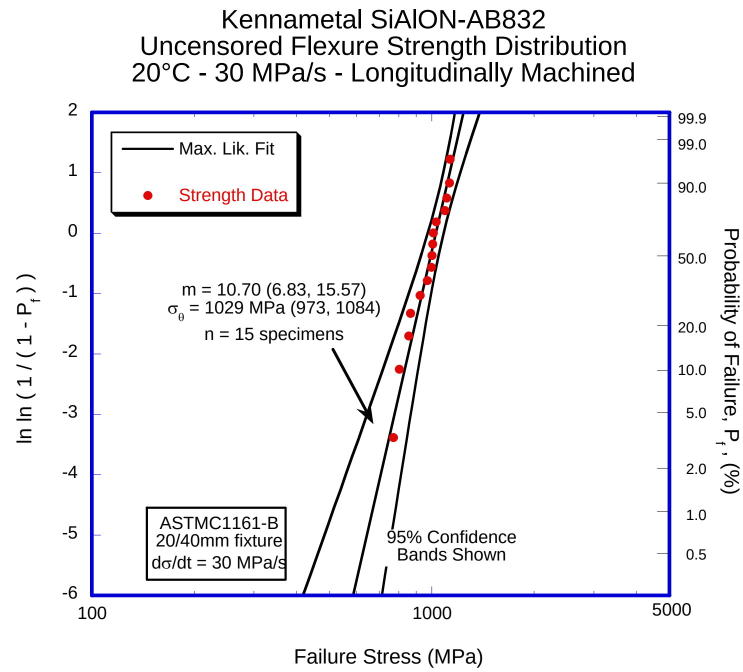

Figure 8. Uncensored flexure strength distribution at 20°C and 0.003 MPa/s of SiAlON-2308E ceramic with as-machined surface (bulk material).

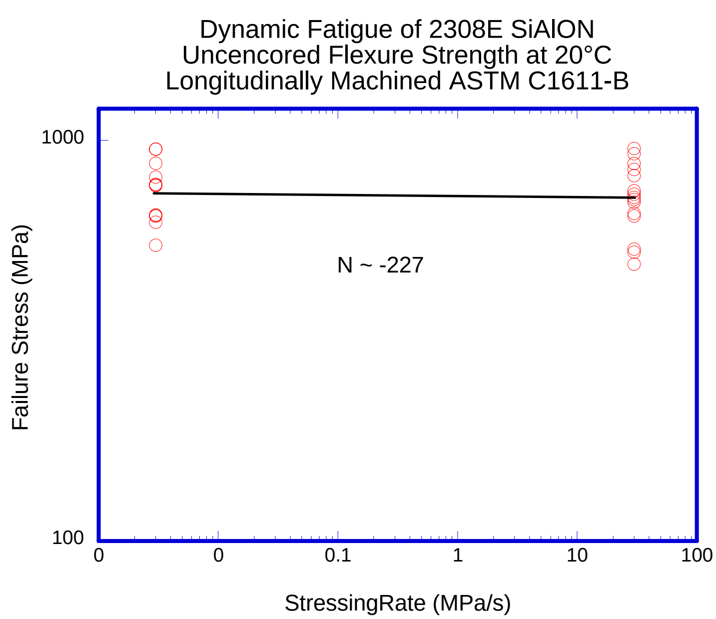

Figure 9. Flexure strength versus stressing rate for SiAlON-2308E with as-machined surface (bulk material) tested at 20°C.

An Ingersoll-Rand type NT154 silicon nitride microturbine rotor, similar to Kyocera SN237 rotor, has been received from Saint-Gobain Ceramics & Plastics (Fig. 10). Biaxial discs will be machined from airfoils for mechanical strength evaluation using ball-on-ring method at room temperature. Test results will be provided to Saint-Gobain for processing optimization and to microturbine companies for their probabilistic component design and life prediction.

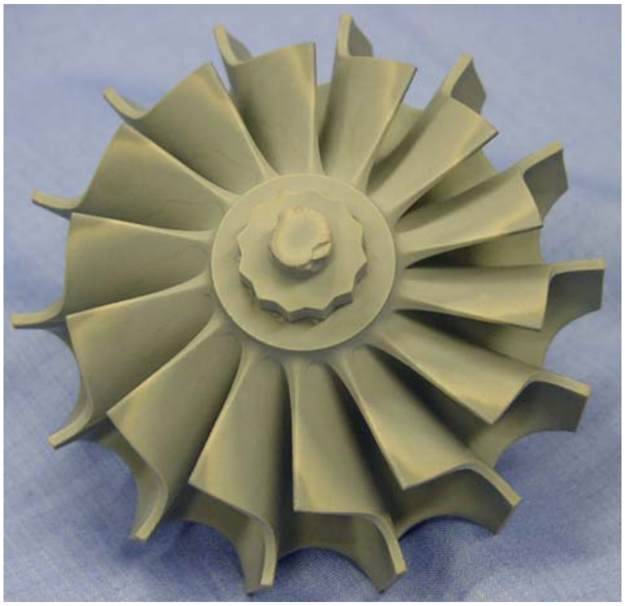

Figure 10. Photo of NT154 silicon nitride microturbine rotor manufactured by Saint-Gobain.

Status of Milestones

1. Complete evaluation of next generation Si_3N_4 with EBC from SMRC, Japan after long-term steam jet testing. September 2004. On schedule.

Industry Interactions

Communication with John Holowczak, Venkata Vedula, and Jun Shih at UTRC to discuss the mechanical results of SN282 integral vane ring.

Communication with Vimal Pujari and Ara Vartabedian at Saint-Gobain Ceramics & Plastics on the updates of the testing status and results for NT154 silicon nitride materials manufactured during Task II effort under Phase I contract, and also the preparation status for NT154 microturbine rotor.

Communication with Russ Yeckley at Kennemetal on the dynamic fatigue test results of SiAlON ceramics manufactured during Task I effort.

Communication with Professor Rishi Raj at University of Colorado on the testing and evaluation of SiCN EBC materials under steam environments.

Problems Encountered

None

Publications/Presentations

H. T. Lin and M. K. Ferber, “Evaluation Methodology for Mechanical Property of Complex-Shaped Ceramic Components.” Presented at International Cocoa Beach Conference & Exposition on Advanced Ceramics & Composites, Cocoa Beach, FL, January 25-30, 2004

M. K. Ferber, H. T. Lin, S. F. Duffy, J. K. Kesseli, and M. Costen, “Characterization of a Ceramic Rotor Developed for the IR Power Works Microturbine,” Presented at International Cocoa Beach Conference & Exposition on Advanced Ceramics & Composites, Cocoa Beach, FL, January 25-30, 2004.