



## **Mechanical and Thermal Properties of Advanced Ceramics for Gun Barrel Applications**

**by Jeffrey J. Swab, Andrew A. Wereszczak, Jason Tice, Russ Caspe,  
Reuben H. Kraft, and Jane W. Adams**

**ARL-TR-3417**

**February 2005**

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Weapons and Materials Research Directorate, ARL**

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14. ABSTRACT Eight commercially available ceramic materials were procured and evaluated for potential application as gun barrel liners. These materials included an alumina, zirconia, and SiAlON, as well as three silicon carbides and two silicon nitrides. Preliminary evaluation determined the strength, fracture toughness, Vickers hardness, thermal conductivity, specific heat, and linear coefficient of thermal expansion. An uncensored Weibull analysis was performed on all of the strength data. These databases were developed for use in the probabilistic modeling and design efforts of the program to predict performance, identify optimum gun barrel designs, and to rank and down select ceramics for further evaluation.					
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## **Foreword**

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Jason Tice and Rueben Kraft performed this work while undergraduates at the University of Maryland Baltimore County and with support by an appointment to the Research Participation Program of the U.S. Army Research Laboratory (ARL) administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and ARL.

Russ Caspe performed this work while an undergraduate student in the Department of Ceramic and Materials Engineering, Rutgers University, Piscataway, NJ, with support from the ARL Materials Center of Excellence at Rutgers University, High Fidelity Design, and Processing of Advanced Armor Ceramics.

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- Netzsch Instruments, Billerica, MA, for conducting the thermal conductivity, heat capacity, and coefficient of thermal expansion experiments for each material.
- John Underwood at Benét Labs for his helpful discussions and insights on the thermal property analysis.

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## 1. Background

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The U.S. Army Research Laboratory is currently assessing the feasibility of ceramic gun barrels in an attempt to provide a significant increase in barrel life, a reduction in weight (primarily for smaller caliber systems), and enable the use of higher energetic propellants. This investigation spans a range of calibers from the 5.56-mm rifle to the 155-mm artillery system. The steel gun barrels currently used by the Army for these systems have a short lifecycle and cannot withstand many of the higher energy propellants that are currently available or under development. It is anticipated that ceramic gun barrel liners will provide a 50% increase in barrel life with sustained accuracy for direct and indirect fire, enable a 20% increase in muzzle kinetic energy for direct fire, and provide a 5%–25% weight reduction (per unit length of barrel) owing to the combination of superior wear resistance, high temperature capability, and relatively low density that are inherent to ceramic materials. The development of a ceramic gun barrel will reduce maintenance costs while serving as an enabling technology for the use of higher energy propellants.

The program to examine ceramic materials for gun barrel applications includes material evaluation of commercially-available advanced ceramics, probabilistic modeling to develop an optimized ceramic gun barrel design, erosion testing to simulate the gun barrel environment, extensive examination of sheathing technology to provide the necessary hoop and axial confinement, and finally, ballistic testing of a barrel segment. This report presents a summary of the mechanical and thermal property data generated on eight advanced ceramic materials.

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## 2. Materials Information

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The materials examined in this study are all commercially-available ceramics that include two silicon nitrides, a SiAlON, three silicon carbides, one alumina, and one zirconia.\* Traditional sintering methods were used to fabricate all materials, with the exception of the SiAlON (STK4), which was subjected to a post sintering hot isostatic pressing process. Table 1 lists the materials evaluated. The microstructure of each material is shown in figures 1–8. In some cases, it was necessary to thermally or chemically etch a material to highlight the microstructure. If a material required etching, the etchant is

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\* Certain commercial materials or equipment are identified in this report to adequately specify the experimental procedure. This in no way implies endorsement of materials or equipment by the U.S. Army Research Laboratory, or that these are necessarily the best for these purposes.

noted in the figure caption. Each material was ordered from the respective vendors in the three geometries shown in figure 9. Circumferential machining and a minimum surface finish of 0.8  $\mu\text{m}$  on the outer diameter of all tubes (geometry B) were requested of each vendor.

Table 1. Material information.

Material	Vendor	Vendor Code	ARL Code	Vintage	Density (g/cm <sup>3</sup> )
Al <sub>2</sub> O <sub>3</sub>	CoorsTek	AD995	ALOX	2001	3.8
ZrO <sub>2</sub>	CoorsTek	Ce-TZP	ZRO2	2001	6.1
SiC	Saint-Gobain	Enhanced hexoloy SA	SCEH	2001	3.1
SiC	Saint-Gobain	LPS hexoloy SA	SCLH	2001	3.1
SiC	Ceradyne	Ceralloy 146-5S	SC46	2001	3.1
Si <sub>3</sub> N <sub>4</sub>	Ceradyne	Ceralloy 147-31N	SN47	2001	3.2
SiAlON	Kennametal	TK4	STK4	2001	3.4
Si <sub>3</sub> N <sub>4</sub>	Kyocera	SN235P	SN5P	2002	3.2

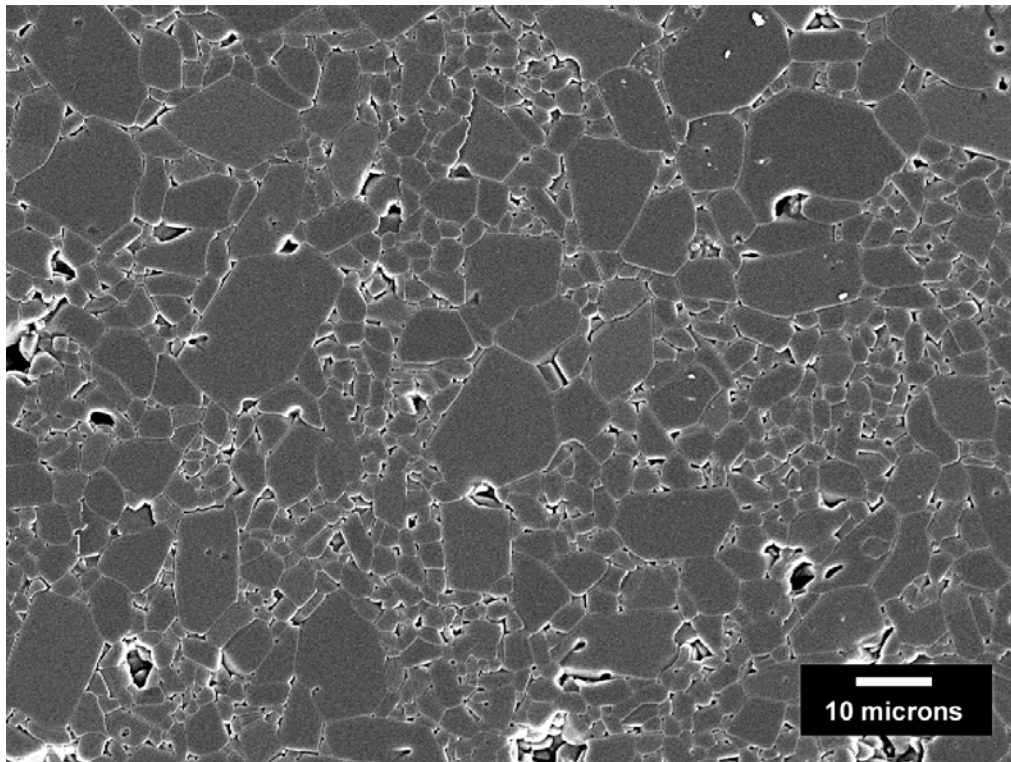


Figure 1. Microstructure of the CoorsTek AD-995 alumina (ALOX) after thermal etching.

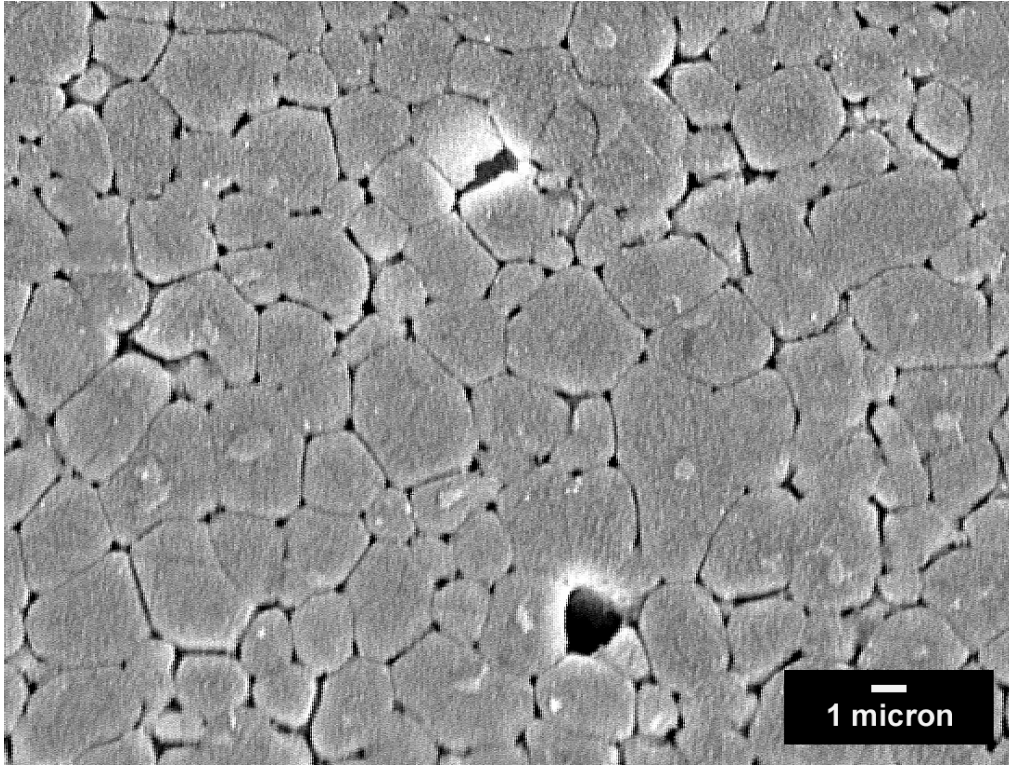


Figure 2. Microstructure of the CoorsTek Ce-TZP zirconia (ZrO<sub>2</sub>) after thermal etching.

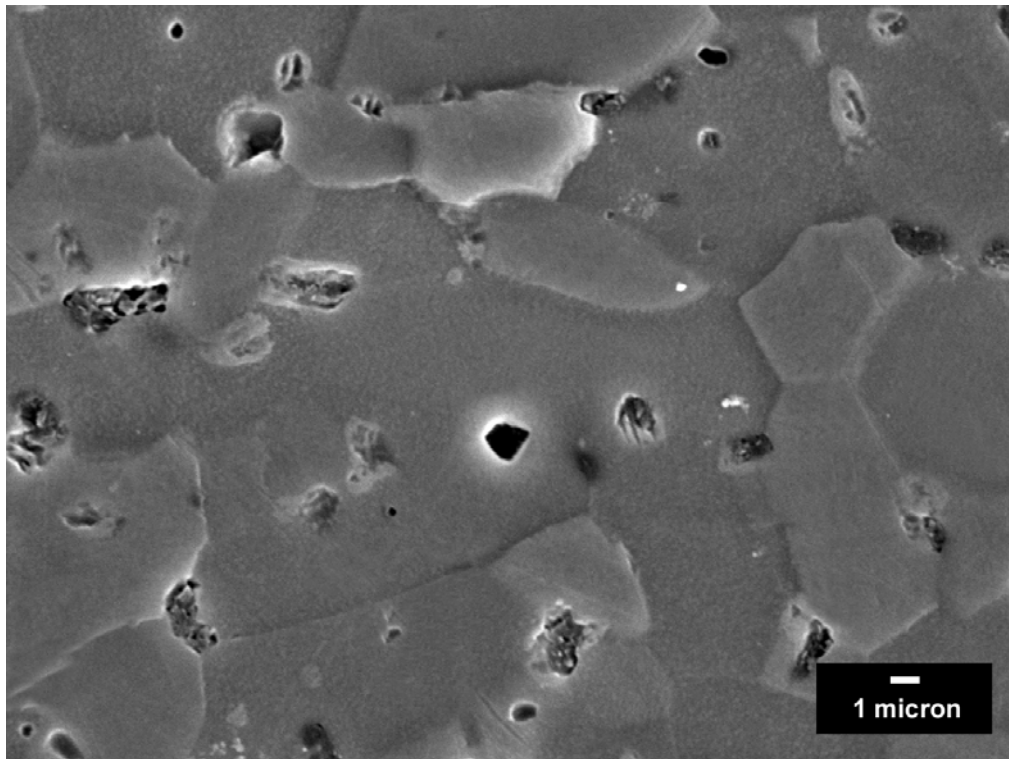


Figure 3. Microstructure of the Saint-Gobain enhanced hexoloy SA silicon carbide (SCEH).

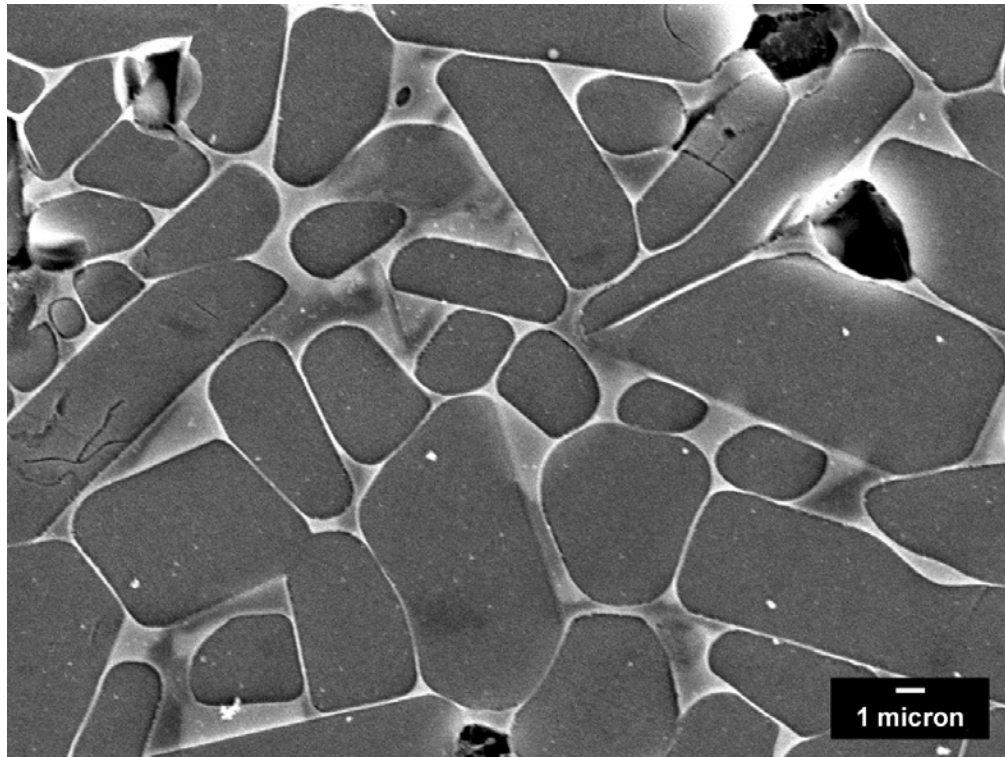


Figure 4. Microstructure of the Saint-Gobain liquid phase sintered hexoloy SA silicon carbide (SCLH).

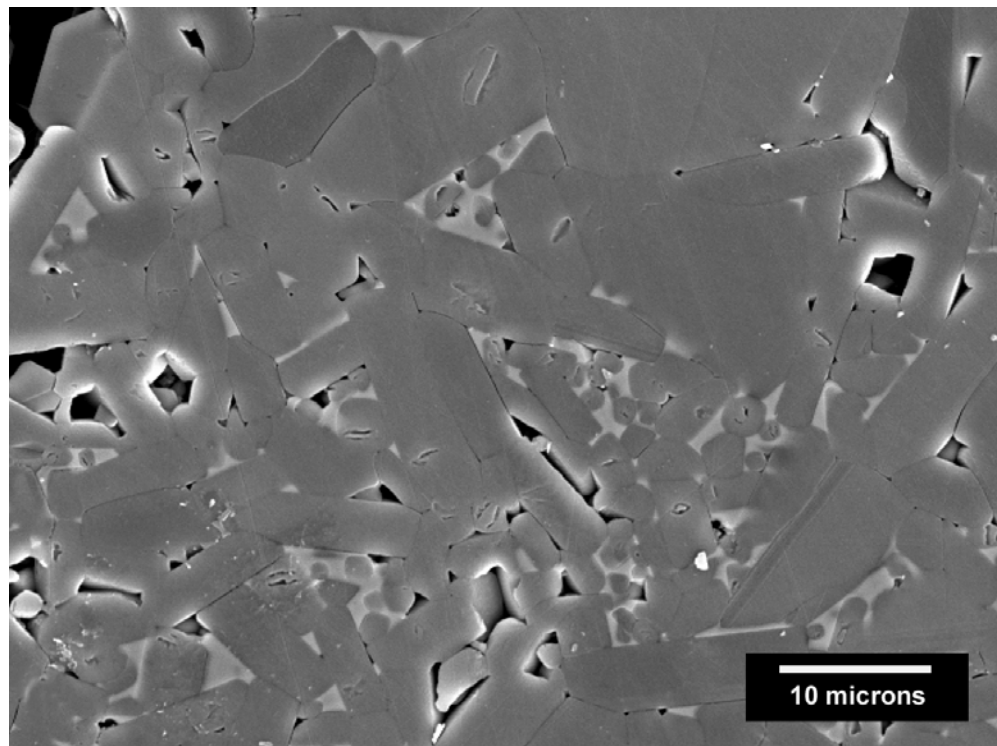


Figure 5. Microstructure of the ceradyne cer alloy 146-5S silicon carbide (SC46).

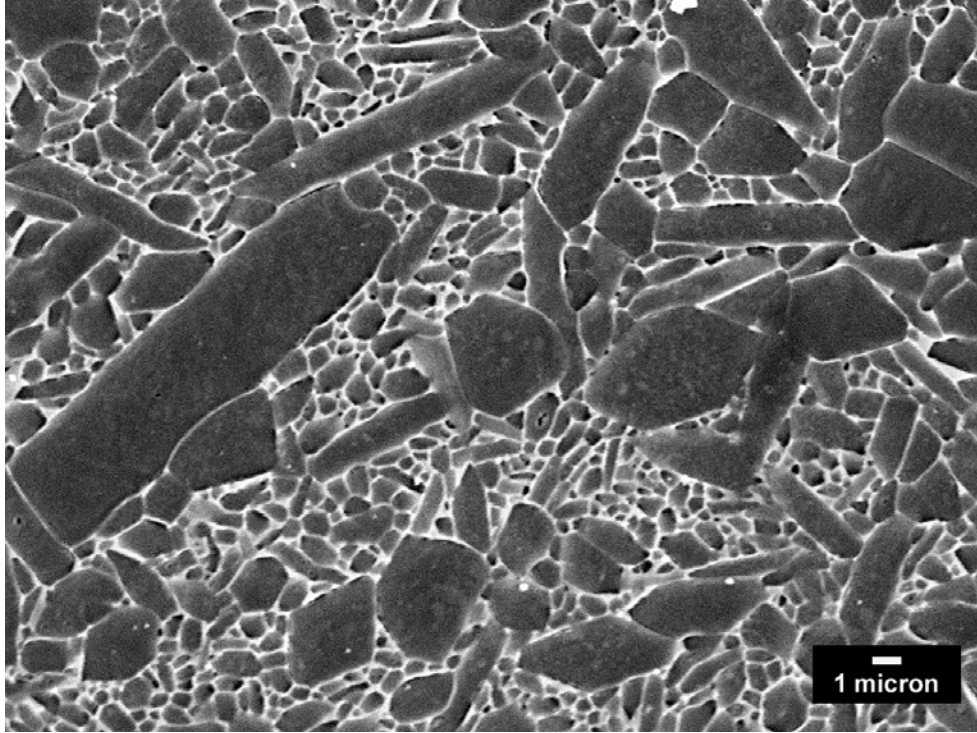


Figure 6. Microstructure of the ceradyne ceralloloy 147-31N silicon nitride (SN47) after etching in molten KOH.

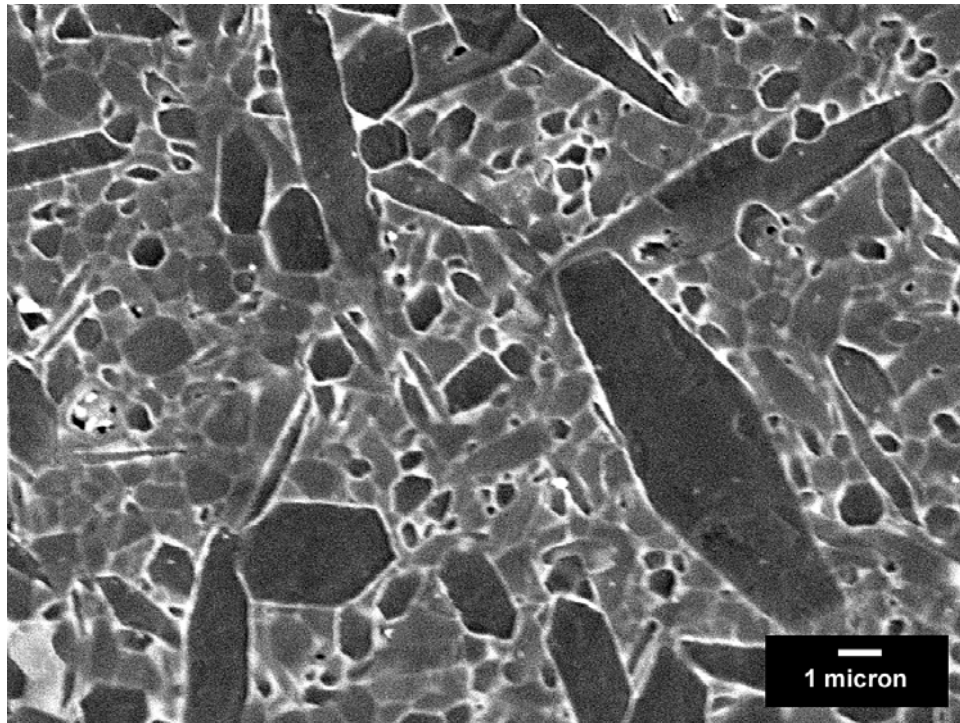


Figure 7. Microstructure of the Kennametal TK4 SiAlON (STK4) after etching in molten KOH.

