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Metals and Ceramics Division

**CERAMIC TECHNOLOGY PROJECT DATA BASE:
SEPTEMBER 1992 SUMMARY REPORT**

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NOTICE: This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

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ABSTRACT

Data presented in this report represent an intense effort to improve processing methods, testing methods, and general mechanical properties of candidate ceramics for use in advanced heat engines. This work was performed by many facilities and represents only a small part of the data generated by the Ceramic Technology Project (CTP) since 1986. Materials discussed include GTE PY6, GN-10, NT-154, NT-164, SN-260, SN-251, SN-252, AY6, silicon nitride combined with rare-earth oxides, Y-TZP, ZTA, NC-433, NT-230, Hexoloy SA, MgO-PSZ-to-MgO-PSZ joints, MgO-PSZ-to-cast iron, and a few whisker/fiber-reinforced ceramics.

Information in this report was taken from the project's semiannual and bimonthly progress reports and from final reports summarizing the results of individual studies. Test results are presented in tabular form and in graphs. All data, including test rig descriptions and material characterizations, are stored in the CTP data base and are available to all project participants on request.

The objective of this report is to make available the test results from these studies but not to draw conclusions from those data.

1. INTRODUCTION

Corrosion and heat tolerance features of ceramics make them attractive as components in the hostile environments of vehicular heat engines. Yet, conventional ceramics are very brittle and lack the toughness needed for reasonable service life. Participants in the Ceramic Technology Project (CTP) are constantly improving existing materials, altering testing and analytical methods, and developing new materials and methodologies that would make ceramic engines and engine components feasible.

The purpose of this effort is to gather and make available all test results generated within the CTP. Information in this report represents a cross section of that work. A variety of materials are represented, including numerous silicon nitride-based, silicon carbide-based, alumina-based, zirconia-based, and whisker/fiber-reinforced ceramics. Programs generating these data are described briefly as well. Most of the information was extracted from the project's semiannual and bimonthly progress reports, facility data sheets, and technical reports from individual programs. Test results are represented in tabular and graphical forms and include associated details about the test facilities, material characteristics, and compositions, if such information was available.

Tribology studies were excluded due to the amount of detail needed to describe and characterize such data; wear data will be published in the future in a separate report comprised only of tribology information.

Note that file names and field names may not be spelled fully in this document and in the data base. Computer software limits the size of the file name to 8 characters (not including the 3 character file extension) and field names to 10 characters. An effort was made to retain the essence of the descriptive words within the available space.

2. DATA BASE STATUS

The CTP data base presently contains 7446 records on 27 different types of tests, 596 material characterizations, 13 lubricant characterizations, 101 coating characterizations, and 2186 other associated records. A more detailed description may be found in Table 1.

The data base was partially updated during the past year to locate missing information, to express existing values in a standard form, and to include more recent test data. During the life of the data base, test procedures have changed, methods of nomenclature for several fields (BATCH_ID and CLASS_IN, for example) have fluctuated, and missing information was never tracked down. Although a block of time was set aside during Fiscal Year (FY) 1992 to catch up on all those tasks, updating the data base to the desired level required more time than was originally allotted. The cause of this problem arose from lack of a standard format that would adequately provide the user's data needs and from the broad scatter of sources of the associated details on some of the tests. Progress was made on the solution but more time is needed.

Efforts were made to standardize test procedure names within the data base, especially in the area of fracture toughness. Confusion about the differences among controlled flaw, modified controlled flaw, and multiple indentation test methods was cleared by adding definitions to the data base that allow the user to quickly distinguish among the different methods. These definitions are stored in the TESTBKGD file under WBS_STUDY as "GENERAL." Table 2 gives the data base definitions for the fracture toughness methods listed above. Brief descriptions of American Society for Testing and Materials (ASTM) standards for testing procedures for ceramics will be included in the TESTBKGD file as they become available and will be accessible through WBS_STUDY = "ASTM." References to the sources of these standards will be stored in CERSOURC, the bibliographic reference file for the data base.

Composite materials and metals have been removed from the general material characterization file and placed in separate files respectively (COMPOSIT and REINFORC), due to different characterization requirements for each class of material. (Note: Because file names are limited to 8 characters by the operating system, the "E" on the end of both file names was omitted intentionally to comply with the size requirement.) Metals characterizations were segregated into a file of their own (appropriately named METALS) since they normally play a supporting role in ceramic development. Fields were added to COMPOSIT to better identify the reinforcement, and

Table 1. CTP Data Base Summary as of September 30, 1992

Material Class	Braze Specimens							Dynamic Fatigue	Elasticity
	MOR ^a	Shear Str.	Toughness	Torsion	Tor. Fatigue	Creep	Cyclic Fatigue	Density	
Alumina							15	5	28
Alumina + reinforcements								7	
Alumina + Zirconia									
Mullite									2
Mullite + reinforcements									11
Silicon Carbide		12					17	10	23
Silicon Nitride	87	48		15	7	131	36	28	76
Silicon Nitride + reinforcements							15	2	14
Zirconia	241	58	43				51	158	119
Zirconia + reinforcements									
Other				f				4	
Totals	328	118	43	21	7	131	134	214	215

Material Class	Fracture Toughness	Hardness	Interrupted Fatigue	MOR ^a 3-Pt Bend	MOR ^a 4-Pt Bend	Oxidation Rate	Poisson's Ratio	Shear Modulus	Tensile	Stress Rupture
Alumina	39	4			418				15	13
Alumina + reinforcements	39				144				11	
Alumina + Zirconia					7					
Mullite	1			1	4					
Mullite + reinforcements	12			9	20					
Silicon Carbide	30	27			254				81	4
Silicon Nitride	109	112		10	1157	1	2	1	216	63
Silicon Nitride + reinforcements	53				144	3	17	16	50	
Zirconia	377	24	239		1613				16	20
Zirconia + reinforcements					2					
Other	2	39			61					
Totals	662	206	239	20	3824	4	19	17	389	100

^a MOR = modulus of rupture.

Table 1. Continued

Material Class	Thermal Conductivity	Thermal Contraction	Thermal Diffusivity	Thermal Expansion	Thermal Shock	Torsion	X-Ray Diffraction	Material Char.	Chemistry
Alumina	3			1	2			20	14
Alumina + reinforcements	34		18	4	6			102	
Alumina + Zirconia		23		21				7	
Mullite								2	
Mullite + reinforcements								35	
Silicon Carbide				23			17	11	57
Silicon Nitride	23		23	44		3	19	155	7
Silicon Nitride + reinforcements	9		17	14				57	
Zirconia							72	51	44
Zirconia + reinforcements								5	
Other				35		4		36	17
Totals	69	23	58	142	8	7	138	481	139

Material Class	Wear Resistance	Coatings	Lubricants
Alumina-based	9	3	
Alumina + reinforcements	1		
Silicon Carbide	3		
Silicon Nitride	22		
Chromia-based	98	20	
Zirconia-based	13	16	
Enamels	5	10	
Other	126	53	13
Totals	277	102	13
Grand Total(characterization data)			596
Grand Total (test data only)			7466

Table 2. Descriptions of Several Fracture Toughness Tests

Toughness Test Designation	Description
MICROINDENT (Microindentation)	Microindentation method - Several indentations are made on polished specimen surface using a Vickers or Knoop diamond pyramid indenter. Fracture toughness is then calculated using the lengths of the resulting microcracks and the hardness value for the tested material. Reference: G. R. Anstis et al., "A Critical Evaluation of Indentation Techniques for Measuring Fracture Toughness: I, Direct Crack Measurements," <u>J. Am. Ceram. Soc.</u> 64(9), 533-38 (1981).
CONTROLLED FL (Controlled Flaw)	Controlled flaw technique - an MOR bend specimen is indented on a polished tensile surface using a Vickers or Knoop indenter, aligning the pyramid edges with the longitudinal axis of the specimen. The bar is then broken in a 4-point bend fixture. For this method, no crack lengths have to be measured. Fracture strength is relative to indentation load. This method also takes residual stress existence into consideration. Reference: P. Chantikul et al., "A Critical Evaluation of Indentation Techniques for Measuring Fracture Toughness: II, Strength Method," <u>J. Am. Ceram. Soc.</u> 64(9), 539-43 (1981).
MODIFIED CFT (Modified Controlled Flaw)	Like controlled flaw, except more than one indentation is made on the tensile surface of the specimen. The first indentation is made in the center of an MOR bend bar. The other indentations are made within the inner span for a 4-point fixture but far enough away from the center to avoid interaction. The bar is then bend tested. KIC is calculated based on indentation load, applied stress, and a crack-geometry parameter. This method attempts to merge the controlled flaw and the multiple indentation techniques and is useful in assessing toughness in materials suspected of deforming by other than constrained plastic flow. Reference: R. F. Cook and B. R. Lawn, "A Modified Indentation Toughness Technique," <u>J. Am. Ceram. Soc.</u> 66(11), C-200 (1983).
CHEVRON NOTCH	A standard MOR bar specimen is chevron-notched ("V"-notch) in the center of the specimen perpendicular to the long axis, then broken in a 4-point bend fixture.
CHEVRON NOTCH3	A chevron-notched MOR bar is broken in a 3-point bend fixture.
CONTROLLED F3	An MOR bar is indented once with a Vickers or Knoop diamond indenter, then broken in a 3-point bend fixture.

the WHISKERS file was renamed REINFORC, since not all reinforcements are whiskers. More fields were added to REINFORC to characterize and identify more completely the reinforcing material. Tables 3 through 8 list the altered formats for characterization files available in the data base.

Current methods of storing ceramic processing information were found to be difficult to access and somewhat inadequate in content. Past methods included summarizing process descriptions without all the intricate details. A new data base is now being designed to document each step of ceramic fabrication, from raw materials to finished product, and will tie into the test results data base through material name and batch code. Several files (in draft form) are already in place but not yet stocked with data. The new structure consists of seven main files:

1. PROCESS - a master file linking detailed processing information to test results;
2. BASICS - contains the basic list of components used to make a particular ceramic;
3. MIXING - pre-mixing treatments and mixing methods used to make the ceramic;
4. FORMING - a detailed description on how the green form was shaped, for example injection molded or slip cast;
5. DENSIFY - densification method used, described in detail;
6. FINISH - any methods used to complete the ceramic to its finished state, such as polishing, machining, coating, etc.; and
7. HEATREAT - any additional heat treatments the ceramic undergoes after densification.

Field structure within these files is still in development but will be published in a future report. This processing information will apply to an entire batch of a given ceramic. Any additional treatments applied to individual components of a batch should be documented with the test results reported for the individual components. The draft file formats will be reviewed during FY 1993, and data entry should begin soon after.

Work on the computerized user interface for the data base began in FY 1992. The original version is being written for IBM/PC-compatible microcomputers using dBASE IV™ (version 1.5) programming language and should run with only the dBASE IV runtime modules that will be supplied with the interface. Work on the Macintosh version will begin once the PC version has been debugged.

Minor modifications were made to some of the existing file structures during the early stages of work on the interface. These changes were necessary for the program to access the correct information based on a user's request. Most of the changes were structural only and had

Table 3. COATINGS

General Information on Coatings			
Field Name	Type	Size	Comments
COATING	Character	20	Name of coating material
BATCH_ID	Character	16	Batch code assigned to this material
MAT_CLASS	Character	12	Primary classification of this material: metal, ceramic, cermet...
MATRIX	Character	30	List of material components
APPLY_ABBV	Character	4	Application method abbreviation
APPLY_TYPE	Character	30	Method used to apply the coating
COAT_THICK	Character	8	Average thickness of this coating
FABRICATOR	Character	24	Maker of this coating material
VINTAGE	Character	10	Date assigned to this material
OTHER_NAME	Character	20	Another name for this material
WBS_STUDY	Character	12	Work breakdown structure
CLASS_IN	Character	10	Material class access code
REF_CODE	Character	13	Source of this information
TEXTUF	Logical	1	If "Y", more comments in TEXTUF
COMMENTS	Character	29	Short notes

Table 4. COMPOSIT

Composite Materials General Information and Characterization				
Field Name	Type	Size	Units	Comments
MATERIAL	Character	24		Name of coating material
BATCH_ID	Character	16		Batch code assigned to this material
COMP_CLASS	Character	16		Primary classification of this type of composite
CLASS_IN	Character	10		Material class code
REF_CODE	Character	13		Information source
WBS_STUDY	Character	12		Work breakdown structure code
PRI_MATRIX	Character	24		Basic material components
PRIM_POWDR	Character	20		Primary matrix powder
ADDITIVES	Character	20		Anything added to the primary matrix
MIX_PROC	Character	20		Mixing process
FORM_PROC	Character	20		Forming process
DENSIFY	Character	30		Densification process
HEATREAT	Character	24		Extra heat treatments
REIN_NAME	Character	16		Name of reinforcing material
REIN_CHEM	Character	16		Composition of reinforcement
BATCH_IDR	Character	16		Batch code for reinforcement
REIN_QUANT	Character	12		Quantity of reinforcement
REIN_FORM	Character	16		Form of reinforcement
REIN_COAT	Character	16		Coating on reinforcement, if any
REIN_TREAT	Character	20		Premixing treatment
FABRICATOR	Character	24		Maker of this coating material
FAB_NAME	Character	12		Fabricator's name for composite
VINTAGE	Character	10		Date assigned to this material
DENSTY_GCC	Numeric	8	g/cm ³	Measured density
THDENS_PCT	Numeric	6	%	Percent of theoretical density
TYPE_MOE	Character	10		Method used to derive modulus of elasticity (MOE)

Table 4. continued

Field Name	Type	Size	Units	Comments
MOE_GPA	Numeric	6	GPa	Young's modulus at room temperature
MOR4_MPA	Numeric	6	MPa	MOR4 at room temperature
TYPE_HARD	Character	16		Type of hardness test
HARDNESS	Character	12		Value and units for hardness
TEMP_RNG_C	Character	10	°C	Temperature range for thermal expansion
THERM_EXP	Numeric	8	1.E-06/°C	Coefficient of thermal expansion
POISSONS	Numeric	6		Poisson's ratio
TYPE_TUFF	Character	16		Type of toughness test used
KIC_MPAM	Numeric	6	MPa√m	K _{IC} , fracture toughness
SEETEXT	Logical	1		"Y" if more information in TEXTUF

Table 5. LUBRICNTS

General Information on Lubricants Used in Wear Tests

Field Name	Type	Size	Units	Comments
LUBRICANT	Character	16		Name of lubricant
WBS_STUDY	Character	12		Work breakdown structure
REF_CODE	Character	13		Information source
FABRICATOR	Character	20		Manufacturer
BASE	Character	30		Substance forming the base stock for this lubricant
MAX_TEMP_C	Character	6	°C	Maximum operating temperature
SEETEXT	Logical	1		If "Y", then more notes in TEXTUF
COMMENTS	Character	27		Short notes

Table 6. MATLCHAR

General Information and Characterization Information on Unreinforced Ceramics				
Field Name	Type	Size	Units	Comments
MATERIAL	Character	24		Name of material
MAT_CLASS	Character	16		Material classification
BATCH_ID	Character	16		Batch or lot identity
CLASS_IN	Character	10		Material class code
REF_CODE	Character	13		Source of this information
WBS_STUDY	Character	12		Work breakdown structure code
FABRICATOR	Character	24		Material maker
FAB_NAME	Character	15		Maker's name for material
VINTAGE	Character	8		Date material was made
MATRIX	Character	30		Primary matrix in material
ADDITIVES	Character	48		Anything added to the primary matrix
DENSIFY	Character	30		Densification process, summarized
DENSTY_GCC	Numeric	8	g/cm ³	Measured density
THDENS_PCT	Numeric	6	%	Percentage of theoretical density
TYPE_MOE	Character	10		Method used to derive MOE
MOE_GPA	Numeric	6	GPa	Young's modulus at room temperature
MOR_MPA	Numeric	6	MPa	MOR ₄ at room temperature
TYPE_HARD	Character	10		Type of hardness test
HARDNESS	Character	12		Value and units for hardness
TEMP_RNG_C	Character	10	°C	Temperature range for thermal expansion
THERM_EXP	Numeric	8	1.E-06/°C	Coefficient of thermal expansion
POISSONS	Numeric	6		Poisson's ratio
TYPE_TUFF	Character	16		Type of toughness test used
KIC_MPAM	Numeric	6	MPa√m	K _{IC} , fracture toughness
SEETEXT	Logical	1		"Y" if more information in TEXTUF

Table 7. METALS

General Characterization and Information on Metals Used in Some Ceramic Material Tests				
Field Name	Type	Size	Units	Comments
MATERIAL	Character	24		Material name
LOT_NUMBER	Character	16		Batch or lot identification
CLASS_IN	Character	10		Material class code
REF_CODE	Character	13		Information source
WBS_STUDY	Character	12		Work breakdown structure code
FABRICATOR	Character	24		Material maker
FAB_NAME	Character	18		Maker's name for material
VINTAGE	Character	8		Date material was made
MATRIX	Character	30		Primary matrix in material
TYPE_MOE	Character	10		Method used to derive MOE
MOE_GPA	Numeric	6	GPa	Young's modulus at room temperature
UTS_MPA	Numeric	6	MPa	Tensile strength at room temperature
YIELD_MPA	Numeric	6	MPa	Yield strength at room temperature
TOT_ELONG	Numeric	5	%	Total elongation
TYPE_HARD	Character	16		Type of hardness test
HARDNESS	Character	12		Value and units for hardness
POISSONS	Numeric	6		Poisson's ratio
TYPE_TUFF	Character	16		Type of toughness test used
KIC_MPAM	Numeric	6	MPa√m	K _{IC} , fracture toughness
SEETEXT	Logical	1		"Y" if more information in TEXTUF

Table 8. REINFORC

Reinforcement Information for Composites				
Field Name	Type	Size	Units	Comments
REIN_NAME	Character	16		Whisker name
REIN_CHEM	Character	20		Chemical composition
BATCH_IDR	Character	16		Batch or lot identification
REIN_FORM	Character	16		Material form (e.g., fiber, powder)
COATING	Character	16		Substance used to coat whiskers, if any
MAKER	Character	24		Reinforcement fabricator
SPEC_TREAT	Character	24		Special treatment, if any
CONDITION	Character	20		Condition at mixing time
VINTAGE	Character	8		Date reinforcement was made
AVG_LEN_UM	Numeric	6	μm	Average length (fibers)
AVG_DIA_UM	Numeric	6	μm	Average diameter (fibers)
DIA_RANGE	Character	12		Range of diameters for this batch of reinforcement
LEN_RANGE	Character	12		Range of lengths for this batch of reinforcement
ASPECT_RAT	Numeric	6		Ratio of length to diameter
CLASS_IN	Character	10		Material class code
REF_CODE	Character	13		Information source
WBS_STUDY	Character	12		Work breakdown structure code
SEETEXT	Logical	1		"Y" if more information in TEXTUF
COMMENTS	Character	25		Any other information

no major impact on the information already stored. Since the interface is still being written, more changes may be forthcoming. All alterations will be documented in a future publication.

Barring an unexpected crisis, the interface should be ready for user testing by the end of FY 1993. The initial version will include a hardcopy draft version of the user manual and disks containing the data base and interface.

3. DATA BACKGROUND

Tracking down background information for a specific batch of a material is a time-consuming, usually frustrating, experience which is often necessary to confirm the validity of the data. The fabricator's assigned batch number of a material is frequently lost as the material proceeds through its processing life. Some of the data in this report include the original batch codes assigned to the materials by the fabricators. When no batch identifier is reported with data in the source document, a code is assigned by data base personnel based on the name of the material-fabricating facility and the company, lab, or individual reporting the data. It is possible for material with a fabricator's batch code to be the same as a material with a locally assigned batch code if, for example, data for the material were reported without the original fabricator's code. Unless the unknown-batch-code data are exact duplicates of known-batch-code data, the unknown-batch-code data are assigned a unique identifier to distinguish them from other batches of the same material.

All Weibull analyses shown in this report were performed using the rank regression method, in which a least-squares fit to the data is used to estimate the modulus. Specifically, the data were sorted and the X-Y coordinates, $\ln(\text{MOR strength})$ and $\ln[1/(1-F)]$, were calculated using Microsoft EXCEL™ (version 4.0) on an Apple Macintosh. The data were then transferred to Cricket Graph™ (version 1.3.1), where they were plotted with the best fit line, using Cricket Graph's built-in curve-fitting routines.

Data tables for this report are organized according to type of data: Appendix A contains available background information on the ceramics presented in this report; Appendix B contains the experimental text data arranged in sections by property type. Some of the test data listed in Appendix B may not be represented by materials in Appendix A but will be included in a later report if and when such information becomes available. It is the policy for this data base to store the available information for future use, whether or not a complete set of information is available on a material. However, complete sets are preferred and sought as time permits.

All information presented in this report was produced by programs funded by the CTP. Many of these programs sought to improve specific types of structural ceramics, with silicon nitrides being the most studied, followed closely by zirconia-based ceramics. Other programs

developed new test methods to predict more accurately the mechanical behavior of advanced ceramics at room and elevated temperatures. Test results from both types of programs were extracted from the CTP semiannual and bimonthly progress reports and from technical reports generated within the individual programs. Data sheets were received from Ken Liu and Matt Ferber, both from Oak Ridge National Laboratory (ORNL). A brief description of the programs generating data for this report follows. The work breakdown structure (WBS) designation (element) precedes each program title.

1.1.2.1 - Sintered Silicon Nitride - G. E. Gazza (Army Materials Technology Laboratory) and J. Mangels (Ceradyne, Inc.)

The purpose of this program is to develop scale-up processing conditions for a silicon nitride having a general matrix of 85.5m% Si_3N_4 , 4.73m% Y_2O_3 , 9.47m% SiO_2 , and 1.0m% Mo_2C , and characterizing properties for these materials. Several batches have been made and subdivided into smaller batches, called mixes, for further processing. These may be identified in the appendices by a batch code in the form CERA/MATn/MIXm, where "n" is a material batch number and "m" is a mix number. All are listed under the material name " Si_3N_4 ."

1.2.3.1 - Dispersion-Toughened Ceramic Composites - T. N. Tieggs, P. F. Becher, P. A. Menchhofer, W. H. Elliott, D. J. Kim, and D. W. Coffey (ORNL)

Improving toughness properties of structural ceramics using silicon carbide whiskers or other forms of reinforcement in various matrices is the goal of this activity. Present studies involve using rare-earth oxides to promote in situ acicular grain growth in silicon nitrides. These data are identified by the rare-earth oxides following " Si_3N_4 " in the material name, and "ORNL" in the batch code.

1.2.3.2 - Processing of Improved Transformation-Toughened Ceramics - E. Lilley and G. A. Rossi (Norton Company)

The purpose of this activity was to produce zirconia-toughened ceramics that were stronger and tougher at elevated temperatures and after prolonged exposure to elevated temperatures than current state-of-the-art toughened ceramics. All tests listed in the appendices on Ce-ZTA (a cerium-doped zirconia-toughened alumina) and Y-TZP (a yttria-doped zirconia) were generated by this program.

1.4.1.3 - Analytical and Experimental Evaluation of Joining Ceramic Oxides to Ceramic Oxides and Ceramic Oxides to Metal for Advanced Heat Engine Applications - J. Ahmad et al. (Battelle Columbus Laboratories)

The objective of this program was to develop analytical tools to design reliable, high-strength, ceramic-to-ceramic and ceramic-to-metal joints. Experimental joints using

various interlayers between Mg-PSZ components (as split disks or split bend bar specimens) were fabricated with Mg-PSZ-to-nodular cast-iron joints, and both types were tested for strength and toughness. These test results are located in Appendix B, Sects. 9 and 10. Test results on the unjointed component materials are included in other sections and may be identified by batch codes beginning with "BCL/." Joining details may be found in Sect. 5 of Appendix A. Specimen geometry diagrams may be found in Fig. 1.

3.2.1.4 - Tensile Cyclic Fatigue of Structural Ceramics - K. C. Liu, C. O. Stevens, and C. R. Brinkman (ORNL)

This ongoing program has the task of designing, developing, and demonstrating uniaxial tension-tension dynamic fatigue testing of structural ceramics at elevated temperatures and to develop baseline data on tensile fatigue behavior of ceramics at room and elevated temperatures. The cyclic fatigue test data using test rig designation "CFATORNL1" were produced by this activity. See Fig. 2 for a diagram of the cylindrical buttonheaded rod specimen used in this program.

3.2.1.5 - Tensile Stress-Rupture Development - K. C. Liu, C. O. Stevens, H. Pih, and C. R. Brinkman (ORNL)

The primary purpose of this program is to develop the capability for performing uniaxial tensile stress-rupture and creep tests at high temperatures in the region where creep can occur. Stress-rupture and creep data on NT-154 and GN-10 with batch codes of "ORNL/KCL" were generated by this activity. See Fig. 2 for a diagram of the cylindrical buttonheaded rod specimen used in this program.

3.2.1.6 - Rotor Data Base Generation - M. K. Ferber and M. G. Jenkins (ORNL)

This activity involves studying the tensile strength of a silicon nitride ceramic as a function of temperature and time in an air environment. Another phase is investigating the microstructural aspects of high-temperature failure using stress-rupture data. The resulting data base should help the development of a design methodology for high-temperature structural ceramics. Creep and dynamic fatigue data on GTE PY6 from this activity have batch codes beginning with "ORNL/LOT."

3.2.1.7 - Toughened Ceramics Life Prediction - J. A. Salem and S. R. Choi (NASA Lewis Research Center)

The purpose of this activity is to understand the relationship between microstructure and mechanical behavior of a few materials and to determine behavior as a function of time and temperature. As-manufactured and long-term exposed materials are compared for this study. Dynamic fatigue, fracture toughness, and MOR 4-point bend tests were run on GN-10 and GN-10 reinforced with silicon nitride whiskers. Japanese silicon nitrides from Kyocera, designated

Fig. 1. Battelle Columbus Laboratory Joint Specimen Geometries. All dimensions are nominal values given in millimeters.

Fig. 2. ORNL Cylindrical Buttonheaded Tensile Specimen. All dimensions are given in millimeters.

SN-251, SN-252, and SN-260, and a silicon carbide from Norton Company, NC-233, were also tested. Data from this study contain "NLRC" in the batch code.

3.2.2.2 - Life-Prediction Methodology for Ceramic Components of Advanced Vehicular Heat Engines - P. K. Khandelwal (Allison Gas Turbine Division, General Motors Corporation)

The objective of this program is to develop and demonstrate the necessary nondestructive examination technology, materials data base, and design methodology for predicting useful life of structural ceramic components of advanced heat engines. The methodology will be demonstrated through confirmatory testing of ceramic components in near-anticipated-use conditions, addressing fast fracture, slow crack growth, creep, and oxidation failure modes. Tensile and creep tests on GTE PY6 (batch code = AGTD/HIP) were run at Southern Research Institute at elevated temperatures and are reported in Appendix B. See Fig. 3 for a diagram of the cylindrical buttonheaded rod specimen used in this program.

3.3.1.4 - Environmental Effects in Toughened Ceramics - N. L. Hecht [University of Dayton Research Institute (UDRI)]

Environmental effects on mechanical properties of commercially available ceramics for use in vehicular heat engines are the primary concern of this program. UDRI also characterizes many materials for this and other activities. This report contains UDRI test results on NT-154, NT-164 (an improved version of NT-154), GN-10, GTE-PY6, NT-230, and Hexoloy SA, all identified through batch codes containing "UDRI."

All data in this report are contained in two appendices. Material characterizations and background information are located in Appendix A. Tabular and graphical representations of the test results may be found in Appendix B. Please note that all Weibull analyses shown in Appendix B were calculated using the least-squares method. The least-squares method is not the most accepted method, but the software to produce maximum likelihood analyses is being revised for data base purposes and should be operable for use in the next data base summary report.

4. SYSTEM ACCESS

Direct access to the master data base is very limited to protect the integrity of the master files. Experience has shown that major disasters often occur when too many people have direct access to unprotected files at microcomputer level. Since most users would prefer to have the data in a familiar format, to subset, analyze, and rearrange to suit their needs, this method satisfies both situations; the master files are protected and the user gets the data in a readily consumable form. While direct access is faster, the process of downloading across phone lines can be time

Fig. 3. Allison Gas Turbine Division Cylindrical Rod Specimen. All dimensions are nominal values in millimeters.

consuming and hazardous to the integrity of the data being transmitted. This data base was designed as a repository, not a full-function analytical tool.

Access to the data is attained by calling the data base administrator and requesting all files or just those pertaining to certain materials or test types. The information requested by the user (in the user-designated format, including software and disk type) will then be downloaded from the master files, reformatted, if necessary, and sent to the user when possible. No plans are being considered for direct access from outside systems at this time. Direct transfer is available by special arrangement but may be time consuming due to the size and number of files. No guarantee is given for the validity of data transmitted directly because of possible phone line problems.

Several file formats, other than dBASE IV, are available for files downloaded for users. These formats have been categorized as either Apple Macintosh-compatible files (on 3.5-in. floppy disks) or IBM PC-compatible files (on 3.5-in. floppy disks up to 1.44 MB or 5.25-in. floppy disks from 360 kB to 1.2 MB). Available Macintosh file types include Microsoft EXCEL™, SYLK, FOXBASE™, and plain printable ASCII. IBM file types are Lotus 1-2-3™, Microsoft EXCEL™, DIF, SDF, SYLK, plain ASCII, delimited ASCII, and dBASE IV. Other formats may be available by special arrangement. When requesting information from the data base, please indicate disk size, disk density, and file type.

With computer diseases becoming so rampant, users should be aware that precautions are taken to ensure that the disks they receive from the data base are disease free. Only new disks are used for transmittals to avoid spreading any computer diseases that might be hiding. No recycled, reformatted disks are sent to users. Both the master system, a Northgate Elegance 486/25, and the Macintosh IIcx are checked regularly for such illnesses; none have been found so far. Use of both computers is limited to one person who screens incoming software carefully to avoid contamination of either system. No information is downloaded from public bulletin boards to either system. Both computers have virus detection software installed, and all efforts are made to ensure both systems stay disease free. If users have problems with disks received from the data base, please inform data base personnel immediately so steps can be taken to correct the problems.

5. FUTURE PLANS

Creation of a new data base for material processing information has begun and should develop during 1993. This data base will tie into the existing test results data base through material name and batch code. It contains no data now but will be stocked when the final format is established and time permits data input.