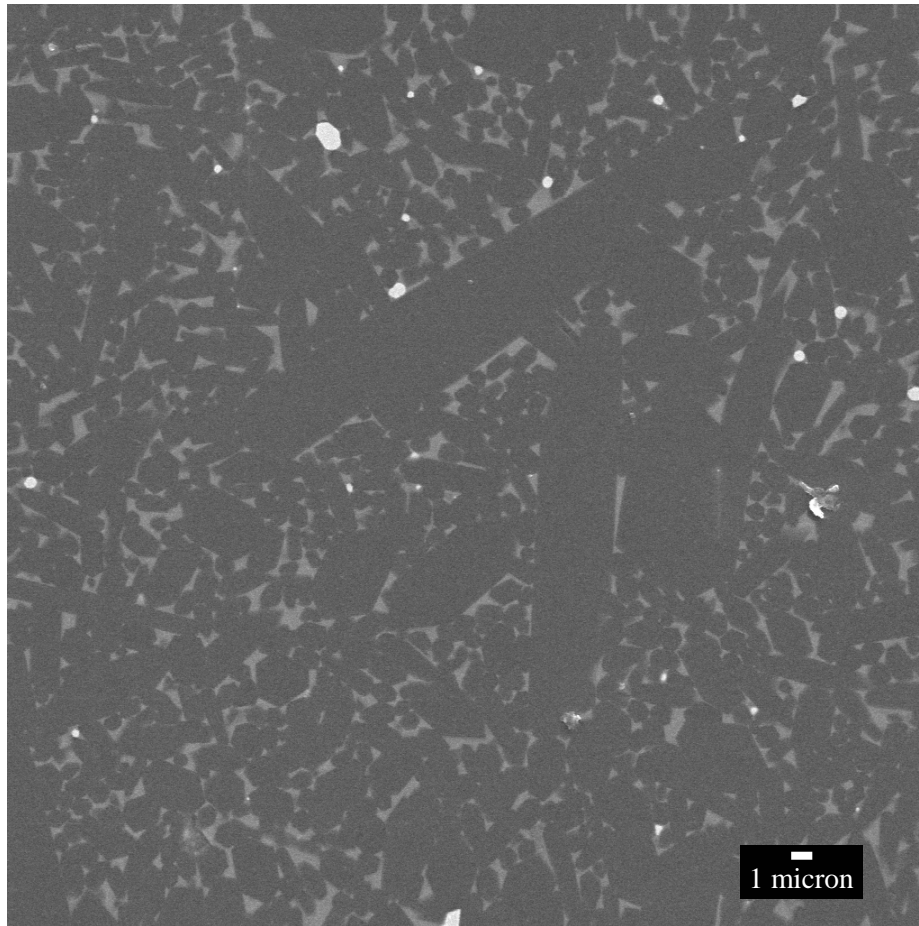


Figure 8. Microstructure of the Kyocera SN235P (SN5P) after plasma etching.

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### 3. Experimental Procedure

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All of the specimens required to generate the mechanical and thermal property data in this report were prepared using conventional diamond grinding methods.

#### 3.1 Elastic Properties

Modal analysis resulting from finite-element analysis (FEA) (e.g., ANSYS), in combination with the capturing of resonance frequencies using resonant ultrasound spectroscopy (RUS) from any two of the three resonance modes (i.e., flexural, torsional, and longitudinal), was used in the determination of the elastic properties of the eight candidate ceramics. The method consisted of (1) running three FEA modal analyses for a given geometry and material density to “bracket” two of the three elastic constants (e.g.,  $E$  and  $\nu$ ), and (2) fitting their functionalities to the measured resonance frequencies. For example, if the ceramic was a  $\text{Si}_3\text{N}_4$ , and its  $E$  and  $\nu$  were estimated to be 300 GPa and 0.25, respectively, then the three  $E$ - $\nu$  combinations for the three

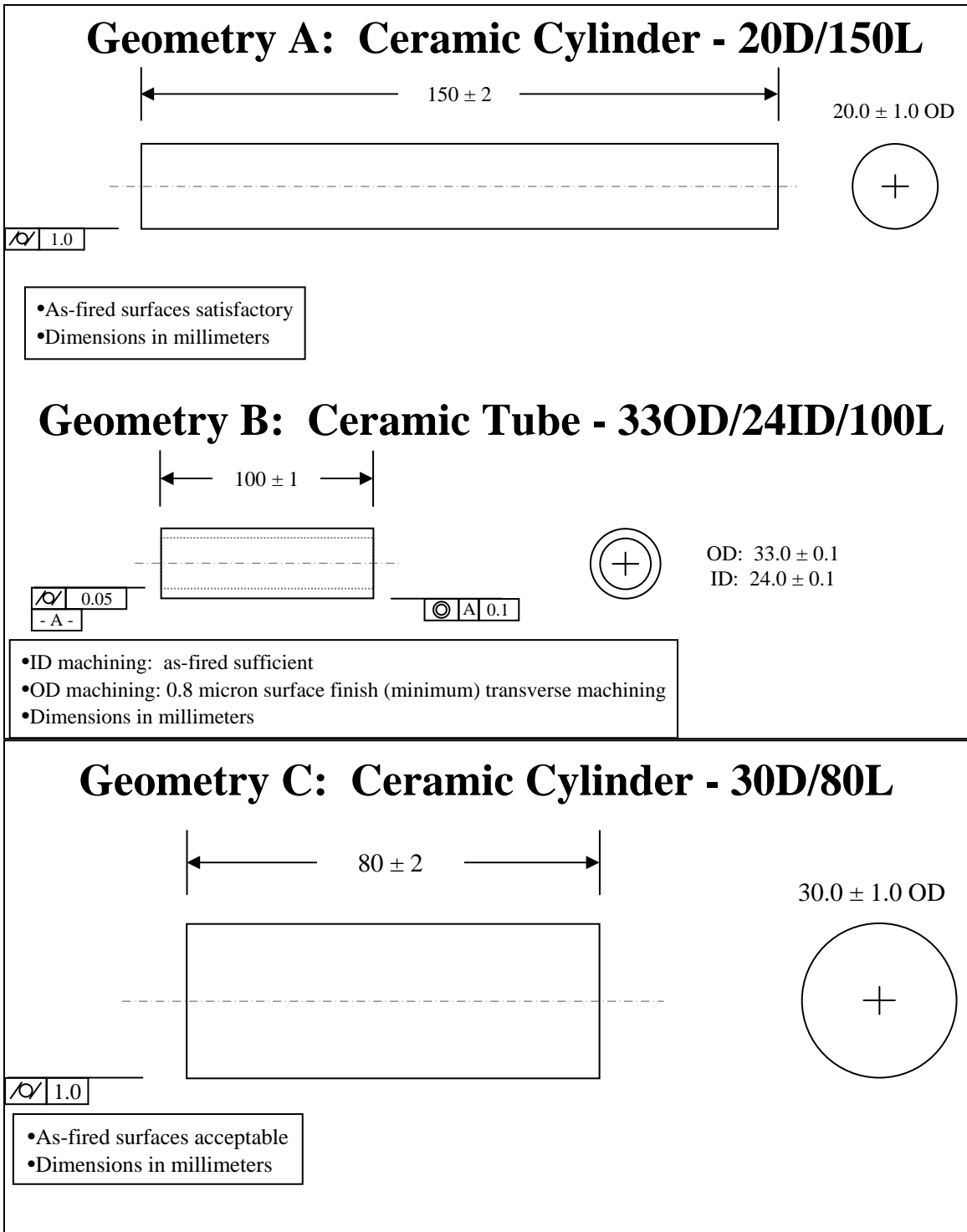


Figure 9. Material geometries ordered from each manufacturer.

modal analyses could be (semi-arbitrarily) chosen to be 150 GPa - 0.15, 450 GPa - 0.15, and 450 GPa - 0.30. These FEA results then enabled the determination of the torsional frequency ( $f_{\text{tors}}$ ) and a flexural resonant frequency ( $f_{\text{flex}}$ ) as multilinear functions of E and  $\nu$  for the modeled geometry and density; namely,

$$f_{\text{tors}} = A_t + B_t \cdot E + C_t \cdot \nu \quad (1)$$

and

$$f_{\text{flex}} = A_f + B_f \cdot E + C_f \cdot \nu \quad (2)$$

where  $A_t$ ,  $B_t$ , and  $C_t$  are regression constants for  $f_{\text{tors}}$  and  $A_f$ ,  $B_f$ , and  $C_f$  are constants for  $f_{\text{flex}}$ .

A torsional ( $f_{\text{tors}}$ ) and flexural ( $f_{\text{flex}}$ ) resonance frequency were measured with the RUS and then applied against equations 1 and 2. There is not a unique combination of E and  $\nu$  that singly represents the measured torsional or flexural frequency but instead a locus of E- $\nu$  pairs that do; however, a unique E- $\nu$  combination does result when those two resonances are combined.

### 3.2 Mechanical Properties

Three different specimens were prepared and used to determine the strength of each ceramic. Uniaxial tension tests were used in an attempt to promote the volume-distributed flaws in the material while c-ring and sectored flexure tests highlighted the surface-distributed machining flaws. The c-ring testing specifically addressed the machining flaws introduced perpendicular to the circumferential grinding done on the outer diameter of the tubes, while the sectored flexure tests highlighted the parallel machining flaws associated with this grinding direction.

Cylindrical button-head tensile specimens were machined from the geometry A components (figure 9) to the gage section dimensions listed in figure 9 of ASTM C1273 (1), with an overall specimen length of 135 mm. The room temperature uniaxial strength was determined using 15–20 specimens per material following the guidelines and equations in ASTM C1273. The uniaxial tensile strength was calculated using this equation:

$$S_u = \frac{P_{\text{max}}}{A} \quad (3)$$

where  $S_u$  is the tensile strength,  $P_{\text{max}}$  is the breaking load, and A is the cross-sectional area of the specimen.

C-ring specimens having a width of 8 mm with longitudinal 45° chamfers to a distance of 0.15 mm, and a slot height of 5.7 mm were machined from the tubular components

(geometry B) and tested in accordance with ASTM C1323 (2). A displacement rate of 0.5 mm/min was used to compressively and diametrically load 16 to 18 c-ring specimens to failure for each material. Paper shims were placed between the upper and lower contact locations to minimize the likelihood of contact-induced fracture. The geometry and failure loads were used to calculate the hoop or OD tangential failure stress ( $\sigma_{\theta_{max}}$ ) for each specimen according to the strength of materials solution in ASTM C1323:

$$\sigma_{\theta_{max}} = \frac{PR}{btr_o} \left[ \frac{r_o - r_a}{r_a - R} \right], \quad (4)$$

where P is the failure load,  $R = (r_o - r_i)/\ln(r_o/r_i)$ ,  $r_o$  is the outer c-ring radius,  $r_i$  is the inner c-ring radius,  $r_a$  is the average of  $r_o$  and  $r_i$ , b is width, and t is thickness or  $r_o - r_i$ .

A new test specimen configuration, the sectored tube flexure specimen, was also machined from the tubular component according to the guidelines shown in figure 10. These specimens were then broken in four-point flexure at room temperature using inner and outer spans of 40 mm and 80 mm, respectively, with a loading rate of 1 mm/min. The upper and lower supports were made of SiC with the lower support contoured to fit the outer radius of the specimen to achieve line loading (figure 11).

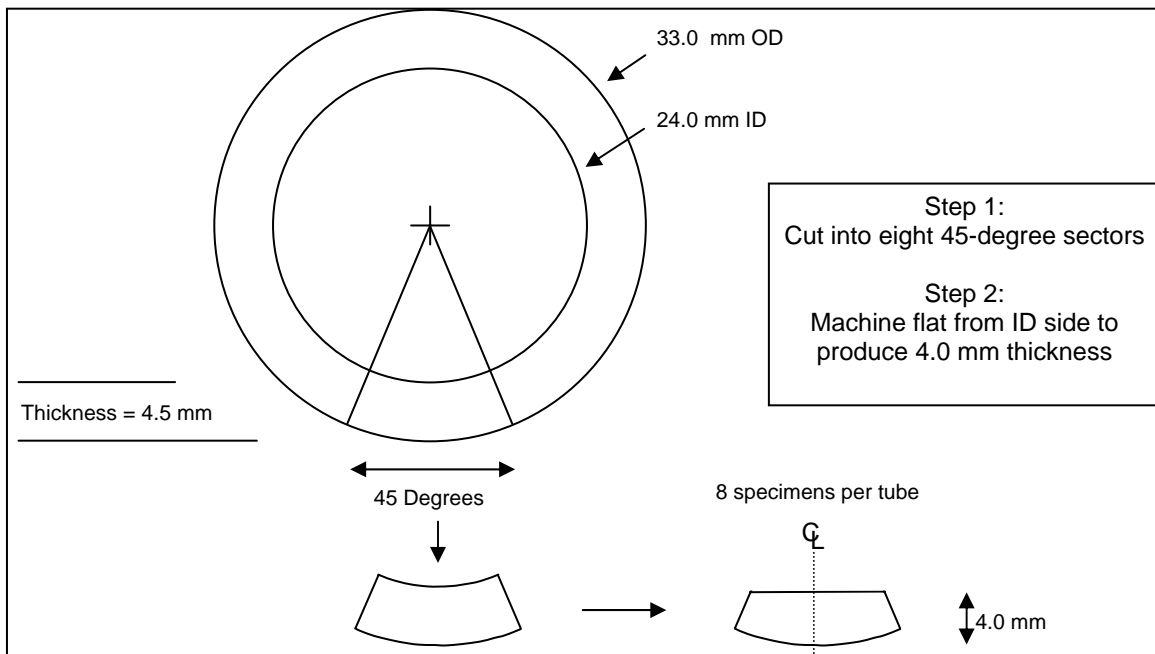


Figure 10. Schematic for the fabrication of sectored tube flexure specimens.

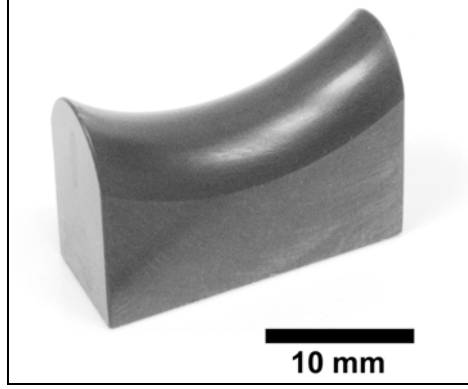


Figure 11. SiC lower support used in the room and elevated temperature sectored flexure testing.

The sectored flexure strength was also determined at 700 °C using the same loading configuration and loading rate, and with a heating rate of 10 °C/min. The specimen was held at temperature for 10 min before the load was applied. Twenty specimens were used to determine the room temperature strength and 10 were used to determine the elevated temperature strength. The sectored flexure strength ( $\sigma_{flex}$ ) was calculated using

$$\sigma_{flex} = \frac{P(L_2 - L_1)c}{4I}, \quad (5)$$

where  $P$  is the failure load,  $L_1$  is the upper span,  $L_2$  is lower span,  $c$  is the distance between the neutral axis and the outer fiber, and  $I$  is moment of inertia. The moment of the inertia,  $I$ , in equation 5 can be determined through correct usage of the parallel axis theorem in combination with equations 6–11.

$$I = I_{zz-Sect} - I_{zz-Tri}, \quad (6)$$

where  $I_{zz-Sect}$  is the moment of inertia of a sector of a solid cylinder and  $I_{zz-Tri}$  is the moment of inertia of a triangle whose subtraction from the sectored solid cylinder will produce a specimen with the cross section shown in figure 10. Generically, the moment of inertia of the sectored solid cylinder is

$$I_{zz-Sect} = I_A + \alpha R_o^2 \left[ R_o \left( 1 - \frac{2 \sin \alpha}{3\alpha} \right) - \bar{Y} \right]^2, \quad (7)$$

where  $\alpha = 22.5^\circ$  (and hence  $2\alpha = 45^\circ$ ),  $R_o$  is the outer radius (16.5 mm), and

$$I_A = \frac{1}{4} R_o^4 \left[ \alpha + \frac{1}{2} \sin(2\alpha) \right] - \frac{4}{9\alpha} R_o^4 \sin^2 \alpha, \quad (8)$$

and the centroid for the sectored flexure specimen is

$$\bar{Y} = \frac{\alpha R_o^3 \left[ 1 - \frac{2 \sin \alpha}{3\alpha} \right] - \left( \frac{R_o + 2h}{3} \right) (R_o - h)^2 \tan \alpha}{\alpha R_o^2 - (R_o - h)^2 \tan \alpha}, \quad (9)$$

where  $h$  is the specimen height (4 mm). The value of the parameter  $c$  in equation 5 is simply  $R_o - Y$ . The moment of inertia of the triangle in equation 6 is

$$I_{zz-Tri} = I_B + (R_o - h)^2 \tan \alpha \left[ \frac{R_o + 2h}{3} - \bar{Y} \right]^2, \quad (10)$$

where

$$I_B = \frac{(R_o - h)^4}{18} \tan \alpha. \quad (11)$$

Each set of raw strength data was subsequently analyzed using a two-parameter Weibull regression according to ASTM C1239 (3). This analysis yielded a biased Weibull modulus and characteristic strength.

Fracture toughness was determined using the procedures and equations in ASTM C1421 (4). Chevron notch specimens, nominally  $3 \times 4 \times 50$  mm in size with the D configuration notch ( $a_o = 1.40 \pm 0.07$  mm), were machined and then fractured in three- or four-point bending. The fracture toughness ( $K_{Ivb}$ ) was calculated using

$$K_{Ivb} = Y_{\min}^* \left[ \frac{P_{\max} (S_o - S_i) 10^{-6}}{bw^{3/2}} \right], \quad (12)$$

where  $Y_{\min}^*$  is the minimum stress intensity factor,  $P_{\max}$  is the relevant maximum load that occurs during stable crack propagation,  $S_o$  and  $S_i$  are outer and inner support spans, respectively,  $b$  is the specimen width, and  $w$  the specimen height.

The Vickers hardness ( $H_v$ ) was determined for each material from room temperature to 800 °C and in select materials to 1000 °C using an indentation load of 300 g on a Nikon QM2 hardness machine.

### 3.3 Thermal Properties

The thermal conductivity, heat capacity, and coefficient of thermal expansion (CTE) were determined for all eight materials between room temperature and 1000 °C. ASTM E1461 (5) and ASTM C714 (6) were used to obtain thermal diffusivity and heat capacity values using the laser flash method on specimens nominally  $8 \times 8 \times 2$  mm in size. A thermal conductivity was calculated from these values. The linear coefficient of thermal expansion was obtained using a prismatic specimen nominally  $3 \times 4 \times 25$  mm in size. Tests were conducted in a dual-rod dilatometer using a heating rate of 1 °C/min following

the procedure outlined in ASTM E228 (7). The data collection rate for this test was 2 datapoints/°C.

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#### 4. Elastic Property Results

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The results for room temperature E and  $\nu$  for specimens that had nominal dimensions of  $2 \times 8 \times 8$  mm, as well as the calculated shear modulus (G), are summarized in table 2.

Table 2. Room temperature elastic properties measured as determined by resonant ultrasound spectroscopy (RUS).

Material	Density (g/cm <sup>3</sup> )	E (GPa)	Poisson's Ratio ( $\nu$ )	G (GPa)
ALOX	3.875	384	0.226	157
ZRO2	6.022	195	0.249	78
SCEH	3.135	425	0.161	193
SCLH	3.152	387	0.173	165
SC46	3.104	405	0.167	174
SN47	3.183	326	0.258	130
STK4	3.349	336	0.247	135
SN5P	3.193	313	0.253	125

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#### 5. Mechanical Property Results

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The mechanical properties for each candidate gun barrel ceramic are summarized in table 3; the raw data can be found in appendix A. The average strength values listed in this table are graphically depicted in figure 12 and the uncensored Weibull modulus information is shown in figure 13. The two Si<sub>3</sub>N<sub>4</sub> materials and the SiAlON are the strongest group of materials, but the Weibull modulus data shows that, even though these materials possess high average strength values, there is a relatively wide distribution in strength. Fractography and data censoring of each material is underway. These results along with the censored strength data will be the subject of a separate report.

The hardness of each ceramic was essentially linear between room temperature and 800–1000 °C, but the hardness decreases at a different rate for each ceramic. Figure 14 graphically depicts the hardness of all eight ceramics, while figures 15–17 show with better clarity the linear decrease in hardness for each class of ceramic. The SCEH has the highest hardness value at room temperature, but this value drops significantly as the temperature increases. The hardest materials at room temperature after the SCEH are the SCLH, SC46, and STK4 ceramics, which all have hardness values around 20 GPa. However, only three materials (SCEH, SN47, and STK4) have hardness values above

Table 3. Summary of mechanical properties for candidate gun barrel ceramics.

Property	Manufacturer							
	ALOX	ZRO2	SCEH	SCLH	SC46	SN47	STK4	SN5P
<b>Avg. Tensile Strength (MPa)</b>	314	558	320	286	284	784	446	586
<b>Weibull Modulus</b>	17.1	22.2	10.0	14.7	21.5	9.4	9.3	16.9
<b>Avg. Sect Flex Strength (MPa)</b>								
25 °C	265	578	192	311	271	546	653	563
700 °C	241	119	243	301	284	618	691	528
<b>Weibull Modulus</b>								
25 °C	31.5	22.9	5.5	12.9	29.3	12.0	12.7	10.8
700 °C	20.4	9.1	4.9	12.6	21.0	17.2	23.9	15.7
<b>Avg. C-ring Strength (MPa)</b>	275	581	299	330	276	753	694	654
<b>Weibull Modulus</b>	17.4	9.3	4.6	9.5	14.4	13.7	4.7	12.3
<b>K<sub>Ic</sub> (MPa*√m) (Chevron Notch)</b>	3.94 ± 0.12	5.68 ± 0.36	3.02 ± 0.06	2.42 ± 0.09	4.99 ± 0.15	6.58 ± 0.14	7.61 ± 0.11	8.67 ± 0.19
<b>Hardness (Hv) – 300g (GPa)</b>								
25 °C	15.9 ± 1.2	8.6 ± 1.6	27.1 ± 0.3	20.8 ± 0.4	20.7 ± 2.9	14.7 ± 0.1	19.9 ± 0.5	13.6 ± 0.4
200 °C	13.1 ± 1.2	8.0 ± 0.5	24.8 ± 0.6	16.6 ± 0.2	17.9 ± 1.1	13.3 ± 0.1	17.9 ± 0.5	12.4 ± 0.6
300 °C	13.1 ± 0.7	7.1 ± 0.2	—	—	18.3 ± 1.2	—	—	—
400 °C	10.7 ± 0.8	5.5 ± 0.1	19.1 ± 0.3	14.0 ± 0.4	16.9 ± 1.2	12.5 ± 0.2	15.9 ± 0.4	11.6 ± 0.4
500 °C	9.7 ± 0.9	4.6 ± 0.2	—	—	15.0 ± 1.3	—	—	—
600 °C	8.0 ± 1.3	3.9 ± 0.3	15.5 ± 0.3	12.0 ± 0.3	12.3 ± 1.3	11.4 ± 0.3	14.8 ± 0.5	10.0 ± 0.3
700 °C	7.1 ± 0.2	3.6 ± 0.1	—	—	10.7 ± 1.9	—	—	—
800 °C	4.8 ± 0.9	3.0 ± 0.3	11.4 ± 0.3	9.8 ± 0.3	9.8 ± 0.4	10.7 ± 0.3	13.7 ± 0.2	9.0 ± 0.5

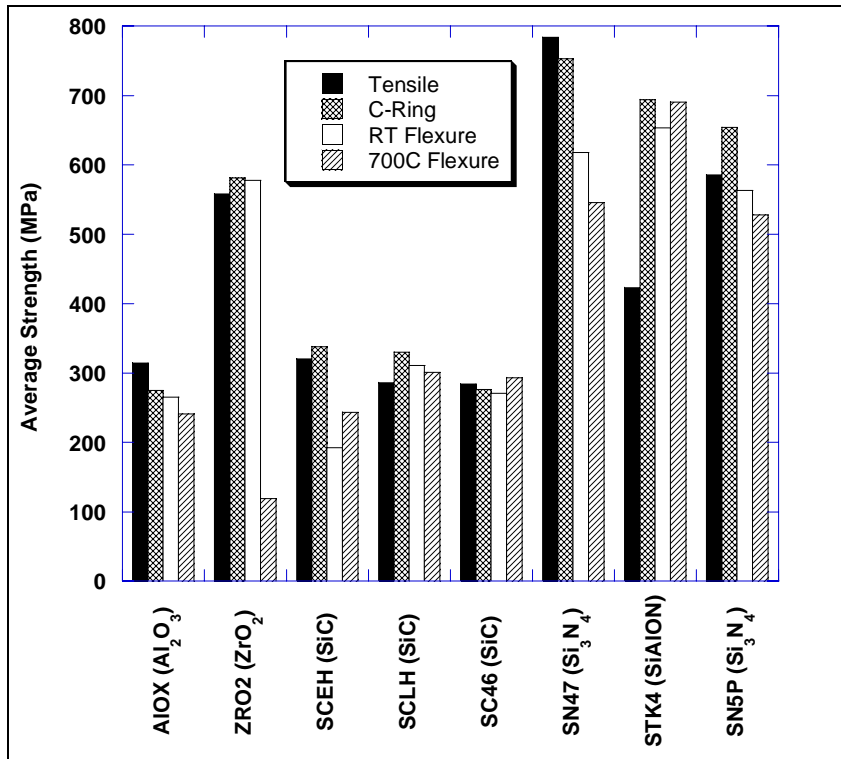


Figure 12. Uncensored average strength data.

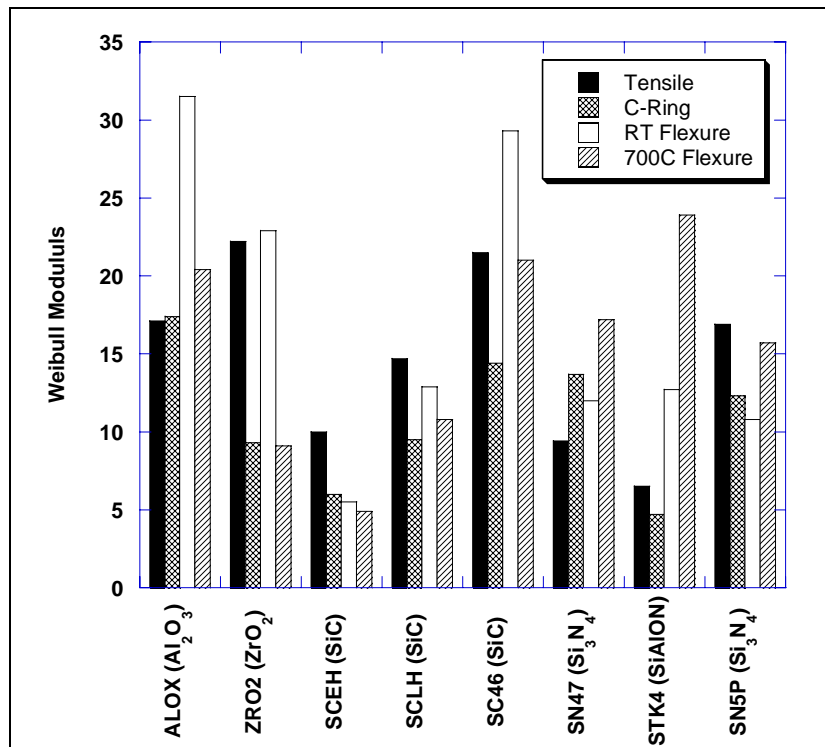


Figure 13. Uncensored Weibull modulus.

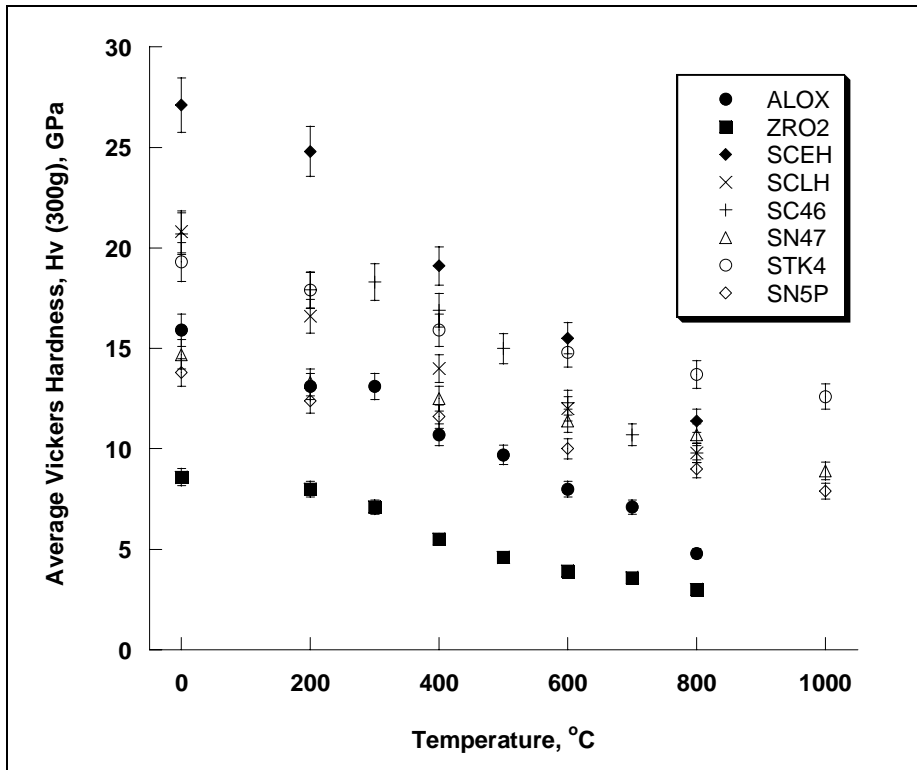


Figure 14. Hardness as a function of temperature for all eight ceramics.

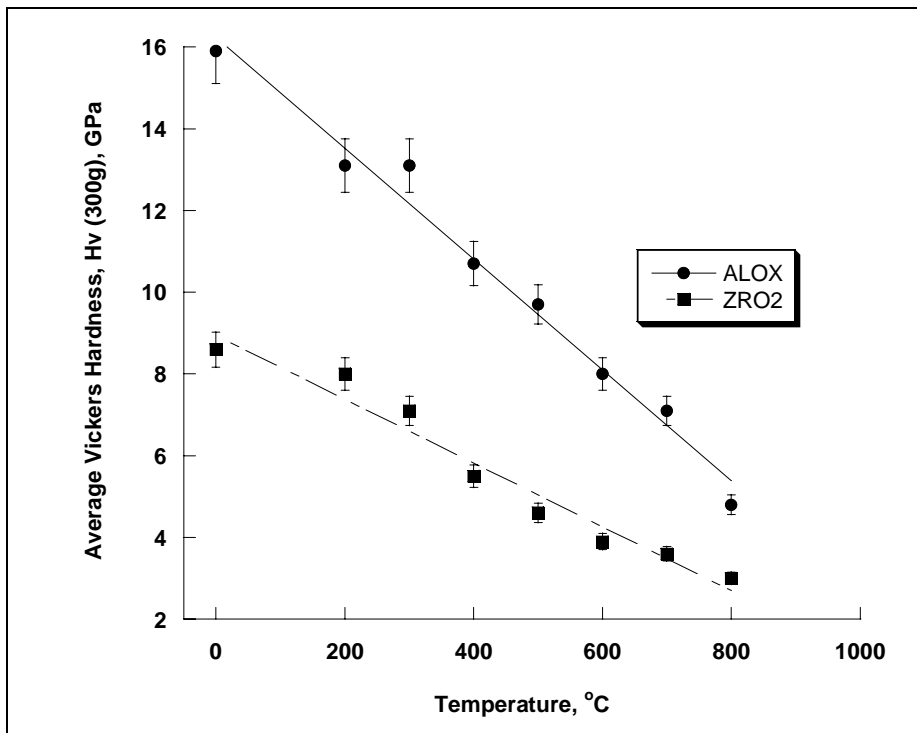


Figure 15. Hardness as a function of temperature for ALOX and ZRO2.

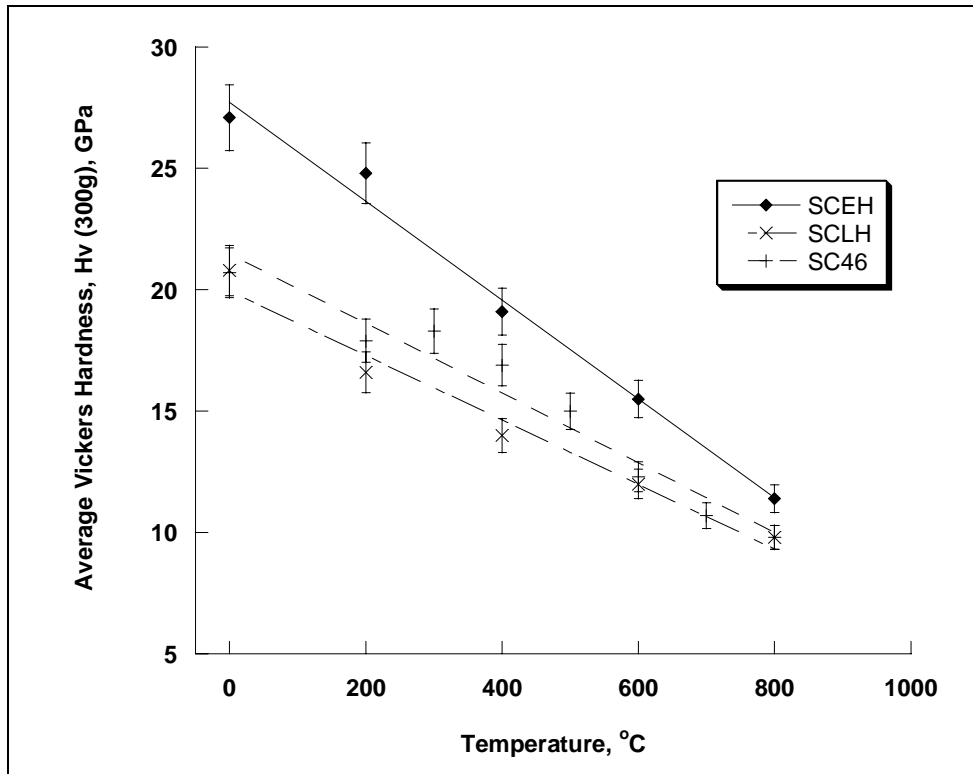


Figure 16. Hardness as a function of temperature for the SiC ceramics.

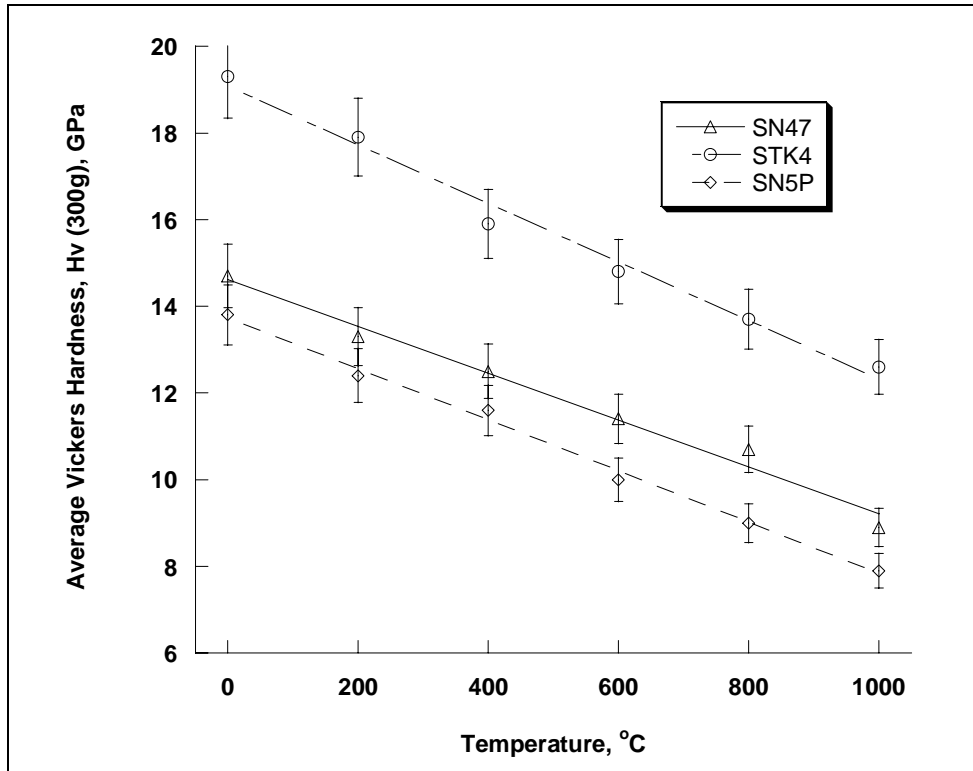


Figure 17. Hardness as a function of temperature for the Si<sub>3</sub>N<sub>4</sub> ceramics.

10 GPa at 800 °C. The hot hardness of the SN47 and STK4 ceramics was measured at two different times with a different indenter but by the same operator using the same hardness machine. The first set of data was measured from room temperature to 800 °C and the second set from room temperature to 1000 °C. Only the second set of data is included in the table and figure. All the data is, however, included in the appendix. There was no significant difference in the hardness values for these two ceramics measured at different times.

## 6. Thermal Property Results

The average thermal conductivity, heat capacity, and CTE for each candidate gun barrel ceramic are summarized in table 4, and the raw data for these three thermal properties can be found in appendix B. As expected, the thermal conductivity of the three SiC ceramics was the highest, and the ZRO2 was the lowest, while the ALOX, both silicon nitrides, and the SiAION had values well below the SiCs, but not as low as the ZRO2. The heat capacity of all the ceramics was very similar except the ZRO2, which was significantly lower. The oxides have the largest average CTE, followed by the SiCs, and then the nitrides.

Table 4. Summary of the average thermal properties of the candidate gun barrel ceramics between room temperature and 1000 °C.

Material	Property		
	TC, $\lambda$ (W/m-K)	Heat Capacity, Cp (J/kg-K)	Avg. CTE ( $\times 10^{-6}/^{\circ}\text{C}$ )
<b>ALOX</b>	31.4–7.2	788–1300	8.5
<b>ZRO2</b>	3.13–2.21	462–640	11.8
<b>SCEH</b>	170–45.2	719–1250	4.5
<b>SCLH</b>	74.6–33.2	733–1270	4.9
<b>SC46</b>	99.9–37.3	696–1280	4.9
<b>SN47</b>	26.5–14.1	690–1270	3.2
<b>STK4</b>	10.8–8.49	736–1240	3.3
<b>SN5P</b>	32.2–16.1	695–1250	3.4

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## 7. Summary

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A mechanical and thermal property database was created for eight commercially-available ceramics under consideration for gun barrel applications. The mechanical properties measured included strength, fracture toughness, and Vickers hardness. An uncensored Weibull analysis was performed on all of the strength data that was generated. Thermal conductivity, specific heat, and linear CTE were also determined between room temperature and 1000 °C for each material. All of this data was incorporated in a probabilistic modeling effort to predict ceramic performance, identify an optimum ceramic gun barrel design for various caliber systems, and rank and down select ceramics for further evaluation. The modeling and design aspects of this ceramic gun barrel effort will be detailed in subsequent reports.

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## 8. References

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1. ASTM C1273. Standard Test Method for Tensile Strength of Monolithic Advanced Ceramics at Ambient Temperatures. *Annu. Book ASTM Stand.* **2003**, Vol. 15.01.
2. ASTM C1323. Standard Test Method for Ultimate Strength of Advanced Ceramics with Diametrically Compressed C-Ring Specimens at Ambient Temperatures. *Annu. Book ASTM Stand.* **2003**, Vol. 15.01.
3. ASTM C1239. Standard Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters fro Advanced Ceramics. *Annu. Book ASTM Stand.* **2003**, Vol. 15.01.
4. ASTM C1421. Standard Test Methods for Determination of Fracture Toughness of Advanced Ceramics at Ambient Temperature. *Annu. Book ASTM Stand.* **2003**, Vol. 15.01.
5. ASTM E1461. Standard Test Method for Thermal Diffusivity of Solids by the Flash Method. *Annu. Book ASTM Stand.* **1998**, Vol. 14.02.
6. ASTM C714. Standard Test Method for Thermal Diffusivity of Carbon and Graphite by a Thermal Pulse Method. *Annu. Book ASTM Stand.* **1998**, Vol. 15.01.
7. ASTM E228. Standard Test Method for Linear Thermal Expansion of Solid Materials With a Vitreous Silica Dilatometer. *Annu. Book ASTM Stand.* **1998**, Vol. 14.02.

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## **Appendix A. Mechanical Properties**

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### A-1. Room Temperature Strength Data From C-Ring Specimens

Table A-1.1. C-ring data for CoorsTek AD995 (ALOX).