Development of the computerized user interface using the dBASE IV programming language is in progress. The interface will link the many data base files together, providing better access to information in the system. This interface will be available to all users of the data base who request it and will not require a full copy of dBASE IV to operate. Runtime modules of dBASE IV will be included with the interface for the users' convenience. A test version is expected to be in operation by the end of September 1993.

The next data base summary report is scheduled for September 1993.

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8. ACKNOWLEDGMENTS

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APPENDIX A. MATERIAL CHARACTERISTICS AND BACKGROUND DATA

Section 1A - Material Background Information

Material	Batch Code	Material Class	Fabricator	Commercial Name	Vintage
Alumina-based Ceramics					
Ce-ZTA	NORT/Z16CE80A	ALO/ZRO/CE	Norton Company	Ce-ZTA	
Ce-ZTA	NORT/Z24CE80A	ALO/ZRO/CE	Norton Company	Ce-ZTA	
Ce-ZTA	NORT/Z16CE60A	ALO/ZRO/CE	Norton Company	Ce-ZTA	
Ce-ZTA	NORT/Z16CE60AM	ALO/ZRO/CE	Norton Company	Ce-ZTA	
Ce-ZTA	NORT/Z18.5CE62A	ALO/ZRO/CE	Norton Company	Ce-ZTA	
Silicon Nitride-based Ceramics					
GN-10	GCCD/NLRC-90	SIN	Garrett Ceramics	GN-10	
GN-10	GCCD/UDRI-90	SIN	Garrett Ceramics	GN-10	
GTE PY6	AGTD/HIP	SIN/HIP	GTE Laboratory	PY6	1989
GTE PY6	AGTD/HIP/MODI	SIN/HIP	GTE Laboratory	PY6	1989
GTE PY6	ORNL/LOT n	SIN/HIP	GTE Laboratory	PY6	1989
NT-154	ORNL/KCL92	SIN	Norton Company	NT-154	1989
NT-164	NORTON/UDRI-92	SIN	Norton Company	NT-164	
Si3N4	CERAMAT4/MIX6	SIN/YO/SINTERED	Ceradyne, Inc.		1991
Si3N4	CERAMAT4/MIX7	SIN/YO/SINTERED	Ceradyne, Inc.		1991
Si3N4	CERAMAT5/MIX10	SIN/SRBSN	Ceradyne, Inc.		1991
Si3N4	CERAMAT5/MIX11	SIN/SRBSN	Ceradyne, Inc.		1991
Si3N4	CERAMAT6/MIX18	SIN/SRBSN	Ceradyne, Inc.		1991
Si3N4	CERAMAT7/MIX25	SIN/SRBSN	Ceradyne, Inc.		1991
Si3N4	ORNL/SC-283/GPS1	SIN/LAO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%La2O3+4%SiO2	ORNL/SC-283/GPS2	SIN/LAO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%La2O3+4%SiO2	ORNL/SC-283/GPS3	SIN/LAO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%La2O3+4%SiO2	ORNL/SC-283/GPS4	SIN/LAO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%La2O3+4%SiO2	ORNL/SC-283/GPS5	SIN/LAO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%LaO+2%SiO+3%SiO	ORNL/SC-290/GPS1	SIN/LAO/SRO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%LaO+2%SiO+3%SiO	ORNL/SC-290/GPS2	SIN/LAO/SRO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%LaO+2%SiO+3%SiO	ORNL/SC-290/GPS3	SIN/LAO/SRO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%LaO+2%SiO+3%SiO	ORNL/SC-290/GPS4	SIN/LAO/SRO/SIO	Oak Ridge National Laboratory		1992
Si3N4+11%LaO+2%SiO+3%SiO	ORNL/SC-290/GPS5	SIN/LAO/SRO/SIO	Oak Ridge National Laboratory		1992
Si3N4+2%Y2O3+8%La2O3	ORNL/SC-209/GPS1	SIN/LAO/YO	Oak Ridge National Laboratory		1992
Si3N4+2%Y2O3+8%La2O3	ORNL/SC-209/GPS2	SIN/LAO/YO	Oak Ridge National Laboratory		1992
Si3N4+3%YO+4%LaO+2%AIO	ORNL/SINYL-1	SIN/LAO/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+3%YO+4%LaO+2%AIO	ORNL/SINYL-2	SIN/LAO/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+3%YO+4%LaO+2%AIO	ORNL/SINYL-2	SIN/LAO/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+3%YO+5%LaO+4%SiO	ORNL/SC-282/GPS1	SIN/LAO/YO/SIO	Oak Ridge National Laboratory		1992
Si3N4+3%YO+5%LaO+4%SiO	ORNL/SC-282/GPS2	SIN/LAO/YO/SIO	Oak Ridge National Laboratory		1992
Si3N4+3%YO+5%LaO+4%SiO	ORNL/SC-282/GPS3	SIN/LAO/YO/SIO	Oak Ridge National Laboratory		1992
Si3N4+3%YO+5%LaO+4%SiO	ORNL/SC-282/GPS4	SIN/LAO/YO/SIO	Oak Ridge National Laboratory		1992
Si3N4+3%YO+5%LaO+4%SiO	ORNL/SC-282/GPS5	SIN/LAO/YO/SIO	Oak Ridge National Laboratory		1992

Material	Batch Code	Material Class	Fabricator	Commercial Name	Vintage
Silicon Nitride-based Ceramics					
Si3N4+4%Y2O3+2%SiO	ORNL/SC-261/GPS1	SIN/YO/SRO	Oak Ridge National Laboratory		1992
Si3N4+4%Y2O3+2%SiO	ORNL/SC-261/GPS2	SIN/YO/SRO	Oak Ridge National Laboratory		1992
Si3N4+4%Y2O3+6%La2O3	ORNL/SC-220/GPS1	SIN/YO/LAO	Oak Ridge National Laboratory		1992
Si3N4+4%Y2O3+8%SiO2	ORNL/SN4YO8/SIO-1	SIN/YO/SIO	Oak Ridge National Laboratory		1991
Si3N4+4%YO+6%LaO+2%SiO	ORNL/SC-276/GPS1	SIN/YO/LAO/SIO	Oak Ridge National Laboratory		1992
Si3N4+4%YO+6%LaO+2%SiO	ORNL/SC-276/GPS2	SIN/YO/LAO/SIO	Oak Ridge National Laboratory		1992
Si3N4+4%YO+6%LaO+2%SiO+0.2%SiO	ORNL/SC-277/GPS1	SIN/YO/LAO/SIO/SRO	Oak Ridge National Laboratory		1992
Si3N4+4%YO+6%LaO+2%SiO+0.2%SiO	ORNL/SC-277/GPS2	SIN/YO/LAO/SIO/SRO	Oak Ridge National Laboratory		1992
Si3N4+6%La2O3+4%Y2O3	ORNL/SNL Y-U10/1	SIN/LAO/YO	Oak Ridge National Laboratory		1991
Si3N4+6%La2O3+4%Y2O3	ORNL/SNL Y-U10/2	SIN/LAO/YO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+1%SiO+4%SiO	ORNL/SC-261/GPS1	SIN/YO/SRO/SIO	Oak Ridge National Laboratory		1992
Si3N4+6%Y2O3+1%SiO+4%SiO	ORNL/SC-261/GPS2	SIN/YO/SRO/SIO	Oak Ridge National Laboratory		1992
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-1	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-2	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-3	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-4	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-5	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-B1	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-B2	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-12SX/1	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-9FW	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-LC12SX	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-P21C3	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-TS-10	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-TS-10Y	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-TS-8	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-U10/1	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-U10/2	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-UBE-10	SIN/YO/ALO	Oak Ridge National Laboratory		1991
Si3N4+8%La2O3+2%Al2O3	CRNL/SNLA-12SX/1	SIN/LAO/ALO	Oak Ridge National Laboratory		1991
Si3N4+8%La2O3+2%Al2O3	ORNL/SNLA-U10/1	SIN/LAO/ALO	Oak Ridge National Laboratory		1991
Si3N4+8%La2O3+2%SiO	ORNL/SC-263/GPS1	SIN/LAO/SRO	Oak Ridge National Laboratory		1992
Si3N4+8%La2O3+2%SiO	ORNL/SC-263/GPS2	SIN/LAO/SRO	Oak Ridge National Laboratory		1992
Si3N4+8%LaO+2%SiO+4%SiO	ORNL/SC-264/GPS1	SIN/LAO/SRO/SIO	Oak Ridge National Laboratory		1992
Si3N4+8%LaO+7%YbO+4%SiO	ORNL/SNL YS-1	SIN/LAO/YBO/SIO	Oak Ridge National Laboratory		1991
Si3N4+8%LaO2+2%Al2O3	ORNL/SINALOALO-1	SIN /LAO/ALO	Oak Ridge National Laboratory		1991
Si3N4+8%LaO2+2%Al2O3	ORNL/SINALOALO-2	SIN /LAO/ALO	Oak Ridge National Laboratory		1991
Si3N4+8%LaO2+2%Al2O3	ORNL/SINALOALO-3	SIN /LAO/ALO	Oak Ridge National Laboratory		1991
Si3N4+8%LaO2+2%Al2O3	ORNL/SINALOALO-5	SIN /LAO/ALO	Oak Ridge National Laboratory		1991
Si3N4+8%Y2O3	ORNL/SC-205/GPS1	SIN /YO	Oak Ridge National Laboratory		1992

Material	Batch Code	Material Class	Fabricator	Commercial Name	Vintage
Silicon Nitride-based Ceramics					
SI3N4+8%Y2O3	ORNL/SC-205/GPS2	SIN /YO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.2%BaO+.3%SiO	ORNL/SC-293/GPS3	SIN /YOBAO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.2%BaO+.3%SiO	ORNL/SC-293/GPS4	SIN /YOBAO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.2%BaO+.3%SiO	ORNL/SC-293/GPS5	SIN /YOBAO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.2%SiO	ORNL/SC-253/GPS1	SIN /YO/SRO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.3%BaO+.3%SiO	ORNL/SC-291/GPS3	SIN /YOBAO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.3%BaO+.3%SiO	ORNL/SC-291/GPS4	SIN /YOBAO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.3%BaO+.3%SiO	ORNL/SC-291/GPS5	SIN /YOBAO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.4%SiO2	ORNL/SC-281/GPS1	SIN/YO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.4%SiO2	ORNL/SC-281/GPS2	SIN/YO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.4%SiO2	ORNL/SC-281/GPS3	SIN/YO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.4%SiO2	ORNL/SC-281/GPS4	SIN/YO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.4%SiO2	ORNL/SC-281/GPS5	SIN/YO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%Y2O3+.4%SiO2	ORNL/SC-281/GPS5	SIN/YO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%YO+.2%SiO+.3%SiO	ORNL/SC-293/GPS1	SIN/YO/SRO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%YO+.2%SiO+.3%SiO	ORNL/SC-293/GPS2	SIN/YO/SRO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%YO+.3%BaO+.3%SiO	ORNL/SC-291/GPS1	SIN/YOBAO/SIO	Oak Ridge National Laboratory		1992
SI3N4+8%YO+.3%BaO+.3%SiO	ORNL/SC-291/GPS2	SIN/YOBAO/SIO	Oak Ridge National Laboratory		1992
SI3N4+Y2O3+SrO	ORNL/SINGN10-1	SIN	Oak Ridge National Laboratory		1991
SI3N4+Y2O3+SrO	ORNL/SINGN10-2	SIN	Oak Ridge National Laboratory		1991
SI3N4+Y2O3+SrO	ORNL/SINGN10-3	SIN	Oak Ridge National Laboratory		1991
SN-251	KYOCERA/NLRC-90	SIN	Kyocera	SN 251	1992
SN-252	KYOCERA/NLRC-92	SIN	Kyocera	SN 252	1992
SN-260	KYOCERA/NLRC-91	SIN	Kyocera	SN-260	1992
Silicon Carbide-based Ceramics					
HEXOLOVSA	CARBNDM/UDRI/2	SIC	Carborundum Company	HEXOLOVSA	1992
NC-433	NORTON/NLRC/1	SIC	Norton Company	NC 433 SiC	1992
NT-230	NORTON/UDRI-91	SIC	Norton Company	NT-230 SiC	1992
Zirconia-based Ceramics					
MASZ-67	BCL/ZRO-ZRO/1	ZROBRAZE		MASZ-67	1992
MASZ-80	BCL/ZRO-ZRO/1	ZROBRAZE		MASZ-80	1992
Mg-PSZ	BCL/ZYCORN/L/1	ZROMGO	Zircoa, Inc.	ZYCORN/L	1992
Mg-PSZ	BCL/ZYCORN/L/1+HT	ZROMGO	Zircoa, Inc.	ZYCORN/L	1992
Y-TZP	NORT/MG008	ZROYO	Norton Company	Y-TZP	1991
Y-TZP	NORT/MG024/FGS	ZROYO	Norton Company	Y-TZP	1991
Y-TZP	NORT/MG024/NGS	ZROYO	Norton Company	Y-TZP	1991

Section 1A - Material Background Information, continued

Material	Batch Code	Material Class	Fabricator	Commercial Name	Vintage
Zirconia-based Ceramics					
Y-TZP	NORT/MG026	ZROYO	Norton Company	Y-TZP	
Y-TZP	NORT/MG032	ZROYO	Norton Company	Y-TZP	
Y-TZP	NORT/MG100	ZROYO	Norton Company	Y-TZP	
Y-TZP	NORT/MG100	ZROYO	Norton Company	Y-TZP	
Y-TZP	NORT/SD039	ZROYO	Norton Company	Y-TZP	

Section 1B - Material Background - Matrix/Processing

Material	Batch Code	Primary Matrix	Additives	Densification Process
Alumina-based Ceramics				
Ce-ZTA	NORT/Z16CE80A	Al ₂ O ₃	3.2w%CeO ₂ , 16.8w%ZrO ₂	SINTERED AND HIPED
Ce-ZTA	NORT/Z24CE80A	Al ₂ O ₃	4.8w%CeO ₂ , 15.2w%ZrO ₂	SINTERED AND HIPED
Ce-ZTA	NORT/Z16CE60A	Al ₂ O ₃	6.4w%CeO ₂ , 33.6w%ZrO ₂	SIN/3H/1500C+HIP/1500C/.75H
Ce-ZTA	NORT/Z16CE60AM	Al ₂ O ₃	6.4w%CeO ₂ , 33.6w%ZrO ₂	SIN/3H/1500C+HIP/1500C/.75H
Ce ZTA	NORT/Z18 5CE62A	Al ₂ O ₃	7.0w%CeO ₂ , 31w%ZrO ₂	SIN/1600C/PRESSURELESS/TIME VAR.
Silicon Nitride-based Ceramics				
GN-10	GCCD/NLRC-90	Si ₃ N ₄	Y ₂ O ₃ + SrO	HOT ISOSTATIC PRESSED HOT ISOSTATIC PRESSED HOT-ISOSTATICALLY PRESSED
GN-10	GCCD/UDRI-90	Si ₃ N ₄	Y ₂ O ₃ + SrO	
GTE PV6	AGTD/HIP	Si ₃ N ₄	6w%Y ₂ O ₃	
GTE PV6	AGTD/HIP/MODI	Si ₃ N ₄ -see notes	6w%Y ₂ O ₃	SINTERED/1850C/5H SINTERED/1850C/5H SINT/1910C/5H/1910C/3H/1200C/2H SINT/1910C/5H/1910C/3H/1200C/2H SINT/1910C/5H/1910C/3H/1200C/2H SINTERING RUN MTL47
GTE PV6	ORNL/LOT	Si ₃ N ₄	6w%Y ₂ O ₃	
NT-154	ORNL/KCL92	Si ₃ N ₄	4w%Y ₂ O ₃	
NT-164	NORTON/UDRI-92	Beta-Si ₃ N ₄	4w%Y ₂ O ₃	SINTERED/1850C/5H SINTERED/1850C/5H SINT/1910C/5H/1910C/3H/1200C/2H SINT/1910C/5H/1910C/3H/1200C/2H SINT/1910C/5H/1910C/3H/1200C/2H SINTERING RUN MTL47
Si ₃ N ₄	CERA/MAT4/MIX6	Si ₃ N ₄	7.8%Y ₂ O ₃ +4.16%SiO ₂	
Si ₃ N ₄	CERA/MAT4/MIX7	Si ₃ N ₄	1.48w%M ² C+4.14%SiO ₂ +7.8%Y ₂ O ₃	
Si ₃ N ₄	CERA/MAT5/MIX10	Si ₃ N ₄	7.8%Y ₂ O ₃ +4.2%SiO ₂	1850C/2H/50psiN/1900C/2H/300psi 1850C/2H/50psiN/1950C/2H/300psi SINT/1750C/4H/15psi N2 SINT/1800C/4H/15psi N2 SINT/1850C/4H/15psi N2
Si ₃ N ₄	CERA/MAT5/MIX11	Si ₃ N ₄	1.48w%Mo ₂ C+4.14%SiO ₂ +7.8%Y ₂ O ₃	
Si ₃ N ₄	CERA/MAT6/MIX18	Si ₃ N ₄	1w%Al ₂ O ₃ +0.2%Mo ₂ C+7.8%Y ₂ O ₃ +4.14%SiO ₂	
Si ₃ N ₄	CERA/MAT7/MIX25	Si ₃ N ₄	7.8w%Y ₂ O ₃ +1.0%Al ₂ O ₃ +2.0%SiO ₂ +0.6%Mo ₂ C	1850C/2H/50psiN/1900C/2H/300psi 1850C/2H/50psiN/1950C/2H/300psi SINT/1750C/4H/15psi N2 SINT/1800C/4H/15psi N2 SINT/1850C/4H/15psi N2
Si ₃ N ₄	ORNL/SC-283/GPS1	Si ₃ N ₄	11w%La ₂ O ₃ +4w%SiO ₂	
Si ₃ N ₄	ORNL/SC-283/GPS2	Si ₃ N ₄	11w%La ₂ O ₃ +4w%SiO ₂	
Si ₃ N ₄	ORNL/SC-283/GPS3	Si ₃ N ₄	11w%La ₂ O ₃ +4w%SiO ₂	1850C/2H/.3MPaPaN/1900/2H/2MPa N2 1850C/2H/.3MPaPaN/1950/2H/2MPa N2 SINT/1750C/4H/15psi N2 SINT/1800C/4H/15psi N2 SINT/1850C/4H/15psi N2
Si ₃ N ₄	ORNL/SC-283/GPS4	Si ₃ N ₄	11w%La ₂ O ₃ +4w%SiO ₂	
Si ₃ N ₄	ORNL/SC-283/GPS5	Si ₃ N ₄	11w%La ₂ O ₃ +4w%SiO ₂	
Si ₃ N ₄	ORNL/SC-290/GPS1	Si ₃ N ₄	11w%La ₂ O ₃ +2w%SiO ₂ +3w%SiO ₂	1850C/2H/50psiN/1900C/2H/300psi 1850C/2H/50psiN/1950C/2H/300psi SINT/1750C/4H/15psi N2 SINT/1800C/4H/15psi N2 SINT/1850C/4H/15psi N2
Si ₃ N ₄	ORNL/SC-290/GPS2	Si ₃ N ₄	11w%La ₂ O ₃ +2w%SiO ₂ +3w%SiO ₂	
Si ₃ N ₄	ORNL/SC-290/GPS3	Si ₃ N ₄	11w%La ₂ O ₃ +2w%SiO ₂ +3w%SiO ₂	
Si ₃ N ₄	ORNL/SC-290/GPS4	Si ₃ N ₄	11w%La ₂ O ₃ +2w%SiO ₂ +3w%SiO ₂	1850C/2H/50psiN/1900C/2H/300psi 1850C/2H/50psiN/1950C/2H/300psi HP/1725/60MIN HP/1800/90MIN HP/1800/180MIN
Si ₃ N ₄	ORNL/SC-290/GPS5	Si ₃ N ₄	11w%La ₂ O ₃ +2w%SiO ₂ +3w%SiO ₂	
Si ₃ N ₄	ORNL/SC-209/GPS1	Si ₃ N ₄	2w%Y ₂ O ₃ +8w%La ₂ O ₃	
Si ₃ N ₄	ORNL/SC-209/GPS2	Si ₃ N ₄	2w%Y ₂ O ₃ +8w%La ₂ O ₃	1850C/2H/50psiN/1900C/2H/300psi 1850C/2H/50psiN/1950C/2H/300psi SINT/1750C/4H/15psiN SINT/1800C/4H/15psiN SINT/1850C/4H/15psiN
Si ₃ N ₄	ORNL/SINYL A-1	Si ₃ N ₄	3w%Y ₂ O ₃ +4w%La ₂ O ₃ +2w%Al ₂ O ₃	
Si ₃ N ₄	ORNL/SINYL A-2	Si ₃ N ₄	3w%Y ₂ O ₃ +4w%La ₂ O ₃ +2w%Al ₂ O ₃	
Si ₃ N ₄	ORNL/SINYL A-2	Si ₃ N ₄	3w%Y ₂ O ₃ +5w%La ₂ O ₃ +4w%SiO ₂	1850C/2H/50psiN/1900C/2H/300psi 1850C/2H/50psiN/1950C/2H/300psi SINT/1750C/4H/15psiN SINT/1800C/4H/15psiN SINT/1850C/4H/15psiN
Si ₃ N ₄	ORNL/SC-282/GPS1	Si ₃ N ₄	3w%Y ₂ O ₃ +5w%La ₂ O ₃ +4w%SiO ₂	
Si ₃ N ₄	ORNL/SC-282/GPS2	Si ₃ N ₄	3w%Y ₂ O ₃ +5w%La ₂ O ₃ +4w%SiO ₂	
Si ₃ N ₄	ORNL/SC-282/GPS3	Si ₃ N ₄	3w%Y ₂ O ₃ +5w%La ₂ O ₃ +4w%SiO ₂	1850C/2H/50psiN/1900C/2H/300psi 1850C/2H/50psiN/1950C/2H/300psi SINT/1750C/4H/15psiN SINT/1800C/4H/15psiN SINT/1850C/4H/15psiN
Si ₃ N ₄	ORNL/SC-282/GPS4	Si ₃ N ₄	3w%Y ₂ O ₃ +5w%La ₂ O ₃ +4w%SiO ₂	
Si ₃ N ₄	ORNL/SC-282/GPS5	Si ₃ N ₄	3w%Y ₂ O ₃ +5w%La ₂ O ₃ +4w%SiO ₂	

Material	Batch Code	Primary Matrix	Additives	Densification Process
Silicon Nitride-based Ceramics	ORNL/SC-261/GPS1	Si3N4	4w%Y2O3+2w%SiO	1850C/2H/3MPa/1900/2H/2MPa/N
	ORNL/SC-261/GPS2	Si3N4	4w%Y2O3+2w%SiO	1850C/2H/3MPa/1950/2H/2MPa/N
	ORNL/SC-220/GPS1	Si3N4	8w%Y2O3+6w%La2O3	1850C/2H/50psi/N/1900C/2H/300psi
	ORNL/SN4YOB8IO-1	Si3N4	4w%Y2O3+8w%SiO2	HOT-PRESSED
	ORNL/SC-276/GPS1	Si3N4	4w%Y2O3+6w%La2O3+2w%SiO2	1850C/2H/50psi/N/1900C/2H/300psi
	ORNL/SC-276/GPS2	Si3N4	4w%Y2O3+6w%La2O3+2w%SiO2	1850C/2H/50psi N2/1950C/2H/300psi
	ORNL/SC-277/GPS1	Si3N4	6w%La2O3+2%SiO2+4%Y2O3+0.2%SiO	1850C/2H/50psi N2/1900C/2H/300psi
	ORNL/SC-277/GPS2	Si3N4	6w%La2O3+2%SiO2+4%Y2O3+0.2%SiO	1850C/2H/50psi N2/1950C/2H/300psi
	ORNL/SNL Y-U10/1	Si3N4	6w%La2O3+4w%Y2O3	GPS/1850/4H/2MPa N2
	ORNL/SNL Y-U10/2	Si3N4	6w%La2O3+4w%Y2O3	GPS/1900/4H/2MPa N2
	ORNL/SC-261/GPS1	Si3N4	6w%Y2O3+1w%SiO+4w%SiO2	1850C/2H/3MPa N2/1900/2H/2MPa N2
	ORNL/SC-261/GPS2	Si3N4	6w%Y2O3+1w%SiO+4w%SiO2	1850C/2H/3MPa N2/1950/2H/2MPa N2
	ORNL/SINYOALO-1	Si3N4	6w%Y2O3+2w%Al2O3	HOT-PRESS 1725C/60MIN
	ORNL/SINYOALO-2	Si3N4	6w%Y2O3+2w%Al2O3	HOT-PRESS 1800C/90MIN
	ORNL/SINYOALO-3	Si3N4	6w%Y2O3+2w%Al2O3	HOT-PRESS 1800C/180MIN
	ORNL/SINYOALO-4	Si3N4	6w%Y2O3+2w%Al2O3	HP/1650C/60MIN/1800C/90MIN
	ORNL/SINYOALO-5	Si3N4	6w%Y2O3+2w%Al2O3	HOT-PRESS 1900C/90MIN
	ORNL/SINYOALO-B1	Si3N4	6w%Y2O3+2%Al2O3/Al2O3 has beta Si3N4)	HOT-PRESS 1725C/60MIN
	ORNL/SINYOALO-B2	Si3N4	6w%Y2O3+2%Al2O3/Al2O3 has beta Si3N4)	HOT-PRESS 1900C/90MIN
	ORNL/SNYA-12SX/1	Si3N4	6w%Y2O3+2w%Al2O3	GPS/1850/4H/2MPa N2
	ORNL/SNYA-9FW	Si3N4	6w%Y2O3+2w%Al2O3	HP/1800C/90MIN.
	ORNL/SNYA-LC12SX	Si3N4	6w%Y2O3+2w%Al2O3	HP/1800C/90MIN.
	ORNL/SNYA-P21C3	Si3N4	6w%Y2O3+2w%Al2O3	HP/1800C/90MIN.
	ORNL/SNYA-TS-10	Si3N4	6w%Y2O3+2w%Al2O3	HP/1800C/90MIN.
	ORNL/SNYA-TS-10Y	Si3N4	6w%Y2O3+2w%Al2O3	HP/1800C/90MIN.
	ORNL/SNYA-TS-8	Si3N4	6w%Y2O3+2w%Al2O3	GPS/1850/4H/2MPa N2
	ORNL/SNYA-U10/1	Si3N4	6w%Y2O3+2w%Al2O3	GPS/1900/4H/2MPa N2
	ORNL/SNYA-U10/2	Si3N4	6w%Y2O3+2w%Al2O3	HP/1800C/90MIN.
	ORNL/SNYA-UBE-10	Si3N4	6w%Y2O3+2w%Al2O3	GPS/1850/4H/2MPa N2
	ORNL/SNYA-12SX/1	Si3N4	8w%La2O3+2w%Al2O3	GPS/1850/4H/2MPa N2
	ORNL/SNLA-U10/1	Si3N4	8w%La2O3+2w%Al2O3	1850C/2H/3MPa N2/1900/2H/2MPa N2
	ORNL/SC-263/GPS1	Si3N4	8w%La2O3+2w%SiO	1850C/2H/3MPa N2/1950/2H/2MPa N2
	ORNL/SC-263/GPS2	Si3N4	8w%La2O3+2w%SiO	1850C/2H/3MPa N2/1900/2H/2MPa N2
	ORNL/SC-264/GPS1	Si3N4	8w%La2O3+2w%SiO	HOT-PRESSED
	ORNL/SNL YS-1	Si3N4	8w%Al2O3+4%SiO2+7%Yb2O3	HP/1725/60MIN
	ORNL/SINALOALO-1	Si3N4	8w%LaO2+2w%Al2O3	HP/1800/90MIN
	ORNL/SINALOALO-2	Si3N4	8w%LaO2+2w%Al2O3	HP/1800/180MIN
	ORNL/SINALOALO-3	Si3N4	8w%LaO2+2w%Al2O3	HP/1900/90MIN
	ORNL/SINALOALO-5	Si3N4	8w%LaO2+2w%Al2O3	1850C/2H/50psi N2/1900C/2H/300psi
	ORNL/SC-205/GPS1	Si3N4	8w%Y2O3	