Specimen	Do (mm)	Di (mm)	Slot (mm)	Height, b (mm)	Width, t (mm)	Mass (g)	Density (g/cm <sup>3</sup> )	Load (N)	Stress (MPa)	Break, b (mm)	$\theta$ (°)
ALOX-B1-1	33.03	23.88	5.69	8.04	4.58	11.89	3.858	631.8	271.8	32.85	2.05
ALOX-B1-2	33.04	23.89	5.69	8.05	4.58	11.90	3.855	542.8	233.3	32.94	1.00
ALOX-B1-3	33.03	23.75	5.68	8.04	4.64	11.92	3.822	644.9	268.4	32.20	15.84
ALOX-B1-4	33.02	23.84	5.70	8.04	4.59	11.93	3.862	593.8	253.4	32.62	7.91
ALOX-B1-5	33.02	23.94	5.69	8.04	4.54	11.91	3.891	693.1	303.5	32.14	16.59
ALOX-B1-6	33.04	23.91	5.69	8.03	4.57	11.91	3.875	659.2	285.5	32.90	0.64
ALOX-B1-7	33.03	23.75	5.64	8.03	4.64	11.90	3.819	673.4	280.6	32.65	7.57
ALOX-B1-8	33.03	23.86	5.75	8.05	4.59	11.91	3.855	653.2	279.2	32.61	8.27
ALOX-B1-9	33.03	23.72	5.75	8.04	4.66	11.91	3.812	664.1	274.2	32.93	1.11
ALOX-B2-1	33.03	23.79	5.66	8.03	4.62	11.85	3.817	668.2	281.3	32.91	0.10
ALOX-B2-2	33.02	23.82	5.69	8.05	4.60	11.88	3.834	654.3	277.4	32.85	1.71
ALOX-B2-3	33.02	23.94	5.64	8.05	4.54	11.86	3.867	661.2	289.2	32.68	6.62
ALOX-B2-4	33.03	23.90	5.74	8.05	4.57	11.86	3.853	662.4	286.1	32.70	6.20
ALOX-B2-5	33.02	23.89	5.72	8.04	4.57	11.88	3.865	683.7	295.5	32.25	14.82
ALOX-B2-6	33.04	23.91	5.69	8.04	4.57	11.85	3.851	652.0	282.1	32.81	3.61
ALOX-B2-7	33.02	23.78	5.74	8.03	4.62	11.88	3.832	678.4	285.4	32.96	3.10
ALOX-B2-8	33.01	23.78	5.70	8.02	4.62	11.88	3.840	648.9	273.9	32.36	12.83
ALOX-B2-9	33.01	23.88	5.70	8.04	4.57	11.86	3.859	582.8	251.8	31.72	22.20
m =	17.35										
sigma_theta =	282.3	MPa									
sigma_avg =	275.3	MPa									
std dev =	16.6	MPa									

Table A-1.2. C-ring data for CoorsTek Ce-TZP (ZRO2).

Specimen	Do (mm)	Di (mm)	Slot (mm)	Height, b (mm)	Width, t (mm)	Mass (g)	Density (g/cm <sup>3</sup> )	Load (N)	Stress (MPa)	Break, b (mm)	θ (°)
ZRO2-B1-1	33.05	23.85	5.85	8.03	4.60	18.87	6.110	1423.5	605.8	32.81	3.62
ZRO2-B1-2	33.07	23.92	5.81	8.01	4.58	18.77	6.112	1486.2	642.8	32.95	0.35
ZRO2-B1-3	33.05	23.81	5.88	8.06	4.62	18.86	6.064	1306.9	548.5	32.68	6.91
ZRO2-B1-4	33.04	23.83	5.80	8.03	4.61	18.81	6.083	1423.4	604.0	31.25	27.78
ZRO2-B1-5	33.07	23.77	5.73	8.04	4.65	18.83	6.022	1387.9	575.5	32.22	16.06
ZRO2-B1-6	33.05	23.82	5.83	8.06	4.62	18.87	6.069	1362.9	573.5	33.05	10.16
ZRO2-B1-7	33.05	23.84	5.80	8.05	4.61	18.88	6.089	961.1	407.0	32.92	0.06
ZRO2-B1-8	33.05	23.86	5.78	8.05	4.60	18.87	6.095	1432.9	609.9	32.47	11.43
ZRO2-B1-9	33.07	23.84	5.82	8.05	4.62	18.85	6.065	1395.0	588.2	32.68	7.48
ZRO2-B2-1	33.05	23.86	5.72	8.05	4.60	18.83	6.078	1384.0	589.1	32.73	5.99
ZRO2-B2-2	33.06	23.85	5.70	8.05	4.61	18.83	6.063	1406.7	595.9	32.22	15.96
ZRO2-B2-3	33.06	23.81	5.70	8.02	4.63	18.87	6.077	1273.6	536.0	32.70	7.00
ZRO2-B2-4	33.06	23.83	5.77	8.05	4.62	18.88	6.073	1177.2	496.1	32.24	15.52
ZRO2-B2-5	33.06	23.93	5.76	8.05	4.57	18.86	6.121	1438.7	622.1	31.48	25.54
ZRO2-B2-6	33.05	23.87	5.70	8.07	4.59	18.89	6.086	1478.0	629.1	32.92	0.24
ZRO2-B2-7	33.05	23.90	5.75	8.06	4.58	18.86	6.104	1462.2	628.0	33.05	10.02
ZRO2-B2-8	33.06	23.90	5.79	8.02	4.58	18.81	6.113	1404.3	604.8	33.01	3.78
ZRO2-B2-9	33.06	23.83	5.74	8.05	4.62	18.88	6.071	1419.4	598.2	33.02	4.36
m =		9.34									
sigma_theta =		607.3 MPa									
sigma_avg =		580.8 MPa									
std dev =		56.3 MPa									

Table A-1.3. C-ring data for Saint-Gobain enhanced hexoloy SA (SCEH).

Specimen	Do (mm)	Di (mm)	Slot (mm)	Height, b (mm)	Width, t (mm)	Mass (g)	Density (g/cm <sup>3</sup> )	Load (N)	Stress (MPa)	Break, b (mm)	$\theta$ (°)
SCEH-B5-1	33.09	23.82	5.72	8.10	4.64	9.73	3.094	771.1	320.1	32.09	18.29
SCEH-B5-2	33.07	23.88	5.72	8.10	4.60	9.70	3.109	691.6	292.8	32.57	9.99
SCEH-B5-3	33.06	23.92	5.72	8.09	4.57	9.70	3.128	575.6	247.0	30.54	35.07
SCEH-B5-4	33.07	23.87	5.68	7.91	4.60	9.48	3.108	751.4	324.9	30.89	31.95
SCEH-B5-5	33.08	23.85	5.68	8.00	4.62	9.58	3.095	825.8	350.5	32.79	5.30
SCEH-B5-6	33.08	23.88	5.70	8.08	4.60	9.70	3.112	792.3	335.5	31.50	25.64
SCEH-B5-7	33.08	23.83	5.75	8.09	4.63	9.70	3.096	690.4	288.3	32.32	14.60
SCEH-B5-8	33.08	23.82	5.64	8.10	4.63	9.73	3.095	856.2	356.2	32.62	9.32
SCEH-B5-9	33.08	23.83	5.67	8.09	4.63	9.71	3.097	818.3	341.7	32.46	12.35
SCEH-B6-1	32.94	23.93	5.65	8.09	4.51	9.51	3.115	366.3	161.8	32.81	0.31
SCEH-B6-2	32.94	23.93	5.69	8.09	4.51	9.51	3.117	856.1	378.2	32.64	5.53
SCEH-B6-3	32.96	23.90	5.73	8.00	4.53	9.39	3.097	699.2	308.5	32.16	15.29
SCEH-B6-4	32.95	23.91	5.74	8.09	4.52	9.49	3.102	656.8	288.0	31.72	21.38
SCEH-B6-5	32.96	23.91	5.63	8.10	4.53	9.55	3.110	765.8	334.6	32.65	5.89
SCEH-B6-6	32.99	23.91	5.75	8.06	4.54	9.49	3.100	463.0	202.2	31.62	23.04
SCEH-B6-7	32.94	23.91	5.77	8.09	4.52	9.49	3.107	470.4	206.7	31.03	29.13
SCEH-B6-8	32.95	23.96	5.69	8.10	4.50	9.46	3.101	651.9	289.2	32.17	15.04
SCEH-B6-9	32.97	23.94	5.67	8.02	4.52	9.65	3.180	804.6	357.1	32.86	0.54
m = 4.63 sigma_theta = 323.2 MPa sigma_avg = 299.1 MPa std dev = 59.9 MPa											

Table A-1.4. C-ring data for Saint-Gobain liquid phase sintered hexoloy SA (SCLH).

Specimen	Do (mm)	Di (mm)	Slot (mm)	Height, b (mm)	Width, t (mm)	Mass (g)	Density (g/cm <sup>3</sup> )	Load (N)	Stress (MPa)	Break, b (mm)	θ (°)
SCLH-B1-1	32.97	23.95	5.62	8.01	4.51	9.30	3.070	885.0	394.3	32.92	3.50
SCLH-B1-2	32.97	23.89	5.64	8.10	4.54	9.42	3.058	831.7	360.8	32.45	10.53
SCLH-B1-3	32.98	23.90	5.69	8.02	4.54	9.35	3.067	637.9	279.6	32.59	7.71
SCLH-B1-4	32.98	23.73	5.63	8.04	4.63	9.32	3.001	789.2	330.2	32.30	13.48
SCLH-B1-5	32.98	23.81	5.73	8.05	4.59	9.44	3.061	781.0	333.2	32.70	4.94
SCLH-B1-6	32.98	23.90	5.60	7.99	4.54	9.29	3.055	825.7	363.2	32.61	7.40
SCLH-B1-7	32.98	23.84	5.68	8.00	4.57	9.29	3.038	663.0	286.8	32.12	16.31
SCLH-B1-8	32.98	23.86	5.65	8.10	4.56	9.40	3.040	709.1	304.5	32.20	15.11
SCLH-B1-9	32.97	23.80	5.60	8.04	4.59	9.37	3.039	722.2	308.3	32.87	0.85
SCLH-B2-1	33.04	23.82	5.60	8.10	4.61	9.48	3.030	652.5	273.8	32.15	16.90
SCLH-B2-2	33.04	23.80	5.65	8.08	4.62	9.41	3.011	858.6	359.3	32.83	3.08
SCLH-B2-3	33.03	23.86	5.66	8.09	4.59	9.52	3.063	872.7	371.2	32.38	12.90
SCLH-B2-4	33.04	23.82	5.65	8.08	4.61	9.40	3.013	737.9	310.4	32.85	2.45
SCLH-B2-5	33.03	23.87	5.66	8.07	4.58	9.38	3.029	616.0	263.3	32.28	14.60
SCLH-B2-6	33.03	23.85	5.66	8.08	4.59	9.42	3.032	818.0	347.5	32.44	11.82
SCLH-B2-7	33.04	23.81	5.65	8.09	4.62	9.40	3.007	812.4	340.4	31.58	24.35
SCLH-B2-8	33.03	23.83	5.65	8.08	4.60	9.42	3.026	725.1	306.4	32.15	16.66
SCLH-B2-9	33.03	23.84	5.68	8.07	4.60	9.39	3.024	726.2	308.1	32.25	15.05
m =		9.55									
sigma_theta =		344.4 MPa									
sigma_avg =		330.1 MPa									
std dev =		37.3 MPa									

Table A-1.5. C-ring strength data for ceradyne cerallloy 146-5S (SC46).

Specimen	Do (mm)	Di (mm)	Slot (mm)	Height, b (mm)	Width, t (mm)	Mass (g)	Density (g/cm <sup>3</sup> )	Load (N)	Stress (MPa)	Break, b (mm)	$\theta$ (°)
SC46-B1-1	33.05	23.83	5.68	8.07	4.61	9.64	3.094	635.3	267.7	32.19	16.30
SC46-B1-2	33.05	23.84	5.69	8.05	4.61	9.64	3.105	593.7	251.4	32.78	4.74
SC46-B1-3	33.05	23.80	5.69	8.05	4.63	9.65	3.097	710.4	297.8	32.40	12.85
SC46-B1-4	33.05	23.86	5.68	8.05	4.60	9.65	3.113	689.2	293.3	32.59	9.25
SC46-B1-5	33.04	23.82	5.71	8.07	4.61	9.65	3.100	634.7	267.3	32.31	14.18
SC46-B1-6	33.05	23.85	5.71	8.06	4.60	9.66	3.111	545.7	231.4	32.44	12.10
SC46-B1-7	33.04	23.93	5.68	8.07	4.56	9.65	3.129	615.4	266.6	31.84	21.08
SC46-B1-8	33.04	23.77	5.68	8.07	4.64	9.67	3.091	597.8	248.6	32.91	0.27
SC46-B1-9	BROKEN UPON RECEIPT										
SC46-B1-10	33.06	23.77	5.68	8.07	4.65	9.66	3.080	597.8	247.5	32.91	1.03
SC46-B2-1	33.05	23.78	5.70	8.01	4.64	9.47	3.049	661.3	277.1	32.40	12.83
SC46-B2-2	33.04	23.93	5.71	8.05	4.56	9.52	3.096	714.4	310.3	32.08	17.74
SC46-B2-3	33.04	23.84	5.69	8.06	4.60	9.53	3.070	694.2	294.2	32.79	4.19
SC46-B2-4	33.04	23.88	5.74	8.05	4.58	9.52	3.083	705.1	302.3	32.94	1.09
SC46-B2-5	33.05	23.73	5.69	8.05	4.66	9.53	3.040	707.4	291.3	32.98	2.45
SC46-B2-6	33.04	23.78	5.69	8.05	4.63	9.53	3.057	687.4	287.3	32.42	12.32
SC46-B2-7	33.04	23.87	5.68	8.06	4.59	9.53	3.078	653.9	279.3	32.67	7.27
SC46-B2-8	33.04	23.81	5.67	8.05	4.62	9.52	3.061	649.0	273.3	32.97	2.42
SC46-B2-9	33.04	23.90	5.68	8.05	4.57	9.53	3.090	639.6	275.6	32.40	12.69
m =		14.42									
sigma_theta =		284.5 MPa									
sigma_avg =		276.2 MPa									
std dev =		20.7 MPa									

Table A-1.6. C-ring strength data for ceradyne ceralloy 147-31N (SN47).

Specimen	Do (mm)	Di (mm)	Slot (mm)	Height, b (mm)	Width, t (mm)	Mass (g)	Density (g/cm <sup>3</sup> )	Load (N)	Stress (MPa)	Break, b (mm)	$\theta$ (°)
SN47-B1-1	33.04	23.87	5.71	8.04	4.59	9.85	3.212	1791.9	767.3	31.87	20.63
SN47-B1-2	33.02	23.90	5.70	8.05	4.56	9.87	3.231	1703.2	737.2	32.45	11.38
SN47-B1-3	33.01	23.81	5.73	8.06	4.60	9.87	3.206	1717.6	727.1	32.5	10.17
SN47-B1-4	33.05	23.84	5.70	8.07	4.61	9.88	3.197	2040.1	861.7	32.23	15.65
SN47-B1-5	33.05	23.90	5.73	8.06	4.58	9.86	3.213	1752.2	752.6	32.93	0.22
SN47-B1-6	33.08	23.90	5.78	8.06	4.59	9.87	3.206	1851.3	790.0	33.04	4.43
SN47-B1-7	33.05	23.90	5.74	8.05	4.58	9.88	3.224	1742.3	749.2	32.47	11.50
SN47-B1-8	33.05	23.90	5.73	8.05	4.58	9.86	3.217	1804.9	776.2	31.52	25.02
SN47-B2-1	33.05	23.90	5.69	8.06	4.58	9.87	3.214	1826.8	784.6	32.6	9.02
SN47-B2-2	33.05	23.90	5.69	8.04	4.58	9.87	3.222	1918.3	826.0	32.32	14.22
SN47-B2-3	33.05	23.89	5.69	8.05	4.58	9.86	3.212	1733.1	743.4	32.68	7.25
SN47-B2-4	33.05	23.90	5.69	8.07	4.58	9.87	3.210	1756.1	753.3	32.72	6.29
SN47-B2-5	33.05	23.90	5.70	8.05	4.58	9.87	3.219	1665.6	716.3	32.8	4.17
SN47-B2-6	33.05	23.86	5.69	8.06	4.60	9.87	3.203	1639.5	697.0	31.94	19.87
SN47-B2-7	33.06	23.88	5.69	8.05	4.59	9.87	3.208	1836.3	783.9	31.9	20.53
SN47-B2-8	33.06	23.91	5.70	8.06	4.58	9.86	3.210	1796.8	772.0	32.35	13.86
SN47-B2-9	33.05	23.88	5.71	8.06	4.59	9.87	3.209	1666.5	712.1	32.31	14.35
SN47-B2-10	33.06	23.88	5.73	8.06	4.59	9.87	3.206	1403.6	598.5	32.99	2.52
m =		13.70									
sigma_theta =		776.5 MPa									
sigma_avg =		752.7 MPa									
std dev =		55.6 MPa									

Table A-1.7. C-ring strength data for kennametal TK4 SiAlON (STK4).

Specimen	Do (mm)	Di (mm)	Slot (mm)	Height, b (mm)	Width, t (mm)	Mass (g)	Density (g/cm <sup>3</sup> )	Load (N)	Stress (MPa)	Break, b (mm)	θ (°)
STK4-B1-1	33.15	23.91	6.22	7.98	4.62	10.2241	3.321	2022.20	860.7	—	169.19
STK4-B1-2	33.14	23.89	6.24	8.15	4.63	10.2733	3.266	2021.64	840.1	—	169.15
STK4-B1-3	33.12	23.90	6.23	8.02	4.61	10.2490	3.322	1863.19	792.2	—	169.16
STK4-B1-4	33.10	23.91	6.25	8.12	4.60	10.2660	3.299	2181.78	922.5	—	169.12
STK4-B1-5	33.10	23.89	6.23	8.05	4.61	10.2748	3.324	887.00	376.4	33.03	3.39
STK4-B1-6	33.11	23.91	6.24	8.07	4.60	10.2312	3.303	1018.98	432.6	31.57	24.22
STK4-B1-7	33.10	23.91	6.24	8.07	4.60	10.2367	3.309	1355.62	576.7	32.29	14.54
STK4-B1-8	33.11	23.91	6.23	8.05	4.60	10.2779	3.326	969.92	412.8	30.74	32.77
STK4-B1-9	33.11	23.91	6.24	8.11	4.60	10.2707	3.300	2012.67	850.2	28.39	51.08
STK4-B3-1	33.11	23.88	6.24	8.07	4.62	10.3150	3.321	1399.07	589.4	—	169.14
STK4-B3-2	33.13	23.90	6.24	8.10	4.62	10.3309	3.312	1665.07	699.4	31.03	30.16
STK4-B3-3	33.10	23.89	6.25	8.12	4.61	10.3297	3.313	1436.44	604.3	31.51	24.78
STK4-B3-4	33.11	23.90	6.26	8.12	4.61	10.3171	3.308	1997.36	840.6	—	169.10
STK4-B3-5	33.11	23.90	6.24	8.12	4.61	10.3145	3.307	2011.16	846.4	—	169.14
STK4-B3-6	33.12	23.88	6.25	8.17	4.62	10.3083	3.275	1632.17	677.7	31.79	21.71
STK4-B3-7	33.12	23.89	6.24	8.06	4.62	10.3174	3.325	1586.02	669.3	28.13	52.86
STK4-B3-8	33.12	23.91	6.25	8.02	4.61	10.2627	3.330	1774.58	756.4	—	169.12
STK4-B3-9	33.12	23.91	6.24	8.07	4.61	10.3253	3.329	1756.80	744.2	—	169.14
m = — sigma_theta = — MPa sigma_avg = 694.0 MPa std dev = 166.0 MPa											

Table A-1.8. C-ring strength data for kyocera SN235P (SN5P).

<b>Specimen</b>	<b>Do (mm)</b>	<b>Di (mm)</b>	<b>Slot (mm)</b>	<b>Height, b (mm)</b>	<b>Width, t (mm)</b>	<b>Mass (g)</b>	<b>Density (g/cm<sup>3</sup>)</b>	<b>Load (N)</b>	<b>Stress (MPa)</b>	
SN5P-B1-1	33.06	24.01	6.28	7.988	4.53	9.7369	3.19	1528.51	680.1	
SN5P-B1-2	33.05	24.00	6.30	7.986	4.53	9.7492	3.19	1263.60	562.1	
SN5P-B1-3	33.06	24.02	6.29	8.011	4.52	9.7735	3.19	1584.87	704.9	
SN5P-B1-4	33.06	24.04	6.29	8.002	4.51	9.7685	3.20	1560.66	698.6	
SN5P-B1-5	33.05	24.03	6.29	8.016	4.51	9.7624	3.19	1421.66	635.0	
SN5P-B1-6	33.05	24.04	6.29	7.992	4.51	9.7574	3.20	1620.42	727.8	
SN5P-B1-7	33.04	24.02	6.30	8.010	4.51	9.7669	3.20	1574.84	703.6	
SN5P-B1-8	33.04	24.03	6.28	7.990	4.51	9.7491	3.20	1508.65	677.5	
SN5P-B1-9	33.05	24.06	6.29	8.017	4.50	9.7829	3.21	1061.61	477.8	
SN5P-B2-1	33.02	24.00	6.30	7.999	4.51	9.7564	3.20	1544.07	690.3	
SN5P-B2-2	33.01	24.03	6.35	7.999	4.49	9.7381	3.21	1586.05	716.2	
SN5P-B2-3	33.02	24.03	6.33	7.977	4.50	9.6947	3.20	1191.86	538.5	
SN5P-B2-4	33.02	24.02	6.26	7.999	4.50	9.7511	3.20	1418.12	637.3	
SN5P-B2-5	33.00	24.07	6.27	7.996	4.47	9.6947	3.21	1525.72	698.0	
SN5P-B2-6	33.02	24.01	6.27	7.994	4.51	9.7422	3.20	1570.55	704.4	
SN5P-B2-7	33.02	24.03	6.27	8.007	4.50	9.7604	3.21	1200.18	540.2	
SN5P-B2-8	33.03	24.00	6.28	7.999	4.52	9.7537	3.20	1680.23	749.5	
SN5P-B2-9	33.04	24.00	6.28	7.998	4.52	9.7549	3.19	1413.05	629.0	
							Average	3.20	1458.59	653.94
							Std. dev.	0.01	171.81	76.52

## A-2. Room Temperature Uniaxial Tensile Strength Data

Table A-2.1. Tensile test results; CoorsTek AD 995 (ALOX); 25 October 2002.