Section 1B - Material Background - Matrix/Processing, continued

Material	Batch Code	Primary Matrix	Additives	Densification Process
Silicon Nitride-based Ceramics				
Si3N4+8%Y2O3	ORNL/SC-205/GPS2	Si3N4	8w%Y2O3	1850C/2H/50psi N2/1950C/2H/300psi
Si3N4+8%Y2O3+2%BaO+3%SiO	ORNL/SC-293/GPS3	Si3N4	8w%Y2O3+2w%SiO+3w%SiO2	SINT/1750C/4H/15psi N2
Si3N4+8%Y2O3+2%BaO+3%SiO	ORNL/SC-293/GPS4	Si3N4	8w%Y2O3+2w%SiO+3w%SiO2	SINT/1800C/4H/15psi N2
Si3N4+8%Y2O3+2%BaO+3%SiO	ORNL/SC-293/GPS5	Si3N4	8w%Y2O3+2w%SiO+3w%SiO2	SINT/1850C/4H/15psi N2
Si3N4+8%Y2O3+2%SiO	ORNL/SC-253/GPS1	Si3N4	8w%Y2O3+2w%SiO	1850C/2H/.3MPa N2/1900/2H/2MPa N2
Si3N4+8%Y2O3+3%BaO+3%SiO	ORNL/SC-291/GPS3	Si3N4	8w%Y2O3+3w%SiO+3w%SiO2	SINT/1750C/4H/15psi N
Si3N4+8%Y2O3+3%BaO+3%SiO	ORNL/SC-291/GPS4	Si3N4	8w%Y2O3+3w%SiO+3w%SiO2	SINT/1800C/4H/15psi N
Si3N4+8%Y2O3+3%BaO+3%SiO	ORNL/SC-291/GPS5	Si3N4	8w%Y2O3+3w%SiO+3w%SiO2	SINT/1850C/4H/15psi N
Si3N4+8%Y2O3+4%SiO2	ORNL/SC-281/GPS1	Si3N4	4w%Y2O3+4w%SiO2	1850C/2H/50psiN/1900C/2H/300ps
Si3N4+8%Y2O3+4%SiO2	ORNL/SC-281/GPS2	Si3N4	4w%Y2O3+4w%SiO2	1850C/2H/50psiN/1950C/2H/300ps
Si3N4+8%Y2O3+4%SiO2	ORNL/SC-281/GPS3	Si3N4	8w%Y2O3+4w%SiO2	SINT/1750C/4H/15psiN
Si3N4+8%Y2O3+4%SiO2	ORNL/SC-281/GPS4	Si3N4	8w%Y2O3+4w%SiO2	SINT/1800C/4H/15psiN
Si3N4+8%Y2O3+4%SiO2	ORNL/SC-281/GPS5	Si3N4	8w%Y2O3+4w%SiO2	SINT/1850C/4H/15psiN
Si3N4+8%Y2O3+4%SiO2	ORNL/SC-281/GPS5	Si3N4	8w%Y2O3+4w%SiO2	HOT-PRESSED
Si3N4+8%Y2O3+4%SiO2	ORNL/SC-293/GPS1	Si3N4	8w%Y2O3+4w%SiO2	1850C/2H/.3MPaN/1900/2H/2MPaN
Si3N4+8%YO+2%SiO+3%SiO	ORNL/SC-293/GPS2	Si3N4	8w%Y2O3+2w%SiO+3w%SiO2	1850C/2H/.3MPaN/1950/2H/2MPaN
Si3N4+8%YO+2%SiO+3%SiO	ORNL/SC-293/GPS2	Si3N4	8w%Y2O3+2w%SiO+3w%SiO2	1850C/2H/.3MPaN/1900/2H/2MPaN
Si3N4+8%YO+3%BaO+3%SiO	ORNL/SC-291/GPS1	Si3N4	8w%Y2O3+3w%BaO+3w%SiO2	1850C/2H/.3MPaN/1950/2H/2MPaN
Si3N4+8%YO+3%BaO+3%SiO	ORNL/SC-291/GPS2	Si3N4	8w%Y2O3+3w%BaO+3w%SiO2	HP/1725/60MIN
Si3N4+GN-10ADDITIVES	ORNL/SINGN10-1	Si3N4	Y2O3 +SiO	HP/1800/90MIN
Si3N4+GN-10ADDITIVES	ORNL/SINGN10-2	Si3N4	Y2O3 +SiO	HP/1800/180MIN
Si3N4+GN-10ADDITIVES	ORNL/SINGN10-3	Si3N4	Y2O3 +SiO	
Si3N4+GN-10ADDITIVES	KYOCERA/NLRC-90	Si3N4		
Si3N4+GN-10ADDITIVES	KYOCERA/NLRC-92	Si3N4		
Si3N4+GN-10ADDITIVES	KYOCERA/NLRC-91	Si3N4		
Silicon Carbide-based Ceramics				
HEXQLOYSA	CARBNDM/UDRI/2	SiC		
NC-433	NLRC/NORTON-1	Siliconized SiC		
NT-230	NORTON/UDRI-91	Siliconized SiC		
Zirconia-based Ceramics				
MASZ-67	BCL/ZRO-ZRO/1	ZrO2	MgO+Al2O3+SiO2+TiO2	+1350C/2H/AIR
MASZ-80	BCL/ZRO-ZRO/1	ZrO2	MgO+Al2O3+SiO2+TiO2	SINTERED/1500C/207MPa
Mg-PSZ	BCL/ZYCRONL/1	ZrO2	MgO	SINTERED/1500C/207MPa
Mg-PSZ	BCL/ZYCRONL/1+HT	ZrO2	MgO	SINTERED/1500C/207MPa
Y-TZP	NORT/MG008	ZrO2	4.66w%Y	
Y-TZP	NORT/MG024/FGS	ZrO2	5.27w%Y	
Y-TZP	NORT/MG024/NGS	ZrO2	5.27w%Y	

Section 1B - Material Background - Matrix/Processing, continued

Material	Batch Code	Primary Matrix	Additives	Densification Process
Silicon Nitride-based Ceramics				
Y-TZP	NORT/MG026	ZrO2	5.52w%Y	SINTERED/1500C/207MPa
Y-TZP	NORT/MG032	ZrO2	4.7w%Y	SINTERED/1500C/207MPa
Y-TZP	NORT/MG100	ZrO2	4.53w%Y,1.91w%Ce	SINTERED/1500C/207MPa
Y-TZP	NORT/MG100	ZrO2	4.49w%Y,3.99w%Ce	SINTERED/1500C/207MPa
Y-TZP	NORT/SD039	ZrO2	4.7w%Y	SINTERED/1500C/207MPa

Section 1C - Room-Temperature Properties

Material	Batch Code	Density g/cm ³	% Theo. Density	MCE Test	Young's Modulus GPa	Bend Strength MPa	Hardness Test	Hardness Value	Poisson's Ratio	Toughness Test	KIC MPa√m
Alumina-based Ceramics											
Ce-ZTA	NORT/Z16CE80A					889.0				DOUBLE TORSION	6.10
Ce-ZTA	NORT/Z24CE80A					840.0				DOUBLE TORSION	5.20
Ce-ZTA	NORT/Z16CE60A					1020.0				DOUBLE TORSION	7.50
Ce-ZTA	NORT/Z16CE60AM					889.0					
Ce-ZTA	NORT/Z18.5CE62A	4.67				889.0					
Silicon Nitride-based Ceramics											
GN-10	GCCD/NLRC-90	3.33		SONIC	283.0	779.0			0.250	CONTROLLED FLAW MICROINDENTATION	3.60 5.80
GN-10	GCCD/UDRI-90	3.24									
GTE PY6	AGTD/HIP										
GTE PY6	AGTD/HIP/MODI										
GTE PY6	ORN/LLOT										
NT-154	ORN/LKCL92										
NT-164	NORTON/UDRI-92										
Si3N4	CERA/MAT4/MIX6	3.25	1.00					VICKERS5KG 1480			5.50
Si3N4	CERA/MAT4/MIX7	3.28	1.00					VICKERS5KG 1450			6.05
Si3N4	CERA/MAT5/MIX10	3.26						VICKERS5KG 1399			6.30
Si3N4	CERA/MAT5/MIX11	3.29						VICKERS5KG 1421			9.00
Si3N4	CERA/MAT6/MIX18	3.28						VICKERS5KG 1358			8.80
Si3N4	CERA/MAT7/MIX25	3.29									
Si3N4	ORN/SC-283/GPS1	3.32	99.50			617.0					
Si3N4+11%La2O3+4%SiO2	ORN/SC-283/GPS2	3.32	99.50								
Si3N4+11%La2O3+4%SiO2	ORN/SC-283/GPS3	3.30	98.80								
Si3N4+11%La2O3+4%SiO2	ORN/SC-283/GPS4	3.31	99.00								
Si3N4+11%La2O3+4%SiO2	ORN/SC-283/GPS5	3.32	99.50								
Si3N4+11%LaO+2%SiO+3%SiO	ORN/SC-290/GPS1	3.34	99.10								
Si3N4+11%LaO+2%SiO+3%SiO	ORN/SC-290/GPS2	3.34	99.10								
Si3N4+11%LaO+2%SiO+3%SiO	ORN/SC-290/GPS3	3.31	98.20								
Si3N4+11%LaO+2%SiO+3%SiO	ORN/SC-290/GPS4	3.34	99.20								
Si3N4+11%LaO+2%SiO+3%SiO	ORN/SC-290/GPS5	3.35	99.40								
Si3N4+2%Y2O3+8%La2O3	ORN/SC-209/GPS1	2.86	87.80								
Si3N4+2%Y2O3+8%La2O3	ORN/SC-209/GPS2	3.00	92.00								
Si3N4+3%YO+4%LaO+2%AlO	ORN/SIN/YLA-1		98.60			883.0					6.70
Si3N4+3%YO+4%LaO+2%AlO	ORN/SIN/YLA-2		99.50			1052.0					
Si3N4+3%YO+4%LaO+2%AlO	ORN/SIN/YLA-2		100.00			1010.0					
Si3N4+3%YO+5%LaO+4%SiO	ORN/SC-282/GPS1	3.27	99.10								
Si3N4+3%YO+5%LaO+4%SiO	ORN/SC-282/GPS2	3.28	99.50								
Si3N4+3%YO+5%LaO+4%SiO	ORN/SC-282/GPS3	3.21	97.20								
Si3N4+3%YO+5%LaO+4%SiO	ORN/SC-282/GPS4	3.22	97.70								
Si3N4+3%YO+5%LaO+4%SiO	ORN/SC-282/GPS5	3.28	99.40								

Section 1C - Room-Temperature Properties, continued

Material	Batch Code	Density g/cm ³	% Theo. Density	MOE Test	Young's Modulus GPa	Bend Strength MPa	Hardness Test	Hardness Value	Poisson's Ratio	Toughness Test	KIC MPa√m
Silicon Nitride-based Ceramics											
Si ₃ N ₄ +8%Y ₂ O ₃	ORNL/SC-205/GPS2	2.28	69.20								
Si ₃ N ₄ +8%Y ₂ O ₃ +2%BaO+3%SiO	ORNL/SC-293/GPS3	3.20	97.90								
Si ₃ N ₄ +8%Y ₂ O ₃ +2%BaO+3%SiO	ORNL/SC-293/GPS4	3.23	98.90								
Si ₃ N ₄ +8%Y ₂ O ₃ +2%BaO+3%SiO	ORNL/SC-293/GPS5	3.21	98.20								
Si ₃ N ₄ +8%Y ₂ O ₃ +2%SiO	ORNL/SC-253/GPS1	2.38	72.60								
Si ₃ N ₄ +8%Y ₂ O ₃ +3%BaO+3%SiO	ORNL/SC-291/GPS3	2.55	77.60								
Si ₃ N ₄ +8%Y ₂ O ₃ +3%BaO+3%SiO	ORNL/SC-291/GPS4	2.81	85.40								
Si ₃ N ₄ +8%Y ₂ O ₃ +3%BaO+3%SiO	ORNL/SC-291/GPS5	2.67	81.30								
Si ₃ N ₄ +8%Y ₂ O ₃ +4%SiO ₂	ORNL/SC-281/GPS1	3.24	99.70								
Si ₃ N ₄ +8%Y ₂ O ₃ +4%SiO ₂	ORNL/SC-281/GPS2	3.27	100.00								
Si ₃ N ₄ +8%Y ₂ O ₃ +4%SiO ₂	ORNL/SC-281/GPS3	3.10	95.40								
Si ₃ N ₄ +8%Y ₂ O ₃ +4%SiO ₂	ORNL/SC-281/GPS4	3.19	98.10								
Si ₃ N ₄ +8%Y ₂ O ₃ +4%SiO ₂	ORNL/SC-281/GPS5	3.21	98.90			635.0					
Si ₃ N ₄ +8%Y ₂ O ₃ +4%SiO ₂	ORNL/SN8YO4SiO-1										
Si ₃ N ₄ +8%YO+2%SiO+3%SiO	ORNL/SC-293/GPS1	3.26	99.60								
Si ₃ N ₄ +8%YO+2%SiO+3%SiO	ORNL/SC-293/GPS2	3.29	100.00								
Si ₃ N ₄ +8%YO+3%BaO+3%SiO	ORNL/SC-291/GPS1	3.02	91.90								
Si ₃ N ₄ +8%YO+3%BaO+3%SiO	ORNL/SC-291/GPS2	3.06	93.10			943.0					6.20
Si ₃ N ₄ +GN-10ADDITIVES	ORNL/SINGN10-1		98.00			1042.0					
Si ₃ N ₄ +GN-10ADDITIVES	ORNL/SINGN10-2		100.00			1044.0					
Si ₃ N ₄ +GN-10ADDITIVES	ORNL/SINGN10-3		100.00			710.0					
SN-251	KYOCERA/NLRC-90			STRAINGAGE	309.0		VICKERS	15.87GPa		INDENTATION STRN	7.11
SN-252	KYOCERA/NLRC-92	3.39									
SN-260	KYOCERA/NLRC-91										
Silicon Carbide-based Ceramics											
HEXOLOYS A	CARBNDM/UDRI/2	3.17		SONIC	427.0	331.0	VICKERS	2539kg/mm ²		CONTROLLED FLAW	2.00
NC-433	NLRC/NORTON-1										
NT-230	NORTON/UDRI-91	3.08		ULTRASONIC	402.3	435.0	VICKERS200g	2195kg/mm ²		CONTROLLED FLAW	2.30
Zirconia-based Ceramics											
MASZ-67	BCL/ZRO-ZRO/1				111.7	122.0			0.220		
MASZ-80	BCL/ZRO-ZRO/1				141.2	158.0			0.220		
Mg-PSZ	BCL/ZYCRONL/1				202.0	589.0			0.220		
Mg-PSZ	BCL/ZYCRONL/1+HT				201.4	291.0			0.220		
Y-TZP	NORT/MG008					1164.0					
Y-TZP	NORT/MG024/FGS										
Y-TZP	NORT/MG024/NGS					1220.0					

Section 1C - Room-Temperature Properties, continued

Material	Batch Code	Density g/cm³	% Theo. Density	MOE Test	Young's Modulus GPa	Bend Strength MPa	Hardness Test	Hardness Value	Poisson's Ratio	Toughness Test	KIC MPa√m
Silicon Nitride-based Ceramics											
Si3N4+4%Y2O3+2%SiO	ORNL/SC-261/GPS1	3.06	91.30								
Si3N4+4%Y2O3+2%SiO	ORNL/SC-261/GPS2	3.00	89.60								
Si3N4+4%Y2O3+6%La2O3	ORNL/SC-220/GPS1	2.43	73.70			848.0					
Si3N4+4%Y2O3+8%SiO2	ORNL/SN4YO8SiO-1										
Si3N4+4%YO+6%LaO+2%SiO	ORNL/SC-276/GPS1	3.13	93.90								
Si3N4+4%YO+6%LaO+2%SiO	ORNL/SC-276/GPS2	3.22	96.60								
Si3N4+4%YO+6%LaO+2%SiO+0.2%SiO	ORNL/SC-277/GPS1	3.28	98.50								
Si3N4+4%YO+6%LaO+2%SiO+0.2%SiO	ORNL/SC-277/GPS2	3.22	96.70								
Si3N4+6%La2O3+4%Y2O3	ORNL/SNLY-U10/1	2.91				649.0					7.00
Si3N4+6%La2O3+4%Y2O3	ORNL/SNLY-U10/2	3.12									
Si3N4+6%Y2O3+1%SiO+4%SiO	ORNL/SC-261/GPS1	3.20	95.50								
Si3N4+6%Y2O3+1%SiO+4%SiO	ORNL/SC-261/GPS2	3.12	93.20							6.6	
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-1		100.00			916.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-2		100.00			1142.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-3		100.00			942.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-4					849.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-5		99.60			1234.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-B1		98.00			777.0				7.66.6	
Si3N4+6%Y2O3+2%Al2O3	ORNL/SINYOALO-B2		99.20			809.0				7.66.6	
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-12SX/1	3.26				720.0					6.10
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-9FW					960.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-LC12SX					1048.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-P21C3					1014.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-TS-10					798.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-TS-10Y					834.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-TS-8					598.0					
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-U10/1	3.24				703.0					5.70
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-U10/2	3.22									5.90
Si3N4+6%Y2O3+2%Al2O3	ORNL/SNYA-UBE-10					1142.0					
Si3N4+8%La2O3+2%Al2O3	ORNL/SNLA-12SX/1	3.32				650.0					6.70
Si3N4+8%La2O3+2%Al2O3	ORNL/SNLA-U10/1	3.30				827.0					6.80
Si3N4+8%La2O3+2%Al2O3	ORNL/SC-263/GPS1	2.32	69.30								
Si3N4+8%La2O3+2%SiO	ORNL/SC-263/GPS2	2.41	72.00								
Si3N4+8%La2O3+2%SiO	ORNL/SC-264/GPS1	2.76	82.30								
Si3N4+8%LaO+7%YbO+4%SiO	ORNL/SNLYS-1					872.0					5.90
Si3N4+8%LaO2+2%Al2O3	ORNL/SINALOLAO-1		98.20			1088.0					
Si3N4+8%LaO2+2%Al2O3	ORNL/SINALOLAO-2		100.00			1043.0					
Si3N4+8%LaO2+2%Al2O3	ORNL/SINALOLAO-3					1075.0					
Si3N4+8%LaO2+2%Al2O3	ORNL/SINALOLAO-5		99.70			1065.0					
Si3N4+8%Y2O3	ORNL/SC-205/GPS1	2.37	71.80								

Section 1C - Room-Temperature Properties, continued

Material	Batch Code	Density g/cm ³	% Theo. Density	MCE Test	Young's Modulus GPa	Bend Strength MPa	Hardness Test	Hardness Value	Poisson's Ratio	Toughness Test	KIC MPa√m
Silicon Nitride-based Ceramics											
Y-TZP	NORT/MG026					909.0					
Y-TZP	NORT/MG032					1137.0					
Y-TZP	NORT/MG100					986.0					
Y-TZP	NORT/MG100					806.0					
Y-TZP	NORT/SD039					1146.0					

Section 2A - Notes on Alumina-based Ceramics

Material Batch Code Note Topic	Notes
Ce-ZTA NORT/Z24CE80A PROCESS	<p>This material was made from CeO₂+ZrO₂ powder and Sumitomo AKP-30 Al₂O₃ powder. The CeO₂-ZrO₂ powder was prepared from rapidly solidified pebbles by vibratory milling in water. All powders were then planetary milled using PSZ containers and Y-TZP balls. This aqueous slurry was then poured into liquid N₂ and freeze-dried to produce a fluffy powder with soft agglomerates. Billets were formed by steel die-pressing at 70 MPa and CIPing at 210 MPa. The green forms were sintered at 1500°C/3 h in a furnace with MoSi₂ elements, then HIPed at 1500°C for 45 min at 210 MPa in argon.</p>
Ce-ZTA NORT/Z16CE60A PROCESS	<p>This material was made from: CeO₂+ZrO₂ powder and Sumitomo AKP-30 Al₂O₃ powder. The CeO₂-ZrO₂ powder was prepared from rapidly solidified pebbles by vibratory milling in water. All powders were then planetary milled using PSZ containers and Y-TZP balls. This aqueous slurry was then poured into liquid N₂ and freeze-dried to produce a fluffy powder with soft agglomerates. Billets were formed by steel die-pressing at 70 MPa and CIPing at 210 MPa. The green forms were sintered at 1500°C/3 h in a furnace with MoSi₂ elements, then HIPed at 1500°C for 45 min at 210 MPa in argon.</p>
Ce-ZTA NORT/Z16CE80A PROCESS	<p>This material was made from CeO₂+ZrO₂ powder and Sumitomo AKP-30 Al₂O₃ powder. The CeO₂-ZrO₂ powder was prepared from rapidly solidified pebbles by vibratory milling in water. All powders were then planetary milled using PSZ containers and Y-TZP balls. This aqueous slurry was then poured into liquid N₂ and freeze-dried to produce a fluffy powder with soft agglomerates. Billets were formed by steel die-pressing at 70 MPa and CIPing at 210 MPa. The green forms were sintered at 1500°C/3 h in a furnace with MoSi₂ elements, then HIPed at 1500°C for 45 min at 210 MPa in argon.</p>

Section 2A - Notes on Alumina-based Ceramics, continued

Material Batch Code Note Topic	Notes
Ce-ZTA NORT/Z18.5CE62A PROCESS	The CeO ₂ -ZrO ₂ -Al ₂ O ₃ rapidly solidified powder was made by planetary milling in water of a crude made by rapid-solidification technique developed at Norton Plasma Materials. Before milling, the Al ₂ O ₃ was calcined at 1050°C to crystallize the amorphous Al ₂ O ₃ and to reduce its reactivity toward water. Billets were formed by either die-pressing/CIPing or by pressure casting electrostatically stabilized and filtered (5-μm filter) aqueous solution. After drying, the billets were CIPed at 210 MPa, then pressureless sintered at 1600°C for varying times.
Ce-ZTA NORT/Z18.5CE62AM PROCESS	The CeO ₂ -ZrO ₂ -Al ₂ O ₃ rapidly solidified powder was made by planetary milling in water of a crude made by rapid-solidification technique developed at Norton Plasma Materials. Before milling, the Al ₂ O ₃ was calcined at 1050°C to crystallize the amorphous Al ₂ O ₃ and to reduce its reactivity toward water. A small amount of PVA was added to the slurry which was then flocculated with acetone, a non-solvent for PVA. The results were then colloid-pressed into a disc which was sintered at 1500°C for 3 h, then HIPed at 1500°C for 45 min at 210 MPa in argon.

Section 2B - Notes on Silicon Nitride-based Ceramics

Material Batch Code	Topic	Notes
GTE PY6 AGTD/HIP	GENERAL	This particular batch was made from a blend of fine and coarse particle powders. Another batch was made with less of the coarse powder, but the strength values turned out to be higher. See GTE PY6, AGTD/HIP/MODI, for details.
GTE PY3 AGTD/HIP/MODI	GENERAL	This batch was made with less of the coarse particle powder when GTE decided that there wouldn't be enough to complete specimen production for this program. The results indicate that this modified PY6 is slightly stronger than the material made with more coarse powder.
NKK NLRC-91	GENERAL	Given density measured by buoyancy method. Given hardness is average of 5 indents each at 4 loads: 49, 98, 196, and 294N. Nominal fracture toughness evaluated by measuring the cracks produced by indentations of same loads as used for hardness measurements. KIC at 22°C using indentation strength method was 8.48 MPa m ^{1/2} . KIIC calculated to be =10.84 MPa m ^{1/2} -1.30.
NT-164 NORTON/JDRI-92	GENERAL	NT-164 is an improved version of Norton's NT-154. The improvements were made in processing parameters to improve properties. Microstructural differences in the two ceramics indicate both share bimodal distributions of grain sizes and shapes. The NT-164 contains a secondary phase, Si ₂ ON ₂ , not present in the NT-154. High-resolution microscopy indicates the lack of an amorphous film separating the Si ₃ N ₄ grains in the NT-164, but is present in NT-154. Transmission electron microscopy indicates very small quantities of yttrium-containing material remain in some of the grain boundaries. The lack of an amorphous film in NT-164 appears to be the most significant improvement.
Si ₃ N ₄ CERA/MAT4/MIX6	MICROSTRUC	18- to 25-μm pores, about 0.06v%. Only beta-Si ₃ N ₄ phase present in finished product.
Si ₃ N ₄ CERA/MAT4/MIX6	PROCESS	Starting powders: Si ₃ N ₄ (Ube SN-10), Y ₂ O ₃ (H. C. Starck gr. std.), and SiO ₂ (Cab-O-Sil from Cabot Corp.). SiO ₂ and Y ₂ O ₃ were added to water and mechanically dispersed using an attritor. After 2 min, the ultrasonic chamber was turned on and the slurry was recirculated through both for 20 more min. The Si ₃ N ₄ powder was added and the slurry was mixed in both for an hour. PH adjustment to 9 was made by adding NH ₄ OH. Viscosity was adjusted by adding up to 5 mL of dispersant and wetting

Section 2B - Notes on Silicon Nitride-based Ceramics

Material Batch Code	Topic	Notes
Si3N4(continued) CERA/MAT4/MIX6	PROCESS	agent. Slurry was screened through 325 mesh, then dried. Powder was isopressed into rods and billets for sintering at 1850°C for 5 h. Fifty percent of billets formed shrinkage cracks - slowing down heating should help this problem. BOMAS Machine Spec. made the MOR bars by MIL-STD-1942B.
Si3N4 CERA/MAT4/MIX7	MICROSTRUCTURE	30- to 40- μ m pores, about 0.05v%. Phases present include: beta-Si3N4, γ -Si2O7, Mo2C, and MoSi2.
Si3N4 CERA/MAT4/MIX7	PROCESS	Starting powders: Si3N4(Ube SN-10), Y2O3(H. C. Starck gr. std), SiO2(Cab-O-Sil) from Cabot Corp.), and Mo2C (H. C. Starck gr. 1.5 to 2.5). SiO2, Y2O3, and Mo2C were added to water using an attritor. After 2 min, the ultrasonic chamber was turned on and the slurry was recirculated through both for 20 more min. The Si3N4 powder was added and the slurry was mixed in both for an hour. PH adjustment to 9 was made by adding NH4OH. Viscosity was adjusted by adding up to 5 mL of dispersant and wetting agent. Slurry was screened through 325 mesh, then dried. Powder was isopressed into rods and billets for sintering at 1850°C for 5 h. Fifty percent of billets formed shrinkage cracks - slowing down heating should help this problem. BOMAS Machine Spec. made the MOR bars by MIL-STD-1942B.
Si3N4+6%Y2O3+2%Al2O3 ORNLSNYA-9FW	GENERAL	Starting Si3N4 powder was Denka's 9FW: Surface area = 10.9m ² /g, alpha phase content = 92.1%, oxygen content = 0.98w%, total impurity content = <0.5w%, mean particle size = 0.80 μ m.
Si3N4+6%Y2O3+2%Al2O3 ORNLSNYA-LC12SX	GENERAL	Starting Si3N4 powder was Starck's LC-12SX: Surface area = 19.1m ² /g, alpha phase content = 97.5%, oxygen content = 2.06w%, total impurity content = <200 ppm, mean particle size = 0.41 μ m.
Si3N4+6%Y2O3+2%Al2O3 ORNLSNYA-P21C3	GENERAL	Starting Si3N4 powder was Denka's P21C3: Surface area = 11m ² /g, alpha phase content = 94.4%, oxygen content = 1.3w%, total impurity content = <300 ppm, mean particle size = 0.80 μ m.
Si3N4+6%Y2O3+2%Al2O3 ORNLSNYA-TS-10	GENERAL	Starting Si3N4 powder was Tosoh's TS-10: Surface area = 14.6m ² /g, alpha phase content = 97%, oxygen content = 1.3w%, total impurity content = <400 ppm.

Section 2B - Notes on Silicon Nitride-based Ceramics

Material Batch Code	Topic	Notes
Si3N4+6%Y2O3+2%Al2O3 ORNL/SNYA-TS-10Y	GENERAL	Starting Si3N4 powder was Tosoh's TS-10Y: Surface area = 9.6m ² /g, alpha phase content = 99%, oxygen content = 0.8w%, total impurity content = <0.06w%.
Si3N4+6%Y2O3+2%Al2O3 ORNL/SNYA-TS-8	GENERAL	Starting Si3N4 powder was Tosoh's TS-8: Surface area = 15m ² /g, alpha phase content = 93%, oxygen content = 1.5w%, total impurity content = <0.11w%.
Si3N4+6%Y2O3+2%Al2O3 ORNL/SNYA-UBE-10	GENERAL	Starting Si3N4 powder was Ube's E-10: Surface area = 11.7m ² /g, alpha phase = >95%, oxygen content = 1.40w%, total impurity content = <300 ppm.
SN-252 KYOCERANLRC-92	GENERAL	Given density measured by buoyancy method. Given hardness is average of 5 indents each at 4 loads: 49, 98, 196, and 294N. Nominal fracture toughness evaluated by measuring the cracks produced by indentations of same loads as used for hardness measurements. KIC at 22°C using crack size method was 5.03 MPa·m ^{1/2} .

Section 2C - Notes on Zirconia-based Ceramics

Material Batch Code	Topic	Notes
Y-TZP NORT/MG008	PROCESS	Yttria and Ce-doped ZrO ₂ were prepared by arc-melting and rapid solidification. The crude material was then vibratory milled (Sweco) to produce average size of 0.7 µm. Powder was then dry-pressed and CIPed at 207 MPa and fired at 1500°C. A few billets were also gas-pressure sintered at 1500°C.
Y-TZP NORT/MG024FGS	PROCESS	Yttria and Ce-doped ZrO ₂ were prepared by arc-melting and rapid solidification. The crude material was then vibratory milled (Sweco) to produce average particle size of 0.5 µm. Powder was then dry-pressed and CIPed at 207 MPa and fired at 1500°C. A few billets were also gas-pressure sintered at 1500°C.
Y-TZP NORT/MG024NGS	PROCESS	Yttria and Ce-doped ZrO ₂ were prepared by arc-melting and rapid solidification. The crude material was then vibratory milled (Sweco) to produce average particle size of 0.7 µm. Powder was then dry-pressed and CIPed at 207 MPa and fired at 1500°C. A few billets were also gas-pressure sintered at 1500°C.
Y-TZP NORT/MG026	PROCESS	Yttria and Ce-doped ZrO ₂ were prepared by arc-melting and rapid solidification. The crude material was then vibratory milled (Sweco) to produce average particle size of 0.7 µm. Powder was then dry-pressed and CIPed at 207 MPa and fired at 1500°C. A few billets were also gas-pressure sintered at 1500°C.
Y-TZP NORT/MG026CL	PROCESS	Yttria and Ce-doped ZrO ₂ were prepared by arc-melting and rapid solidification. The crude material was then vibratory milled (Sweco) to produce average particle size of 0.4 µm. Powder was then dry-pressed and CIPed at 207 MPa and fired at 1500°C. A few billets were also gas-pressure sintered at 1500°C.
Y-TZP NORT/MG032	PROCESS	Yttria and Ce-doped ZrO ₂ were prepared by arc-melting and rapid solidification. The crude material was then vibratory milled (Sweco) to produce average particle size of 0.7 µm. Powder was then dry-pressed and CIPed at 207 MPa and fired at 1500°C. A few billets were also gas-pressure sintered at 1500°C.

Section 2C - Notes on Zirconia-based Ceramics, continued

Material Batch Code	Topic	Notes
Y-TZP NORT/MG100	PROCESS	Yttria and Ce-doped ZrO ₂ were prepared by arc-melting and rapid solidification. The crude material was then vibratory milled (Sweco) to produce average particle size of 0.7 μm . Powder was then dry-pressed and CIPed at 207 MPa and fired at 1500°C. A few billets were also gas-pressure sintered at 1500°C.