Specimen Number	Diameter (in)	Load (lb)	Tensile Strength		Fracture Origin	Relative Humidity (%)
			(ksi)	(MPa)		
10	0.2500	1803	36.7	253	Surface @ pit	28
13	0.2506	1987	40.3	278	Volume @ void	30
5	0.2505	2038	41.4	285	Surface	30
6	0.2502	2111	42.9	296	Surface	30
17	0.2502	2127	43.3	298	Surface	30
14	0.2498	2150	43.9	302	Surface	54
16	0.2504	2191	44.5	307	Surface	30
18	0.2500	2212	45.1	311	Volume	28
3	0.2505	2260	45.9	316	Volume	28
4	0.2505	2274	46.1	318	Volume	31
2	0.2505	2304	46.7	322	Volume	54
20	0.2498	2296	46.8	323	Volume	54
7	0.2505	2328	47.2	326	Volume	37
11	0.2504	2333	47.4	327	Volume	29
15	0.2500	2345	47.8	329	Volume	29
8	0.2502	2351	47.8	330	Surface	29
12	0.2506	2370	48.1	331	Volume	28
9	0.2502	2383	48.5	334	Surface	30
19	0.2504	2408	48.9	337	Surface	37
1	0.2504	2532	51.4	355	Volume	30
		Average	45.5	314		
		Std. dev.	3.4	23		

Notes: Test temperature: 70 °F (21 °C).

Stressing rate: 150 MPa/s.

Atmosphere: air.

Relative humidity: as noted.

Test fixture: Instron super grips.

Table A-2.2. Tensile test results; CoorsTek Ce-TZP (ZRO2); 06 November 2002.

Specimen Number	Diameter (in)	Load (lb)	Tensile Strength		Fracture Origin	Relative Humidity (%)
			(ksi)	(MPa)		
14	0.2493	3073	63.0	434	Surface	24
4	0.2502	3390	68.9	475	Surface	25
17	0.2619	3737	69.4	478	Volume	26
13	0.2498	3730	76.1	525	Volume @ void	31
15	0.2497	3787	77.3	533	Surface	24
19	0.2499	3937	80.3	553	Surface	32
12	0.2483	3904	80.6	556	Volume @ void	31
6	0.2503	4011	81.5	562	Volume @ void	24
3	0.2497	4019	82.1	566	Surface	24
10	0.2491	4007	82.2	567	Volume	25
9	0.2492	4025	82.5	569	Volume @ agglomerate	30
1	0.2498	4053	82.7	570	Volume	30
8	0.2494	4069	83.3	574	Volume @ void	27
20	0.2499	4114	83.9	578	Volume	25
16	0.2494	4108	84.1	580	Surface	29
5	0.2503	4151	84.4	582	Volume @ void	24
18	0.2491	4124	84.6	583	Surface	27
11	0.2493	4145	84.9	585	Surface @ inclusion	31
2	0.2501	4241	86.3	595	Surface @ pit	31
7	0.2492	4283	87.8	605	Surface	25
		Average	80.3	554		
		Std. dev.	6.4	44		

Notes: Test temperature: 70 °F (21 °C).

Stressing rate: 150 MPa/s.

Atmosphere: air.

Relative humidity: as noted.

Test fixture: Instron super grips.

Specimen 17 failed in the top transition region.

Specimen 9 failed at agglomerate that was recovered and analyzed. The agglomerate was found to be aluminum oxide. When the agglomerate was removed the fracture surface looked like the volume at void fracture initiation sites.

Table A-2.3. Tensile test results; carborundum liquid phase sintered hexoloy SA (SCLH); 15 November 2002.

Specimen Number	Diameter (in)	Load (lb)	Tensile Strength		Fracture Origin	Relative Humidity (%)
			(ksi)	(MPa)		
A-19	0.2499	1335	27.2	188	Volume	20
A-17	0.2501	1743	35.5	245	Surface @ pit	48
A-3	0.2502	1852	37.7	260	Volume	23
A-4	0.2483	1826	37.7	260	Surface	27
A-5	0.2501	1962	39.9	275	Surface	28
A-16	0.2499	2014	41.1	283	Volume @ pore	21
A-6	0.2499	2054	41.9	289	Volume @ pore	28
A-20	0.2521	2101	42.1	290	Volume @ pore	29
A-9	0.2492	2087	42.8	295	Volume @ pore	48
A-7	0.2498	2120	43.3	298	Volume @ pore	21
A-12	0.2501	2137	43.5	300	Volume @ pore	44
A-13	0.2500	2137	43.5	300	Volume	46
A-8	0.2501	2139	43.5	300	Surface	38
A-18	0.2501	2156	43.9	303	Volume @ pore	21
A-11	0.2494	2170	44.4	306	Surface	22
A-2	0.2496	2183	44.6	308	Surface	20
A-10	0.2501	2202	44.8	309	Volume @ pore	23
A-15	0.2501	2234	45.5	314	Volume @ pore	23
A-1	0.2495	2264	46.3	319	Volume	21
		Average	41.5	286		
		Std. dev.	4.5	31		

Notes: Test temperature: 70 °F (21 °C).

Stressing rate: 150 MPa/s.

Atmosphere: air.

Relative humidity: as noted.

Test fixture: Instron super grips

Specimen A-14 was not suitable for testing due to its irregular shape.

Specimen A-20 failed in the upper transition region.

Specimen A-4 had a large undercut in the top shank.

Specimens A-8 and A-18 had scuff marks in the shank.

Table A-2.4. Tensile test results; Ceradyne 146-5S (SC46); 15 November 2002.

Specimen Number	Diameter (in)	Load (lb)	Tensile Strength		Fracture Origin	Relative Humidity (%)
			(ksi)	(MPa)		
13	0.2502	1573	32.0	221	Volume	28
3	0.2501	1845	37.6	259	Surface @ pit	29
12	0.2475	1887	39.2	270	Volume	30
7	0.2503	1986	40.4	278	Surface	30
5	0.2506	1995	40.4	279	Surface	26
8	0.2499	2031	41.4	286	Surface	26
4	0.2498	2048	41.8	288	Volume @ pullout	26
16	0.2492	2047	42.0	289	Surface	27
11	0.2493	2066	42.3	292	Surface	29
10	0.2497	2092	42.7	295	Surface	29
1	0.2499	2126	43.3	299	Surface	29
9	0.2500	2143	43.7	301	Volume	28
15	0.2499	2146	43.8	302	Surface @ pit	26
6	0.2502	2152	43.8	302	Volume	29
2	0.2503	2178	44.3	305	Surface	26
		Average	41.2	284		
		Std. dev.	3.2	22		

Notes: Ceradyne 146-5S (SC46).

Test temperature: 70 °F (21 °C).

Stressing rate: 150 MPa/s.

Atmosphere: air.

Relative humidity: as noted.

Test fixture: Instron super grips.

Specimen A-20 failed in the upper transition region.

Table A-2.5. Tensile test results; Ceradyne Ceralloy 147-31N (SN47); 23 October 2002.

Specimen Number	Diameter (in)	Load (lb)	Tensile Strength		Fracture Origin	Relative Humidity (%)
			(ksi)	(MPa)		
14	0.2631	4295	79.0	545	Volume	40
11	0.2505	3916	79.5	548	Surface	55
16	0.2504	3930	79.8	550	Volume	55
10	0.2673	4501	80.2	553	Surface	55
12	0.2460	4316	90.8	626	Volume	36
20	0.2504	5294	107.5	741	Surface	58
17	0.2561	5560	107.9	744	Surface	55
15	0.2506	5549	112.5	776	Surface	55
18	0.2506	5572	113.0	779	Volume	40
4	0.2506	5601	113.6	783	Surface	55
9	0.2505	5655	114.7	791	Volume	55
1	0.2503	5717	116.2	801	Surface	55
6	0.2506	5807	117.7	812	Volume	40
3	0.2505	6008	121.9	841	Surface	40
13	0.2507	6068	122.9	848	Volume	40
2	0.2492	6102	125.1	863	Surface	55
8	0.2483	6236	128.8	888	Volume	58
7	0.2501	6342	129.1	890	Volume	55
19	0.2502	6438	130.9	903	Volume	55
5	0.2500	6452	131.4	906	Volume	57
		Average	110.1	759		
		Std. dev.	18.3	126		

Notes: Test temperature: 70 °F (21 °C).

Stressing rate: 150 MPa/s.

Atmosphere: air.

Relative humidity: as noted.

Test fixture: Instron super grips.

No fracture origin could be positively identified for specimen 6.

Specimens 17 and 14 failed in the top transition region. Specimen 1 failed at or very near the top transition region.

Specimen 10 failed in the bottom transition region. Specimen 4 failed at or very near the bottom transition region.

Table A-2.6. Tensile test results; Kennametal STK-4 SiAlON (STK4); 19 December 2002.

Specimen Number	Diameter (in)	Load (lb)	Tensile Strength		Fracture Origin	Relative Humidity (%)
			(ksi)	(MPa)		
A-8	0.2504	3228	65.6	452	Volume @ inclusion	19
A-16	0.2574	3392	65.2	449	Surface @ inclusion	19
A-19	0.2500	3652	74.4	513	Volume @ inclusion	22
A-1	0.2704	2815	49.0	338	Volume @ inclusion	22
A-15	0.2503	3285	66.8	460	Volume @ inclusion	23
A-12	0.2502	2162	44.0	303	Volume @ inclusion	24
A-3	0.2501	2554	52.0	358	Volume @ inclusion	24
A-17	0.2500	3686	75.1	518	Volume @ inclusion	24
A-23	0.2501	3285	66.9	461	Volume @ inclusion	25
A-10	0.2506	3717	75.4	520	Volume @ inclusion	27
A-14	0.2753	2537	42.6	294	Surface @ radial scratch	27
A-22	0.2504	3043	61.8	426	Volume @ inclusion	25
A-9	0.2909	3266	49.1	339	Surface @ inclusion	27
A-20	0.2502	3113	63.3	437	Surface	27
A-7	0.2501	2649	53.9	372	Volume @ inclusion	27
A-18	0.2501	3246	66.1	456	Volume @ inclusion	37
A-13	0.2505	3586	72.8	502	Volume @ inclusion	37
A-4	0.2504	2932	59.5	411	Volume @ inclusion	23
A-21	0.2499	3620	73.8	509	Surface	23
		Average	62.0	427		
		Std. dev.	10.7	74		

Notes: Test temperature: 70 °F (21 °C).

Stressing rate: 150 MPa/s.

Atmosphere: air.

Relative humidity: as noted.

Test fixture: Instron super grips.

The inclusion in specimen A1 was examined using x-ray fluorescence and was determined to be stainless steel.

All the inclusions in this sample have a similar appearance but vary in size.

Specimens A-16, A-1, and A-9 failed in the upper transition region. Specimen A-14 failed in the lower transition region.

Table A-2.7. Tensile test results; Kyocera SN235P (SN5P); 20 April 2004.

Specimen Number	Diameter (in)	Load (lb)	Tensile Strength		Fracture Origin	Relative Humidity (%)
			(ksi)	(MPa)		
16	0.2500	3837	78.2	539	Surface	20
14	0.2500	3481	70.9	489	Volume	20
9	0.2499	4056	82.7	570	Surface	20
11	0.2500	4101	83.5	576	See note	22
15	0.2499	4254	86.7	598	Surface	22
8	0.2505	3173	64.4	444	Volume	22
2	0.2499	4294	87.5	604	Volume	22
13	0.2497	4000	81.7	563	Volume	24
17	0.2500	4030	82.1	566	Surface	24
20	0.2496	4253	86.9	599	Surface	24
5	0.2496	4424	90.4	623	Volume	24
7	0.2501	4474	91.1	628	Surface	24
3	0.2500	4581	93.3	643	Volume	54
4	0.2501	4581	93.2	643	Surface	54
10	0.2498	4071	83.1	573	Volume	54
19	0.2500	4524	92.2	635	Volume	54
18	0.2500	4442	90.5	624	See note	54
6	0.2499	4211	85.9	592	Volume	54
1	0.2501	4447	90.5	624	Surface	54
12	0.2501	4242	86.3	595	Surface	29
		Average	85.1	586		
		Std. dev.	7.4	51		

Notes: Test temperature: 70 °F (21 °C).

Stressing rate: 150 MPa/s.

Atmosphere: air.

Relative humidity: as noted.

Test fixture: Instron super grips.

Specimens 16, 11, 18, and 12 had multiple failures. A positive identification of the fracture was difficult.

Specimens 16 and 12 appear to be surface failures. Specimens 16 and 11 had both apparent volume and surface failures.

The volume failures of specimens 14, 10, and 6 appear to be at low density areas.

### A-3. Room Temperature Strength Data From Sectored Flexure Specimens

Table A-3.1. Contoured flexural strength results; CoorsTek AD 995 (ALOX); 22 November 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
AB-5-5	1.299	45	0.1582	129.0	36.7	253
AB-4-4	1.299	45	0.1582	130.2	37.1	256
AB-3-2	1.299	45	0.1582	138.5	39.4	272
AB-3-1	1.299	45	0.1580	137.2	39.2	270
AB-4-1	1.299	45	0.1583	139.8	39.7	274
AB-6-4	1.299	45	0.1583	143.4	40.8	281
AB-5-2	1.299	45	0.1580	130.8	37.3	257
AB-3-5	1.299	45	0.1587	140.3	39.7	273
AB-4-5	1.299	45	0.1583	136.1	38.7	267
AB-6-1	1.299	45	0.1588	135.8	38.3	264
AB-3-3	1.299	45	0.1583	140.9	40.1	276
AB-4-3	1.299	45	0.1586	135.9	38.5	265
AB-3-4	1.299	45	0.1588	142.4	40.2	277
AB-6-2	1.299	45	0.1570	123.8	35.8	247
AB-4-2	1.299	45	0.1586	133.4	37.8	260
AB-6-3	1.299	45	0.1587	135.9	38.4	265
AB-6-5	1.299	45	0.1589	142.1	40.1	276
AB-53	1.299	45	0.1582	133.7	38.1	262
AB-5-1	1.299	45	0.1580	128.6	36.7	253
AB-5-4	1.299	45	0.1585	127.5	36.1	249
				Average	38.4	265
				Std. dev.	1.5	10

Notes: Test temperature: 70 °F (21 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Relative humidity: 19%–38%.  
 Test fixture: SiC2.

Table A-3.2. Contoured flexural strength results; CoorsTek Ce-TZP (ZRO2); 15 November 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
ZB-3-4	1.299	45	0.1577	309.5	88.7	612
ZB-6-5	1.299	45	0.1577	307.1	88.0	607
ZB-3-1	1.299	45	0.1578	297.3	85.1	587
ZB-4-3	1.299	45	0.1577	283.7	81.3	561
ZB-5-5	1.299	45	0.1585	282.3	80.0	552
ZB-4-2	1.299	45	0.1581	303.9	86.6	597
ZB-5-4	1.299	45	0.1579	301.3	86.1	594
ZB-4-1	1.299	45	0.1577	298.1	85.4	589
ZB-5-2	1.299	45	0.1587	285.7	80.8	557
ZB-6-2	1.299	45	0.1577	266.6	76.4	527
ZB-4-4	1.299	45	0.1579	321.8	92.0	634
ZB-3-2	1.299	45	0.1573	290.0	83.6	576
ZB-4-5	1.299	45	0.1580	288.1	82.2	567
ZB-6-1	1.299	45	0.1579	277.3	79.3	547
ZB-3-3	1.299	45	0.1580	294.7	84.1	580
ZB-3-5	1.299	45	0.1578	280.2	80.2	553
ZB-5-3	1.299	45	0.1583	304.3	86.5	596
ZB-6-4	1.299	45	0.1548	261.5	78.1	538
ZB-5-1	1.299	45	0.1578	308.1	88.2	608
ZB-6-3	1.299	45	0.1580	294.8	84.1	580
				Average	83.8	578
				Std. dev.	4.0	28

Notes: Test temperature: 70 °F (21 °C).

Crosshead speed: 0.04 in/min.

Atmosphere: air.

Relative humidity: 19%–26%.

Test fixture: see notes.

The fixture failed during the testing of specimen ZB-6-3 at a load of 115.4 lb. The specimen was retested in a fixture SiC1.

At the conclusion of testing specimen ZB-4-2 the top half of the fixture was broken. It is not known if the fixture or specimen failed first.

Specimens ZB-5-4 through ZB-6-3 were tested using the bottom of fixture SiC1 with an new inconel top.

Table A-3.3. Contoured flexural strength results; carborundum enhanced hexoloy SA (SCEH);  
22 November 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
EB-3-4	1.299	45	0.1591	101.0	28.4	196
EB-2-5	1.299	45	0.1581	86.0	24.5	169
EB-4-4	1.299	45	0.1585	98.4	27.9	192
EB-3-2	1.299	45	0.1585	130.6	37.0	255
EB-1-3	1.299	45	0.1572	86.5	25.0	172
EB-4-1	1.299	45	0.1587	94.3	26.7	184
EB-1-2	1.299	45	0.1577	81.3	23.3	161
EB-3-3	1.299	45	0.1586	142.3	40.3	278
EB-1-4	1.299	45	0.1577	90.6	26.0	179
EB-4-3	1.299	45	0.1585	97.4	27.6	190
EB-1-1	1.299	45	0.1576	78.7	22.6	156
EB-4-2	1.299	45	0.1583	92.0	26.2	180
EB-3-5	1.299	45	0.1583	116.6	33.1	229
EB-2-4	1.299	45	0.1584	92.9	26.4	182
EB-3-1	1.299	45	0.1566	122.3	35.6	245
EB-4-5	1.299	45	0.1573	92.1	26.5	183
EB-1-5	1.299	45	0.1590	88.9	25.0	173
EB-2-3	1.299	45	0.1568	82.8	24.0	166
EB-2-1	1.299	45	0.1571	93.4	27.0	186
EB-2-2	1.299	45	0.1559	80.8	23.8	164
				Average	27.8	192
				Std. dev.	4.8	33

Notes: Test temperature: 70 °F (21 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Relative humidity: 27%.  
 Test fixture: SiC1.

Table A-3.4. Contoured flexural strength results; carborundum liquid phase sintered hexoloy SA (SCLH);  
22 November 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
LB-3-2	1.299	45	0.1578	166.9	47.8	329
LB-6-5	1.299	45	0.1583	173.0	49.2	339
LB-5-3	1.299	45	0.1583	157.3	44.7	308
LB-5-1	1.299	45	0.1581	139.6	39.8	274
LB-6-4	1.299	45	0.1595	172.3	48.2	332
LB-4-3	1.299	45	0.1588	175.4	49.5	341
LB-5-5	1.299	45	0.1580	147.1	42.0	290
LB-6-3	1.299	45	0.1589	175.6	49.5	341
LB-3-3	1.299	45	0.1585	146.5	41.5	286
LB-5-2	1.299	45	0.1587	141.9	40.1	277
LB-4-4	1.299	45	0.1583	168.2	47.8	330
LB-3-1	1.299	45	0.1588	145.8	41.2	284
LB-6-2	1.299	45	0.1580	158.7	45.3	312
LB-5-4	1.299	45	0.1575	128.1	36.8	254
LB-5-6	1.299	45	0.1568	147.1	42.7	294
LB-4-1	1.299	45	0.1581	166.6	47.5	327
LB-3-4	1.299	45	0.1587	152.1	43.0	296
LB-6-1	1.299	45	0.1585	185.1	52.5	362
LB-4-5	1.299	45	0.1588	158.6	44.8	309
LB-4-2	1.299	45	0.1585	173.5	49.2	339
				Average	45.1	311
				Std. dev.	4.1	29

Notes: Test temperature: 70 °F (21 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Relative humidity: 26%–27%.  
 Test fixture: SiC1.

Table A-3.5. Contoured flexural strength results; ceradyne 146-5S (SC46); 15 November 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
SB-3-1	1.299	45	0.1589	129.1	36.4	251
SB-5-5	1.299	45	0.1590	134.2	37.8	260
SB-3-3	1.299	45	0.1595	150.0	41.9	289
SB-6-3	1.299	45	0.1592	140.1	39.3	271
SB-5-3	1.299	45	0.1586	143.4	40.6	280
SB-3-2	1.299	45	0.1589	140.6	39.6	273
SB-4-1	1.299	45	0.1584	132.9	37.7	260
SB-4-3	1.299	45	0.1582	139.0	39.6	273
SB-6-1	1.299	45	0.1594	140.1	39.2	270
SB-4-4	1.299	45	0.1588	147.2	41.6	286
SB-3-5	1.299	45	0.1592	143.9	40.4	279
SB-4-5	1.299	45	0.1592	142.8	40.1	276
SB-5-4	1.299	45	0.1592	146.3	41.1	283
SB-5-2	1.299	45	0.1583	143.7	40.8	282
SB-6-2	1.299	45	0.1586	129.9	36.8	254
SB-5-1	1.299	45	0.1587	142.3	40.2	277
SB-4-6	1.299	45	0.1588	141.1	39.8	275
SB-3-4	1.299	45	0.1599	134.2	37.3	257
SB-4-2	1.299	45	0.1593	145.5	40.8	281
SB-6-4	1.299	45	0.1593	130.1	36.5	251
				Average	39.4	271
				Std. dev.	1.7	12

Notes: Test temperature: 70 °F (21 °C).

Crosshead speed: 0.04 in/min.

Atmosphere: air.

Relative humidity: 17%–28%.

Test fixture: SiC3 with contoured load points.

Table A-3.6. Contoured flexural strength results; ceradyne ceralloy 147-31N (SN47).