Section 3 - Density Test Results for Alumina-based Ceramics

Material	Batch Code	Specimen Number	Heat Treatment	Forming Process	Temp °C	Density g/cm ³	Theo. Density %	Comments
Test Method = ARCHIMEDES								
Ce-ZTA	NORT/Z18.5CE62A	SUMMARY	SIN/1600C/1H	DIE-PRESSED/CIPed/FIRED	20	4.7100	100.8	
Ce-ZTA	NORT/Z18.5CE62A	SUMMARY	SIN/1600C/3H	DIE-PRESSED/CIPed/FIRED	20	4.6800	100.2	
Ce-ZTA	NORT/Z18.5CE62A	SUMMARY	SIN/1600C/6H	DIE-PRESSED/CIPed/FIRED	20	4.6200	98.9	
Ce-ZTA	NORT/Z18.5CE62A	SUMMARY	SIN/1600C/1H	PRESSR-CAST/CIPed/FIRED	20	4.6600	99.8	UNFILTERED SUSPENSIN
Ce-ZTA	NORT/Z18.5CE62A	SUMMARY	SIN/1600C/1H	PRESSR-CAST/CIPed/FIRED	20	4.7200	101.1	FILTERED SUSPENSION

Section 4 - Thermal Properties of GTE PY6

Material	Batch Code	Data Type	Temp. °C	Specific Heat Wsec/gmK	Diffusivity cm ² /sec	Conductivity W/cmK
GTE PY6	AGTD/HIP	SUMMARY	23	0.6795	0.3010	0.6633
GTE PY6	AGTD/HIP	SUMMARY	100	0.7730	0.2210	0.5541
GTE PY6	AGTD/HIP	SUMMARY	200	0.8910	0.1670	0.4826
GTE PY6	AGTD/HIP	SUMMARY	300	0.9585	0.1367	0.4243
GTE PY6	AGTD/HIP	SUMMARY	400	1.0230	0.1185	0.3932
GTE PY6	AGTD/HIP	SUMMARY	500	1.0990	0.1034	0.3685
GTE PY6	AGTD/HIP	SUMMARY	600	1.1200	0.0911	0.3309
GTE PY6	AGTD/HIP	SUMMARY	700	1.1550	0.0808	0.3027
GTE PY6	AGTD/HIP	SUMMARY	800	1.1800	0.0733	0.2803
GTE PY6	AGTD/HIP	SUMMARY	900	1.2030	0.0666	0.2596
GTE PY6	AGTD/HIP	SUMMARY	1000	1.2230	0.0606	0.2404
GTE PY6	AGTD/HIP	SUMMARY	1200	1.2550	0.0497	0.2021
GTE PY6	AGTD/HIP	SUMMARY	1400	1.2800	0.0435	0.1806

Material	Batch Code	Data Type	Temp. °C	Coef Therm. Exp. 1.0E-06in./in./°C
GTE PY6	AGTD/HIP	SUMMARY	117	1.578
GTE PY6	AGTD/HIP	SUMMARY	217	1.986
GTE PY6	AGTD/HIP	SUMMARY	317	2.276
GTE PY6	AGTD/HIP	SUMMARY	417	2.498
GTE PY6	AGTD/HIP	SUMMARY	517	2.672
GTE PY6	AGTD/HIP	SUMMARY	617	2.821
GTE PY6	AGTD/HIP	SUMMARY	717	2.951
GTE PY6	AGTD/HIP	SUMMARY	817	3.080
GTE PY6	AGTD/HIP	SUMMARY	917	3.182
GTE PY6	AGTD/HIP	SUMMARY	1017	3.351
GTE PY6	AGTD/HIP	SUMMARY	1117	3.538
GTE PY6	AGTD/HIP	SUMMARY	1217	3.895
GTE PY6	AGTD/HIP	SUMMARY	1317	4.430
GTE PY6	AGTD/HIP	SUMMARY	1417	4.890

Section 5 - Joint Information

Joint Code	Notes
BCL/SA11/ZRZR/HP	<p>2 Mg-PSZ (Zycron L) billets were joined together by hotpressing the Mg-PSZ+CTS(CaO-TiO₂-SiO₂)+Mg-PSZ sandwich in a creep testing unit at 1420°C and 13.79 MPa. Bend bars, 2.54 x 5.08 x 63.5 mm, were machined from the 50.8-mm-diam x 38.1-mm-long cylinder and tested in a 4-point fixture with outer span of 31.75 mm and 19.05 mm inner span. A thermal expansion mismatch between the materials caused a poor quality joint.</p>
BCL/SA11/ZRZR/HPZ	<p>Bend bars, 2.54 x 5.08 x 63.5 mm, were machined from a 50.8-mm-diam x 38.1-mm-long cylinder and tested in a 4-point fixture with inner/outer spans of 19.05/31.75 mm. These specimens were joined in the same manner as for BCL/ZRCTSZR/HP1 except that 30 wt % ZrO₂ was added to the CTS layer to overcome thermal expansion problems which caused extensive cracking. Two D-shaped Mg-PSZ billets were pressed together with the CTS-ZrO₂ layer in between. Specimens were cut so that the joint was in the middle.</p>
BCL/SA12/ZRFE/HP	<p>A 50.8-mm-square x 19.05-mm-thick piece of nodular cast iron (NCI) [ground with 240-grit SiC paper] was brazed to a 50.8-mm-diam x 19.05-mm-thick disk of Mg-PSZ (ZycronL) which had been coated with .3-μm-thick layer of Ti at NASA-Lewis using RF-sputter. The cast iron was NOT coated with copper. Each specimen was ultrasonically cleaned w/acetone, then alcohol. The iron was placed on top the MG-PSZ to provide a load during brazing. Details of the braze: temperature increased 30°C/min to 650°C, then 7°C/min to 720°C. Power was then shut off and the joint allowed to cool to room temperature. All was performed in a vacuum about 1.E-05 torr.</p>
BCL/SA11/ZRFE/S	<p>Copper was applied by vacuum evaporation to NCI using a Kinney vacuum evaporator with 99.9% Cu beads at 1.0E-04 torr for 4 min. Coating was about 20 μm thick. Bonding to the titanium sputter-coated Mg-PSZ took place in a graphite resistance-heated furnace with the materials to be joined in a hot-pressing fixture. Brazing conditions were 4-5E-05 torr at 750°C for 10 min.</p>

Section 5 - Joint Information, continued

Joint Code	Notes
BCL/ZR50ZR/1350	A slurry made from MASZ powder (containing 50% ZrO ₂) and methanol was applied to the joining surfaces of the two Zycron-L (Mg-PSZ) billets. The joining surfaces were then pressed together at about 300 psi and heated to 1350°C.
BCL/ZR67ZR/1350 BCL/ZR67ZR/D	A slurry made from MASZ powder (containing 67% ZrO ₂) and methanol was applied to the joining surfaces of the two Zycron-L (Mg-PSZ) billets. The joining surfaces were then pressed together at about 300 psi and heated to 1350°C.
BCL/ZR80ZR/1350	A slurry made from MASZ powder (containing 80% ZrO ₂) and methanol was applied to the joining surfaces of the two Zycron-L (Mg-PSZ) billets. The joining surfaces were then pressed together at about 300 psi and heated to 1350°C.
BCL/ZR67ZR/1400	A slurry made from MASZ powder (containing 67% ZrO ₂) and methanol was applied to the joining surfaces of the two Zycron-L (Mg-PSZ) billets. The joining surfaces were then pressed together at about 300 psi and heated to 1400°C.
BCL/ZR80ZR/1400	A slurry made from MASZ powder (containing 80% ZrO ₂) and methanol was applied to the joining surfaces of the two Zycron-L (Mg-PSZ) billets. The joining surfaces were then pressed together at about 300 psi and heated to 1400°C.

Section 5 - Joint Information, continued

Joint Code	Notes
BCL/ZRNCI/1	<p>An Mg-PSZ, Zycron-L, was brazed to NCI using the active filler metal process. The filler, Incusil ABA, had a composition of 59.18w%Ag, 27.5w%Cu, 12.13w%In, and 1.18w%Ti. All mating surfaces were ground to a 220-grit finish. The Zycron-L surfaces were further polished with a vibratory polisher to a specular finish using successive grades of diamond paste. Before assembly, the zirconia was cleaned with acetone, then rinsed with methanol. The NCI was left in the as-ground state. Filler metal foils were lightly abraded to remove or break up any native oxides. Brazing was performed at Ohio State University in a graphite resistance-heated vacuum hot press without an applied load. Typical vacuums ranged from 2E-05 to 1E-04 torr. The heating schedule for brazing was: 10 to 12°C/min to 650°C, then 3 to 5°C to 735°C. The cooling rate was about 7°C/min to room temperature. The power was turned off at 732°C to allow for slow cooling.</p>

APPENDIX B. TEST RESULTS

Section 1. Test Background Information

Test Rig Name Test Type WBS Study	Test Background Information
CFATNORT1 CYCLIC FATIGUE 1.2.3-NORTON	MIL-STD-1942 "B" bars (3 x 4 x 50 mm) with the joint in the middle of the bar, were tension-tension loaded (no load reversal) in a 4-point fixture at room temperature. Upper and lower limits were based on a percentage of average MOR at room temperature. Initial stress was at 30%, cycling between 10 and 50% average strength. If samples survived 1000 cycles @ 1 Hz, the stress was raised 10% and the test run 1000 more cycles. This stepping increased until the specimen broke.
CFATORN1L1 CYCLIC FATIGUE 3.2.1.4-ORN1L	Cylindrical rod specimens, like those used in tensile tests, were loaded in tension to a predetermined stress, then unloaded (one cycle = 1 load + 1 unload). No compression was used. If necessary, the stress was stepped up in intermediate increments until failure occurred.
CREPORN1L2 CREEP 3.2.1.5-ORN1L	Specimen geometry: buttonhead tensile rods with a 6.3-mm-diam, 32-mm-long uniform gage section. All circumferential marks in gage section were removed by final longitudinal grinding to a 0.4- μ m (rms) finish. Gage section was not surface polished. Tests were performed on a lever-arm creep-testing machine equipped with a microprocessor-driven slider resting atop the arm to maintain closed-loop, load/stress control. Constant load control precision was about 0.05 kgf. Self-aligning grips were incorporated into the load-train assembly. Furnace was low-profile, 2-zone, controlled-resistance type that heats center of specimen leaving ends for "cold-gripping." Temperature gradient between gage center and end was less than 0.5% of max. temperature at center. Strain was measured using a laser-based diffractive strain extensometer. Specimens were loaded by deadweight using the lever arm.
CREPORN1L2C CYCLIC CREEP 3.2.1.5-ORN1L	These tests were started like normal creep tests, then were "cycled" every 12 to 24 h to a higher stress until failure occurred. Cylindrical buttonhead tensile-type specimens were run in uniaxial tension.

Section 1. Test Background Information, continued

Test Rig Name Test Type WBS Study	Test Background Information
ARCHIMEDES DENSITY 1.2.3-NORT	The Archimedes method uses the weight and volume of water displaced as the object placed in the water container to determine the density.
DFATAGTD1 DYNAMIC FATIGUE 3.2.2.2 - AGTD	Specimens were 3 x 4 x 50-mm MOR-type bend bars. Test fixture was 4-point bend with inner span of 20 mm, outer span of 40 mm. Tests were loaded at 0.508 mm/min and run at 1200°C.
DFATNLRC1 DYNAMIC FATIGUE 3.2.1.7 - NLRC	2.7 x 4 x 50-mm bar specimens were broken in a 4-point bend fixture with inner span of 20 mm, outer span of 40 mm. All tests were run in ambient air. Heating rate of furnace was 12°C/min. Each specimen was held at test temperature about 20 min prior to testing. Load was stepped up until failure occurred.
DFATNORT1 DYNAMIC FATIGUE 3.3.1.4 - UDRI	These tests were performed at Norton to confirm results obtained by UDRI. Cylindrical buttonhead rod specimens with 6.35-mm-diam x 35-mm-long gage sections were used in "identical" test conditions to those used at UDRI on the NT-154 specimens.
DFATORN1 DYNAMIC FATIGUE 3.2.1.6 - ORNL	Test specimens were cylindrical rods with a 35-mm-long x 6.35-mm-diam gage section. Tests were run in uniaxial tension.
DFATUDRI1 DYNAMIC FATIGUE 3.3.1.4 - UDRI	Tests were run at 1328°C using cylindrical buttonhead tensile-type specimens. Speckle interferometry was used to check for off-axis bending. Two thermocouples were used to measure hot zone temperatures in the short furnace, and one thermocouple was used on the gage section.

Section 1. Test Background Information, continued

Test Rig Name Test Type WBS Study	Test Background Information
MOR4AGTD1 MOR 4-PT BEND 3.2.2.2-AGTD	Specimens are nominally 4 x 3 x 50 mm, with an inner load span of 20 mm, outer span of 40 mm. Most bars were tested at a crosshead speed of 0.508 mm/min.
MOR4AGTDX MOR 4-PT BEND 3.2.2.2-AGTD	Two sets of 5 specimens (4 x 3 x 50 mm) were oxidized in an air furnace at 1400°C for 50 and 200 h, respectively. The bars were weighed, then tested in 4-point bending. Fractography indicated an oxide thickness of 2.3 µm for the 50-h specimens, 2.8 µm for the 200-h specimens.
MOR4BCL1 MOR 4-PT BEND 1.4.1-BCL	Specimens 5.08 x 2.54 x 50 mm (nominal) were finished with 110-grit diamond grinding wheel. Inner span of fixture was 19.05 mm, outer span was 31.75 mm. Testing fixture was self-aligning, permitting free rotation in two directions.
MOR4CERA1 MOR 4-PT BEND	Specimens were 3 x 4 x 50-mm bars cut from billets, 83.82 x 83.82 x 13.2 mm, by Bomas Machining Spec., Inc. Tests were performed using MIL-STD-1942(MR) B.
MOR4NLRC1 MOR 4-PT BEND 3.2.1.7-NLRC	Tests were conducted on lever-arm compression creep-test machines. Specimens (2.8 x 4 x 50 mm nominal) were broken using an SiC 4-point bend fixture with outer spans of 40 mm, inner span of 20 mm.
MOR4NLRC2 MOR 4-PT BEND 3.2.1.7-NLRC	Specimen geometry = 4 x 3 x 50 mm nominal. Fixture was SiC with 40-mm outer span, 20-mm inner span. High load rate was used to minimize slow crack growth effects.
MOR4NORTA MOR 4-PT BEND 1.2.3-NORTON	Specimens were 3 x 3 x 30-mm MOR bars (3 x 4 x 50 mm). Testing fixture had an inner span of 13 mm, outer span of 25 mm.

Section 1. Test Background Information, continued

Test Rig Name Test Type WBS Study	Test Background Information
MOR4NORTZ MOR 4-PT BEND 1.2.3 - NORTON	Specimens 3.175 x 3.25 x 35 mm were machined from fired billets, then broken in a 4-point bend fixture using an inner span of 12.7 mm, outer span of 25.4 mm. Tests at room temperature were run at a crosshead speed of 0.0085mm/s, while tests at elevated temperatures used a faster crosshead speed (see test results for specifics).
MOR4ORNL2 MOR 4-PT BEND 3.3.1.5-ORNL	Specimen geometry for MOR bars was 3 x 4 x 50 mm. All specimens were broken in air at room temperature. The test rig outer span was 40 mm, inner span was 20 mm. Specimens were polished longitudinal to .25 μ m. Tests were performed according to MIL-STD-1942(MR).
MOR4UDRI2 MOR 4-PT BEND 3.3.1.4-UDRI	Bend tests were made using 2 Instron Universal Testing Machines (Model 1123) following MIL-STD-1942(MR). High-temperature measurements were conducted in two ATS #3320 high-temperature furnaces. Test specimens were 3 x 4 x 50 mm with the tensile surface ground and polished to 16- μ in. finish [MIL-STD-1942(MR), size B]. Long edges were rounded and polished to minimize edge failures. The 4-point bend tests had outer spans of 40 mm, inner spans of 20 mm. Bend fixtures for room-temperature tests were made from steel. For higher temperatures, the fixtures were made of SiC.
TENSNLRC1 TENSILE 3.2.1.7-NLRC	These were actually static fatigue tests on as-machined flexure bars. Specimen geometry was 6.35 x 3.18 x 40 mm with 30-mm inner span, 10-mm outer span. The fixture was sintered SiC in standard 4-point bend fixture and was used in an Instron electromechanical testing machine. Rapid loading at 2000 MPa/min was used to minimize fatigue effects during the high-temperature strength testing.

Section 1. Test Background Information, continued

Test Rig Name Test Type WBS Study	Test Background Information
TENSORNL1 TENSILE 3.2.1.4-ORNIL	Specimens were buttonheaded, uniform gage with 6.3-mm-diam x 25.4 gage length. Specimen was finished in longitudinal direction with a diamond grinding wheel. No polishing was done in the gage section. Loads were either constant, using a triangular wave, or incremental step, with a hold period after reaching each stress level. Tensile load was at a ramp rate of 70 MPa/s. Specimens were heated by induction heater, with temperature being measured by a 2-color pyrometer. Strain was measured directly with mechanical extensometers capable of accurate reading at high temperatures. Cyclic loads were applied in triangular form at 0.5 Hz.
TENSSRI1 TENSILE 3.2.2.2-AGTD	Tensile specimen geometry: buttonheaded solid cylindrical rods with reduced gage section of 4.76 mm diam, 55.9 mm length. Buttonhead diameter = 15.24 mm. Total length of specimen was about 137 mm. Testing was performed in uniaxial tension at Southern Research Institute for AGTD. Stress rate was 68.95 MPa/s.
TENSUDRI1 TENSILE 3.3.1.4-UDRI	Specimens were cylindrical buttonheaded rods with gage sections of 6.35 mm diam x 35 mm length. Tensile strength measurements were made using an Instron Electro-Mechanical Test System (Model 1361) equipped with Instron "sure-grip" universal coupling and water-cooled holders for high-temperature tensile testing. An Instron high-temperature short furnace was used for high-temperature measurements.
TUFFBCL1 FRACTURE TOUGHNESS 1.4.1 - BCL	Notched bend bars with 5.08 x 5.08-mm cross sections were broken in a 4-point bend fixture with inner span of 19.05 mm, outer span of 31.75 mm. The notch is made with a fine slitting saw and is about 1.52 mm deep, 0.3 mm wide.

Section 1. Test Background Information, continued

Test Rig Name Test Type WBS Study	Test Background Information
TUFFNLRC1 FRACTURE TOUGHNESS 3.2.1.7-NLRC	<p>Two methods were used to measure fracture toughness: SEPB (single-edge precracked beam) and chevron-notched bars in 3-point bending. Specimens were 3 x 4 x 50 mm. Notch parameters were 0.625 for a0 and 1.0 for a1. KIC was determined with a slice model. SEPB specimens were tested at a stroke rate of .5 mm/min, chevron-notched specimens at 0.005 mm/min.</p>
TUFFNORT2 FRACTURE TOUGHNESS 1.2.2.4-NORTON	<p>Testing methods used are listed with each test result record.</p>
TUFFUDRI1 FRACTURE TOUGHNESS 3.3.1.4-UDRI	<p>In the controlled-surface flaw method, a Knoop or Vickers diamond indenter was used to produce a small crack in the tensile surface of a bend bar made from the material being tested. The indented specimens are then loaded into a 3-point bend fixture, with the top knife edge directly over the indentation, and rapidly broken. In the micro-indentation method, toughness is determined by measuring the length of the crack produced by a Vickers indenter. An Instron Universal Testing Machine (model 1123) was used for the 3-point bend test.</p>
BMOR4BCL1 JOINT-SPECIMEN MOR 4-PT BEND 1.4.1-BCL	<p>Bend bars, 2.5 x 5.08 x 38.1 mm, were machined from the 50.8-mm-diam x 38.1-mm-long jointed cylinder and tested in a 4-point fixture with inner/outer spans of 19.05/31.75 mm. The specimens were finish ground to 110 grit using a diamond wheel. Specimens were loaded under 4-point bend using a self-aligning fixture that permitted free rotation in 2 directions. A high-accuracy displacement fixture was used to determine the center displacement of the bend bar with respect to the upper loading pins.</p>

Section 1. Test Background Information, continued

Test Rig Name	Test Background Information
Test Type	
WBS Study	
BTUJFFBCL1 JOINT-SPECIMEN FRACTURE TOUGHNESS 1.4.1-BCL	Notched bend bars with 5.08 x 5.08-mm cross sections were broken in a 4-point bend fixture with inner span of 19.05 mm, outer span of 31.75 mm. The notch is made with a fine slitting saw and is about 1.52 mm deep, 0.3 mm wide.
BTUJFFBCL2 JOINT-SPECIMEN FRACTURE TOUGHNESS 1.4.1-BCL	These specimens were bent from the compression surface bars 2.5 x 6.35 mm deep with a chevron notch extending to 1.067 mm from the tensile surface. The notch was 3.81 mm thick in the middle of the interlayer. Notch specimens (MCF series) were tested in a 4-point bend fixture.

Section 2A - Modulus of Rupture Four-Point Bend Strength Test Results on Alumina-based Ceramics

Material	Batch Code	Specimen Number	Temp °C	Width mm	Thickness mm	Bend Strength MPa	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4NORTA									
Ce-ZTA	NORT/Z18.5CE62A	SUMOF10	25	3.00	3.00	634	0.00833		13 DIE-PRESSED/CIPed
Ce-ZTA	NORT/Z18.5CE62A	SUMOF09	25	3.00	3.00	482	0.00833		24 UNFILTERD/PRESSURE CAST
Ce-ZTA	NORT/Z18.5CE62A	SUMOF10	25	3.00	3.00	799	0.00833		17 FILTERD/PRESSURE CAST
Ce-ZTA	NORT/Z18.5CE62A	SUMOF07	25	3.00	3.00	903	0.00833		14 FILTERD/PRESSURE CAST
Ce-ZTA	NORT/Z18.5CE62A	SUMOF07	25	3.00	3.00	951	0.00833		32 FILTERD/PRESSURE CAST
Ce-ZTA	NORT/Z18.5CE62A	SUMOF10	1000	3.00	3.00	402	0.00833		20 FILTERD/PRESSURE CAST
Ce-ZTA	NORT/Z18.5CE62A	SUMOF09	1000	3.00	3.00	515	0.00833		8 FILTERD/PRESSURE CAST

NOTE: The values presented above represent averages of the number of tests listed in the specimen number, "SUMOFn," where n is the number of tests.

Forming Process

Fig. 2.1. The effects of processing on the modulus of rupture 4-point bend strength of Ce-ZTA.

Section 2B - Modulus of Rupture Four-Point Bend Strength Test Results for Silicon Carbide-based Ceramics

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Description	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4UDRI2 for all												
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/1300C/100H	SUMMARY	20				511			39	
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/1300C/500H	SUMMARY	20				462			14	
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/1300C/1000H	SUMMARY	20				489			32	
HEXOLOY SA	CARBRNDM/UDRI/2	AS RECD	SUMMARY	20				402			52	
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/100H/1300C	132	21	582.7	3.9878	2.9972	488		0.0423		
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/100H/1300C	131	21	667.2	4.0081	2.9972	556		0.0423		
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/100H/1300C	130	21	587.1	4.003	3.015	484		0.0423		
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/100H/1300C	133	21	667.2	4.0107	3.015	549		0.0423		
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/100H/1300C	134	21	573.8	3.9903	3.0124	475		0.0423		
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/1300C/50H	SUMMARY	1000				417			71	
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/1300C/100H	SUMMARY	1300				419			47	
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/1300C/500H	SUMMARY	1300				423			83	
HEXOLOY SA	CARBRNDM/UDRI/2	AGE/1300C/1000H	SUMMARY	1300				416			42	
NT-230	NORTON/TYPICAL		SUMMARY	20				359		0.00008	52	VENDOR DATA
NT-230	NORTON/UDRI-91		SUMRY5	20		3.00	4.00	431	4 VOL., 1 EDGE	0.000004	32	MIL STD 1942B
NT-230	NORTON/UDRI-91		SUMRY9	20		3.00	4.00	443	4 VOL., 5 SURFACE	0.0004	38	MIL STD 1942B
NT-230	NORTON/UDRI-91		SUMRY5	1250		3.00	4.00	475	1 VOL., 4 SURFACE	0.000004	67	MIL STD 1942B
NT-230	NORTON/UDRI-91		SUMRY10	1250		3.00	4.00	504	2 VOL., 7 SURF., 1 EDGE	0.0004	32	MIL STD 1942B
NT-230	NORTON/UDRI-91		SUMRY10	1350		3.00	4.00	466	7 VOL., 3 SURFACE	0.0004	47	MIL STD 1942B
NT-230	NORTON/UDRI-91		SUMRY5	1350		3.00	4.00	518	4 VOL., 1 SURFACE	0.000004	56	MIL STD 1942B
NT-230	NORTON/UDRI-91		SUMRY5	1350		3.00	4.00	521	4 VOL., 1 SURFACE	0.00004	52	MIL STD 1942B
NT-230	NORTON/TYPICAL		SUMMARY	1370		3.00	4.00	489		0.00008	69	VENDOR DATA

NOTE: Entries that contain "SUMMARY" or "SUMRYn" are average values for a group of tests, where n indicated how many were in the group.

HEXOLOY SA

Material Condition

ORNL-DWG 93-5699

Fig. 2.2. Effects of aging on the modulus of rupture 4-pt. bend strength of Hexoloy SA at test temperatures of room temperature and 1300°C.

Fig. 2.3. Effects of crosshead speed and temperature on the modulus of rupture 4-pt. bend strength of NT-230 silicon carbide.

Silicon Carbide

Fig. 2.4. A comparison of two silicon carbide-based ceramics in the as-received condition, tested at room temperature and at 1300°C.

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics

Environment is ambient air unless stated otherwise.

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4UDRI2												
EC-152	NTK/UDRI/2		53	21	649.4	4.0081	3.0124	536.0		0.0423		
EC-152	NTK/UDRI/2		60	21	1040.8	4.0081	3.0099	860.0		0.000423		
EC-152	NTK/UDRI/2		51	21	1169.8	4.0005	3.0074	970.0		0.0423		
EC-152	NTK/UDRI/2		54	21	876.2	4.0107	3.0150	721.0		0.0423		
EC-152	NTK/UDRI/2		56	21	1005.2	4.0107	3.0099	830.0		0.000423		
EC-152	NTK/UDRI/2		55	21	1080.9	4.0132	3.0150	889.0		0.0423		
EC-152	NTK/UDRI/2		59	21	1067.5	4.0030	3.0099	883.0		0.000423		
EC-152	NTK/UDRI/2		50	21	1014.1	4.0107	3.0124	836.0		0.0423		
EC-152	NTK/UDRI/2		57	21	689.4	3.9903	3.0175	569.0		0.000423		
EC-152	NTK/UDRI/2		52	21	1196.5	4.0081	3.0175	984.0		0.0423		
EC-152	NTK/UDRI/2		58	21	978.6	4.0056	3.0099	809.0		0.000423		
Test Rig = MOR4NLRG1												
GN-10	GCCD/NLRC-80	1400C/500H/O2	SUMRY5	25			3	4	457.0	0.000083		
GN-10	GCCD/NLRC-90	25C/500H/FLOW O2	SUMRY5	25			3	4	735.0	0.000083		
GN-10	GCCD/NLRC-90	1200C/500H/O2	SUMRY5	25			3	4	775.0	0.000083		
GN-10	GCCD/NLRC-80	1000C/500H/O2	SUMRY5	25			3	4	860.0	0.000083		
Test Rig = MOR4UDRI2												
GN-10	GCCD/UDRI-90		SUMRY20	20			3	4	779.0	0.0004	83.00	MIL STD 1942B
GN-10	GCCD/UDRI-90		SUMRY	1300			3	4	444.0	0.000004	63.00	MIL STD 1942B
GN-10	GCCD/UDRI-90		SUMRY10	1300			3	4	563.0	0.0004	40.00	MIL STD 1942B
Test Rig = MOR4NLRG1												
GN-10+SiCw30v%	GCCD/NLRC-90	1200C/500H/O2	SUMRY5	25			3	4	447.0	0.000083		
GN-10+SiCw30v%	GCCD/NLRC-90	1400C/500H/O2	SUMRY5	25			3	4	555.0	0.000083		
GN-10+SiCw30v%	GCCD/NLRC-90	25C/500H/O2	SUMRY5	25			3	4	700.0	0.000083		
GN-10+SiCw30v%	GCCD/NLRC-90	1000C/500H/O2	SUMRY5	25			3	4	715.0	0.000083		
Test Rig = MOR4AGTD1												
GTE PY6	AGTD/HIP		34.1410	20	511.2	4.0310	3.0050	421.7				
GTE PY6	AGTD/HIP		34.1603	20		4	3	486.6		0.00847		
GTE PY6	AGTD/HIP		34.1602	20		4	3	502.1		0.00847		
GTE PY6	AGTD/HIP		34.1600	20		4	3	550.0		0.00847		
GTE PY6	AGTD/HIP		34.1723	20		4	3	553.6		0.00847		
GTE PY6	AGTD/HIP		34.1722	20		4	3	574.5		0.00847		
GTE PY6	AGTD/HIP		34.1965	20		4	3	575.7		0.00847		
GTE PY6	AGTD/HIP			20		4	3	595.0		0.00847		
GTE PY6	AGTD/HIP		34.1605	20		4	3	604.5		0.00847		
GTE PY6	AGTD/HIP			20		4	3	610.9		0.00847		
GTE PY6	AGTD/HIP		34.1396	20	747.3	4.0280	3.0070	615.4				
GTE PY6	AGTD/HIP		34.1718	20		4	3	617.6		0.00847		
GTE PY6	AGTD/HIP		34.1721	20		4	3	631.9		0.00847		
GTE PY6	AGTD/HIP		34.1717	20		4	3	653.5		0.00847		
GTE PY6	AGTD/HIP		34.1724	20		4	3	655.0		0.00847		