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
B-4-4	1.299	45	0.1588	243.3	68.7	474
B-4-2	1.299	45	0.1578	280.9	80.4	554
B-4-5	1.299	45	0.1581	283.3	80.8	557
B-4-3	1.299	45	0.1587	293.6	83.0	572
B-6-2	1.299	45	0.1571	293.7	84.9	585
B-4-1	1.299	45	0.1584	301.2	85.5	589
B-5-5	1.299	45	0.1570	296.6	85.9	592
B-6-1	1.299	45	0.1572	303.2	87.5	603
B-3-5	1.299	45	0.1588	310.5	87.6	604
B-5-2	1.299	45	0.1574	311.6	89.7	618
B-5-3	1.299	45	0.1574	313.3	90.2	622
B-5-1	1.299	45	0.1569	316.1	91.6	632
B-5-4	1.299	45	0.1576	323.4	92.8	640
B-3-2	1.299	45	0.1583	329.4	93.6	646
B-3-1	1.299	45	0.1580	330.8	94.4	651
B-6-4	1.299	45	0.1570	326.8	94.6	652
B-6-5	1.299	45	0.1571	332.0	96.0	662
B-6-3	1.299	45	0.1575	335.8	96.5	666
B-3-4	1.299	45	0.1581	352.1	100.4	692
B-3-3	1.299	45	0.1586	379.3	107.4	740
				Average	89.6	618
				Std. dev.	8.3	57

Notes: Test temperature: 70 °F (21 °C).

Crosshead speed: 0.04 in/min.

Atmosphere: air.

Relative humidity: 19%–29%.

Specimens B-4-4 and B-4-5 failed at tool marks identified during pretest inspection.

Table A-3.7. Contoured flexural strength results; Kennametal TK-4 (STK4); 11 February 2003.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
B-8-5	1.299	45	0.1574	282.8	81.4	561
B-9-4	1.299	45	0.1576	331.0	95.0	655
B-6-2	1.299	45	0.1581	305.8	87.2	601
B-9-3	1.299	45	0.1575	362.8	104.3	719
B-9-5	1.299	45	0.1580	365.6	104.4	720
B-6-3	1.299	45	0.1582	356.8	101.6	700
B-10-2	1.299	45	0.1571	317.1	91.7	632
B-6-1	1.299	45	0.1579	360.9	103.2	711
B-8-4	1.299	45	0.1583	357.1	101.5	700
B-10-5	1.299	45	0.1577	329.0	94.3	650
B-9-1	1.299	45	0.1579	307.2	87.8	605
B-6-5	1.299	45	0.1585	297.4	84.3	581
B-8-2	1.299	45	0.1581	323.8	92.3	636
B-9-2	1.299	45	0.1575	341.8	98.2	677
B-6-4	1.299	45	0.1581	376.8	107.4	741
B-10-4	1.299	45	0.1575	334.3	96.1	663
B-8-3	1.299	45	0.1578	376.8	107.9	744
B-10-1	1.299	45	0.1578	327.7	93.8	647
B-8-1	1.299	45	0.1575	314.2	90.3	623
B-10-3	1.299	45	0.1576	244.5	70.2	484
				Average	94.6	653
				Std. dev.	9.5	66

Notes: Test temperature: 70 °F (21 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Relative humidity: 19%–26%.  
 Test fixture: SiC/Inc 1.

Table A-3.8. Contoured flexural strength results; Kyocera SN235P (SN5P); 2 February 2004.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
SN5P-B-3-5	1.299	45	0.1576	241.0	69.2	477
SN5P-B-3-2	1.299	45	0.1580	268.7	76.7	529
SN5P-B-3-4	1.299	45	0.1573	245.3	70.7	488
SN5P-B-3-3	1.299	45	0.1580	285.2	81.4	561
SN5P-B-3-1	1.299	45	0.1582	284.6	81.0	559
SN5P-B-4-3	1.299	45	0.1578	314.1	89.9	620
SN5P-B-4-4	1.299	45	0.1583	267.2	76.0	524
SN5P-B-4-1	1.299	45	0.1577	286.2	82.0	566
SN5P-B-4-5	1.299	45	0.1581	251.5	71.7	494
SN5P-B-4-2	1.299	45	0.1578	290.3	83.1	573
SN5P-B-5-5	1.299	45	0.1571	324.5	93.8	647
SN5P-B-5-3	1.299	45	0.1583	278.6	79.2	546
SN5P-B-5-4	1.299	45	0.1577	266.9	76.5	527
SN5P-B-5-1	1.299	45	0.1578	259.8	74.4	513
SN5P-B-5-2	1.299	45	0.1580	311.5	88.9	613
SN5P-B-6-2	1.299	45	0.1578	274.4	78.5	542
SN5P-B-6-1	1.299	45	0.1576	305.3	87.6	604
SN5P-B-6-4	1.299	45	0.1579	284.7	81.4	561
SN5P-B-6-3	1.299	45	0.1579	342.4	97.9	675
SN5P-B-6-5	1.299	45	0.1583	326.2	92.7	639
				Average	81.6	563
				Std. dev.	8.0	55

Notes: Test temperature: 70 °F (21 °C).

Crosshead speed: 0.04 in/min.

Atmosphere: air.

Relative humidity: 8%.

Test fixture: SiC/Inc 1.

#### A-4. Elevated Temperature (700 °C) Strength Data From Sector Flexure Specimens

Table A-4.1. Contoured flexural strength results; CoorsTek AD 995; 13 December 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
AB-3-5-8	1.299	45	0.1580	132.4	37.8	261
AB-3-3-7	1.299	45	0.1569	116.6	33.8	233
AB-3-4-7	1.299	45	0.1584	108.9	30.9	213
AB-3-5-7	1.299	45	0.1580	127.0	36.3	250
AB-3-6-8	1.299	45	0.1585	129.9	36.8	254
AB-3-4-6	1.299	45	0.1586	114.1	32.3	223
AB-3-6-7	1.299	45	0.1590	120.7	34.0	234
AB-3-3-6	1.299	45	0.1582	125.6	35.8	247
AB-3-6-6	1.299	45	0.1587	129.1	36.5	252
				Average	34.9	241
				Std. dev.	2.3	16

Notes: Test temperature: 1292 °F (700 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Heating rate: 10 °C/min.  
 Test fixture: SiC1.  
 Specimen AB-5-6 was broken during heating.

Table A-4.2. Contoured flexural strength results; CoorsTek Ce-TZP (ZRO2); 2 December 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
ZB-6-6	1.299	45	0.1573	69.4	20.0	138
ZB-3-7	1.299	45	0.1577	59.3	17.0	117
ZB-6-7	1.299	45	0.1581	37.1	10.6	73
ZB-4-7	1.299	45	0.1575	57.2	16.4	113
ZB-4-6	1.299	45	0.1580	56.2	16.0	111
ZB-5-7	1.299	45	0.1580	67.9	19.4	134
ZB-3-8	1.299	45	0.1580	64.0	18.3	126
ZB-4-8	1.299	45	0.1580	63.1	18.0	124
ZB-3-6	1.299	45	0.1579	58.6	16.7	115
ZB-5-6	1.299	45	0.1583	71.2	20.2	139
				Average	17.3	119
				Std. dev.	2.8	19

Notes: Test temperature: 1292 °F (700 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Heating rate: 10 °C/min.  
 Soak time: 10 min.  
 Test fixture: SiC/Inc 1.

Table A-4.3. Contoured flexural strength results; carborundum enhanced hexoloy SA (SCEH); 8 January 2003.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
EB-4-7	1.299	45	0.1582	117.7	33.5	231
EB-3-6	1.299	45	0.1553	165.3	49.0	338
EB-1-7	1.299	45	0.1589	110.0	31.0	214
EB-3-8	1.299	45	0.1585	130.5	37.0	255
EB-2-6	1.299	45	0.1575	107.9	31.0	214
EB-2-8	1.299	45	0.1583	107.0	30.4	210
EB-3-7	1.299	45	0.1589	165.5	46.7	322
EB-1-6	1.299	45	0.1571	99.7	28.8	199
EB-2-7	1.299	45	0.1564	90.2	26.3	182
EB-4-6	1.299	45	0.1581	121.4	34.6	239
				Average	34.8	240
				Std. dev.	7.5	52

Notes: Test temperature: 1292 °F (700 °C).

Crosshead speed: 0.04 in/min.

Atmosphere: air.

Heating rate: 10 °C/min.

Test fixture: SiC3.

There was no Grafoil used between the specimen EB-2-6 and the contoured load points.

Table A-4.4. Contoured flexural strength results; carborundum liquid phase sintered hexoloy SA (SCLH); 20 December 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
LB-4-7	1.299	45	0.1593	163.3	45.8	316
LB-3-5	1.299	45	0.1587	157.3	44.5	307
LB-6-8	1.299	45	0.1589	154.6	43.6	300
LB-4-8	1.299	45	0.1575	148.5	42.7	294
LB-4-6	1.299	45	0.1577	173.8	49.8	343
LB-3-6	1.299	45	0.1590	118.0	33.2	229
LB-6-7	1.299	45	0.1587	149.1	42.1	291
LB-6-6	1.299	45	0.1588	173.3	48.9	337
LB-5-7	1.299	45	0.1583	148.5	42.2	291
LB-5-8	1.299	45	0.1560	148.5	43.6	301
				Average	43.6	301
				Std. dev.	4.5	31

Notes: Test temperature: 1292 °F (700 °C).

Crosshead speed: 0.04 in/min.

Atmosphere: air.

Heating rate: 10 °C/min.

Soak time: 10 min.

Test fixture: SiC3.

Table A-4.5. Contoured flexural strength results; ceradyne ceralloy 146-5S (SC46); 6 December 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
SB-6-6	1.299	45	0.1587	147.3	41.6	287
SB-3-8	1.299	45	0.1589	147.4	41.6	286
SB-4-7	1.299	45	0.1585	140.8	39.9	275
SB-3-6	1.299	45	0.1590	157.2	44.3	305
SB-3-7	1.299	45	0.1600	158.9	44.1	304
SB-4-8	1.299	45	0.1592	127.3	35.7	246
SB-5-7	1.299	45	0.1590	153.9	43.3	299
SB-5-6	1.299	45	0.1588	149.3	42.1	291
SB-6-5	1.299	45	0.1588	140.3	39.6	273
SB-5-8	1.299	45	0.1588	138.8	39.2	270
				Average	41.1	284
				Std. dev.	2.6	18

Notes: Test temperature: 1292 °F (700 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Heating rate: 10 °C/min.  
 Soak time: 10 min.  
 Test fixture: SiC/Inc 1.

Table A-4.6. Contoured flexural strength results; ceradyne ceralloy 147-31N (SN47); 22 November 2002.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
47-B-3-7	1.299	45	0.1582	300.9	85.6	591
47-B-4-7	1.299	45	0.1576	279.7	80.3	554
47-B-6-7	1.299	45	0.1573	301.8	87.0	600
47-B-4-6	1.299	45	0.1587	278.9	78.8	544
47-B-5-6	1.299	45	0.1577	255.4	73.2	505
47-B-6-8	1.299	45	0.1583	297.0	84.4	582
47-B-6-6	1.299	45	0.1576	248.1	71.2	491
47-B-3-6	1.299	45	0.1586	289.2	81.9	564
47-B-5-8	1.299	45	0.1573	264.5	76.2	526
47-B-5-7	1.299	45	0.1569	254.1	73.7	508
				Average	79.2	546
				Std. dev.	5.5	38

Notes: Test temperature: 1292 °F (700 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Heating rate: 10 °C/min.  
 Test fixture: SiC/Inc 1.

Table A-4.7. Contoured flexural strength results; kennametal TK-4 (STK4); 4 March 2003.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
B-6-7	1.299	45	0.1578	370.9	106.2	732
B-6-6	1.299	45	0.1575	368.9	106.0	731
B-9-6	1.299	45	0.1576	357.2	102.5	707
B-8-6	1.299	45	0.1578	341.9	97.9	675
B-9-7	1.299	45	0.1577	372.6	106.8	736
B-6-8	1.299	45	0.1574	324.2	93.3	643
B-9-8	1.299	45	0.1580	352.7	100.7	694
B-8-7	1.299	45	0.1567	326.8	95.0	655
B-10-6	1.299	45	0.1580	346.6	98.9	682
B-10-7	1.299	45	0.1577	333.1	95.5	658
				Average	100.3	691
				Std. dev.	5.0	34

Notes: Test temperature: 1292 °F (700 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Heating rate: 10 °C/min.  
 Test fixture: SiC/Inc 1.

Table A-4.8. Contoured flexural strength results; Kyocera SN235P (SN5P); 2 February 2004.

Specimen Number	Outer Diameter (in)	$\theta$ (°)	Height (in)	Load (lb)	Flexural Strength	
					(ksi)	(MPa)
SN5P-B-4-7	1.299	45	0.1583	272.3	77.4	534
SN5P-B-3-7	1.299	45	0.1580	254.4	72.6	501
SN5P-B-6-7	1.299	45	0.1581	268.0	76.4	527
SN5P-B-4-6	1.299	45	0.1583	254.2	72.3	498
SN5P-B-6-6	1.299	45	0.1581	273.6	78.0	538
SN5P-B-3-6	1.299	45	0.1571	245.5	71.0	489
SN5P-B-4-8	1.299	45	0.1576	249.7	71.7	494
SN5P-B-5-8	1.299	45	0.1579	299.9	85.7	591
SN5P-B-5-7	1.299	45	0.1575	291.5	83.8	578
SN5P-B-5-6	1.299	45	0.1576	266.5	76.5	527
				Average	76.5	528
				Std. dev.	5.0	35

Notes: Test temperature: 1292 °F (700 °C).  
 Crosshead speed: 0.04 in/min.  
 Atmosphere: air.  
 Heating rate: 10 °C/min.  
 Test fixture: SiC/Inc 1.

## A-5. Chevron Notch Fracture Toughness Data

Table A-5.1. ALOX.

Material	B (mm)	W (mm)	a <sub>0</sub> (mm)	Dry Mass (g)	Wet Mass (g)	Density (g/cm <sup>3</sup> )	Max Load (N)	K <sub>IC</sub> (MPa*m <sup>1/2</sup> )
1	3.014	4.002	1.425	0.5476	0.4074	3.91	11.50	3.92
2	3.005	4.000	1.410	0.5863	0.4365	3.91	11.55	3.92
3	3.009	4.001	1.419	1.1494	0.8550	3.90	12.20	4.15
4	3.002	3.985	1.415	1.1483	0.8539	3.90	11.20	3.85
5	3.010	4.002	1.454	1.1577	0.8612	3.90	11.20	3.88
						3.91	Average	3.94
						0.00	Std. dev.	0.12

Table A-5.2. ZRO2.

Material	B (mm)	W (mm)	a <sub>0</sub> (mm)	Dry Mass (g)	Wet Mass (g)	Density (g/cm <sup>3</sup> )	Max Load (N)	K <sub>IC</sub> (MPa*m <sup>1/2</sup> )
1	3.013	4.004	1.396	1.8269	1.5296	6.14	15.60	5.22
2	3.015	4.009	1.395	1.8333	1.5352	6.15	17.90	5.97
3	3.014	4.006	1.380	1.8288	1.5317	6.16	18.45	6.11
4	3.021	4.003	1.413	1.8310	1.5332	6.15	16.40	5.53
5	3.012	4.006	1.367	1.8329	1.5347	6.15	17.00	5.58
						6.15	Average	5.68
						0.00	Std. dev.	0.36

Table A-5.3. SCEH.

Material	B (mm)	W (mm)	a <sub>0</sub> (mm)	Dry Mass (g)	Wet Mass (g)	Density (g/cm <sup>3</sup> )	Max Load (N)	K <sub>IC</sub> (MPa*m <sup>1/2</sup> )
2	3.015	3.999	1.485	1.8851	1.2865	3.15	16.2	2.98
3	3.015	4.006	1.486	1.8856	1.2930	3.18	16.7	3.06
						3.17	Average	3.02
						0.02	Std. dev.	0.06

Note: Specimens 1, 4, and 5 were broken upon arrival from the machinist.

Table A-5.4. SCLH.

Material	B (mm)	W (mm)	a <sub>0</sub> (mm)	Dry Mass (g)	Wet Mass (g)	Density (g/cm <sup>3</sup> )	Max Load (N)	K <sub>IC</sub> (MPa*m <sup>1/2</sup> )
1	3.011	4.008	1.466	1.8247	1.2258	3.05	12.9	2.34
2	3.017	4.011	1.469	1.8746	1.2792	3.15	13.8	2.50
3	3.019	4.013	1.463	1.8529	1.2531	3.09	13.8	2.49
4	3.025	4.007	1.465	1.8379	1.2402	3.07	13.0	2.35
						3.09	Average	2.42
						0.04	Std. dev.	0.09

Note: Specimen 5 was broken upon arrival from the machinist.

Table A-5.5. SC46.

Material	B (mm)	W (mm)	a <sub>o</sub> (mm)	Dry Mass (g)	Wet Mass (g)	Density (g/cm <sup>3</sup> )	Max Load (N)	K <sub>IC</sub> (MPa*m <sup>1/2</sup> )
1	3.008	3.976	1.411	0.9026	0.6109	3.09	14.10	4.85
2	3.008	4.003	1.470	0.8996	0.6113	3.12	13.90	4.86
3	3.011	3.953	1.435	0.9214	0.6247	3.11	14.45	5.10
4	3.011	3.978	1.448	0.8958	0.6060	3.09	14.65	5.13
						3.10	Average	4.99
						0.01	Std. dev.	0.15

Table A-5.6. SN47.

Material	B (mm)	W (mm)	a <sub>o</sub> (mm)	Dry Mass (g)	Wet Mass (g)	Density (g/cm <sup>3</sup> )	Max Load (N)	K <sub>IC</sub> (MPa*m <sup>1/2</sup> )
1	3.017	4.008	1.302	0.9729	0.6702	3.21	20.50	6.79
2	3.018	4.004	1.403	0.9506	0.6534	3.20	19.51	6.55
3	3.020	4.007	1.393	0.9651	0.6645	3.21	19.45	6.47
4	3.016	4.006	1.406	0.9346	0.6432	3.21	12.41	4.17
5	3.016	4.009	1.378	0.9391	0.6464	3.21	19.75	6.52
						3.21	Average	6.58
						0.01	Std. dev.	0.14

Table A-5.7. STK4.

Material	B (mm)	W (mm)	a <sub>o</sub> (mm)	Dry Mass (g)	Wet Mass (g)	Density (g/cm <sup>3</sup> )	Max Load (N)	K <sub>IC</sub> (MPa*m <sup>1/2</sup> )
1	3.012	4.006	1.448	2.0161	1.4187	3.37	42.9	7.72
2	3.018	4.005	1.464	2.0149	1.4154	3.36	41.7	7.56
3	3.021	4.007	1.444	2.0161	1.4171	3.37	41.8	7.48
4	3.01	4.006	1.441	2.0162	1.4179	3.37	42.7	7.66
						3.37	Average	7.61
						0.01	Std. dev.	0.11

Table A-5.8. SN5P.

Material	B (mm)	W (mm)	a <sub>o</sub> (mm)	Dry Mass (g)	Wet Mass (g)	Density (g/cm <sup>3</sup> )	Max Load (N)	K <sub>IC</sub> (MPa*m <sup>1/2</sup> )
1	2.999	4.014	1.391	1.9358	1.3415	3.26	48.5	8.47
2	3.004	4.02	1.421	1.9558	1.3598	3.28	48.7	8.59
3	2.999	4.005	1.406	1.9332	1.3422	3.27	50.1	8.86
4	2.999	4.023	1.427	1.9441	1.3504	3.27	48.2	8.53
5	2.999	4.017	1.415	1.9403	1.3544	3.31	50.3	8.88
						3.28	Average	8.67
						0.02	Std. dev.	0.19

**A-6. Vickers Hardness Data at a 300-g Indentation Load Between Room Temperature and 1000 °C**

Table A-6.1. ALOX.

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		22		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	18.3	18.0	18.2	0.0182	1688.8	16.6
2	17.4	17.4	17.4	0.0174	1837.5	18.0
3	19.8	19.0	19.4	0.0194	1478.2	14.5
4	19.5	18.3	18.9	0.0189	1557.4	15.3
5	18.6	18.6	18.6	0.0186	1608.0	15.8
6	18.8	18.8	18.8	0.0188	1574.0	15.4
<b>Average</b>	18.7	18.4	18.5	0.0185	1624.0	15.9
<b>Std. dev.</b>	0.9	0.6	0.7	0.0007	125.1	1.2
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		200		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	20.5	21.1	20.8	0.0208	1285.9	12.6
2	22.1	21.8	22.0	0.0220	1154.7	11.3
3	20.9	20.9	20.9	0.0209	1273.6	12.5
4	19.8	19.5	19.7	0.0197	1440.8	14.1
5	19.8	19.8	19.8	0.0198	1419.0	13.9
6	20.1	19.1	19.6	0.0196	1448.1	14.2
<b>Average</b>	20.5	20.4	20.5	0.0205	1337.0	13.1
<b>Std. dev.</b>	0.9	1.1	0.9	0.0009	118.1	1.2
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		300		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	20.2	21.2	20.7	0.0207	1298.3	12.7
2	20.7	20.0	20.4	0.0204	1343.4	13.2
3	20.5	21.4	21.0	0.0210	1267.5	12.4
4	20.1	20.1	20.1	0.0201	1377.0	13.5
5	20.0	19.3	19.7	0.0197	1440.8	14.1
6	20.9	20.9	20.9	0.0209	1273.6	12.5
<b>Average</b>	20.4	20.5	20.4	0.0204	1333.4	13.1
<b>Std. dev.</b>	0.4	0.8	0.5	0.0005	67.3	0.7

Table A-6.1. ALOX (continued).

	gf	N		Temp (°C)		
Load =	300	2.9421		300		
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	21.3	21.3	21.3	0.0213	1226.2	12.0
2	22.7	22.7	22.7	0.0227	1079.6	10.6
3	23.5	23.5	23.5	0.0235	1007.4	9.9
4	22.7	22.2	22.5	0.0225	1103.8	10.8
5	22.4	22.4	22.4	0.0224	1108.7	10.9
6	23.5	23.5	23.5	0.0235	1007.4	9.9
<b>Average</b>	22.7	22.6	22.6	0.0226	1088.9	10.7
<b>Std. dev.</b>	0.8	0.8	0.8	0.0008	81.1	0.8
	gf	N		Temp (°C)		
Load =	300	2.9421		500		
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	25.7	25.1	25.4	0.0254	862.3	8.5
2	24.1	25.2	24.7	0.0247	915.6	9.0
3	22.8	22.4	22.6	0.0226	1089.2	10.7
4	22.8	22.2	22.5	0.0225	1098.9	10.8
5	23.8	23.8	23.8	0.0238	982.1	9.6
6	23.6	23.6	23.6	0.0236	998.9	9.8
<b>Average</b>	23.8	23.7	23.8	0.0238	991.2	9.7
<b>Std. dev.</b>	1.1	1.3	1.1	0.0011	93.5	0.9
	gf	N		Temp (°C)		
Load =	300	2.9421		600		
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	29.9	29.0	29.5	0.0295	641.4	6.3
2	24.5	23.7	24.1	0.0241	957.8	9.4
3	25.0	23.3	24.2	0.0242	953.9	9.4
4	27.1	28.8	28.0	0.0280	712.1	7.0
5	26.6	26.6	26.6	0.0266	786.3	7.7
6	26.1	25.0	25.6	0.0256	852.2	8.4
<b>Average</b>	26.5	26.1	26.3	0.0263	817.3	8.0
<b>Std. dev.</b>	1.9	2.5	2.1	0.0021	128.5	1.3

Table A-6.1. ALOX (continued).