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig - MOR4AGTD1												
GTE PY6	AGTD/HIP/MOD1			20		4	3	877.0		0.00847		
GTE PY6	AGTD/HIP		34.1998	20		4	3	881.2		0.00847		
GTE PY6	AGTD/HIP		34.2007	20		4	3	886.0		0.00847		
GTE PY6	AGTD/HIP		34.2006	20		4	3	890.9		0.00847		
GTE PY6	AGTD/HIP		34.1996	20		4	3	898.7		0.00847		
GTE PY6	AGTD/HIP		34.1949	20		4	3	898.9		0.00847		
GTE PY6	AGTD/HIP/MOD1			20		4	3	899.1		0.00847		
GTE PY6	AGTD/HIP		34.1964	20		4	3	910.9		0.00847		
GTE PY6	AGTD/HIP/MOD1			20		4	3	912.9		0.00847		
GTE PY6	AGTD/HIP		34.1402	20	1112.1	4.0340	3.0070	914.5		0.00847		
GTE PY6	AGTD/HIP		34.1995	20		4	3	917.6		0.00847		
GTE PY6	AGTD/HIP		34.1415	20	1116.5	4.0310	3.0050	920.3		0.00847		
GTE PY6	AGTD/HIP		34.1997	20		4	3	932.4		0.00847		
GTE PY6	AGTD/HIP		34.1414	20	1138.7	4.0310	3.0050	938.7		0.00847		
GTE PY6	AGTD/HIP		34.1951	20		4	3	939.4		0.00847		
GTE PY6	AGTD/HIP		34.2003	20		4	3	947.7		0.00847		
GTE PY6	AGTD/HIP		34.1999	20		4	3	947.9		0.00847		
GTE PY6	AGTD/HIP		34.2004	20		4	3	949.2		0.00847		
GTE PY6	AGTD/HIP		34.1720	20		4	3	951.5		0.00847		
GTE PY6	AGTD/HIP		34.1596	20		4	3	961.9		0.00847		
GTE PY6	AGTD/HIP		34.2001	20		4	3	973.7		0.00847		
GTE PY6	AGTD/HIP		34.1959	20		4	3	978.4		0.00847		
GTE PY6	AGTD/HIP		34.1598	20		4	3	978.7		0.00847		
GTE PY6	AGTD/HIP		34.1958	20		4	3	989.1		0.00847		
GTE PY6	AGTD/HIP		34.1950	20		4	3	992.9		0.00847		
GTE PY6	AGTD/HIP		34.2002	20		4	3	1003.9		0.00847		
GTE PY6	AGTD/HIP		34.1962	20		4	3	1008.3		0.00847		
GTE PY6	AGTD/HIP/MOD1			20		4	3	1021.1		0.00847		
GTE PY6	AGTD/HIP		34.1960	20		4	3	1029.7		0.00847		
GTE PY6	AGTD/HIP		34.2005	20		4	3	1036.4		0.00847		
GTE PY6	AGTD/HIP		34.1947	20		4	3	1059.1		0.00847		
GTE PY6	AGTD/HIP		34.1946	20		4	3	1086.9		0.00847		
GTE PY6	AGTD/HIP		34.1953	20		4	3	1114.9		0.00847		
GTE PY6	AGTD/HIP		34.1442	1000		4	3	400.1		0.000847		
GTE PY6	AGTD/HIP		34.1528	1000		4	3	610.6		0.00847		
GTE PY6	AGTD/HIP		34.1728	1000		4	3	628.3		0.00847		
GTE PY6	AGTD/HIP		34.1527	1000		4	3	636.2		0.00847		
GTE PY6	AGTD/HIP		34.1443	1000		4	3	658.6		0.000847		
GTE PY6	AGTD/HIP		34.1444	1000		4	3	659.9		0.000847		
GTE PY6	AGTD/HIP		34.1526	1000		4	3	666.9		0.00847		
GTE PY6	AGTD/HIP		34.1727	1000		4	3	676.3		0.00847		
GTE PY6	AGTD/HIP		34.1469	1000		4	3	707.1		0.00847		
GTE PY6	AGTD/HIP		34.1467	1000		4	3	720.5		0.00847		

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig - MOR4AGTD1												
GTE PY6	AGTD/HIP		34.1466	1000		4	3	728.1		0.00847		
GTE PY6	AGTD/HIP		34.1468	1000		4	3	739.2		0.00847		
GTE PY6	AGTD/HIP		34.2024	1000		4	3	745.1		0.00847		
GTE PY6	AGTD/HIP		34.1441	1000		4	3	754.9		0.000847		
GTE PY6	AGTD/HIP		34.2025	1000		4	3	764.8		0.00847		
GTE PY6	AGTD/HIP		34.2023	1000		4	3	768.9		0.00847		
GTE PY6	AGTD/HIP		34.1440	1000		4	3	769.4		0.000847		
GTE PY6	AGTD/HIP		34.1530	1000		4	3	769.4		0.00847		
GTE PY6	AGTD/HIP		34.1465	1000		4	3	772.7		0.00847		
GTE PY6	AGTD/HIP		34.2022	1000		4	3	817.6		0.00847		
GTE PY6	AGTD/HIP		34.2021	1000		4	3	818.2		0.00847		
GTE PY6	AGTD/HIP		34.1725	1000		4	3	821.7		0.00847		
GTE PY6	AGTD/HIP		34.1529	1000		4	3	835.7		0.00847		
GTE PY6	AGTD/HIP		34.1726	1000		4	3	848.9		0.00847		
GTE PY6	AGTD/HIP		34.1729	1000		4	3	853.4		0.00847		
GTE PY6	AGTD/HIP		34.1633	1100		4	3	481.8		0.00847		
GTE PY6	AGTD/HIP		34.1533	1100		4	3	516.6		0.00847		
GTE PY6	AGTD/HIP		34.1531	1100		4	3	536.3		0.00847		
GTE PY6	AGTD/HIP		34.1436	1100		4	3	545.5		0.00847		
GTE PY6	AGTD/HIP		34.1532	1100		4	3	547.0		0.00847		
GTE PY6	AGTD/HIP		34.1475	1100		4	3	547.5		0.00847		
GTE PY6	AGTD/HIP		34.1535	1100		4	3	557.6		0.00847		
GTE PY6	AGTD/HIP		34.1634	1100		4	3	575.1		0.00847		
GTE PY6	AGTD/HIP		34.1437	1100		4	3	576.3		0.00847		
GTE PY6	AGTD/HIP		34.1534	1100		4	3	587.4		0.00847		
GTE PY6	AGTD/HIP		34.2010	1100		4	3	603.8		0.00847		
GTE PY6	AGTD/HIP		34.1631	1100		4	3	613.8		0.00847		
GTE PY6	AGTD/HIP		34.2008	1100		4	3	619.5		0.00847		
GTE PY6	AGTD/HIP		34.1630	1100		4	3	620.1		0.00847		
GTE PY6	AGTD/HIP		34.1438	1100		4	3	622.5		0.00847		
GTE PY6	AGTD/HIP		34.1632	1100		4	3	627.4		0.00847		
GTE PY6	AGTD/HIP		34.2011	1100		4	3	641.3		0.00847		
GTE PY6	AGTD/HIP		34.2009	1100		4	3	642.3		0.00847		
GTE PY6	AGTD/HIP		34.2012	1100		4	3	667.8		0.00847		
GTE PY6	AGTD/HIP		34.1439	1100		4	3	544.4		0.00847		
GTE PY6	AGTD/HIP		34.1775	1200		4	3	453.7		0.00847		
GTE PY6	AGTD/HIP/MODI			1200		4	3	453.7		0.00847		
GTE PY6	AGTD/HIP			1200		4	3	457.8		0.00847		
GTE PY6	AGTD/HIP		34.1431	1200		4	3	460.7		0.00847		
GTE PY6	AGTD/HIP/MODI			1200		4	3	475.8		0.00847		
GTE PY6	AGTD/HIP			1200		4	3	479.9		0.00847		
GTE PY6	AGTD/HIP		34.2036	1200		4	3	480.2		0.00847		
GTE PY6	AGTD/HIP			1200		4	3	488.2		0.00847		

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig - MOR/AGTD:												
GTE PY6	AGTD/HIP/MODI			1200		4	3	490.2		0.00847		
GTE PY6	AGTD/HIP/MODI			1200		4	3	497.1		0.00847		
GTE PY6	AGTD/HIP		34.1434	1200		4	3	505.0		0.00847		
GTE PY6	AGTD/HIP		34.1765	1200		4	3	522.9		0.00847		
GTE PY6	AGTD/HIP/MODI			1200		4	3	527.5		0.00847		
GTE PY6	AGTD/HIP		34.1540	1200		4	3	531.5		0.00847		
GTE PY6	AGTD/HIP		34.1774	1200		4	3	542.2		0.00847		
GTE PY6	AGTD/HIP		34.1772	1200		4	3	546.5		0.00847		
GTE PY6	AGTD/HIP		34.1524	1200		4	3	548.3		0.00847		
GTE PY6	AGTD/HIP		34.1515	1200		4	3	549.2		0.00847		
GTE PY6	AGTD/HIP/MODI			1200		4	3	550.2		0.00847		
GTE PY6	AGTD/HIP/MODI			1200		4	3	558.5		0.00847		
GTE PY6	AGTD/HIP		34.1461	1200		4	3	559.6		0.00847		
GTE PY6	AGTD/HIP/MODI			1200		4	3	568.1		0.00847		
GTE PY6	AGTD/HIP		34.1463	1200		4	3	571.7		0.00847		
GTE PY6	AGTD/HIP		34.1430	1200		4	3	577.4		0.00847		
GTE PY6	AGTD/HIP		34.1459	1200		4	3	577.4		0.00847		
GTE PY6	AGTD/HIP		34.1435	1200		4	3	585.4		0.00847		
GTE PY6	AGTD/HIP		34.1464	1200		4	3	587.2		0.00847		
GTE PY6	AGTD/HIP		34.2039	1200		4	3	587.6		0.00847		
GTE PY6	AGTD/HIP		34.1523	1200		4	3	588.5		0.00847		
GTE PY6	AGTD/HIP		34.1427	1200		4	3	593.0		0.00847		
GTE PY6	AGTD/HIP		34.1456	1200		4	3	593.0		0.00847		
GTE PY6	AGTD/HIP		34.1522	1200		4	3	598.9		0.00847		
GTE PY6	AGTD/HIP		34.1514	1200		4	3	599.2		0.00847		
GTE PY6	AGTD/HIP		34.1539	1200		4	3	604.7		0.00847		
GTE PY6	AGTD/HIP		34.1777	1200		4	3	608.4		0.00847		
GTE PY6	AGTD/HIP		34.1538	1200		4	3	608.5		0.00847		
GTE PY6	AGTD/HIP		34.2037	1200		4	3	618.9		0.00847		
GTE PY6	AGTD/HIP		34.1462	1200		4	3	621.7		0.00847		
GTE PY6	AGTD/HIP		34.1455	1200		4	3	625.7		0.00847		
GTE PY6	AGTD/HIP		34.1426	1200		4	3	625.7		0.00847		
GTE PY6	AGTD/HIP		34.1769	1200		4	3	629.4		0.00847		
GTE PY6	AGTD/HIP		34.2038	1200		4	3	630.6		0.00847		
GTE PY6	AGTD/HIP		34.1512	1200		4	3	630.9		0.00847		
GTE PY6	AGTD/HIP		34.1766	1200		4	3	645.7		0.00847		
GTE PY6	AGTD/HIP		34.1433	1200		4	3	648.0		0.00847		
GTE PY6	AGTD/HIP		34.1511	1200		4	3	649.9		0.00847		
GTE PY6	AGTD/HIP		34.2032	1200		4	3	654.9		0.00847		
GTE PY6	AGTD/HIP		34.1521	1200		4	3	659.4		0.00847		
GTE PY6	AGTD/HIP		34.2040	1200		4	3	661.8		0.00847		
GTE PY6	AGTD/HIP		34.1432	1200		4	3	663.0		0.00847		
GTE PY6	AGTD/HIP		34.2031	1200		4	3	666.7		0.00847		

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4AGTD1												
GTE PY6	AGTD/HIP		34.1460	1200		4	3	666.9		0.00847		
GTE PY6	AGTD/HIP		34.2034	1200		4	3	675.6		0.00847		
GTE PY6	AGTD/HIP		34.1767	1200		4	3	680.8		0.00847		
GTE PY6	AGTD/HIP		34.1513	1200		4	3	684.2		0.00847		
GTE PY6	AGTD/HIP		34.1771	1200		4	3	693.4		0.00847		
GTE PY6	AGTD/HIP		34.1428	1200		4	3	694.8		0.00847		
GTE PY6	AGTD/HIP		34.1457	1200		4	3	694.8		0.00847		
GTE PY6	AGTD/HIP		34.1536	1200		4	3	697.3		0.00847		
GTE PY6	AGTD/HIP		34.1537	1200		4	3	698.6		0.00847		
GTE PY6	AGTD/HIP		34.1510	1200		4	3	705.2		0.00847		
GTE PY6	AGTD/HIP		34.1776	1200		4	3	706.9		0.00847		
GTE PY6	AGTD/HIP		34.2033	1200		4	3	713.7		0.00847		
GTE PY6	AGTD/HIP		34.1429	1200		4	3	716.7		0.00847		
GTE PY6	AGTD/HIP		34.1458	1200		4	3	716.7		0.00847		
GTE PY6	AGTD/HIP		34.2035	1200		4	3	672.9		0.00847		
GTE PY6	AGTD/HIP		34.1644	1300		4	3	386.8		0.00847		
GTE PY6	AGTD/HIP		34.1543	1300		4	3	490.3		0.00847		
GTE PY6	AGTD/HIP		34.1642	1300		4	3	506.1		0.00847		
GTE PY6	AGTD/HIP		34.2027	1300		4	3	522.1		0.00847		
GTE PY6	AGTD/HIP		34.1635	1300		4	3	527.1		0.00847		
GTE PY6	AGTD/HIP		34.2029	1300		4	3	528.1		0.00847		
GTE PY6	AGTD/HIP		34.2026	1300		4	3	533.8		0.00847		
GTE PY6	AGTD/HIP		34.1639	1300		4	3	538.1		0.00847		
GTE PY6	AGTD/HIP		34.1762	1300		4	3	541.9		0.00847		
GTE PY6	AGTD/HIP		34.2028	1300		4	3	545.8		0.00847		
GTE PY6	AGTD/HIP		34.1641	1300		4	3	556.9		0.00847		
GTE PY6	AGTD/HIP		34.1544	1300		4	3	561.6		0.00847		
GTE PY6	AGTD/HIP		34.1424	1300		4	3	572.2		0.00847		
GTE PY6	AGTD/HIP		34.1421	1300		4	3	572.8		0.00847		
GTE PY6	AGTD/HIP		34.2030	1300		4	3	580.0		0.00847		
GTE PY6	AGTD/HIP		34.1643	1300		4	3	582.4		0.00847		
GTE PY6	AGTD/HIP		34.1423	1300		4	3	583.7		0.00847		
GTE PY6	AGTD/HIP		34.1764	1300		4	3	592.8		0.00847		
GTE PY6	AGTD/HIP		34.1636	1300		4	3	597.1		0.00847		
GTE PY6	AGTD/HIP		34.1422	1300		4	3	598.3		0.00847		
GTE PY6	AGTD/HIP		34.1545	1300		4	3	601.7		0.00847		
GTE PY6	AGTD/HIP		34.1763	1300		4	3	603.5		0.00847		
GTE PY6	AGTD/HIP		34.1425	1300		4	3	606.4		0.00847		
GTE PY6	AGTD/HIP		34.1760	1300		4	3	608.6		0.00847		
GTE PY6	AGTD/HIP		34.1638	1300		4	3	613.1		0.00847		
GTE PY6	AGTD/HIP		34.1542	1300		4	3	615.0		0.00847		
GTE PY6	AGTD/HIP		34.1761	1300		4	3	620.3		0.00847		
GTE PY6	AGTD/HIP		34.1541	1300		4	3	623.2		0.00847		

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4AGTD1												
GTE PY6	AGTD/HIP		34.1637	1300		4	3	634.4		0.00847		
GTE PY6	AGTD/HIP		34.1640	1300		4	3	676.3		0.00847		
GTE PY6	AGTD/HIP			1400		4	3	304.8		0.00847		
GTE PY6	AGTD/HIP			1400		4	3	342.0		0.00847		
GTE PY6	AGTD/HIP		34.1473	1400		4	3	349.5		0.00847		
GTE PY6	AGTD/HIP			1400		4	3	353.7		0.00847		
GTE PY6	AGTD/HIP		34.1470	1400		4	3	362.0		0.00847		
GTE PY6	AGTD/HIP/MODI			1400		4	3	379.2		0.00847		
GTE PY6	AGTD/HIP		34.1793	1400		4	3	382.5		0.00847		
GTE PY6	AGTD/HIP			1400		4	3	385.4		0.00847		
GTE PY6	AGTD/HIP		34.1474	1400		4	3	388.8		0.00847		
GTE PY6	AGTD/HIP		34.1471	1400		4	3	394.5		0.00847		
GTE PY6	AGTD/HIP		34.1798	1400		4	3	395.5		0.00847		
GTE PY6	AGTD/HIP		34.1798	1400		4	3	395.5		0.00847		
GTE PY6	AGTD/HIP			1400		4	3	396.5		0.00847		
GTE PY6	AGTD/HIP/MODI			1400		4	3	397.2		0.00847		
GTE PY6	AGTD/HIP		34.1780	1400		4	3	403.6		0.00847		
GTE PY6	AGTD/HIP/MODI			1400		4	3	405.4		0.00847		
GTE PY6	AGTD/HIP		34.1794	1400		4	3	405.5		0.00847		
GTE PY6	AGTD/HIP/MODI			1400		4	3	409.6		0.00847		
GTE PY6	AGTD/HIP			1400		4	3	412.3		0.00847		
GTE PY6	AGTD/HIP		34.1787	1400		4	3	413.2		0.00847		
GTE PY6	AGTD/HIP		34.1781	1400		4	3	415.1		0.00847		
GTE PY6	AGTD/HIP		34.1625	1400		4	3	415.6		0.00847		
GTE PY6	AGTD/HIP		34.1472	1400		4	3	419.1		0.00847		
GTE PY6	AGTD/HIP		34.1792	1400		4	3	421.8		0.00847		
GTE PY6	AGTD/HIP		34.1629	1400		4	3	421.9		0.00847		
GTE PY6	AGTD/HIP/MODI			1400		4	3	423.4		0.00847		
GTE PY6	AGTD/HIP		34.1799	1400		4	3	425.1		0.00847		
GTE PY6	AGTD/HIP		34.1624	1400		4	3	426.6		0.00847		
GTE PY6	AGTD/HIP		34.1791	1400		4	3	429.5		0.00847		
GTE PY6	AGTD/HIP		34.1784	1400		4	3	430.5		0.00847		
GTE PY6	AGTD/HIP		34.1785	1400		4	3	430.5		0.00847		
GTE PY6	AGTD/HIP		34.1982	1400		4	3	431.2		0.00847		
GTE PY6	AGTD/HIP		34.1795	1400		4	3	431.3		0.00847		
GTE PY6	AGTD/HIP			1400		4	3	433.7		0.00847		
GTE PY6	AGTD/HIP		34.1623	1400		4	3	433.9		0.00847		
GTE PY6	AGTD/HIP		34.1786	1400		4	3	437.2		0.00847		
GTE PY6	AGTD/HIP		34.1503	1400		4	3	437.7		0.00847		
GTE PY6	AGTD/HIP			1400		4	3	438.5		0.00847		
GTE PY6	AGTD/HIP		34.1546	1400		4	3	439.2		0.00847		
GTE PY6	AGTD/HIP		34.1782	1400		4	3	443.5		0.00847		
GTE PY6	AGTD/HIP/MODI			1400		4	3	446.1		0.00847		

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4AGTD1												
GTE PY6	AGTD/HIP		34.1778	1400		4	3	447.1		0.00847		
GTE PY6	AGTD/HIP		34.1548	1400		4	3	447.1		0.00847		
GTE PY6	AGTD/HIP		34.1783	1400		4	3	448.0		0.00847		
GTE PY6	AGTD/HIP		34.1790	1400		4	3	448.6		0.00847		
GTE PY6	AGTD/HIP		34.1788	1400		4	3	448.6		0.00847		
GTE PY6	AGTD/HIP		34.1500	1400		4	3	453.0		0.00847		
GTE PY6	AGTD/HIP		34.1986	1400		4	3	454.8		0.00847		
GTE PY6	AGTD/HIP		34.1626	1400		4	3	463.9		0.00847		
GTE PY6	AGTD/HIP		34.1507	1400		4	3	470.3		0.00847		
GTE PY6	AGTD/HIP		34.1502	1400		4	3	471.5		0.00847		
GTE PY6	AGTD/HIP		34.1985	1400		4	3	472.3		0.00847		
GTE PY6	AGTD/HIP		34.1801	1400		4	3	472.6		0.00847		
GTE PY6	AGTD/HIP		34.1622	1400		4	3	473.3		0.00847		
GTE PY6	AGTD/HIP		34.1417	1400		4	3	474.6		0.00847		
GTE PY6	AGTD/HIP		34.1989	1400		4	3	475.3		0.00847		
GTE PY6	AGTD/HIP/MODI			1400		4	3	475.8		0.00847		
GTE PY6	AGTD/HIP		34.1627	1400		4	3	477.0		0.00847		
GTE PY6	AGTD/HIP		34.1547	1400		4	3	477.6		0.00847		
GTE PY6	AGTD/HIP		34.1990	1400		4	3	481.0		0.00847		
GTE PY6	AGTD/HIP		34.1981	1400		4	3	481.1		0.00847		
GTE PY6	AGTD/HIP/MODI			1400		4	3	483.3		0.00847		
GTE PY6	AGTD/HIP		34.1508	1400		4	3	483.7		0.00847		
GTE PY6	AGTD/HIP		34.1416	1400		4	3	484.3		0.00847		
GTE PY6	AGTD/HIP		34.1988	1400		4	3	485.2		0.00847		
GTE PY6	AGTD/HIP		34.1509	1400		4	3	490.3		0.00847		
GTE PY6	AGTD/HIP		34.1550	1400		4	3	491.2		0.00847		
GTE PY6	AGTD/HIP		34.1501	1400		4	3	499.3		0.00847		
GTE PY6	AGTD/HIP		34.1797	1400		4	3	501.3		0.00847		
GTE PY6	AGTD/HIP		34.1504	1400		4	3	502.5		0.00847		
GTE PY6	AGTD/HIP		34.1620	1400		4	3	505.4		0.00847		
GTE PY6	AGTD/HIP		34.1506	1400		4	3	508.4		0.00847		
GTE PY6	AGTD/HIP		34.1984	1400		4	3	510.1		0.00847		
GTE PY6	AGTD/HIP		34.1621	1400		4	3	511.2		0.00847		
GTE PY6	AGTD/HIP		34.1983	1400		4	3	511.9		0.00847		
GTE PY6	AGTD/HIP		34.1419	1400		4	3	518.6		0.00847		
GTE PY6	AGTD/HIP		34.1628	1400		4	3	535.4		0.00847		
GTE PY6	AGTD/HIP		34.1420	1400		4	3	536.6		0.00847		
GTE PY6	AGTD/HIP		34.1549	1400		4	3	541.5		0.00847		
GTE PY6	AGTD/HIP		34.1418	1400		4	3	557.2		0.00847		
GTE PY6	AGTD/HIP		34.1505	1400		4	3	598.8		0.00847		
GTE PY6	AGTD/HIP		34.1987	1400		4	3	483.0		0.00847		

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4AGTDX												
GTE PY6	AGTD/HIP	OXID/1400C/50h	34.1445	20		4	3	509.0				
GTE PY6	AGTD/HIP	OXID/1400C/200h	34.1450	20		4	3	600.7				
GTE PY6	AGTD/HIP	OXID/1400C/200h	34.1454	20		4	3	671.4				
GTE PY6	AGTD/HIP	OXID/1400C/200h	34.1452	20		4	3	679.9				
GTE PY6	AGTD/HIP	OXID/1400C/200h	34.1453	20		4	3	679.9				
GTE PY6	AGTD/HIP	OXID/1400C/50h	34.1449	20		4	3	722.8				
GTE PY6	AGTD/HIP	OXID/1400C/50h	34.1446	20		4	3	745.6				
GTE PY6	AGTD/HIP	OXID/1400C/200h	34.1451	20		4	3	748.2				
GTE PY6	AGTD/HIP	OXID/1400C/50h	34.1448	20		4	3	750.1				
GTE PY6	AGTD/HIP	OXID/1400C/50h	34.1447	20		4	3	765.8				
Test Rig = MOR4UDRI2												
GTE PY6	GTEL/UDRI/2	AGE/1300C/100H	SUMMARY	20		4	3	571.0			87.00	
GTE PY6	GTEL/UDRI/2	AS RECD	SUMMARY	20		4	3	863.0			86.00	
GTE PY6	GTEL/UDRI/2	AGE/100H/1300C	152	21	560.4	4.0132	3.0150	461.0		0.0423		
GTE PY6	GTEL/UDRI/2	AGE/100H/1300C	154	21	667.2	4.0056	3.0099	552.0		0.0423		
GTE PY6	GTEL/UDRI/2	AGE/100H/1300C	155	21	685.0	3.9929	2.9845	578.0		0.0423		
GTE PY6	GTEL/UDRI/2	AGE/100H/1300C	153	21	689.4	4.0056	3.0251	689.4		0.0423		
GTE PY6	GTEL/UDRI/2	AGE/100H/1300C	151	21	845.1	4.0030	3.0023	703.0		0.0423		
GTE PY6	GTEL/UDRI/2	AGE/100H/1300C	147	21	894.0	3.9903	3.0023	746.0		0.000423		
GTE PY6	GTEL/UDRI/2		144	21	947.4	3.9929	2.9870	798.0		0.000423		
GTE PY6	GTEL/UDRI/2		150	21	974.0	3.9853	2.9947	818.0		0.000423		
GTE PY6	GTEL/UDRI/2		143	21	969.7	3.9853	2.9845	820.0		0.000423		
GTE PY6	GTEL/UDRI/2		145	21	1009.7	3.9903	2.9921	848.0		0.000423		
GTE PY6	GTEL/UDRI/2		146	21	1049.7	4.0030	2.9997	874.0		0.000423		
GTE PY6	GTEL/UDRI/2		148	21	1072.0	3.9929	2.9997	895.0		0.000423		
GTE PY6	GTEL/UDRI/2	AGE/1300C/50H	SUMMARY	1000		4	3	864.0			89.00	
GTE PY6	GTEL/UDRI/2	AGE/1300C/100H	SUMMARY	1300		4	3	563.0			110.00	
GTE PY6	GTEL/UDRI/2	AGE/1300C/1000H	SUMMARY	1300		4	3	606.0			66.00	
GTE PY6	GTEL/UDRI/2	AGE/1300C/500H	SUMMARY	1300		4	3	624.0			72.00	
Test Rig = MOR4UDRI2												
NT-154	NORTON/UDRI/2	AS RECD	SUMMARY	20		4	3	749.0		0.000004	51.00	
NT-154	NORTON/UDRI/2	AS RECD	SUMMARY	20		4	3	769.0		0.000004	95.00	
NT-154	NORTON/UDRI/2	AGE/1400C/5H	SUMMARY	20		4	3	815.0		0.000004	63.00	
NT-154	NORTON/UDRI/2	AGE/1400C/5H	SUMMARY	20		4	3	906.0		0.0004	31.00	
NT-154	NORTON/UDRI/2	AS RECD	SUMMARY	20		4	3	907.0		0.0004	79.00	
NT-154	NORTON/UDRI/2	AGE/1000C/50H	SUMMARY	20		4	3	1051.0		0.000004	53.00	
NT-154	NORTON/UDRI/2	AGE/1000C/50H	SUMMARY	20		4	3	1067.0		0.0004	74.00	

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig - MOR4CERA1												
Si3N4	CERA/MAT5/MIX10	SINTERED	4	25		4	3	432.2				
Si3N4	CERA/MAT5/MIX10	SINTERED	5	25		4	3	440.1				
Si3N4	CERA/MAT5/MIX10	SINTERED	14	25		4	3	457.7				
Si3N4	CERA/MAT5/MIX10	SINTERED	3	25		4	3	460.6				
Si3N4	CERA/MAT5/MIX10	SINTERED	10	25		4	3	460.9				
Si3N4	CERA/MAT5/MIX10	SINTERED	11	25		4	3	463.0				
Si3N4	CERA/MAT5/MIX10	SINTERED	2	25		4	3	479.6				
Si3N4	CERA/MAT5/MIX10	SINTERED	7	25		4	3	481.0	PORE			
Si3N4	CERA/MAT5/MIX10	SINTERED	12	25		4	3	507.6	PORE SUBSURFACE			
Si3N4	CERA/MAT5/MIX10	SINTERED	15	25		4	3	514.4	PORE SUBSURFACE			
Si3N4	CERA/MAT5/MIX11	SINTERED	4	25		4	3	425.5				
Si3N4	CERA/MAT5/MIX11	SINTERED	3	25		4	3	439.6				
Si3N4	CERA/MAT5/MIX11	SINTERED	2	25		4	3	463.0	GRAN SUBSURFACE			
Si3N4	CERA/MAT5/MIX11	SINTERED	14	25		4	3	482.6	LARGE GRAIN			
Si3N4	CERA/MAT5/MIX11	SINTERED	6	25		4	3	508.4				
Si3N4	CERA/MAT5/MIX11	SINTERED	10	25		4	3	508.8				
Si3N4	CERA/MAT5/MIX11	SINTERED	11	25		4	3	510.4				
Si3N4	CERA/MAT5/MIX11	SINTERED	1	25		4	3	518.5	GRAN SUBSURFACE			
Si3N4	CERA/MAT5/MIX11	SINTERED	8	25		4	3	528.8				
Si3N4	CERA/MAT5/MIX11	SINTERED	12	25		4	3	539.7				
Si3N4	CERA/MAT5/MIX11	SINTERED	5	25		4	3	541.3				
Si3N4	CERA/MAT5/MIX11	SINTERED	15	25		4	3	546.9				
Si3N4	CERA/MAT5/MIX11	SINTERED	13	25		4	3	550.3	LARGE GRAIN			
Si3N4	CERA/MAT5/MIX11	SINTERED	7	25		4	3	553.2				
Si3N4	CERA/MAT5/MIX11	SINTERED	9	25		4	3	565.8				
Si3N4	CERA/MAT5/MIX11	SINTERED	4	25		4	3	371.2	PORE			
Si3N4	CERA/MAT6/MIX18	SINTERED	8	25		4	3	391.5				
Si3N4	CERA/MAT6/MIX18	SINTERED	6	25		4	3	424.8	PORE			
Si3N4	CERA/MAT6/MIX18	SINTERED	3	25		4	3	429.2				
Si3N4	CERA/MAT6/MIX18	SINTERED	2	25		4	3	634.1				
Si3N4	CERA/MAT6/MIX18	SINTERED	7	25		4	3	660.5				
Si3N4	CERA/MAT6/MIX18	SINTERED	5	25		4	3	674.3				
Si3N4	CERA/MAT6/MIX18	SINTERED	1	25		4	3	700.2				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	2	25		4	3	555.5				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	8	25		4	3	560.0				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	6	25		4	3	587.3				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	9	25		4	3	588.1	MICROPOROUS AREA 35UM			
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	11	25		4	3	598.1				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	4	25		4	3	600.9	PORE OR GRAIN(60UM)			
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	10	25		4	3	608.5	SURFACE PORE 25UM			
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	3	25		4	3	613.1				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	7	25		4	3	613.8	MICROPOROUS AREA 30UM			
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	1	25		4	3	619.1				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	5	25		4	3	628.0				