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		700		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	28.2	28.2	28.2	0.0282	699.6	6.9
2	28.3	27.8	28.1	0.0281	707.1	6.9
3	27.3	27.3	27.3	0.0273	746.4	7.3
4	28.7	27.3	28.0	0.0280	709.6	7.0
5	27.9	27.9	27.9	0.0279	714.7	7.0
6	27.4	27.4	27.4	0.0274	741.0	7.3
<b>Average</b>	28.0	27.7	27.8	0.0278	719.7	7.1
<b>Std. dev.</b>	0.5	0.4	0.4	0.0004	19.3	0.2
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	34.7	34.7	34.7	0.0347	462.0	4.5
2	31.7	30.9	31.3	0.0313	567.9	5.6
3	38.1	38.1	38.1	0.0381	383.2	3.8
4	36.0	34.8	35.4	0.0354	443.9	4.4
5	35.6	34.1	34.9	0.0349	458.1	4.5
6	30.0	30.0	30.0	0.0300	618.1	6.1
<b>Average</b>	34.4	33.8	34.1	0.0341	488.9	4.8
<b>Std. dev.</b>	3.0	2.9	2.9	0.0029	86.9	0.9

Table A-6.2. ZRO2.

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		22		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	25.0	25.7	25.4	0.0254	865.7	8.5
2	28.6	28.2	28.4	0.0284	689.7	6.8
3	24.2	23.4	23.8	0.0238	982.1	9.6
4	23.8	23.4	23.6	0.0236	998.9	9.8
5	22.3	23.2	22.8	0.0228	1074.9	10.5
6	28.3	28.9	28.6	0.0286	680.1	6.7
<b>Average</b>	25.4	25.5	25.4	0.0254	881.9	8.6
<b>Std. dev.</b>	2.5	2.6	2.5	0.0025	166.7	1.6
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		200		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	26.2	26.3	26.3	0.0263	807.4	7.9
2	25.5	25.5	25.5	0.0255	855.5	8.4
3	26.1	26.1	26.1	0.0261	816.7	8.0
4	26.4	25.7	26.1	0.0261	819.8	8.0
5	27.8	27.8	27.8	0.0278	719.8	7.1
6	25.3	25.0	25.2	0.0252	879.5	8.6
<b>Average</b>	26.2	26.1	26.1	0.0261	816.5	8.0
<b>Std. dev.</b>	0.9	1.0	0.9	0.0009	54.7	0.5
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		300		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	27.6	27.3	27.5	0.0275	738.3	7.2
2	27.1	27.1	27.1	0.0271	757.5	7.4
3	28.1	28.1	28.1	0.0281	704.6	6.9
4	28.1	27.6	27.9	0.0279	717.3	7.0
5	27.9	27.9	27.9	0.0279	714.7	7.0
<b>Average</b>	27.8	27.6	27.7	0.0277	726.5	7.1
<b>Std. dev.</b>	0.4	0.4	0.4	0.0004	21.3	0.2
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		400		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	31.9	31.3	31.6	0.0316	557.1	5.5
2	31.9	31.9	31.9	0.0319	546.7	5.4
3	32.1	32.1	32.1	0.0321	539.9	5.3
4	31.1	31.1	31.1	0.0311	575.2	5.6
5	31.6	31.1	31.4	0.0314	566.0	5.6
<b>Average</b>	31.7	31.5	31.6	0.0316	557.0	5.5
<b>Std. dev.</b>	0.4	0.5	0.4	0.0004	14.2	0.1

Table A-6.2. ZRO2 (continued).

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		500		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	34.2	34.2	34.2	0.0342	475.6	4.7
2	33.8	33.8	33.8	0.0338	487.0	4.8
3	34.1	34.1	34.1	0.0341	478.4	4.7
4	35.7	35.7	35.7	0.0357	436.5	4.3
5	34.7	33.5	34.1	0.0341	478.4	4.7
6	34.3	34.3	34.3	0.0343	472.9	4.6
<b>Average</b>	34.5	34.3	34.4	0.0344	471.5	4.6
<b>Std. dev.</b>	0.7	0.8	0.7	0.0007	17.8	0.2
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		600		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	37.4	37.4	37.4	0.0374	397.7	3.9
2	36.2	36.2	36.2	0.0362	424.5	4.2
3	36.5	36.9	36.7	0.0367	413.0	4.1
4	39.6	39.2	39.4	0.0394	358.4	3.5
5	36.0	37.2	36.6	0.0366	415.3	4.1
<b>Average</b>	37.1	37.4	37.3	0.0373	401.8	3.9
<b>Std. dev.</b>	1.5	1.1	1.3	0.0013	26.1	0.3
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		700		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	40.0	39.7	39.9	0.0399	350.3	3.4
2	40.1	39.9	40.0	0.0400	347.7	3.4
3	38.9	38.9	38.9	0.0389	367.6	3.6
4	38.0	38.9	38.5	0.0385	376.3	3.7
5	38.7	37.9	38.3	0.0383	379.3	3.7
<b>Average</b>	39.1	39.1	39.1	0.0391	364.2	3.6
<b>Std. dev.</b>	0.9	0.8	0.8	0.0008	14.6	0.1
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	46.6	48.7	47.7	0.0477	245.0	2.4
2	42.0	41.0	41.5	0.0415	323.0	3.2
3	43.0	42.5	42.8	0.0428	304.4	3.0
4	42.0	41.6	41.8	0.0418	318.4	3.1
5	42.4	42.2	42.3	0.0423	310.9	3.0
6	44.1	43.5	43.8	0.0438	290.0	2.8
7	41.8	41.8	41.8	0.0418	318.4	3.1
<b>Average</b>	43.1	43.0	43.1	0.0431	301.4	3.0
<b>Std. dev.</b>	1.7	2.6	2.2	0.0022	27.2	0.3

Table A-6.3. SCEH.

	gf	N		Temp (°C)		
Load =	300	2.9421		22		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	14.5	14.1	14.3	0.0143	2720.5	26.7
2	14.1	14.2	14.2	0.0142	2778.5	27.2
3	14.3	14.1	14.2	0.0142	2759.0	27.1
4	14.2	14.0	14.1	0.0141	2798.2	27.4
5	14.1	14.4	14.3	0.0143	2739.6	26.9
Average	14.2	14.2	14.2	0.0142	2759.2	27.1
Std. dev.	0.2	0.2	0.1	0.0001	30.7	0.3
	gf	N		Temp (°C)		
Load =	300	2.9421		200		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	14.7	14.8	14.8	0.0148	2557.1	25.1
2	14.9	15.1	15.0	0.0150	2472.5	24.2
3	15.4	14.6	15.0	0.0150	2472.5	24.2
4	14.6	14.6	14.6	0.0146	2609.9	25.6
5	14.8	14.7	14.8	0.0148	2557.1	25.1
Average	14.9	14.8	14.8	0.0148	2533.8	24.8
Std. dev.	0.3	0.2	0.2	0.0002	59.9	0.6
	gf	N		Temp (°C)		
Load =	300	2.9421		400		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	17.3	16.6	17.0	0.0170	1936.4	19.0
2	16.8	16.6	16.7	0.0167	1994.8	19.6
3	16.9	17.0	17.0	0.0170	1936.4	19.0
4	16.9	16.9	16.9	0.0169	1947.8	19.1
5	17.0	17.1	17.1	0.0171	1913.7	18.8
Average	17.0	16.8	16.9	0.0169	1945.8	19.1
Std. dev.	0.2	0.2	0.1	0.0001	30.0	0.3
	gf	N		Temp (°C)		
Load =	300	2.9421		600		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	18.4	18.7	18.6	0.0186	1616.7	15.9
2	18.6	18.9	18.8	0.0188	1582.4	15.5
3	18.8	19.2	19.0	0.0190	1541.1	15.1
4	18.7	18.8	18.8	0.0188	1582.4	15.5
5	18.7	18.9	18.8	0.0188	1574.0	15.4
Average	18.6	18.9	18.8	0.0188	1579.3	15.5
Std. dev.	0.2	0.2	0.2	0.0002	27.0	0.3

Table A-6.3. SCEH (continued).

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	22.1	22.2	22.2	0.0222	1133.9	11.1
2	21.9	21.7	21.8	0.0218	1170.6	11.5
3	21.6	21.5	21.6	0.0216	1197.9	11.7
4	21.7	21.9	21.8	0.0218	1170.6	11.5
5	22.2	22.5	22.4	0.0224	1113.7	10.9
<b>Average</b>	21.9	22.0	21.9	0.0219	1157.4	11.4
<b>Std. dev.</b>	0.3	0.4	0.3	0.0003	33.4	0.3

Table A-6.4. SCLH.

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		22		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	16.4	16.1	16.3	0.0163	2106.8	20.7
2	16.2	16.0	16.1	0.0161	2146.2	21.0
3	16.2	16.2	16.2	0.0162	2119.8	20.8
4	16.0	16.1	16.1	0.0161	2159.6	21.2
5	16.4	16.5	16.5	0.0165	2055.9	20.2
<b>Average</b>	16.2	16.2	16.2	0.0162	2117.6	20.8
<b>Std. dev.</b>	0.2	0.2	0.2	0.0002	40.4	0.4
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		200		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	18.5	17.8	18.2	0.0182	1688.8	16.6
2	18.3	18.0	18.2	0.0182	1688.8	16.6
3	18.1	18.4	18.3	0.0183	1670.3	16.4
4	18.4	18.0	18.2	0.0182	1679.5	16.5
5	18.1	17.8	18.0	0.0180	1726.6	16.9
<b>Average</b>	18.3	18.0	18.1	0.0181	1690.8	16.6
<b>Std. dev.</b>	0.2	0.2	0.1	0.0001	21.4	0.2
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		400		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	19.1	19.5	19.3	0.0193	1493.5	14.6
2	19.5	20.0	19.8	0.0198	1426.2	14.0
3	20.2	20.0	20.1	0.0201	1377.0	13.5
4	19.7	20.0	19.9	0.0199	1411.9	13.8
5	19.7	19.6	19.7	0.0197	1440.8	14.1
<b>Average</b>	19.6	19.8	19.7	0.0197	1429.9	14.0
<b>Std. dev.</b>	0.4	0.2	0.3	0.0003	42.7	0.4
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		600		
<b>Indent #</b>	<b>d1 (<math>\mu\text{m}</math>)</b>	<b>d2 (<math>\mu\text{m}</math>)</b>	<b>Ave d (<math>\mu\text{m}</math>)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	22.1	21.3	21.7	0.0217	1181.4	11.6
2	21.1	21.3	21.2	0.0212	1237.8	12.1
3	21.5	21.3	21.4	0.0214	1214.8	11.9
4	21.1	21.1	21.1	0.0211	1249.6	12.3
5	21.4	21.4	21.4	0.0214	1214.8	11.9
<b>Average</b>	21.4	21.3	21.4	0.0214	1219.7	12.0
<b>Std. dev.</b>	0.4	0.1	0.2	0.0002	26.1	0.3

Table A-6.4. SCLH (continued).

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (μm)</b>	<b>d2 (μm)</b>	<b>Ave d (μm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	24.2	23.8	24.0	0.0240	965.8	9.5
2	23.4	23.5	23.5	0.0235	1011.7	9.9
3	23.2	23.3	23.3	0.0233	1029.2	10.1
4	23.4	23.5	23.5	0.0235	1011.7	9.9
5	24.1	24.2	24.2	0.0242	953.9	9.4
<b>Average</b>	23.7	23.7	23.7	0.0237	994.4	9.8
<b>Std. dev.</b>	0.5	0.4	0.4	0.0004	32.6	0.3

Table A-6.5. SC46.

	gf	N		Temp (°C)		
Load =	300	2.9421		22		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	15.2	16.7	16.0	0.0160	2186.8	21.4
2	14.7	14.7	14.7	0.0147	2574.5	25.2
3	17.5	17.1	17.3	0.0173	1858.8	18.2
4	17.4	18.2	17.8	0.0178	1755.8	17.2
5	15.2	16.5	15.9	0.0159	2214.5	21.7
6	16.4	16.5	16.5	0.0165	2055.9	20.2
Average	16.1	16.6	16.3	0.0163	2107.7	20.7
Std. dev.	1.2	1.1	1.1	0.0011	291.2	2.9
	gf	N		Temp (°C)		
Load =	300	2.9421		200		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	17.4	18.0	17.7	0.0177	1775.7	17.4
2	16.5	16.7	16.6	0.0166	2018.9	19.8
3	17.0	18.3	17.7	0.0177	1785.8	17.5
4	18.1	18.1	18.1	0.0181	1698.1	16.7
5	16.6	17.5	17.1	0.0171	1913.7	18.8
6	17.7	17.7	17.7	0.0177	1775.7	17.4
Average	17.2	17.7	17.5	0.0175	1828.0	17.9
Std. dev.	0.6	0.6	0.5	0.0005	116.5	1.1
	gf	N		Temp (°C)		
Load =	300	2.9421		300		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	16.4	17.1	16.8	0.0168	1982.9	19.4
2	17.6	16.7	17.2	0.0172	1891.5	18.5
3	17.7	16.6	17.2	0.0172	1891.5	18.5
4	18.8	18.2	18.5	0.0185	1625.5	15.9
5	17.3	16.5	16.9	0.0169	1947.8	19.1
6	17.2	17.6	17.4	0.0174	1837.5	18.0
Average	17.5	17.1	17.3	0.0173	1862.8	18.3
Std. dev.	0.8	0.7	0.6	0.0006	126.7	1.2

Table A-6.5. SC46 (continued).

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		400		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	17.9	17.9	17.9	0.0179	1736.3	17.0
2	19.0	19.0	19.0	0.0190	1541.1	15.1
3	17.9	17.9	17.9	0.0179	1736.3	17.0
4	17.9	17.9	17.9	0.0179	1736.3	17.0
5	17.2	17.2	17.2	0.0172	1880.5	18.4
<b>Average</b>	18.0	18.0	18.0	0.0180	1726.1	16.9
<b>Std. dev.</b>	0.6	0.6	0.6	0.0006	120.8	1.2
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		500		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	17.9	18.3	18.1	0.0181	1698.1	16.7
2	18.2	20.0	19.1	0.0191	1525.0	15.0
3	19.3	18.5	18.9	0.0189	1557.4	15.3
4	20.5	20.5	20.5	0.0205	1323.8	13.0
5	18.5	18.5	18.5	0.0185	1625.5	15.9
6	18.5	20.6	19.6	0.0196	1455.6	14.3
<b>Average</b>	18.8	19.4	19.1	0.0191	1530.9	15.0
<b>Std. dev.</b>	0.9	1.1	0.8	0.0008	131.3	1.3
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		600		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	20.2	20.2	20.2	0.0202	1363.4	13.4
2	20.6	21.9	21.3	0.0213	1232.0	12.1
3	21.0	21.0	21.0	0.0210	1261.5	12.4
4	21.3	21.5	21.4	0.0214	1214.8	11.9
5	22.8	23.6	23.2	0.0232	1033.6	10.1
6	20.2	19.7	20.0	0.0200	1397.8	13.7
<b>Average</b>	21.0	21.3	21.2	0.0212	1250.5	12.3
<b>Std. dev.</b>	1.0	1.4	1.2	0.0012	129.0	1.3

Table A-6.5. SC46 (continued).

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		700		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	23.5	23.5	23.5	0.0235	1007.4	9.9
2	25.9	25.2	25.6	0.0256	852.2	8.4
3	21.7	21.2	21.5	0.0215	1209.1	11.9
4	21.4	21.4	21.4	0.0214	1214.8	11.9
5	24.4	24.4	24.4	0.0244	934.4	9.2
6	20.7	19.8	20.3	0.0203	1356.7	13.3
<b>Average</b>	22.9	22.6	22.8	0.0228	1095.8	10.7
<b>Std. dev.</b>	2.0	2.1	2.0	0.0020	194.0	1.9
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	23.2	23.2	23.2	0.0232	1033.6	10.1
2	23.9	23.1	23.5	0.0235	1007.4	9.9
3	23.6	23.6	23.6	0.0236	998.9	9.8
4	25.4	23.1	24.3	0.0243	946.0	9.3
5	23.1	23.1	23.1	0.0231	1042.6	10.2
6	22.9	25.2	24.1	0.0241	961.8	9.4
<b>Average</b>	23.7	23.6	23.6	0.0236	998.4	9.8
<b>Std. dev.</b>	0.9	0.8	0.5	0.0005	38.3	0.4

Table A-6.6. SN47; September 2002.

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		22		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	19.0	18.5	18.8	0.0188	1582.4	15.5
2	19.7	18.8	19.3	0.0193	1501.3	14.7
3	18.8	18.5	18.7	0.0187	1599.4	15.7
4	18.6	18.2	18.4	0.0184	1643.2	16.1
5	18.4	18.4	18.4	0.0184	1643.2	16.1
6	18.6	18.2	18.4	0.0184	1643.2	16.1
<b>Average</b>	18.9	18.4	18.6	0.0186	1602.1	15.7
<b>Std. dev.</b>	0.5	0.2	0.3	0.0003	55.9	0.5
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		200		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	20.6	20.3	20.5	0.0205	1330.3	13.0
2	20.0	20.0	20.0	0.0200	1390.8	13.6
3	20.3	19.4	19.9	0.0199	1411.9	13.8
4	19.9	19.6	19.8	0.0198	1426.2	14.0
5	20.1	19.3	19.7	0.0197	1433.5	14.1
6	19.5	19.5	19.5	0.0195	1463.0	14.3
<b>Average</b>	20.1	19.7	19.9	0.0199	1409.3	13.8
<b>Std. dev.</b>	0.4	0.4	0.3	0.0003	45.5	0.4
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		300		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	20.6	20.1	20.4	0.0204	1343.4	13.2
2	20.1	19.5	19.8	0.0198	1419.0	13.9
3	20.2	19.6	19.9	0.0199	1404.8	13.8
4	20.7	20.1	20.4	0.0204	1336.8	13.1
5	22.0	21.0	21.5	0.0215	1203.5	11.8
6	21.7	21.7	21.7	0.0217	1181.4	11.6
<b>Average</b>	20.9	20.3	20.6	0.0206	1314.8	12.9
<b>Std. dev.</b>	0.8	0.9	0.8	0.0008	100.4	1.0

Table A-6.6. SN47; September 2002 (continued).

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		400		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	21.7	21.4	21.6	0.0216	1197.9	11.7
2	21.8	21.6	21.7	0.0217	1181.4	11.6
3	21.3	20.2	20.8	0.0208	1292.1	12.7
4	21.5	21.5	21.5	0.0215	1203.5	11.8
5	22.1	21.5	21.8	0.0218	1170.6	11.5
6	22.1	21.3	21.7	0.0217	1181.4	11.6
<b>Average</b>	21.8	21.3	21.5	0.0215	1204.5	11.8
<b>Std. dev.</b>	0.3	0.5	0.4	0.0004	44.6	0.4
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		500		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	22.0	21.2	21.6	0.0216	1192.4	11.7
2	21.6	21.0	21.3	0.0213	1226.2	12.0
3	21.0	21.0	21.0	0.0210	1261.5	12.4
4	21.8	20.7	21.3	0.0213	1232.0	12.1
5	21.5	21.2	21.4	0.0214	1220.5	12.0
6	21.8	20.8	21.3	0.0213	1226.2	12.0
<b>Average</b>	21.6	21.0	21.3	0.0213	1226.5	12.0
<b>Std. dev.</b>	0.3	0.2	0.2	0.0002	22.2	0.2
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		600		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	21.6	21.2	21.4	0.0214	1214.8	11.9
2	23.2	22.4	22.8	0.0228	1070.2	10.5
3	23.4	22.2	22.8	0.0228	1070.2	10.5
4	23.0	22.5	22.8	0.0228	1074.9	10.5
5	23.1	21.5	22.3	0.0223	1118.7	11.0
<b>Average</b>	22.9	22.0	22.4	0.0224	1109.7	10.9
<b>Std. dev.</b>	0.7	0.6	0.6	0.0006	62.2	0.6
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		700		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	22.5	22.0	22.3	0.0223	1123.7	11.0
2	23.7	22.1	22.9	0.0229	1060.8	10.4
3	22.7	21.7	22.2	0.0222	1128.8	11.1
4	22.9	22.5	22.7	0.0227	1079.6	10.6
5	23.7	21.9	22.8	0.0228	1070.2	10.5
<b>Average</b>	23.1	22.0	22.6	0.0226	1092.6	10.7
<b>Std. dev.</b>	0.6	0.3	0.3	0.0003	31.5	0.3

Table A-6.6. SN47; September 2002 (continued).