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig - MOR4UDRI2												
NT-164	NORTONVUDRI-92		SUMRY5	20		4	3	925.0	5 EDGE	0.000004	59.00	MIL STD 1942B
NT-164	NORTONVUDRI-92		SUMRY10	20		4	3	1093.0	8 SURF., 1 EDGE, 1 UNKN	0.0004	97.00	MIL STD 1942B
NT-164	NORTONVUDRI-92		SUMRY5	1250		4	3	676.0	5 SURFACE	0.000004	51.00	MIL STD 1942B
NT-164	NORTONVUDRI-92		SUMRY10	1250		4	3	757.0	9 SURFACE, 1 EDGE	0.0004	67.00	MIL STD 1942B
NT-164	NORTONVUDRI-92		SUMRY10	1350		4	3	654.0	4 SURFACE, 1 EDGE	0.000004	9.00	MIL STD 1942B
NT-164	NORTONVUDRI-92		SUMRY10	1350		4	3	747.0	4 SURFACE, 1 EDGE	0.00004	38.00	MIL STD 1942B
NT-164	NORTONVUDRI-92		SUMRY10	1350		4	3	785.0	10 SURFACE	0.0004	31.00	MIL STD 1942B
Test Rig - MOR4CER41												
Si3N4	CERA/MAT4/MIX6	SINTERED	9	25		4	3	184.8				
Si3N4	CERA/MAT4/MIX6	SINTERED	6	25		4	3	228.2	PORE			
Si3N4	CERA/MAT4/MIX6	SINTERED	3	25		4	3	260.6	PORE			
Si3N4	CERA/MAT4/MIX6	SINTERED	5	25		4	3	270.3				
Si3N4	CERA/MAT4/MIX6	SINTERED	2	25		4	3	306.8	PORE			
Si3N4	CERA/MAT4/MIX6	SINTERED	4	25		4	3	373.7	PORE			
Si3N4	CERA/MAT4/MIX6	SINTERED	1	25		4	3	400.6	INCLUSION			
Si3N4	CERA/MAT4/MIX6	SINTERED	12	25		4	3	456.4				
Si3N4	CERA/MAT4/MIX6	SINTERED	10	25		4	3	482.0				
Si3N4	CERA/MAT4/MIX6	SINTERED	7	25		4	3	501.3				
Si3N4	CERA/MAT4/MIX6	SINTERED	13	25		4	3	506.1	PORE			
Si3N4	CERA/MAT4/MIX6	SINTERED	11	25		4	3	533.7				
Si3N4	CERA/MAT4/MIX6	SINTERED	8	25		4	3	584.7				
Si3N4	CERA/MAT4/MIX6	SINTERED	15	25		4	3	595.0	PORE			
Si3N4	CERA/MAT4/MIX6	SINTERED	14	25		4	3	615.0				
Si3N4	CERA/MAT4/MIX7	SINTERED	9	25		4	3	223.4				
Si3N4	CERA/MAT4/MIX7	SINTERED	8	25		4	3	303.4	PORE			
Si3N4	CERA/MAT4/MIX7	SINTERED	2	25		4	3	368.9	PORE			
Si3N4	CERA/MAT4/MIX7	SINTERED	14	25		4	3	378.5				
Si3N4	CERA/MAT4/MIX7	SINTERED	6	25		4	3	389.6	PORE			
Si3N4	CERA/MAT4/MIX7	SINTERED	5	25		4	3	393.0	INCLUSION(SI)			
Si3N4	CERA/MAT4/MIX7	SINTERED	12	25		4	3	407.5	PORE			
Si3N4	CERA/MAT4/MIX7	SINTERED	3	25		4	3	422.0				
Si3N4	CERA/MAT4/MIX7	SINTERED	1	25		4	3	422.0	PORE			
Si3N4	CERA/MAT4/MIX7	SINTERED	15	25		4	3	429.6				
Si3N4	CERA/MAT4/MIX7	SINTERED	4	25		4	3	430.2	PORE			
Si3N4	CERA/MAT4/MIX7	SINTERED	13	25		4	3	459.2				
Si3N4	CERA/MAT4/MIX7	SINTERED	10	25		4	3	482.0				
Si3N4	CERA/MAT4/MIX7	SINTERED	7	25		4	3	488.2	PORE			
Si3N4	CERA/MAT4/MIX7	SINTERED	11	25		4	3	529.5				
Si3N4	CERA/MAT5/MIX10	SINTERED	1	25		4	3	343.0	PORE SURFACE			
Si3N4	CERA/MAT5/MIX10	SINTERED	13	25		4	3	364.2				
Si3N4	CERA/MAT5/MIX10	SINTERED	6	25		4	3	366.6				
Si3N4	CERA/MAT5/MIX10	SINTERED	9	25		4	3	372.0				
Si3N4	CERA/MAT5/MIX10	SINTERED	8	25		4	3	400.0	PORE			

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4CERA1												
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	12	25		4	3	631.7				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	13	25		4	3	643.4				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	15	25		4	3	651.7				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	14	25		4	3	669.9				
Si3N4	CERA/MAT7/MIX25	SINTERED MTL47	16	25		4	3	707.0				
Test Rig = MOR4ORN12												
Si3N4+11.5%La2O3	ORNLSIN11.5LO-2	HP/1800C/90MIN.	SUMRY	22				788.0			103.00	
Si3N4+11.5%La2O3	ORNLSIN11.5LO-2	HP/1800C/90MIN.	SUMRY	1200				697.0			90.00	
Si3N4+11.5%La2O3	ORNLSIN11.5LO-2	HP/1800C/90MIN.	SUMRY	1400				751.0			101.00	
Test Rig = MOR4ORN12												
Si3N4+3%YO+4%LaO+2%AIO	ORNLSINYLA-2	HP/1800C/90MIN.	SUMRY	22				1052.0			137.00	
Si3N4+3%YO+4%LaO+2%AIO	ORNLSINYLA-2	HP/1800C/90MIN.	SUMRY	1000				834.0			101.00	
Si3N4+3%YO+4%LaO+2%AIO	ORNLSINYLA-2	HP/1800C/90MIN.	SUMRY	1200				715.0			41.00	
Test Rig = MOR4ORN12												
Si3N4+4%Y2O3	ORNLSIN4YO-2	HP/1800C/90MIN.	SUMRY	22				1090.0			121.00	
Si3N4+4%Y2O3	ORNLSIN4YO-2	HP/1800C/90MIN.	SUMRY	1200				917.0			54.00	
Test Rig = MOR4ORN12												
Si3N4+4%Y2O3+8%SiO2	ORNLSN4YO8SIO-1		SUMRY	25				848.0			80.00	
Si3N4+4%Y2O3+8%SiO2	ORNLSN4YO8SIO-1		SUMRY	1200				627.0			97.00	
Si3N4+4%Y2O3+8%SiO2	ORNLSN4YO8SIO-1		SUMRY	1400				472.0			70.00	
Test Rig = MOR4ORN12												
Si3N4+6%Y2O3+2%AIO23	ORNLSINYOALO-2	HP/1800C/90MIN.	SUMRY	22				1142.0			125.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYOALO-2	1200C/4H/24MPa	SUMRY	25				677.0			94.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYOALO-2	1200C/4H w/OPRES	SUMRY	25				681.0			110.00	PRESSED WITHOUT PRESSURE
Si3N4+6%Y2O3+2%AIO23	ORNLSINYOALO-2	AS FABRICATED	SUMRY	25				770.0			83.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYOALO-2	HP/1800C/90MIN.	SUMRY	1200				937.0			28.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYOALO-2	HP/1800C/90MIN.	SUMRY	1400				660.0			4.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-9FW		SUMRY	25				960.0			50.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-9FW		SUMRY	1200				310.0			18.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-LC12SX		SUMRY	25				1048.0			137.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-LC12SX		SUMRY	1200				337.0			36.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-P21C3		SUMRY	25				1014.0			40.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-P21C3		SUMRY	1000				473.0			42.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-P21C3		SUMRY	1200				442.0			8.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-TS-10		SUMRY	25				798.0			26.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-TS-10		SUMRY	1000				701.0			118.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-TS-10Y		SUMRY	25				834.0			54.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-TS-10Y		SUMRY	1000				472.0			34.00	
Si3N4+6%Y2O3+2%AIO23	ORNLSINYA-TS-8		SUMRY	25				598.0			27.00	

Section 2C - Modulus of Rupture Four-Point Bend Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Flaw Type	Crosshead Speed mm/s	Std. Dev.	Comments
Test Rig = MOR4ORN12												
Si3N4-6%Y2O3+2%Al2O3	ORN1/SNYA-TS-8		SUMRY	1000				517.0			161.00	
Si3N4-6%Y2O3+2%Al2O3	ORN1/SNYA-UBE-10		SUMRY	25				1142.0			125.00	
Si3N4-6%Y2O3+2%Al2O3	ORN1/SNYA-UBE-10		SUMRY	1200				938.0			28.00	
Test Rig = MOR4ORN12												
Si3N4-6%Y2O3+2%BaO	ORN1/SINYB-2	HP/1800C/90MIN.	SUMRY	22				1072.0			107.00	
Si3N4-6%Y2O3+2%BaO	ORN1/SINYB-2	HP/1800C/90MIN.	SUMRY	1000				957.0			89.00	
Si3N4-6%Y2O3+2%BaO	ORN1/SINYB-2	HP/1800C/90MIN.	SUMRY	1200				720.0			41.00	
Test Rig = MOR4ORN12												
Si3N4-6%Y2O3+2%SiO	ORN1/SINYS-2	HP/1800C/90MIN.	SUMRY	22				1041.0			121.00	
Si3N4-6%Y2O3+2%SiO	ORN1/SINYS-2	HP/1800C/90MIN.	SUMRY	1200				963.0			8.00	
Si3N4-6%Y2O3+2%SiO	ORN1/SINYS-2	HP/1800C/90MIN.	SUMRY	1300				688.0			106.00	
Si3N4-6%Y2O3+2%SiO	ORN1/SINYS-2	HP/1800C/90MIN.	SUMRY	1400				780.0			33.00	
Test Rig = MOR4ORN12												
Si3N4-8%La2O3+2%Al2O3	ORN1/SINALOAO-2	HP/1800C/90MIN.	SUMRY	22				1043.0			111.00	
Si3N4-8%La2O3+2%Al2O3	ORN1/SINALOAO-2	HP/1800C/90MIN.	SUMRY	1000				842.0			75.00	
Si3N4-8%La2O3+2%Al2O3	ORN1/SINALOAO-2	HP/1800C/90MIN.	SUMRY	1200				726.0			14.00	
Test Rig = MOR4ORN12												
Si3N4-8%LaO+7%YbO+4%SiO	ORN1/SNLYS-1		SUMRY	25				872.0			22.00	
Si3N4-8%LaO+7%YbO+4%SiO	ORN1/SNLYS-1		SUMRY	1200				749.0			29.00	
Si3N4-8%LaO+7%YbO+4%SiO	ORN1/SNLYS-1		SUMRY	1400				614.0			71.00	
Test Rig = MOR4ORN12												
Si3N4-8%Y2O3	ORN1/SIN8YO-2	HP/1800C/90MIN.	SUMRY	22				800.0			137.00	
Test Rig = MOR4ORN12												
Si3N4-8%Y2O3+4%SiO2	ORN1/SN8YO4SiO-1		SUMRY	25				635.0			157.00	
Test Rig = MOR4NLC1												
SN-251	KYOCERA/NLRC-90	ANN/1150C/1.5H	SUMRY26	25		4	3	693.0	SURFACE FLAWS			
SN-251	KYOCERA/NLRC-90	ANN/1150C/1.5H	SUMRY3	25		4	3	749.0	VOLUME FLAWS			
SN-251	KYOCERA/NLRC-90	ANN/1150C/1.5H	SUMRY26	1000		4	3	592.0	SURFACE FLAWS			
SN-251	KYOCERA/NLRC-90	ANN/1150C/1.5H	SUMRY29	1371		4	3	574.0	SURFACE FLAWS			
SN-251	KYOCERA/NLRC-90	ANN/1150C/1.5H	SUMRY21	1371		4	3	585.0	VOLUME FLAWS			
Test Rig = MOR4NLC2												
SN-260	KYOCERA/NLRC-91		SUMRY6	25		4	3	604.9			27.30	LOADRATE = 33.3N/s
SN-260	KYOCERA/NLRC-91		SUMRY2	1000		4	3	494.4			3.00	LOADRATE = 33.3N/s
SN-260	KYOCERA/NLRC-91		SUMRY5	1300		4	3	493.2			24.20	LOADRATE = 33.3N/s
SN-260	KYOCERA/NLRC-91		SUMRY5	1400		4	3	489.0			36.40	LOADRATE = 33.3N/s
SN-260	KYOCERA/NLRC-91		SUMRY5	1500		4	3	480.0			29.60	LOADRATE = 33.3N/s

Fig. 2.5. Weibull analysis (least squares) for modulus of rupture 4-pt. bend tests on GTE PY6 at 20°C.

Fig. 2.6. Weibull analysis (least squares) of modulus of rupture 4-pt. bend tests on GTE PY6 at 1000°C.

Fig. 2.7. Weibull analysis (least squares) for GTE PY6 modulus of rupture 4-pt. bend tests at 1100°C.

Fig. 2.8. Weibull analysis (least squares) for GTE PY6 modulus of rupture 4-pt. bend tests at 1200°C.

Fig. 2.9. Weibull analysis (least squares) of GTE PY6 modulus of rupture 4-pt. bend test at 1300°C.

Fig. 2.10. Weibull analysis (least squares) of GTE PY6 modulus of rupture 4-pt. bend test at 1400°C.

Fig. 2.11. Weibull analysis (least squares) for GTE PY6 (modified) modulus of rupture 4pt. bend tests at 20°C.

Fig. 2.12. Weibull analysis (least squares) of GTE PY6 (modified) modulus of rupture 4-pt. bend tests at 1200°C.

Fig. 2.13. Weibull analysis (least squares) for GTE PY6 (modified) modulus of rupture 4-pt. bend tests at 1400°C.

Fig. 2.14. Weibull analysis (least squares) of silicon nitride (CERA/MAT4/MIX6) tested at 25°C.

Fig. 2.15. Weibull analysis (least squares) of silicon nitride (CERA/MAT4/MIX7) tested at 25°C.

Fig. 2.16. Weibull analysis (least squares) of silicon nitride (CERAMAT5/MIX10) tested at 25°C.

Fig. 2.17. Weibull analysis (least squares) of silicon nitride (CERA/MAT5/MIX11) tested at 25°C.

Fig. 2.18. Weibull analysis (least squares) of silicon nitride (CERA/MAT6/MIX18) tested at 25°C.

Fig. 2.19. Weibull analysis (least squares) of silicon nitride (CERA/MAT7/MIX25) modulus of rupture 4-pt. bend tests at 25°C.

Fig. 2.20. A comparison of aged and as-fabricated NT-154 with as-received NT-164 at 20°C test temperature.

Fig. 2.21. Oxidation effects on the bend strength of GN-10 as a monolithic and reinforced with silicon-carbide whiskers. Test temperature was 25°C.

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Fig. 2.22. A comparison of average bend strength values at room temperature for six silicon nitride ceramics.

Fig. 2.23. Comparison of aged, oxidized, and as-received GTE PY6 tested at 20°C.

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Fig. 2.24. Effects of test temperature on the modulus of rupture 4-pt. bend strength of GTE PY6.

* This batch was processed using MTL47 heat treatment.

Fig. 2.25. Bend strengths of six batches of silicon nitride as fabricated by Ceradyne, Inc.

Fig. 2.26. Effects of rare-earth oxide additives on the modulus of rupture 4-pt. bend strength of silicon nitride.

Fig. 2.27. A comparison of modulus of rupture 4-pt. bend strengths for three silicon nitride-based ceramics.

Section 2D - Modulus of Rupture Four-Point Bend Test Results on Zirconia-based Ceramics

Material	Batch Code	Heat Treatment	Environment	Specimen Number	Temp °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Crosshead Speed mm/s	Std. Dev.
Test Rig = MOR4NORTZ											
Y-TZP	NORT/SD039	HIP'ED	AIR	SUMRY10	25		3.175	3.250	1285 0.00846		36.0
Y-TZP	NORT/MG026	HIP'ED	AIR	SUMRY10	25		3.175	3.250	1600 0.00846		8.0
Y-TZP	NORT/MG100	HIP'ED	AIR	SUMRY10	25		3.175	3.250	1146 0.00846		41.0
Y-TZP	NORT/MG200	HIP'ED	AIR	SUMRY10	25		3.175	3.250	1035 0.00846		20.0
Y-TZP	NORT/SD039	HIP'ED	AIR	SUMRY06	300		3.175	3.250	1174 0.00846		41.0
Y-TZP	NORT/MG026	HIP'ED	AIR	SUMRY07	300		3.175	3.250	1347 0.00846		10.0
Y-TZP	NORT/MG100	HIP'ED	AIR	SUMRY10	300		3.175	3.250	1250 0.00846		22.0
Y-TZP	NORT/MG200	HIP'ED	AIR	SUMRY10	300		3.175	3.250	938 0.00846		17.0
Y-TZP	NORT/SD039	HIP'ED	AIR	SUMRY09	500		3.175	3.250	896 0.00846		32.0
Y-TZP	NORT/MG026	HIP'ED	AIR	SUMRY06	500		3.175	3.250	800 0.00846		12.0
Y-TZP	NORT/MG100	HIP'ED	AIR	SUMRY10	700		3.175	3.250	917 0.00846		17.0
Y-TZP	NORT/MG200	HIP'ED	AIR	SUMRY10	500		3.175	3.250	590 0.00846		18.0
Y-TZP	NORT/SD039	HIP'ED	AIR	SUMRY10	700		3.175	3.250	576 0.00846		59.0
Y-TZP	NORT/MG026	HIP'ED	AIR	SUMRY04	700		3.175	3.250	576 0.00846		24.0
Y-TZP	NORT/MG100	HIP'ED	AIR	SUMRY10	700		3.175	3.250	562 0.00846		26.0
Y-TZP	NORT/MG200	HIP'ED	AIR	SUMRY10	700		3.175	3.250	347 0.00846		12.0
Y-TZP	NORT/SD039	SINTERED	AIR	SUMRY10	25		3.175	3.250	1146 0.00846		29.0
Y-TZP	NORT/MG026	SINTERED	AIR	SUMRY10	25		3.175	3.250	944 0.00846		22.0
Y-TZP	NORT/MG100	SINTERED	AIR	SUMRY10	25		3.175	3.250	986 0.00846		17.0
Y-TZP	NORT/MG200	SINTERED	AIR	SUMRY10	25		3.175	3.250	806 0.00846		16.0
Y-TZP	NORT/SD039	SINTERED	AIR	SUMRY10	300		3.175	3.250	1146 0.00846		6.0
Y-TZP	NORT/MG026	SINTERED	AIR	SUMRY04	300		3.175	3.250	958 0.00846		14.0
Y-TZP	NORT/MG100	SINTERED	AIR	SUMRY06	300		3.175	3.250	868 0.00846		28.0
Y-TZP	NORT/MG200	SINTERED	AIR	SUMRY10	300		3.175	3.250	700 0.00846		12.0
Y-TZP	NORT/SD039	SINTERED	AIR	SUMRY10	500		3.175	3.250	750 0.00846		19.0
Y-TZP	NORT/MG026	SINTERED	AIR	SUMRY10	500		3.175	3.250	653 0.00846		17.0
Y-TZP	NORT/MG100	SINTERED	AIR	SUMRY10	500		3.175	3.250	590 0.00846		26.0
Y-TZP	NORT/MG200	SINTERED	AIR	SUMRY10	500		3.175	3.250	510 0.00846		15.0
Y-TZP	NORT/SD039	SINTERED	AIR	SUMRY10	700		3.175	3.250	563 0.00846		15.0
Y-TZP	NORT/MG026	SINTERED	AIR	SUMRY10	700		3.175	3.250	465 0.00846		22.0
Y-TZP	NORT/MG100	SINTERED	AIR	SUMRY10	700		3.175	3.250	465 0.00846		18.0
Y-TZP	NORT/MG200	SINTERED	AIR	SUMRY10	700		3.175	3.250	366 0.00846		13.0

Section 2D - Modulus of Rupture Four-Point Bend Test Results on Zirconia-based Ceramics, continued

Material	Batch Code	Heat Treatment	Environment	Specimen Number	Temp °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Crosshead Speed mm/s	Sid. Dev.
Test Rig = MOR4BCL1											
Mg-PSZ	ZIRCOA/ZYCRON-L	AS RECD	AIR	BZ-B0	25	983.5	5.010	2.550	575		
Mg-PSZ	ZIRCOA/ZYCRON-L	AS RECD	AIR	BZ-B2	25	1041.3	4.980	2.560	610		
Mg-PSZ	ZIRCOA/ZYCRON-L	AS RECD	AIR	BZ-B7	25	1001.3	5.010	2.560	581		
Mg-PSZ	ZIRCOA/ZYCRON-L	AS RECD	AIR	BZ-B8	25	1014.6	5.030	2.550	593		
Mg-PSZ	ZIRCOA/ZYCRON-L	AS RECD	AIR	BZ-B4	400	235.9	5.000	2.560	249		
Mg-PSZ	ZIRCOA/ZYCRON-L	AS RECD	AIR	BZ-B5	750	224.7	5.090	2.540	237		
Mg-PSZ	ZIRCOA/ZYCRON-L	AS RECD	AIR	BZ-B3	1000	206.9	4.980	2.560	220		
Mg-PSZ	ZIRCOA/ZYCRON-L	AS RECD	AIR	BZ-B9	1000	220.3	5.080	2.560	230		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B11	25	449.5	5.080	2.560	258		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B12	25	491.7	5.070	2.560	282		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B14	25	494.0	5.070	2.550	286		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B17	25	520.7	5.070	2.570	296		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B19	25	498.4	5.070	2.560	285		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B21	25	542.9	5.080	2.570	309		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B22	25	560.7	5.100	2.570	318		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B23	25	525.1	5.090	2.570	298		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B24	1000	212.7	5.090	2.570	220		
Mg-PSZ	ZIRCOA/ZYCRON-L+HP	1350C/2H/AIR	AIR	HP26-B26	1000	195.8	5.070	2.550	206		
Test Rig = MOR4BCL1											
MASZ-50	BCL/INTERLAYER	1350°C	AIR	IL50-3/1	25	104.1	5.080	2.520	62		
MASZ-50	BCL/INTERLAYER	1350°C	AIR	IL50-3/2	25	97.9	5.060	2.530	58		
Test Rig = MOR4BCL1											
MASZ-67	BCL/INTERLAYER	1350°C	AIR	IL67-3/1	25	173.6	5.060	2.540	101		
MASZ-67	BCL/INTERLAYER	1350°C	AIR	IL67-3/2	25	164.7	5.070	2.550	95		
MASZ-67	BCL/INTERLAYER	1350°C	AIR	IL67-3/3	25	158.0	5.070	2.550	92		
MASZ-67	BCL/INTERLAYER	1350°C	AIR	IL67-3/4	25	160.2	5.030	2.550	93		
MASZ-67	BCL/INTERLAYER	1350°C	AIR	IL67-3/5	25	160.2	5.010	2.540	94		
MASZ-67	BCL/INTERLAYER	1350°C	AIR	IL67-3/6	25	142.4	5.060	2.540	83		
MASZ-67	BCL/INTERLAYER	1350°C	AIR	IL67-3/7	1000	65.4	5.070	2.550	69		
MASZ-67	BCL/INTERLAYER	1350°C	AIR	IL67-3/8	1000	65.9	5.070	2.540	70		
MASZ-67	BCL/INTERLAYER	1400°C	AIR	IL67-4/1	25	124.6	5.090	2.550	72		
MASZ-67	BCL/INTERLAYER	1400°C	AIR	IL67-1/2	25	142.4	5.090	2.550	82		

Section 2D - Modulus of Rupture Four-Point Bend Test Results on Zirconia-based Ceramics, continued

Material	Batch Code	Heat Treatment	Environment	Specimen Number	Temp °C	Load N	Width mm	Thickness mm	Bend Strength MPa	Crosshead Speed mm/s	Std. Dev.
Test Rig = MOR4BCL1											
MASZ-67	BCL/INTERLAYER	1400°C	AIR	IL67-4/3	25	138.0	5.070	2.550	80		
MASZ-67	BCL/INTERLAYER	1400°C	AIR	IL67-4/4	25	126.8	5.080	2.550	73		
MASZ-67	BCL/INTERLAYER	1400°C	AIR	IL67-4/5	25	135.7	5.090	2.520	80		
MASZ-67	BCL/INTERLAYER	1400°C	AIR	IL67-4/6	25	142.4	5.090	2.550	82		
Test Rig = MOR4BCL1											
MASZ-80	BCL/INTERLAYER	1350°C	AIR	IL80-3/1	25	218.1	5.090	2.510	130		
MASZ-80	BCL/INTERLAYER	1350°C	AIR	IL80-3/2	25	224.7	5.070	2.520	133		
MASZ-80	BCL/INTERLAYER	1350°C	AIR	IL80-3/3	25	235.9	5.070	2.520	139		
MASZ-80	BCL/INTERLAYER	1350°C	AIR	IL80-3/4	25	211.4	5.080	2.550	122		
MASZ-80	BCL/INTERLAYER	1350°C	AIR	IL80-3/5	25	234.5	5.070	2.530	138		
MASZ-80	BCL/INTERLAYER	1350°C	AIR	IL80-3/6	25	249.2	5.070	2.540	145		
MASZ-80	BCL/INTERLAYER	1350°C	AIR	IL80-3/8	1000	65.0	5.070	2.540	69		
MASZ-80	BCL/INTERLAYER	1400°C	AIR	IL80-4/1	25	191.4	5.050	2.540	112		
MASZ-80	BCL/INTERLAYER	1400°C	AIR	IL80-4/2	25	213.6	5.060	2.530	125		
MASZ-80	BCL/INTERLAYER	1400°C	AIR	IL80-4/3	1000	65.0	5.040	2.540	69

Fig. 2.28. Densification effects on the modulus of rupture 4-pt. bend strength of a yttria-doped transformation-toughened zirconia.

Section 3A - Tensile Test Results on Silicon Carbide-based Ceramics

Material	Batch Code	Environment	Specimen Number	Temp. °C	Fracture Stress MPa	Weibull Modulus
Test Rig = TENSNLRC1						
NC-433	NLRC/NORTON-1	AMBIENT AIR	SUMRY15	25	253.70	11.6
NC-433	NLRC/NORTON-1	AMBIENT AIR	SUMRY5	1000	274.30	
NC-433	NLRC/NORTON-1	AMBIENT AIR	SUMRY15	1200	295.10	16.9
NC-433	NLRC/NORTON-1	AMBIENT AIR	SUMRY5	1300	294.70	
NC-433	NLRC/NORTON-1	AMBIENT AIR	SUMRY15	1370	199.60	10.7
NC-433	NLRC/NORTON-1	AMBIENT AIR	SUMRY5	1400	63.30

Fig. 2.29. Temperature effects on the tensile strength of NC-433.

Section 3B - Tensile Test Results on Silicon Nitride-based Ceramics

Material	Batch Code	Specimen Number	Test Temp. °C	Ultimate Tensile Strength MPa	Std. Dev.	Comments
Test Rig = TENSORN1						
GN-10	ORNL/KCL	357-2	1150	585.60		
GN-10	ORNL/KCL	350-1-2	1200	514.20		
GN-10	ORNL/KCL	338-1-2	1250	472.50		
Test Rig = TENSRI1						
GTE PY6	AGTD/HIP	168A	20	387.77		
GTE PY6	AGTD/HIP	163B	20	445.21		
GTE PY6	AGTD/HIP	166B	20	487.61		
GTE PY6	AGTD/HIP	167B	20	276.55		
GTE PY6	AGTD/HIP	159B	20	402.80		
GTE PY6	AGTD/HIP	177B	20	369.02		
GTE PY6	AGTD/HIP	142B	20	446.72		
GTE PY6	AGTD/HIP	174A	20	516.22		
GTE PY6	AGTD/HIP	104A	20	479.60		
GTE PY6	AGTD/HIP	103B	20	505.80		
GTE PY6	AGTD/HIP	179A	20	455.55		
GTE PY6	AGTD/HIP	103B	20	505.80		
GTE PY6	AGTD/HIP	233B	20	547.04		
GTE PY6	AGTD/HIP	182A	20	490.71		
GTE PY6	AGTD/HIP	229A	20	427.49		
GTE PY6	AGTD/HIP	103B	20	505.80		
GTE PY6	AGTD/HIP	236B	20	447.20		
GTE PY6	AGTD/HIP	182B	20	380.60		
GTE PY6	AGTD/HIP	243B	20	373.02		
GTE PY6	AGTD/HIP	64A	20	483.10		
IM-BH:55.9 mm x 4.762 mm FAIL:INTERNAL FLAW						
FAIL:INTERNAL/SURFACE						

Section 3B - Tensile Test Results on Silicon Nitride-based Ceramics, continued

Material	Batch Code	Specimen Number	Test Temp. °C	Ultimate Tensile Strength MPa	Std. Dev.	Comments
Test Rig = TENSRI1						
GTE PY6	AGTD/HIP	68A	20	420.20		IM-BH:55.9 mm x 4.762 mm
GTE PY6	AGTD/HIP	273A	20	438.93		
GTE PY6	AGTD/HIP	370B	20	383.98		
GTE PY6	AGTD/HIP	363B	20	335.78		
GTE PY6	AGTD/HIP	366A	20	408.04		
GTE PY6	AGTD/HIP	279B	20	392.94		
GTE PY6	AGTD/HIP	366B	20	421.28		
GTE PY6	AGTD/HIP	286A	20	413.70		
GTE PY6	AGTD/HIP	368A	20	486.92		
GTE PY6	AGTD/HIP	291B	20	419.42		
GTE PY6	AGTD/HIP	368B	20	464.86		
GTE PY6	AGTD/HIP	297B	20	369.64		
GTE PY6	AGTD/HIP	369A	20	487.95		
GTE PY6	AGTD/HIP	299B	20	488.30		
GTE PY6	AGTD/HIP	369B	20	451.20		
GTE PY6	AGTD/HIP	324A	20	527.39		
GTE PY6	AGTD/HIP	370A	20	434.38		
GTE PY6	AGTD/HIP	325B	20	328.54		
GTE PY6	AGTD/HIP	276A	20	346.61		
GTE PY6	AGTD/HIP	93A	20	357.70		
GTE PY6	AGTD/HIP	371B	20	442.59		FAIL: SURFACE FLAW
GTE PY6	AGTD/HIP	337B	20	395.01		
GTE PY6	AGTD/HIP	372A	20	414.52		
GTE PY6	AGTD/HIP	360A	20	411.49		
GTE PY6	AGTD/HIP	372B	20	377.08		

Section 3B - Tensile Test Results on Silicon Nitride-based Ceramics, continued

Material	Batch Code	Specimen Number	Test Temp. °C	Ultimate Tensile Strength MPa	Std. Dev.	Comments
Test Rig = TENSRI1						
GTE PY6	AGTD/HIP	363A	20	310.61		
GTE PY6	AGTD/HIP	373A	20	386.94		
GTE PY6	AGTD/HIP	282A	20	359.09		
GTE PY6	AGTD/HIP	173B	20	390.87		
GTE PY6	AGTD/HIP	292A	20	408.94		
GTE PY6	AGTD/HIP	374B	20	394.46		
GTE PY6	AGTD/HIP	308B	20	378.60		
GTE PY6	AGTD/HIP	53B*	20	434.40		FAILED IN BUTTONHEAD
GTE PY6	AGTD/HIP	327B	20	423.90		
GTE PY6	AGTD/HIP	243A	20	494.85		
GTE PY6	AGTD/HIP	348A	20	312.41		
GTE PY6	AGTD/HIP	66B	20	304.80		IM-BH:55.9 mm x 4.762 mm
GTE PY6	AGTD/HIP	96A	20	575.24		
GTE PY6	AGTD/HIP	90B	20	399.80		IM-BH:55.9 mm x 4.762 mm
GTE PY6	AGTD/HIP	298A	20	320.96		
GTE PY6	AGTD/HIP	92B	20	479.20		
GTE PY6	AGTD/HIP	362B	20	337.85		
GTE PY6	AGTD/HIP	291A	20	383.49		
GTE PY6	AGTD/HIP	325A	20	386.39		
GTE PY6	AGTD/HIP	274A	20	373.70		
GTE PY6	AGTD/HIP	274B	20	444.38		
GTE PY6	AGTD/HIP	72A	20	382.74		FAIL:INTERNAL FLAW
GTE PY6	AGTD/HIP	76A	20	418.10		FAIL:INTERNAL FLAW
GTE PY6	AGTD/HIP	83B	20	368.70		IM-BH:55.9 mm x 4.762 mm
GTE PY6	AGTD/HIP	105A	1000	461.97		

Section 3B - Tensile Test Results on Silicon Nitride-based Ceramics, continued

Material	Batch Code	Specimen Number	Test Temp. °C	Ultimate Tensile Strength MPa	Std. Dev.	Comments
Test Rig = TENSRI1						
GTE PY6	AGTD/HIP	118B	1000	451.97		
GTE PY6	AGTD/HIP	651B	1000	243.26		
GTE PY6	AGTD/HIP	121B	1000	451.97		
GTE PY6	AGTD/HIP	115A	1000	240.08		
GTE PY6	AGTD/HIP	124B	1000	482.44		
GTE PY6	AGTD/HIP	652A	1000	299.87		
GTE PY6	AGTD/HIP	123A	1000	498.03		
GTE PY6	AGTD/HIP	95B	1000	469.83		
GTE PY6	AGTD/HIP	122A	1000	521.54		
GTE PY6	AGTD/HIP	125A	1000	423.91		
GTE PY6	AGTD/HIP	125B	1000	264.91		
GTE PY6	AGTD/HIP	97A	1200	377.20		
GTE PY6	AGTD/HIP	94B	1300	309.60		
GTE PY6	AGTD/HIP	234B	1400	363.15		
GTE PY6	AGTD/HIP	178A	1400	383.22		
GTE PY6	AGTD/HIP	232B	1400	179.27		
GTE PY6	AGTD/HIP	232A	1400	411.90		
GTE PY6	AGTD/HIP	179B	1400	356.05		
GTE PY6	AGTD/HIP	161A	1400	236.63		
GTE PY6	AGTD/HIP	157B	1400	387.22		
GTE PY6	AGTD/HIP	158A	1400	111.49		
GTE PY6	AGTD/HIP	159A	1400	387.84		
GTE PY6	AGTD/HIP	154A	1400	173.47		
GTE PY6	AGTD/HIP	161B	1400	368.05		
GTE PY6	AGTD/HIP	172A	1400	291.17		

IM-BH:55.9 mm x 4.762 mm

IM-BH:55.9 mm x 4.762 mm

IM-BH:55.9 mm x 4.762 mm

Section 3B - Tensile Test Results on Silicon Nitride-based Ceramics, continued

Material	Batch Code	Specimen Number	Test Temp. °C	Ultimate Tensile Strength MPa	Std. Dev.	Comments
Test Rig = TENSURI1						
GTE PY6	AGTD/HIP	172B	1400	338.13		
GTE PY6	AGTD/HIP	175B	1400	347.92		
GTE PY6	AGTD/HIP	176A	1400	408.25		
GTE PY6	AGTD/HIP	156B	1400	348.68		
GTE PY6	AGTD/HIP	240B	1400	398.73		
GTE PY6	AGTD/HIP	328B	1400	352.12		
GTE PY6	AGTD/HIP	329B	1400	296.27		
GTE PY6	AGTD/HIP	67B	1400	149.10		
GTE PY6	AGTD/HIP	71B	1400	203.95		
GTE PY6	AGTD/HIP	248A	1400	388.05		
GTE PY6	AGTD/HIP	245A	1400	348.54		
GTE PY6	AGTD/HIP	244A	1400	391.56		
IM-BH:55.9 mm x 4.762 mm						
Test Rig = TENSUDRI1						
GTE PY6	GTEL/UDRI/2	E22	20	200.00		SURFACE FLAW
GTE PY6	GTEL/UDRI/2	H22	20	528.00		INCLUSION IN VOLUME
GTE PY6	GTEL/UDRI/2	H13	20	420.00		LARGE INCLUSION IN VOL
GTE PY6	GTEL/UDRI/2	H12	20	769.00		SURFACE FLAW IN GAGE
GTE PY6	GTEL/UDRI/2	H8	20	165.00		SURFACE FLAW IN B.H.
GTE PY6	GTEL/UDRI/2	H6	20	189.00		SURFACE FLAW IN B.H.
GTE PY6	GTEL/UDRI/2	E19	20	236.00		SURFACE FLAW
GTE PY6	GTEL/UDRI/2	E24	20	626.00		INCLUSION IN VOLUME
GTE PY6	GTEL/UDRI/2	H5	20	182.00		SURFACE FLAW IN B.H.
GTE PY6	GTEL/UDRI/2	E21	20	205.00		SURFACE FLAW
GTE PY6	GTEL/UDRI/2	SUMRY10	20	619.00	123.0	5VOL.INCL,1SURF.INC,1S.F

Section 3B - Tensile Test Results on Silicon Nitride-based Ceramics, continued

Material	Batch Code	Specimen Number	Test Temp. °C	Ultimate Tensile Strength MPa	Std. Dev.	Comments
Test Rig = TENSUDRI1						
GTE PY6	GTEL/UDRI/2	SUMRY5	1000	447.00	111.0	4VOL.INCL,1SURF.FLAW
GTE PY6	GTEL/UDRI/2	SUMRY1	1100	288.00		VOLUME INCLUSION
GTE PY6	GTEL/UDRI/2	SUMRY5	1200	310.00	36.0	4VOL.INCL, 1SURF.FLAW
GTE PY6	GTEL/UDRI/2	SUMRY5	1300	251.00	28.0	3SURF.INCL,1VOL.INCL,1SF
GTE PY6	GTEL/UDRI/2	SUMRY5	1400	153.00	53.0	4SURF.FLAW,1SURF.INCL.
Test Rig = TENSUDRI1						
NT-164	NORTON/UDRI-92	SUMRY4	20	700.00		LOADRATE = 0.0004mm/s
NT-164	NORTON/UDRI-92	SUMRY1	20	546.00		LOADRATE = 0.000004mm/s
NT-164	NORTON/UDRI-92	SUMRY2	1350	388.00		LOADRATE = 0.000004mm/s
NT-164	NORTON/UDRI-92	SUMRY2	1350	567.00		LOADRATE = 0.0004mm/s

Section 4 - Creep Data on Silicon Nitride-based Ceramics

Material	Batch Code	Specimen Number	Temp. °C	Stress MPa	Strain Rate %/s	Rupture Time h	Total Strain %	Specimen Geometry	Comments
Test Rig = ORNL CREP2									
GN-10	ORNL/KCL	GN10-B1	1204	276.0		4.26	0.4600	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-B2	1204	276.0		26.63	0.4210	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-B4	1260	207.0		4.99	0.4970	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-C1	1260	207.0		3.65	0.5610	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-C2	1315	138.0		6.85	0.9840	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-C3	1315	138.0		2.73	0.8700	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-C4	1204	241.0		17.00	0.3800	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-D1	1204	241.0		51.40	0.3450	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-D3	1260	172.0		79.00	0.6500	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-D4	1260	172.0		114.00	0.6050	BH-GAGE = 6.35 X 35 MM	
GN-10	ORNL/KCL	GN10-D5	1315	69.0		150.00	0.3300	BH-GAGE = 6.35 X 35 MM	BROKE IN SPEC. SHANK
Test Rig = ORNL CREP2									
GTE PY6	ORNL/LOT ?	5SNPY11	1150	225.0	2.2E-10	1190TD	0.2450	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT P	3SNPY11	1150	250.0	1.0E-08	23.00	0.2100	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT N	4SNPY11	1150	275.0	1.8E-07	2.00	0.2180	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT ?	2SNPY11	1150	287.0	9.0E-08	1.00	0.1167	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT ?	1SNPY11	1150	300.0	2.7E-08	3.00	0.1252	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT F	4SPY120	1200	188.0	1.5E-09	797.00	0.6470	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT G	3SPY120	1200	200.0	7.9E-08	2.60	0.1470	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT G	3SPY120	1200	225.0	1.0E-07	2.30	0.2120	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT P	4SNPY12	1260	100.0	4.9E-10	2261.00	0.6160	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT P	6SNPY12	1260	113.0	1.0E-09	0.00	0.8120	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT P	5SNPY12	1260	125.0	4.7E-09	502.00	1.4200	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT P	7SNPY12	1260	138.0	2.9E-09	329.00	0.6800	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT P	8SNPY12	1260	150.0	3.3E-09	178.00	0.4280	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT P	9SNPY12	1260	175.0	1.6E-08	60.00	0.8110	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT F	8SNPY13	1370	60.0	1.7E-08	230.00	1.8630	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT ?	4SNPY13	1370	68.0	2.0E-08	106.00	1.3370	BH-GAGE = 6.35 X 35 MM	

Section 4 - Creep Data on Silicon Nitride-based Ceramics, continued

Material	Batch Code	Specimen Number	Temp. °C	Stress MPa	Strain Rate %/s	Rupture Time h	Total Strain %	Specimen Geometry	Comments
Test Rig = ORNL CREP2									
GTE PY6	ORNL/LOT MA	1PH137	1370	68.0	3.7E-08	82.00	1.5100	BH-GAGE = 6.35 X 35 MM	MICROWAVE ANNEAL
GTE PY6	ORNL/LOT ?	3SNPY13	1370	75.0	2.6E-08	90.00	1.4180	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT ?	2SNPY13	1370	87.0	4.8E-08	41.00	1.0760	BH-GAGE = 6.35 X 35 MM	
GTE PY6	ORNL/LOT N	1SNPY13	1370	100.0	1.5E-07	8.00	1.0070	BH-GAGE = 6.35 X 35 MM	
Test Rig = ORNL CREP2C									
GTE PY6	ORNL/LOT CYC *9SNPY13		1370	62.0	1.2E-08	410.00	2.8620	BH-GAGE = 6.35 X 35 MM	See note 1 below.
GTE PY6	ORNL/LOT CYC *7SNPY13		1370	70.0	9.3E-09	886.00	3.7030	BH-GAGE = 6.35 X 35 MM	See note 2 below.
GTE PY6	ORNL/LOT CYC *0SNPY13		1370	85.0	3.4E-08	93.00	1.9800	BH-GAGE = 6.35 X 35 MM	See note 3 below.
Test Rig = CREPORN2									
NT-154	NORTON/GAPD	3-40	982	450.0		631TD	0.0000	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-62	1149	425.0		32.10	0.1640	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	3-109	1149	425.0		509TD	0.0000	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	3-31	1149	435.0		594TD	0.0000	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-47	1149	450.0		0.08	0.1490	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	3-41	1149	450.0		7.00	0.0000	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-3	1204	300.0	1.8E-10	517.00	0.1580	BH-GAGE = 6.35 X 35 MM	

* NOTES:

1. The specimen was cycled through a 25% stress unload/reload cycle at 0.022Hz every 12 to 24 h.
2. The specimen was cycled through a 25% stress unload/reload cycle at 0.022Hz every 12 to 24 h.
3. The specimen was unloaded by a 10% reduction in stress, then reloaded to the previous stress level at 0.014 Hz every 24 h.

Section 4 - Creep Data on Silicon Nitride-based Ceramics, continued

Material	Batch Code	Specimen Number	Temp. °C	Stress MPa	Strain Rate %/s	Rupture Time h	Total Strain %	Specimen Geometry	Comments
Test Rig = CREPORN2									
NT-154	NORTON/GAPD	2-36	1204	300.0		593.00	0.3800	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-31	1204	315.0		594.00	0.3600	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-74	1204	325.0		67.90	0.3900	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-71	1204	350.0	4.4E-08	2.30	0.1190	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-56	1204	415.0	1.1E-08	1.30	0.1380	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-66	1260	200.0		530TD	0.0000	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	3-120	1260	250.0		838.00	0.7430	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-46	1260	275.0		6.10	0.1130	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	3-89	1260	275.0		31.00	0.2690	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	3-112	1260	275.0		474.00	0.6900	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-145	1260	285.0		379.00	0.6910	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-23	1260	300.0	2.2E-7	0.40	0.0790	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-36	1260	300.0		0.35	0.5120	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-102	1260	325.0		1.20	0.1420	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-11	1260	375.0	3.8E-7	0.35	0.2231	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-15	1315	225.0	2.2E-9	675TD	1.3000	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-128	1315	227.5		20.00	0.5260	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-37	1315	230.0		244.00	1.0870	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-112	1315	230.0		168.00	0.9100	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-111	1315	232.5		297.00	1.0660	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-64	1315	235.0		52.00	0.6960	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-24	1315	240.0		2.94	0.2360	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-2	1315	250.0	2.2E-8	24.00	0.3640	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-121	1371	125.0	6.3E-09	728.00	1.6950	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-117	1371	135.0		587.00	1.8780	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	2-134	1371	150.0		171.00	1.5420	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	3-33	1371	150.0		75.00	1.1060	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-20	1371	160.0	1.3E-8	209.00	1.4410	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD	1-6	1371	180.0		62.00	1.3450	BH-GAGE = 6.35 X 35 MM	

Section 4 - Creep Data on Silicon Nitride-based Ceramics, continued

Material	Batch Code	Specimen Number	Temp. °C	Stress MPa	Rupture Time h	Total Strain %	Specimen Geometry	Comments
Test Rig = CREPORN12								
NT-154	NORTON/GAPD 1-9		1371	190.0	2.3E-8	68.00	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 2-55		1371	210.0	4.6E-7	1.40	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 2-35		1400	85.0		597TD	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 2-123		1400	90.0		478.00	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 2-68		1400	100.0	1.3E-08	462.00	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 2-114		1400	110.0		411.00	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 1-4		1400	125.0	1.3E-8	341.00	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 1-10		1400	130.0		17.00	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 2-125		1400	130.0		139.00	BH-GAGE = 6.35 X 35 MM	
NT-154	NORTON/GAPD 1-21		1400	140.0	3.3E-8	96.00	BH-GAGE = 6.35 X 35 MM	
Test Rig = ORNL CREP2								
NT-154	ORNL/KCL	NT154-9	1205	345.0	150.00	0.8570	BH-GAGE = 6.35 X 35 MM	RES. STRESS=437MPa
NT-154	ORNL/KCL	NT154-10	1205	379.0	47.45	0.0990	BH-GAGE = 6.35 X 35 MM	
NT-154	ORNL/KCL	NT154-7	1260	345.0	4.90	0.0731	BH-GAGE = 6.35 X 35 MM	
NT-154	ORNL/KCL	NT154-8	1260	345.0	15.00	0.1080	BH-GAGE = 6.35 X 35 MM	
NT-154	ORNL/KCL	NT154-5	1315	276.0	5.41	0.1890	BH-GAGE = 6.35 X 35 MM	
NT-154	ORNL/KCL	NT154-6	1315	276.0	2.34	0.1620	BH-GAGE = 6.35 X 35 MM	
NT-154	ORNL/KCL	NT154-15	1204	379.0	80.80	0.0690	BH-GAGE = 6.35 X 35 MM	
NT-154	ORNL/KCL	NT154-12	1260	310.0	150.00	0.1550	BH-GAGE = 6.35 X 35 MM	FAIL'D IN BUTTONHEAD
NT-154	ORNL/KCL	NT154-12	1260	310.0	151.00	0.2200	BH-GAGE = 6.35 X 35 MM	

Section 5 - Stress Rupture Test Results on Silicon-based Ceramics

Material	Batch Code	Heat Treatment	Specimen Number	Temp °C	Stress MPa	Rupture Time h	Time Disc. h	Creep Strain %	Minimum Creep Rate m/m/s	Comments
Test Rig = STRPUDRI1										
GN-10	GCCD/UDRI-90		37	1300	274	104.30				SPECIMEN BENDING
GN-10	GCCD/UDRI-90		38	1300	274	14.70				SPECIMEN BENDING
GN-10	GCCD/UDRI-90		39	1300	274	104.90				SPECIMEN BENDING
GN-10	GCCD/UDRI-90		40	1300	274	23.20				SPECIMEN BENDING
GN-10	GCCD/UDRI-90		35	1350	274	5.40				PITTING
GN-10	GCCD/UDRI-90		36	1350	274	112.80				SPECIMEN BENDING
GN-10	GCCD/UDRI-90		33	1350	300	7.00				EDGE FLAW
GN-10	GCCD/UDRI-90		34	1350	300	7.30				EDGE FLAW
GN-10	GCCD/UDRI-90		31	1350	465	3.20				SURFACE FLAW
GN-10	GCCD/UDRI-90		32	1350	465	32.60				
Test Rig= STRPORN1										
NT-154	ORN1/KCL92		NTC-09	1204	345		150.0	0.8370	8.9E-10	See note 1 below.
NT-154	ORN1/KCL92		*NTC-42	1204	345	0.91		0.0127		
NT-154	ORN1/KCL92		NTC-10	1204	379	47.45		0.0990	2.18E-09	
NT-154	ORN1/KCL92		NTC-15	1204	379	80.80		0.0690	1.49E-09	
NT-154	ORN1/KCL92		*NTC-14	1204	379	1.75		0.0100	7.19E-09	See note 1 below.
NT-154	ORN1/KCL92		*NTC-16	1204	379	8.60		0.0170	2.55E-09	See note 1 below.
NT-154	ORN1/KCL92		NTC-17	1204	379		150.0	0.0830	8.77E-10	
NT-154	ORN1/KCL92		NTC-20	1204	414	3.10		0.0200	5.89E-09	
NT-154	ORN1/KCL92		NTC-22	1204	414	1.10		0.0770	1.77E-08	
NT-154	ORN1/KCL92		NTC-12	1260	310		150.0	0.1550	1.92E-09	
NT-154	ORN1/KCL92		NTC-13	1260	310	151.00		0.2180	1.20E-09	
NT-154	ORN1/KCL92		*NTC-44	1260	310	16.67		0.1320		See note 2 below.

Section 5 - Stress Rupture Test Results on Silicon-based Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp °C	Stress MPa	Rupture Time h	Time Disc. h	Creep Strain %	Minimum Creep Rate m/m/s	Comments
Test Rig= STRPORN1										
NT-154	ORNL/KCL92		NTC-27	1260	328	21.20		0.0860	6.45E-09	
NT-154	ORNL/KCL92		NTC-38	1260	328	0.35		0.0096	7.65E-08	INTERNAL FLAW
NT-154	ORNL/KCL92		NTC-40	1260	328	0.10		0.0041	1.12E-07	INTERNAL FLAW
NT-154	ORNL/KCL92		NTC-07	1260	345	4.90		0.0730	3.58E-08	
NT-154	ORNL/KCL92		NTC-08	1260	345	15.00		0.1080	1.59E-08	
NT-154	ORNL/KCL92		NTC-23	1260	345	3.70		0.0350	1.27E-08	
NT-154	ORNL/KCL92		NTC-18	1315	241		150.0	0.3300	3.36E-09	
NT-154	ORNL/KCL92		NTC-19	1315	241		159.0	0.4370	1.74E-09	
NT-154	ORNL/KCL92		NTC-25	1315	241	121.30		0.4710	3.65E-09	
NT-154	ORNL/KCL92		NTC-26	1315	258	10.15		0.2800	4.27E-08	
NT-154	ORNL/KCL92		NTC-29	1315	258	42.90		0.4530	1.03E-07	
NT-154	ORNL/KCL92		NTC-05	1315	276	5.41		0.1890	7.04E-08	
NT-154	ORNL/KCL92		NTC-06	1315	276	2.34		0.1620	1.7E-07	
NT-154	ORNL/KCL92		NTC-24	1315	276	4.00		0.2030	8.68E-08	
Test Rig = STRPUDRI1										
NT-154	NORTON/UDRI/2		11	1200	300	56.31				SURFACE
NT-154	NORTON/UDRI/2		13	1200	300	86.20				
NT-154	NORTON/UDRI/2		7	1200	388	100.00				VOL@INCLUSION
NT-154	NORTON/UDRI/2		9	1200	388	100.00				VOL@INCLUSION
NT-154	NORTON/UDRI/2		8	1200	485	100.00				VOL@INCLUSION
NT-154	NORTON/UDRI/2		10	1200	485	100.00				VOL@INCLUSION
NT-154	NORTON/UDRI/2		12	1200	572	100.00				VOL@INCLUSION
NT-154	NORTON/UDRI/2		14	1250	300	84.00				SURFACE FLAW
NT-154	NORTON/UDRI/2		15	1250	300	56.20				VOLUME FLAW
NT-154	NORTON/UDRI/2		16	1250	300	11.70				VOLUME FLAW
NT-154	NORTON/UDRI/2		17	1250	300	18.10				
NT-154	NORTON/UDRI/2		18	1300	300	3.07				SURFACE FLAW
NT-154	NORTON/UDRI/2		19	1300	300	1.20				VOLUME FLAW

Section 5 - Stress Rupture Test Results on Silicon-based Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp °C	Stress MPa	Rupture Time h	Time Disc. h	Creep Strain %	Minimum Creep Rate m/m/s	Comments
Test Rig = STRPUDRI1										
NT-154	NORTON/UDRI/2		20	1300	300	0.52				VOLUME FLAW
NT-154	NORTON/UDRI/2		21	1300	300	0.80				VOLUME FLAW
NT-154	NORTON/UDRI/2		22	1300	300	1.20				VOLUME FLAW
NT-154	NORTON/UDRI/2		300-36	1328	200	0.10				SURFACE FLAW
NT-154	NORTON/UDRI/2		300-37	1328	200	0.05				SURFACE FLAW
NT-154	NORTON/UDRI/2		300-13	1328	200	0.80				SURFACE FLAW
NT-154	NORTON/UDRI/2		300-29	1328	250	1.60				SURFACE FLAW
NT-154	NORTON/UDRI/2		300-35	1328	250	0.10				SURFACE FLAW
NT-154	NORTON/UDRI/2		300-27	1328	507	50.00				VOLUME INCLUSION
NT-154	NORTON/UDRI/2		4	1400	200	0.07				SURFACE FLAW
NT-154	NORTON/UDRI/2		5	1400	200	0.01				SURFACE FLAW
NT-154	NORTON/UDRI/2		6	1400	200	0.00				SURFACE FLAW
Test Rig = STRPUDRI1										
NT-164	NORTON/UDRI-92		83	1350	261	102.70				SPECIMEN BENDING
NT-164	NORTON/UDRI-92		84	1350	261	102.00				SPECIMEN BENDING
NT-164	NORTON/UDRI-92		13	1350	261	102.00				SPECIMEN BENDING
NT-164	NORTON/UDRI-92			1350	284	1.28				SURFACE FLAW
NT-164	NORTON/UDRI-92			1350	379	0.10				SURFACE FLAW
NT-164	NORTON/UDRI-92		78	1350	385	3.70				SPECIMEN BENDING
NT-164	NORTON/UDRI-92		79	1350	385	108.70				SURFACE FLAW
NT-164	NORTON/UDRI-92		80	1350	385	0.65				SURFACE FLAW
NT-164	NORTON/UDRI-92		81	1350	385	1.05				SURFACE FLAW
NT-164	NORTON/UDRI-92		82	1350	385	0.40				EDGE FLAW
NT-164	NORTON/UDRI-92		76	1350	527	-				SURFACE FLAW
NT-164	NORTON/UDRI-92		77	1350	527	5.30				SURFACE FLAW

Section 5 - Stress Rupture Test Results on Silicon-based Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp °C	Stress MPa	Rupture Time h	Time Disc. h	Creep Strain %	Minimum Creep Rate m/m/s	Comments
Test Rig = STRPUDRI1										
HEXOLOYS A	CARBRNDM/UDRI/2	ANN/1200C/67.2H	3	1150	300	28.00				FAILED IN BUTTONHEAD
HEXOLOYS A	CARBRNDM/UDRI/2		*1	1400	275	119.50				
HEXOLOYS A	CARBRNDM/UDRI/2	ANN/1200C/67.2H	2	1400	315	100.00				
HEXOLOYS A	CARBRNDM/UDRI/2	ANN/1200C/67.2H	4	1400	300	0.01				

NOTES: 1. Fracture was initiated from a large internal flaw - rupture time listed may be invalid.

2. Fracture began in a large inclusion near specimen surface outside of the gage section. Rupture time may be invalid.

Section 6A - Dynamic Fatigue Tests on Silicon Carbide-based Ceramics

Material	Batch Code	Environment	Specimen Number	Temp. °C	Stress Rate MPa/s	Strength MPa	Width mm	Thickness mm	Standard Deviation
Test Rig = DFATNLCR1									
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY4	1200	0.033	340.7	6.36	3.18	16.1
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY5	1200	33.333	288.7	6.36	3.18	34.7
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY5	1300	0.033	344.7	6.36	3.18	22.3
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY5	1300	0.333	317.2	6.36	3.18	19.2
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY5	1300	3.333	303.3	6.36	3.18	17.2
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY5	1300	33.333	294.7	6.36	3.18	15.4
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY4	1370	0.033	241.4	6.36	3.18	21.6
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY4	1370	0.333	218.9	6.36	3.18	27.6
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY4	1370	3.333	213.9	6.36	3.18	21.5
NC-433	NORTON/NLRC-90	AMBIENT AIR	SUMRY5	1370	33.333	222.6	6.36	3.18	16.9

NOTE: The values given above are averages of the number of tests indicated in the specimen number.