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	23.0	23.0	23.0	0.0230	1051.6	10.3
2	22.8	22.8	22.8	0.0228	1070.2	10.5
3	23.0	23.0	23.0	0.0230	1051.6	10.3
4	22.4	21.9	22.2	0.0222	1133.9	11.1
5	23.0	22.5	22.8	0.0228	1074.9	10.5
<b>Average</b>	22.8	22.6	22.7	0.0227	1076.5	10.6
<b>Std. dev.</b>	0.3	0.5	0.3	0.0003	33.8	0.3

Table A-6.7. SN47; February 2004.

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		22	Leco	
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	19.4	19.1	19.3	0.0193	1501.3	14.7
2	18.8	19.1	19.0	0.0190	1549.2	15.2
3	19.2	19.4	19.3	0.0193	1493.5	14.6
4	19.2	19.0	19.1	0.0191	1525.0	15.0
5	19.1	19.1	19.1	0.0191	1525.0	15.0
<b>Average</b>	19.1	19.1	19.1	0.0191	1518.8	14.9
<b>Std. dev.</b>	0.2	0.2	0.1	0.0001	22.1	0.2
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		22	Nikon	
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	19.6	18.9	19.3	0.0193	1501.3	14.7
2	19.0	19.3	19.2	0.0192	1517.0	14.9
3	19.0	19.6	19.3	0.0193	1493.5	14.6
4	19.3	19.3	19.3	0.0193	1493.5	14.6
5	19.3	19.1	19.2	0.0192	1509.1	14.8
<b>Average</b>	19.2	19.2	19.2	0.0192	1502.9	14.7
<b>Std. dev.</b>	0.3	0.3	0.1	0.0001	10.2	0.1
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		200		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	20.3	20.1	20.2	0.0202	1363.4	13.4
2	20.4	20.2	20.3	0.0203	1350.0	13.2
3	20.4	20.4	20.4	0.0204	1336.8	13.1
4	20.1	20.2	20.2	0.0202	1370.2	13.4
5	20.3	20.3	20.3	0.0203	1350.0	13.2
<b>Average</b>	20.3	20.2	20.3	0.0203	1354.1	13.3
<b>Std. dev.</b>	0.1	0.1	0.1	0.0001	13.0	0.1
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		400		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	20.8	20.9	20.9	0.0209	1279.7	12.6
2	21.1	21.2	21.2	0.0212	1243.7	12.2
3	21.3	20.6	21.0	0.0210	1267.5	12.4
4	20.7	20.8	20.8	0.0208	1292.1	12.7
5	21.0	20.3	20.7	0.0207	1304.6	12.8
<b>Average</b>	21.0	20.8	20.9	0.0209	1277.5	12.5
<b>Std. dev.</b>	0.2	0.3	0.2	0.0002	23.4	0.2

Table A-6.7. SN47; February 2004 (continued).

	gf	N		Temp (°C)		
Load =	300	2.9421		600		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	21.7	21.8	21.8	0.0218	1176.0	11.5
2	22.1	22.3	22.2	0.0222	1128.8	11.1
3	22.1	22.3	22.2	0.0222	1128.8	11.1
4	22.0	21.8	21.9	0.0219	1159.9	11.4
5	21.5	21.5	21.5	0.0215	1203.5	11.8
<b>Average</b>	21.9	21.9	21.9	0.0219	1159.4	11.4
<b>Std. dev.</b>	0.3	0.4	0.3	0.0003	32.0	0.3
	gf	N		Temp (°C)		
Load =	300	2.9421		800		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	22.1	22.4	22.3	0.0223	1123.7	11.0
2	22.9	23.1	23.0	0.0230	1051.6	10.3
3	22.9	22.6	22.8	0.0228	1074.9	10.5
4	22.9	22.5	22.7	0.0227	1079.6	10.6
5	22.3	22.6	22.5	0.0225	1103.8	10.8
<b>Average</b>	22.6	22.6	22.6	0.0226	1086.7	10.7
<b>Std. dev.</b>	0.4	0.3	0.3	0.0003	27.8	0.3
	gf	N		Temp (°C)		
Load =	300	2.9421		1000		
Indent #	d1 ( $\mu\text{m}$ )	d2 ( $\mu\text{m}$ )	Ave d ( $\mu\text{m}$ )	Ave d (mm)	HV	HV (GPa)
1	25.2	25.0	25.1	0.0251	883.0	8.7
2	24.8	25.0	24.9	0.0249	897.3	8.8
3	24.9	24.7	24.8	0.0248	904.5	8.9
4	24.5	24.6	24.6	0.0246	923.0	9.1
5	24.5	24.7	24.6	0.0246	919.3	9.0
<b>Average</b>	24.8	24.8	24.8	0.0248	905.4	8.9
<b>Std. dev.</b>	0.3	0.2	0.2	0.0002	16.4	0.2

Table A-6.8. STK4; September 2002.

	gf	N		Temp (°C)		
Load =	300	2.9421		22		
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	16.3	16.4	16.4	0.0164	2081.1	20.4
2	16.1	16.3	16.2	0.0162	2119.8	20.8
3	16.3	15.9	16.1	0.0161	2146.2	21.0
4	16.6	16.4	16.5	0.0165	2043.4	20.0
5	16.3	16.3	16.3	0.0163	2093.9	20.5
Average	16.3	16.3	16.3	0.0163	2096.9	20.6
Std. dev.	0.2	0.2	0.2	0.0002	39.0	0.4
	gf	N		Temp (°C)		
Load =	300	2.9421		200		
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	16.7	16.9	16.4	0.0164	2081.1	20.4
2	17.0	17.1	16.2	0.0162	2119.8	20.8
3	16.9	17.0	16.1	0.0161	2146.2	21.0
4	16.9	17.1	16.5	0.0165	2043.4	20.0
5	17.0	16.8	16.3	0.0163	2093.9	20.5
Average	16.3	16.3	16.3	0.0163	2096.9	20.6
Std. dev.	0.2	0.2	0.2	0.0002	39.0	0.4
	gf	N		Temp (°C)		
Load =	300	2.9421		400		
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	18.2	18.1	16.8	0.0168	1971.1	19.3
2	17.9	17.9	17.1	0.0171	1913.7	18.8
3	18.1	18.2	17.0	0.0170	1936.4	19.0
4	18.3	18.4	17.0	0.0170	1925.0	18.9
5	18.2	18.1	16.9	0.0169	1947.8	19.1
Average	16.9	17.0	16.9	0.0169	1938.8	19.0
Std. dev.	0.1	0.1	0.1	0.0001	22.1	0.2
	gf	N		Temp (°C)		
Load =	300	2.9421		600		
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	18.9	19.2	19.1	0.0191	1533.0	15.0
2	19.3	19.0	19.2	0.0192	1517.0	14.9
3	18.7	18.6	18.7	0.0187	1599.4	15.7
4	19.0	19.2	19.1	0.0191	1525.0	15.0
5	18.8	18.7	18.8	0.0188	1582.4	15.5
Average	18.9	18.9	18.9	0.0189	1551.4	15.2
Std. dev.	0.2	0.3	0.2	0.0002	37.1	0.4

Table A-6.8. STK4; September 2002 (continued).

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (μm)</b>	<b>d2 (μm)</b>	<b>Ave d (μm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	19.8	19.3	19.6	0.0196	1455.6	14.3
2	19.2	19.3	19.3	0.0193	1501.3	14.7
3	19.0	19.4	19.2	0.0192	1509.1	14.8
4	19.2	19.0	19.1	0.0191	1525.0	15.0
5	19.3	19.2	19.3	0.0193	1501.3	14.7
<b>Average</b>	19.3	19.2	19.3	0.0193	1498.4	14.7
<b>Std. dev.</b>	0.3	0.2	0.2	0.0002	25.8	0.3

Table A-6.9. STK4; February 2004.

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		22	Leco	
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	16.8	16.9	16.9	0.0169	1959.4	19.2
2	16.4	16.8	16.6	0.0166	2018.9	19.8
3	16.9	16.9	16.9	0.0169	1947.8	19.1
4	17.1	16.7	16.9	0.0169	1947.8	19.1
5	16.9	16.9	16.9	0.0169	1947.8	19.1
<b>Average</b>	16.8	16.8	16.8	0.0168	1964.4	19.3
<b>Std. dev.</b>	0.3	0.1	0.1	0.0001	30.9	0.3
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		22	Nikon	
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	16.5	16.5	16.5	0.0165	2043.4	20.0
2	16.7	16.4	16.6	0.0166	2031.1	19.9
3	17.4	16.4	16.9	0.0169	1947.8	19.1
4	16.6	16.1	16.4	0.0164	2081.1	20.4
5	16.7	16.5	16.6	0.0166	2018.9	19.8
<b>Average</b>	16.8	16.4	16.6	0.0166	2024.5	19.9
<b>Std. dev.</b>	0.4	0.2	0.2	0.0002	48.8	0.5
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		200		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	17.5	17.3	17.4	0.0174	1837.5	18.0
2	17.3	17.0	17.2	0.0172	1891.5	18.5
3	18.1	17.8	18.0	0.0180	1726.6	16.9
4	17.6	17.1	17.4	0.0174	1848.1	18.1
5	17.5	17.3	17.4	0.0174	1837.5	18.0
6	17.7	17.1	17.4	0.0174	1837.5	18.0
<b>Average</b>	17.6	17.3	17.4	0.0174	1829.8	17.9
<b>Std. dev.</b>	0.3	0.3	0.3	0.0003	54.7	0.5
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		400		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	18.8	18.0	18.4	0.0184	1643.2	16.1
2	18.2	18.4	18.3	0.0183	1661.2	16.3
3	18.7	18.7	18.7	0.0187	1590.9	15.6
4	18.2	18.4	18.3	0.0183	1661.2	16.3
5	19.1	18.7	18.9	0.0189	1557.4	15.3
6	18.6	18.7	18.7	0.0187	1599.4	15.7
<b>Average</b>	18.6	18.5	18.5	0.0185	1618.9	15.9
<b>Std. dev.</b>	0.4	0.3	0.2	0.0002	42.7	0.4

Table A-6.9. STK4; February 2004 (continued).

	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		600		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	19.1	18.8	19.0	0.0190	1549.2	15.2
2	19.7	19.0	19.4	0.0194	1485.8	14.6
3	19.2	18.5	18.9	0.0189	1565.7	15.4
4	19.7	19.3	19.5	0.0195	1463.0	14.3
5	19.5	18.8	19.2	0.0192	1517.0	14.9
6	19.6	19.6	19.6	0.0196	1448.1	14.2
<b>Average</b>	19.5	19.0	19.2	0.0192	1504.8	14.8
<b>Std. dev.</b>	0.3	0.4	0.3	0.0003	47.2	0.5
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	19.9	19.6	19.8	0.0198	1426.2	14.0
2	20.4	19.7	20.1	0.0201	1383.9	13.6
3	20.1	19.6	19.9	0.0199	1411.9	13.8
4	19.8	20.1	20.0	0.0200	1397.8	13.7
5	20.2	19.9	20.1	0.0201	1383.9	13.6
6	20.2	19.8	20.0	0.0200	1390.8	13.6
<b>Average</b>	20.1	19.8	19.9	0.0199	1400.7	13.7
<b>Std. dev.</b>	0.2	0.2	0.1	0.0001	18.4	0.2
	gf	N		Temp (°C)		
<b>Load =</b>	300	2.9421		1000		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	21.2	20.4	20.8	0.0208	1285.9	12.6
2	20.9	20.6	20.8	0.0208	1292.1	12.7
3	21.2	20.6	20.9	0.0209	1273.6	12.5
4	20.9	20.6	20.8	0.0208	1292.1	12.7
5	21.0	21.0	21.0	0.0210	1261.5	12.4
<b>Average</b>	21.0	20.6	20.8	0.0208	1281.0	12.6
<b>Std. dev.</b>	0.2	0.2	0.1	0.0001	13.3	0.1

Table A-6.10. SN5P; February 2004.

	gf	N		Temp (°C)		
Load =	300	2.9421		22	Leco	
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	20.1	19.6	19.9	0.0199	1411.9	13.8
2	20.3	20.3	20.3	0.0203	1350.0	13.2
3	19.7	19.6	19.7	0.0197	1440.8	14.1
4	19.3	19.3	19.3	0.0193	1493.5	14.6
5	20.4	20.4	20.4	0.0204	1336.8	13.1
Average	20.0	19.8	19.9	0.0199	1406.6	13.8
Std. dev.	0.5	0.5	0.5	0.0005	64.9	0.6
	gf	N		Temp (°C)		
Load =	300	2.9421		22	Nikon	
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	19.9	19.9	19.9	0.0199	1404.8	13.8
2	20.2	20.2	20.2	0.0202	1363.4	13.4
3	20.6	20.4	20.5	0.0205	1323.8	13.0
4	20.1	19.6	19.9	0.0199	1411.9	13.8
5	20.0	19.4	19.7	0.0197	1433.5	14.1
Average	20.2	19.9	20.0	0.0200	1387.5	13.6
Std. dev.	0.3	0.4	0.3	0.0003	43.7	0.4
	gf	N		Temp (°C)		
Load =	300	2.9421		200		
Indent #	d1 (µm)	d2 (µm)	Ave d (µm)	Ave d (mm)	HV	HV (GPa)
1	20.0	20.1	20.1	0.0201	1383.9	13.6
2	20.5	20.6	20.6	0.0206	1317.3	12.9
3	21.4	20.8	21.1	0.0211	1249.6	12.3
4	20.7	21.2	21.0	0.0210	1267.5	12.4
5	21.0	20.6	20.8	0.0208	1285.9	12.6
6	21.1	21.3	21.2	0.0212	1237.8	12.1
7	21.8	21.8	21.8	0.0218	1170.6	11.5
8	21.4	21.4	21.4	0.0214	1214.8	11.9
9	20.9	20.9	20.9	0.0209	1273.6	12.5
10	20.6	21.5	21.1	0.0211	1255.5	12.3
Average	20.9	21.0	21.0	0.0210	1265.6	12.4
Std. dev.	0.5	0.5	0.5	0.0005	57.6	0.6

Table A-6.10. SN5P; February 2004 (continued).

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		400		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	21.1	21.6	21.4	0.0214	1220.5	12.0
2	21.6	21.3	21.5	0.0215	1209.1	11.9
3	21.5	22.0	21.8	0.0218	1176.0	11.5
4	21.7	21.8	21.8	0.0218	1176.0	11.5
5	22.2	22.2	22.2	0.0222	1128.8	11.1
<b>Average</b>	21.6	21.8	21.7	0.0217	1182.1	11.6
<b>Std. dev.</b>	0.4	0.3	0.3	0.0003	35.8	0.4
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		600		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	23.4	23.4	23.4	0.0234	1016.0	10.0
2	23.5	24.3	23.9	0.0239	973.9	9.6
3	22.7	24.3	23.5	0.0235	1007.4	9.9
4	23.6	23.4	23.5	0.0235	1007.4	9.9
5	22.3	23.3	22.8	0.0228	1070.2	10.5
<b>Average</b>	23.1	23.7	23.4	0.0234	1015.0	10.0
<b>Std. dev.</b>	0.6	0.5	0.4	0.0004	34.8	0.3
	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		800		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	24.6	25.0	24.8	0.0248	904.5	8.9
2	24.9	25.3	25.1	0.0251	883.0	8.7
3	25.3	25.4	25.4	0.0254	865.7	8.5
4	23.4	23.9	23.7	0.0237	994.6	9.8
5	24.0	24.2	24.1	0.0241	957.8	9.4
<b>Average</b>	24.4	24.8	24.6	0.0246	921.1	9.0
<b>Std. dev.</b>	0.8	0.7	0.7	0.0007	53.7	0.5

Table A-6.10. SN5P; February 2004 (continued).

	<b>gf</b>	<b>N</b>		<b>Temp (°C)</b>		
<b>Load =</b>	300	2.9421		1000		
<b>Indent #</b>	<b>d1 (µm)</b>	<b>d2 (µm)</b>	<b>Ave d (µm)</b>	<b>Ave d (mm)</b>	<b>HV</b>	<b>HV (GPa)</b>
1	26.5	25.9	26.2	0.0262	810.4	7.9
2	27.0	25.9	26.5	0.0265	795.2	7.8
3	26.8	26.0	26.4	0.0264	798.2	7.8
4	26.1	25.8	26.0	0.0260	826.1	8.1
5	25.5	26.6	26.1	0.0261	819.8	8.0
<b>Average</b>	26.4	26.0	26.2	0.0262	810.0	7.9
<b>Std. dev.</b>	0.6	0.3	0.2	0.0002	13.4	0.1

## Appendix B. Thermal Properties

Table B-1. Thermal conductivity and heat capacity data between room temperature and 1000 °C.

Sample	Thickness (mm)	r @ 25 °C (g/cm <sup>3</sup> )	Temperature (°C)	Specific Heat (c <sub>p</sub> ) (J/g-K)	Diffusivity (a) (cm <sup>2</sup> /s)	Conductivity (l) (W/m-K)
ALOX	2.01	3.88	25	0.788	0.103	31.4
	2.01	3.87	150	0.984	0.0548	20.9
	2.01	3.86	300	1.12	0.0352	15.2
	2.02	3.83	600	1.22	0.0218	10.2
	2.03	3.79	1000	1.30	0.0147	7.20
ZR02	2.03	6.11	25	0.462	0.0111	3.13
	2.04	6.09	150	0.529	0.00889	2.87
	2.04	6.06	300	0.566	0.00777	2.66
	2.05	5.99	600	0.607	0.00648	2.36
	2.06	5.91	1000	0.640	0.00585	2.21
SCEH	2.11	3.16	25	0.719	0.748	170
	2.11	3.15	150	0.904	0.456	130
	2.11	3.15	300	1.05	0.300	98.9
	2.11	3.13	600	1.18	0.179	66.1
	2.12	3.11	1000	1.25	0.116	45.2
SCLH	2.11	3.09	25	0.733	0.3298	74.6
	2.11	3.08	150	0.915	0.2378	67.1
	2.11	3.08	300	1.05	0.1812	58.6
	2.11	3.06	600	1.18	0.1225	44.4
	2.12	3.04	1000	1.27	0.0861	33.2
SC46	2.03	3.10	25	0.696	0.463	99.9
	2.03	3.10	150	0.902	0.296	82.8
	2.04	3.09	300	1.05	0.220	71.4
	2.04	3.08	600	1.18	0.138	50.3
	2.04	3.06	1000	1.28	0.0951	37.3
SN47	2.03	3.20	25	0.690	0.120	26.5
	2.03	3.20	150	0.887	0.0839	23.8
	2.04	3.19	300	1.03	0.0644	21.3
	2.04	3.18	600	1.17	0.0462	17.2
	2.04	3.17	1000	1.27	0.0350	14.1

Table B-1. Thermal conductivity and heat capacity data between room temperature and 1000 °C (continued).

Sample	Thickness (mm)	r @ 25 °C (g/cm <sup>3</sup> )	Temperature (°C)	Specific Heat (c <sub>p</sub> ) (J/g-K)	Diffusivity (a) (cm <sup>2</sup> /s)	Conductivity (l) (W/m-K)
STK4	2.11	3.36	25	0.736	0.0438	10.8
	2.11	3.36	150	0.916	0.0329	10.1
	2.11	3.35	300	1.05	0.0272	9.61
	2.11	3.34	600	1.17	0.0225	8.81
	2.11	3.33	1000	1.24	0.0205	8.49
	SN5P	2.08	3.24	25	0.695	0.143
	—	—	150	0.863	0.102	28.4
	—	—	300	1.00	0.0770	24.9
	—	—	600	1.14	0.0538	19.9
	—	—	1000	1.25	0.0397	16.1

Table B-2. Instantaneous coefficient of thermal expansion as a function of temperature (units =  $\times 10^{-6}/^{\circ}\text{C} = \text{ppm}/^{\circ}\text{C}$ ).

Temp (°C)	Material							
	ALOX	SCEH	SCLH	SC46	SN47	SN5P	TK4	ZRO2
50	6.0	2.4	2.8	3.0	1.5	1.6	1.5	10.5
100	6.7	2.9	3.4	3.5	1.9	1.9	2.0	11.1
200	7.4	3.4	4.4	4.2	2.4	2.2	2.4	11.2
300	8.0	3.8	4.0	4.6	2.9	2.9	2.7	11.2
400	8.4	5.3	4.7	4.9	3.3	3.2	2.8	12.2
500	8.8	5.5	5.0	5.3	3.4	3.7	3.1	11.9
600	9.0	6.2	5.1	5.3	3.6	3.8	3.1	12.0
700	9.3	5.5	5.6	5.4	3.7	3.9	3.0	12.1
800	9.4	5.3	5.7	5.7	3.6	4.0	3.7	12.1
900	9.6	5.4	5.5	5.8	3.9	4.2	4.2	11.9
1000	9.4	5.6	5.5	5.7	3.5	4.9	4.6	11.9

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