Section 6B - Dynamic Fatigue Test Results on Silicon Nitride Ceramics

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load Rate N/s	Stress Rate MPa/s	Strength MPa	Time to Failure h	Strain to Failure %	Width mm	Thickness mm	Standard Dev.	Comments
Test Rig = DFATNLR1													
GN-10	GCCD/NLRC-90	AS RECD	SUMRY3	1100	0.0333	0.0333	609.20			2.70	4.00	35.1	
GN-10	GCCD/NLRC-90	AS RECD	SUMRY4	1100	0.3333	0.3333	649.00			2.70	4.00	45.3	
GN-10	GCCD/NLRC-90	AS RECD	SUMRY3	1100	3.3333	3.3333	675.30			2.70	4.00	41.8	
GN-10	GCCD/NLRC-90	AS RECD	SUMRY4	1100	33.3333	33.3333	697.40			2.70	4.00	5.1	
GN-10	GCCD/NLRC-90	AS RECD	SUMRY3	1200	0.0333	0.0333	537.20			2.70	4.00	48.4	
GN-10	GCCD/NLRC-90	AS RECD	SUMRY4	1200	33.3333	33.3333	621.50			2.70	4.00	63.4	
GN-10	GCCD/NLRC-90	AS RECD	SUMRY4	1300	0.0333	0.0333	513.30			2.70	4.00	49.3	
GN-10	GCCD/NLRC-90	AS RECD	SUMRY4	1300	0.3333	0.3333	523.30			2.70	4.00	47.3	
GN-10	GCCD/NLRC-90	AS RECD	SUMRY4	1300	3.3333	3.3333	596.40			2.70	4.00	75.1	
Test Rig = DFATAGTD1													
GTE PY6	AGTD/HIP		34.1966	1200			666.50			4.00	3.00		XH_SPEED = .00508 mm/min
GTE PY6	AGTD/HIP		34.1967	1200			617.44			4.00	3.00		XH_SPEED = .00508 mm/min
GTE PY6	AGTD/HIP		34.1968	1200			578.00			4.00	3.00		XH_SPEED = .00508 mm/min
GTE PY6	AGTD/HIP		34.1969	1200			584.69			4.00	3.00		XH_SPEED = .00508 mm/min
GTE PY6	AGTD/HIP		34.1970	1200			627.00			4.00	3.00		XH_SPEED = .00508 mm/min
Test Rig = DFATORN1													
GTE PY6	ORN/LOT ?	MICROWV ANN	1DNPY115	1150		10E-00	372.00	396S	0.1270				
GTE PY6	ORN/LOT MA		2DNPY115	1150		10E-01	311.00	0.86H	0.1010				
GTE PY6	ORN/LOT G		6DNPY115	1150		10E-01	338.00	0.97H	0.1450				
GTE PY6	ORN/LOT ?		3DNPY115	1150		10E-02	322.00	8.9H	0.1985				
GTE PY6	ORN/LOT F		4DNPY115	1150		10E-03	320.00	88.8H	0.1560				
GTE PY6	ORN/LOT G		5DNPY115	1150		37.0	367.00	9.9S	0.1150				
GTE PY6	ORN/LOT ?		7DNPY115	1150		10E-04	341.00	857H	0.2520				
GTE PY6	ORN/LOT ?		1DNPY126	1260		10E-00	324.00	325S					
GTE PY6	ORN/LOT ?		5DNPY126	1260		10E-01	276.00	0.77H	0.1810				
GTE PY6	ORN/LOT ?		2DNPY126	1260		10E-01	289.00	0.87H	0.2230				
GTE PY6	ORN/LOT ?		3DNPY126	1260		10E-02	339.00	9.4H	0.3890				
GTE PY6	ORN/LOT A		4DNPY126	1260		10E-03	204.00	56.7H	0.3390				
GTE PY6	ORN/LOT ?		7DNPY126	1260		10E-03	304.00	84.4H	0.5310				
GTE PY6	ORN/LOT ?		6DNPY126	1260		10E-04	269.00	676H	0.9130				
GTE PY6	ORN/LOT A		1SNPY126	1260		37	350.00	9.5S	0.1250				
GTE PY6	ORN/LOT A		2SNPY126	1260		37	363.00	9.9S	0.1254				
GTE PY6	ORN/LOT A		3SNPY126	1260		37	368.00	9.7S					
GTE PY6	ORN/LOT A		1DNPY137	1370		10E-00	197.00	196S	0.2640				
GTE PY6	ORN/LOT D		2DNPY137	1370		10E-01	135.00	0.37H	0.4070				

Section 6B - Dynamic Fatigue Test Results on Silicon Nitride Ceramics, continued

Material	Batch Code	Heat Treatment	Specimen Number	Temp. °C	Load Rate N/s	Stress Rate MPa/s	Strength MPa	Time to Failure h	Failure %	Width mm	Thickness mm	Standard Dev.	Comments
Test Rig = DFATORN1													
GTE PY6	ORN/LOT F		3DNPY137	1370		10E-02	217.00	6.0H	0.8010				
GTE PY6	ORN/LOT F		4DNPY137	1370		10E-03	131.00	36.4H	1.0320				
GTE PY6	ORN/LOT F		5DNPY137	1370		10E-04	86.00	216H	1.2240				
GTE PY6	ORN/LOT A		1SNPY137	1370		37.0	274.00	7.4S	0.1500				
GTE PY6	ORN/LOT A		2SNPY137	1370		37.0	302.00	8.2S					
Test Rig = DFATUDRI1													
NT-154	NORTON/UDRI/90		300-15	1328			322.00			4.00	3.00		.042 mm/sec = XH_SPEED
NT-154	NORTON/UDRI/90		300-22	1328			349.00			4.00	3.00		.042 mm/sec = XH_SPEED
NT-154	NORTON/UDRI/90		300-2	1328			253.00			4.00	3.00		.00042 mm/sec = XH_SPD
NT-154	NORTON/UDRI/90		300-18	1328			228.00			4.00	3.00		.00042 mm/sec = XH_SPD
Test Rig = DFATNORT1													
NT-154	NORTON/UDRI/90		300-19	1300			431.00			4.00	3.00		.00042 mm/sec = XH_SPD
NT-154	NORTON/UDRI/90		300-20	1300			392.00			4.00	3.00		.00042 mm/sec = XH_SPD
NT-154	NORTON/UDRI/90		300-8	1300			422.00			4.00	3.00		.00042 mm/sec = XH_SPD
NT-154	NORTON/UDRI/90		300-4	1300			505.00			4.00	3.00		.042 mm/sec = XH_SPEED
NT-154	NORTON/UDRI/90		300-17	1300			447.00			4.00	3.00		.042 mm/sec = XH_SPEED
Test Rig = DFATNLRC1													
SN-252	KYOCERA/NLRC-91	1400C/20MIN	SUMRY5	1400	0.0400		589.90			3.00	4.00	46.1	LOADRATE = N/s
SN-252	KYOCERA/NLRC-92		SUMRY3	1260	40.0000		582.50			3.00	4.00	12.3	LOADRATE = N/s
SN-252	KYOCERA/NLRC-92		SUMRY3	1260	0.0400		568.80			3.00	4.00	52.3	LOADRATE = N/s
SN-252	KYOCERA/NLRC-92		SUMRY4	1370	40.0000		512.80			3.00	4.00	35.1	LOADRATE = N/s
SN-252	KYOCERA/NLRC-92		SUMRY4	1370	4.0000		553.90			3.00	4.00	37.0	LOADRATE = N/s
SN-252	KYOCERA/NLRC-92		SUMRY3	1370	0.4000		525.90			3.00	4.00	27.5	LOADRATE = N/s
SN-252	KYOCERA/NLRC-92		SUMRY4	1370	0.0400		557.10			3.00	4.00	18.6	LOADRATE = N/s
Test Rig = DFATNLRC1													
SN-260	GCCD/NLRC-90	AS RECD	SUMRY4	1300	33.3333	33.333	591.40			2.70	4.00	21.0	LOADRATE = N/s
SN-260	KYOCERA/NLRC-91	1300C/20MIN	SUMRY5	1300	40.0000		493.20			3.00	4.00	24.2	LOADRATE = N/s
SN-260	KYOCERA/NLRC-91	1300C/20MIN	SUMRY5	1300	0.0400		692.20			3.00	4.00	53.7	LOADRATE = N/s
SN-260	KYOCERA/NLRC-91	1300C/20MIN	SUMRY1	1300	0.0040		691.90			3.00	4.00		LOADRATE = N/s
SN-260	KYOCERA/NLRC-91	1400C/20MIN	SUMRY5	1400	40.0000		489.00			3.00	4.00	35.4	LOADRATE = N/s

Section 6C - Dynamic Fatigue Test Results for Silicon Carbide-Reinforced Silicon Nitride Ceramics

Material	Batch Code	Heat Treatment	Environment	Specimen Number	Temp °C	Load Rate N/s	Stress Rate MPa/s	Strength MPa	Width mm	Thickness mm	Std. Dev.
Test Rig = DFATNLC1											
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY5	1100	0.030	0.03	598.90	2.70	4.00	63.1
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY5	1100	0.333	.333	584.50	2.70	4.00	82
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY5	1100	3.333	3.333	615.90	2.70	4.00	54.8
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY5	1100	33.333	33.333	641.50	2.70	4.00	33.8
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY4	1200	0.033	.03333	463.00	2.70	4.00	106.4
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY4	1200	3.333	33.333	558.90	2.70	4.00	19.5
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY4	1300	0.033	0.0333	318.00	2.70	4.00	14.1
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY3	1300	0.333	0.3333	445.20	2.70	4.00	44.2
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY3	1300	3.333	3.3333	487.60	2.70	4.00	48.5
GN-10+SiCw30v%	GCCD/NLRC-90	AS RECD	AIR	SUMRY4	1300	33.333	33.333	553.90	2.70	4.00	38
GN-10+SiCw30v%	GCCD/NLRC-90	INDENTED VIC98kg	AIR	SUMRY3	1100	0.070	0.0333	351.50	2.70	4.00	4.8
GN-10+SiCw30v%	GCCD/NLRC-90	INDENTED VIC98kg	AIR	SUMRY3	1100	0.700	0.3333	353.10	2.70	4.00	11.3
GN-10+SiCw30v%	GCCD/NLRC-90	INDENTED VIC98kg	AIR	SUMRY3	1100	7.000	3.3333	372.40	2.70	4.00	11.1
GN-10+SiCw30v%	GCCD/NLRC-90	INDENTED VIC98kg	AIR	SUMRY3	1100	70.000	33.333	400.50	2.70	4.00	26.9

Section 7 - Cyclic Fatigue Test Results for Silicon Nitride-based Ceramics

Material	Batch Code	Specimen Number	Temp. °C	Stress MPa	Cycles At Stress	Cycles to Failure	Specimen Geometry	Comments
Test Rig = CFATORNL1								
GN-10	ORNL/KCL	350-2-4	1200	300	1139464		BUTTONHEADED ROD	STEP 1
				313	59332			STEP 2
				326	87222			STEP 3
				337	43446	1329464		STEP 4, FAILURE
GN-10	ORNL/KCL	340-2-5	1200	350	41845	41845	BUTTONHEADED ROD	
GN-10	ORNL/KCL	331-1-1	1250	285	59308	59308	BUTTONHEADED ROD	
GN-10	ORNL/KCL	350-2-5	1250	250	221774	221774	BUTTONHEADED ROD	
GN-10	ORNL/KCL	357-3	1150	380	1005272		BUTTONHEADED ROD	STEP 1
				397	44813			STEP 2
				408	50925			STEP 3
				420	148636			STEP 4
				436	51887			STEP 5
				447	69351			STEP 6
				460	10442	1381326		STEP 7, FAILURE
GN-10	ORNL/KCL	357-4	1150	440	4511560		BUTTONHEADED ROD	STEP 1
				460	265600	717160		STEP 2, FAILURE
GN-10	ORNL/KCL	35*-??	1150	480	5359	5359	BUTTONHEADED ROD	

Section 8A- Fracture Toughness Test Results on Silicon Nitride-based Ceramics

Material	Batch Code	Heat Treatment	Specimen Number	Toughness Test	Temp. °C	Width mm	Thickness mm	Load N	Indent. Load Kg	KIC MPa√m	Crack Length μm	Grosshead Speed mm/s	Std. Dev.
Test Rig = TUFFUDRI1													
GN-10	GCCD/UDRI-90		1	CONTROLLED FLAW	20			157.46	10	3.7	120.0	0.008	
GN-10	GCCD/UDRI-90		2	CONTROLLED FLAW	20			156.12	10	3.8	135.0	0.008	
GN-10	GCCD/UDRI-90		3	CONTROLLED FLAW	20			146.34	10	3.3	112.5	0.008	
GN-10	GCCD/UDRI-90		4	CONTROLLED FLAW	20			157.01	10	3.6	117.5	0.008	
GN-10	GCCD/UDRI-90		5	CONTROLLED FLAW	20			152.12	10	3.4	110.0	0.008	
Test Rig = TUFFORN1													
Si3N4+6%Y2O3+2%Al2O3	ORNLSINYOALO-2	AS FABRICATED	SUMMARY	UNKNOWN	25					5.8			0.15
Si3N4+6%Y2O3+2%Al2O3	ORNLSINYOALO-2	1200C/4H w/oPRES	SUMMARY	UNKNOWN	25					5.7			0.11
Si3N4+6%Y2O3+2%Al2O3	ORNLSINYOALO-2	1200C/4H/24MPa	SUMMARY	UNKNOWN	25					5.7			0.25
Test Rig = TUFFNLC1													
SN-251	KYOCERA/NLRC-90		SUMRY5	CHEVRON-NOTCHED	25	3.00	4.00			7.9			0.40
SN-251	KYOCERA/NLRC-90		SUMRY2	SEPB*	25	3.00	4.00			7.4			0.50
SN-251	KYOCERA/NLRC-90		SUMRY5	CHEVRON-NOTCHED	800	3.00	4.00			7.1			0.70
SN-251	KYOCERA/NLRC-90		SUMRY3	CHEVRON-NOTCHED	1000	3.00	4.00			6.9			0.40
SN-251	KYOCERA/NLRC-90		SUMRY4	CHEVRON-NOTCHED	1200	3.00	4.00			6.0			0.30
SN-251	KYOCERA/NLRC-90		SUMRY2	CHEVRON-NOTCHED	1371	3.00	4.00			10.4			0.50
SN-251	KYOCERA/NLRC-90		SUMRY2	SEPB*	1371	3.00	4.00			6.1			0.40

NOTE: Values above containing "SUM" in the specimen number are averages of the number of tests indicated in the specimen number.
 *SEPB = single-edge precracked beam.

Section 8B - Fracture Toughness Test Results on Zirconia-based Ceramics

Material	Batch Code	Heat Treatment	Specimen Number	Toughness Test	Temp. °C	Width mm	Thickness mm	Load N	KIC MPa√m	Crack Length μm	Comments
Test Rig = TUFFBCL1											
MASZ-50	BCU/INTERLAYER	1350C	IL50-3F1	NOTCHED BARMOR4	25	5.07	5.05	122.40	1.54	1.710	
MASZ-67	BCU/INTERLAYER	1350C	IL67-3F1	NOTCHED BARMOR4	25	5.09	5.07	169.10	2.10	1.700	
MASZ-67	BCU/INTERLAYER	1350C	IL67-3F3	NOTCHED BARMOR4	25	5.11	5.05	160.20	1.99	1.700	
MASZ-67	BCU/INTERLAYER	1400C	IL67-4F1	NOTCHED BARMOR4	25	5.12	5.11	146.90	1.71	1.630	
MASZ-67	BCU/INTERLAYER	1400C	IL67-4F2	NOTCHED BARMOR4	25	5.09	5.08	149.10	1.77	1.630	
MASZ-67	BCU/INTERLAYER	1350C	IL67-3F2	NOTCHED BARMOR4	1000	5.10	5.07	68.10	1.60	1.460	
MASZ-80	BCU/INTERLAYER	1350C	IL80-3F1	NOTCHED BARMOR4	25	5.12	5.08	235.90	2.89	1.710	
MASZ-80	BCU/INTERLAYER	1350C	IL80-3F3	NOTCHED BARMOR4	25	5.12	5.09	231.40	2.75	1.650	
MASZ-80	BCU/INTERLAYER	1400C	IL80-4F1	NOTCHED BARMOR4	25	5.09	5.09	445.00	5.27	1.630	
MASZ-80	BCU/INTERLAYER	1350C	IL80-3F2	NOTCHED BARMOR4	1000	5.09	5.09	73.90	1.59	1.630	
Mg-PSZ	BCU/ZYCRONL/1+HT	1350C/2H/AIR	HP26-F16	NOTCHED BARMOR4	25	5.10	5.08	458.80	5.67	1.710	
Mg-PSZ	BCU/ZYCRONL/1+HT	1350C/2H/AIR	HP26-F21	NOTCHED BARMOR4	25	5.05	5.08	458.40	5.47	1.630	
Test Rig = TUFFNORT1											
Y-TZP	NORT/MG200		SUMMARY	CONTROLLED FLAW	25				5.30		15% MONOCLINIC PHASE
Y-TZP	NORT/MG026		SUMMARY	CONTROLLED FLAW	25				6.20		
Y-TZP	NORT/MG100		SUMMARY	CONTROLLED FLAW	25				6.60		
Y-TZP	NORT/MG024/FGS		SUMMARY	CONTROLLED FLAW	25				6.20		7% MONOCLINIC PHASE
Y-TZP	NORT/MG024/FGS		SUMMARY	CONTROLLED FLAW	25				6.20		18% MONOCLINIC PHASE
Y-TZP	NORT/MG024/FGS		SUMMARY	CONTROLLED FLAW	25				6.40		21% MONOCLINIC PHASE
Y-TZP	NORT/MG008	SINTERED	SUMMARY	CONTROLLED FLAW	25				7.30		46% MONOCLINIC PHASE
Y-TZP	NORT/MG005		SUMMARY	CONTROLLED FLAW	25				9.50		67% MONOCLINIC PHASE
Y-TZP	NORT/MG014	SINTERED	SUMMARY	DOUBLE TORSION	25				7.60		
Y-TZP	NORT/MG008	SINTERED	SUMMARY	DOUBLE TORSION	25				7.60		46% MONOCLINIC PHASE
Y-TZP	NORT/MG026		SUMMARY	MICROINDENTATION	25				7.40		2% MONOCLINIC PHASE
Y-TZP	NORT/MG026		SUMMARY	MICROINDENTATION	25				7.80		15% MONOCLINIC PHASE
Y-TZP	NORT/MG024/FGS		SUMMARY	MICROINDENTATION	25				7.90		18% MONOCLINIC PHASE
Y-TZP	NORT/MG024/FGS		SUMMARY	MICROINDENTATION	25				8.30		7% MONOCLINIC PHASE
Y-TZP	NORT/MG026		SUMMARY	MICROINDENTATION	25				8.30		
Y-TZP	NORT/MG024/FGS		SUMMARY	MICROINDENTATION	25				8.40		32% MONOCLINIC PHASE
Y-TZP	NORT/MG008	SINTERED	SUMMARY	MICROINDENTATION	25				8.80		46% MONOCLINIC PHASE
Y-TZP	NORT/MG005		SUMMARY	MICROINDENTATION	25				20.00		67% MONOCLINIC PHASE

Fig. 2.30. Effects of temperature on the average tensile strengths of GTE-PY6 tested by two facilities.

Section 9 - Joint Specimen Modulus of Rupture-Four-Point Bend Test Results

Material 1	Batch Code 1	Filler Material	Material 2	Batch Code 2	Joint Process	Heat Treatment	Specimen Number	Temp °C	Load N	MOR4 MPa	Width mm	Thickness mm	Comments
Joint Code = BCL/SA111/ZRZR/HP													
Joining Conditions = HP/1420C/13.79MPa													
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	ZZB-3	25	135.7	81.9	5.08	2.54	CTS-BONDED ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	ZZB-4	25	105.0	63.7	5.08	2.54	CTS-BONDED ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	ZZB-5	25	117.9	71.5	5.08	2.54	CTS-BONDED ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	ZZB-6	25	130.8	79.5	5.08	2.54	CTS-BONDED ZrO2
Joint Code = BCL/SA111/ZRZR/HPZ													
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB3	25		81.9	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB4	25		63.7	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB5	25		71.5	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB6	25		79.5	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB8	25		60.9	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB9	25		53.6	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB10	25		54.4	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB11	25		49.3	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB12	25		72.9	5.08	2.54	**CTS + 30w% ZrO2
Mg-PSZ	ZIRCOAZZYCRON-L	CaO-TiO2-SiO2*	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES	AS PRESSED	HP5-ZZB13	25		68.9	5.08	2.54	**CTS + 30w% ZrO2
Joint Code = BCL/SA111/ZRFE/S													
Joining Conditions = HP/750C/10min./vac.													
Mg-PSZ/Ti	ZIRCOAZZYCRON-L	LM 604	NCU/Cu	60% PEARLITE	AS	AS BRAZED	MCB-1	25	151.0	88.9	5.08	2.54	
Mg-PSZ/Ti	ZIRCOAZZYCRON-L	LM 604	NCU/Cu	60% PEARLITE	AS	AS BRAZED	MCB-2	25	138.0	81.4	5.08	2.54	
Mg-PSZ/Ti	ZIRCOAZZYCRON-L	LM 604	NCU/Cu	60% PEARLITE	AS	AS BRAZED	MCB-3	25	138.0	80.9	5.08	2.54	
Joint Code = BCL/SA12/ZRFE/HP													
Mg-PSZ/Ti	ZIRCOAZZYCRON-L	LM 604	NCI	60% PEARLITE	HOIPRES	AS PRESSED	MCB-4	25	0.0	164.0	5.08	2.54	
Mg-PSZ/Ti	ZIRCOAZZYCRON-L	LM 604	NCI	60% PEARLITE	HOIPRES	AS PRESSED	MCB-5	25	0.0	76.0	5.08	2.54	
Mg-PSZ/Ti	ZIRCOAZZYCRON-L	LM 604	NCI	60% PEARLITE	HOIPRES	AS PRESSED	MCB-6	25	0.0	161.0	5.08	2.54	
Joint Code = BCL/ZR67ZR/1350													
Joining Conditions = BRAZED AT 1350C													
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B01	25	360.5	123.0	5.87	3.08	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B02	25	367.2	138.0	5.87	3.02	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B03	25	369.4	130.0	5.86	3.04	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B04	25	369.4	138.0	5.87	2.95	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B05	25	275.9	107.0	5.85	2.90	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B11	25	222.5	108.0	5.32	2.72	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B12	25	231.4	108.0	5.51	2.72	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B13	25	233.6	107.0	5.59	2.73	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B14	25	264.8	126.0	5.36	2.73	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B15	25	267.0	123.0	5.52	2.73	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B16	25	244.8	118.0	5.30	2.73	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B21	25	214.0	121.0	5.15	2.56	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B23	25	242.5	137.0	5.15	2.56	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B25	25	182.5	103.0	5.15	2.56	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOAZZYCRON-L	HOIPRES		HP22-B26	25	264.8	149.0	5.15	2.56	

Section 9 - Joint Specimen Modulus of Rupture-Four-Point Bend Test Results, continued

Material 1	Batch Code 1	Filler Material	Material 2	Batch Code 2	Joint Process	Heat Treatment	Specimen Number	Temp °C	Load N	MOF4 MPa	Width mm	Thickness mm	Comments
Joint Code = BCL/ZR67ZR/1350													
Joining Conditions = BRAZED AT 1350C													
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP22-B27	25	174.4	98.0	5.15	2.56	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP22-B28	25	244.8	140.0	5.13	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP23-B22	25	213.6	127.0	5.08	2.51	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP23-B11	1000	58.7	62.0	5.06	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP24-B11	1000	51.6	54.0	5.09	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP24-B13	1000	55.2	58.0	5.08	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP24-B14	1000	62.3	67.0	5.07	2.52	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP24-B15	1000	60.1	63.0	5.09	2.56	
Joint Code = BCL/ZR80ZR/1350													
Joining Conditions = BRAZED AT 1350C													
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B11	25	240.3	140.0	5.09	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B12	25	284.4	163.0	5.08	2.56	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B13	25	204.7	118.0	5.08	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B17	25	262.6	151.0	5.09	2.56	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B21	25	329.3	194.0	5.08	2.52	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B22	25	293.7	170.0	5.08	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B28	25	195.8	113.0	5.08	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B23	25	329.3	194.0	5.08	2.52	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B29	25	316.0	182.0	5.07	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B24	1000	71.6	75.0	5.08	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B15	1000	75.7	80.0	5.06	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP25-B18	1000	82.3	87.0	5.07	2.55	
Joint Code = BCL/ZR50ZR/1350													
Joining Conditions = BRAZED AT 1350C													
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-50	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP27-B13	25	93.5	54.0	5.07	2.54	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-50	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP27-B14	25	89.0	52.0	5.07	2.54	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-50	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP27-B17	25	89.0	52.0	5.07	2.54	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-50	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP27-B21	25	77.9	45.0	5.09	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-50	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP27-B22	25	102.4	59.0	5.09	2.54	
Joint Code = BCL/ZR80ZR/1400													
Joining Conditions = BRAZED AT 1400C													
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B11	25	173.6	102.0	5.06	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B11	25	182.5	107.0	5.06	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B13	25	186.9	109.0	5.06	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B14	25	160.2	94.0	5.06	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B21	25	204.7	119.0	5.09	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B22	25	191.4	112.0	5.09	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B23	25	184.7	107.0	5.09	2.54	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B24	25	173.6	101.0	5.09	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP29-B25	25	178.0	104.0	5.09	2.53	

Section 9 - Joint Specimen Modulus of Rupture-Four-Point Bend Test Results, continued

Material 1	Batch Code 1	Filler Material	Material 2	Batch Code 2	Joint Process	Heat Treatment	Specimen Number	Temp °C	Load N	MORa MPa	Width mm	Thickness mm	Comments
Joint Code = BCL/ZR67ZR/1400													
Joining Conditions = BRAZED AT 1400C													
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP30-B11	25	104.6	62.0	5.09	2.52	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP30-B12	25	93.5	55.0	5.09	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP30-B14	25	93.5	55.0	5.09	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP30-B15	25	111.3	65.0	5.09	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP30-B23	25	102.4	59.0	5.09	2.54	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP30-B24	25	135.7	79.0	5.10	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HOIPRES		HP30-B25	25	102.4	60.0	5.10	2.53	
Joint Code = BCL/ZRNCI/1													
Joining Conditions = BRAZED AT 750C													
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B21	25	471.7	267.0	5.08	2.57	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B22	25	309.3	212.0	5.09	2.34	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B23	25	427.2	248.0	5.08	2.54	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B24	25	316.0	185.0	5.09	2.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B27	25	356.0	210.0	5.09	2.52	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B31	25	289.3	166.0	5.06	2.56	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B32	25	373.8	215.0	5.07	2.56	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B33	25	471.7	272.0	5.07	2.56	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B34	25	445.0	256.0	5.06	2.56	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B11	25	311.5	214.0	5.09	2.34	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B12	25	1068.0	328.0	5.76	3.28	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B21	25	371.6	211.0	5.07	2.57	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B22	25	342.7	195.0	5.07	2.57	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B24	25	391.6	223.0	5.07	2.57	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B28	25	467.3	267.0	5.07	2.57	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B31	25	331.5	196.0	5.09	2.51	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B32	25	498.4	295.0	5.10	2.51	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B33	25	252.8	149.0	5.09	2.52	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC4-B36	25	369.4	218.0	5.10	2.51	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC5-B13	25	218.1	130.0	5.08	2.50	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC5-B14	25	436.1	261.0	5.08	2.50	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC5-B25	25	319.5	191.0	5.08	2.51	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC5-B12	400	97.0	102.0	5.09	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC5-B16	400	100.1	105.0	5.07	2.55	
Mg-PSZ	ZIRCOA/ZYCRON-L	Incusil ABA	NCI	SANDIA/BCL	AF		LMC3-B35	400	104.1	109.0	5.07	2.56

Fig. 2.31. Modulus of rupture 4-pt. bend strength comparison for monolithic and joint specimens.

Section 10 - Joint Specimen Fracture Toughness Test Results on Zirconia-based Ceramics

Material 1	Batch Code 1	Filler Material	Material 2	Batch Code 2	Specimen Number	Temp. °C	Load N	KIC MPa√m	Width mm	Thickness mm	Crack Length μm	Comments
Test Description Code = TUFFBCL1												
Specimen Type = NOTCHED BAR/MOR4												
Joint Code = BCL/ZR67ZR/1350												
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP22-F15	25	140.2	3.000	2.56	5.14	1.53	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP23-F18	25	209.2	2.360	5.08	5.10	1.54	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP23-F27	25	213.6	2.420	5.09	5.09	1.54	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP24-F15	25	173.6	2.070	5.08	5.07	1.63	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP24-F14	1000	80.5	1.690	5.08	5.09	1.57	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP24-F23	1000	69.9	1.460	5.10	5.07	1.56	
Joint Code = BCL/ZR67ZR/1400												
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP30-F16	25	107.7	1.280	5.09	5.08	1.63	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP30-F27	25	160.2	1.900	5.09	5.08	1.63	
Test Description Code = TUFFBCL2												
Specimen Type = CRACKED DISK												
Joint Code = BCL/ZR67ZR/D												
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP22-CD3	25	1441.8	2.470	27.43	2.53	12.70	ANG1 = 0, ANG2 = 0.0
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP22-CD1	25	2202.8	1.210	27.43	2.43	11.51	ANG1 = 30, ANG2 = 101.3
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP22-CD4	25	2225.0	1.960	27.43	2.53	11.94	ANG1 = 15, ANG2 = 63.8
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP23-CD2	25	2047.0	2.080	35.56	3.59	16.51	ANG1 = 0, ANG2 = 0
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP23-CD3	25	2314.0	2.350	35.56	3.59	16.51	ANG1 = 0, ANG2 = 0
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP24-CD2	25	1691.0	1.720	35.56	3.62	16.51	ANG1 = 0, ANG2 = 0
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP24-CD3	25	1958.0	1.980	35.56	3.61	16.51	ANG1 = 0, ANG2 = 0
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP24-CD4	25	3168.4	0.270	35.56	3.60	15.49	ANG1 = 22.5, ANG2 = 86.8
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP24-CD5	25	2296.2	1.880	35.56	3.63	16.51	ANG1 = 10.0, ANG2 = 47.1
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP23-CD4	25	3982.8	1.600	35.56	3.63	14.99	ANG1 = 18.0, ANG2 = 72.3
Specimen Type = UNCRACKED DISK												
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP22-UD1	25	5785.0	0.000	27.43	2.41	0.00	ANG1 = 30.0
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-67	Mg-PSZ	ZIRCOA/ZYCRON-L	HP22-UD4	25	7120.0	0.000	27.43	2.43	0.00	ANG1 = 10.0
Test Description Code = TUFFBCL1												
Specimen Type = NOTCHED BAR/MOR4												
Joint Code = BCL/ZR80ZR/1350												
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HP25-F16	25	264.8	3.140	5.09	5.09	1.63	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HP25-F26	25	268.3	3.190	5.08	5.07	1.63	
Mg-PSZ	ZIRCOA/ZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOA/ZYCRON-L	HP25-F14	1000	82.3	1.770	5.09	5.07	1.61	

Section 10 - Joint Specimen Fracture Toughness Test Results on Zirconia-based Ceramics, continued

Material 1	Batch Code 1	Filler Material	Material 2	Batch Code 2	Specimen Number	Temp. °C	Load N	KIC MPa√m	Width mm	Thickness mm	Crack Length μm	Comments
Test Description Code = TUFFBCL1 Specimen Type = NOTCHED BAR/MOR4 Joint Code = BCL/ZR80ZR/1400												
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOAZZYCRON-L	HP29-F26	25	195.8	2.280	5.09	5.09	1.60	
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOAZZYCRON-L	HP29-F27	25	200.3	2.370	5.06	5.10	1.63	
Test Description Code = TUFFBCL2 Specimen Type = CRACKED DISK Joint Code = BCL/ZR80ZR/D												
Mg-PSZ	ZIRCOAZZYCRON-L	MASZ-80	Mg-PSZ	ZIRCOAZZYCRON-L	HP25-CD4	25	2420.8	2.460	35.56	3.63	16.51	ANG1 = 0, ANG2 = 0.0
Test Description Code = TUFFBCL1 Specimen Type = NOTCHED BAR/MOR4 Joint Code = BCL/ZRNCI/1												
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC2-F25	25	529.6	5.030	5.00	5.09	1.17	
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC3-F25	25	445.0	5.230	5.07	5.11	1.63	
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC3-F36	25	429.4	5.000	5.12	5.11	1.63	
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC4-F25	25	600.8	7.120	5.11	5.07	1.63	
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC4-F26	25	547.4	6.420	5.07	5.08	1.60	
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC4-F34	25	534.0	6.310	5.09	5.09	1.63	
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC5-F18	25	422.8	5.000	5.09	5.09	1.63	
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC5-F26	25	596.3	6.970	5.08	5.09	1.60	
Test Description Code = TUFFBCL2 Specimen Type = CRACKED DISK Joint Code = BCL/ZRNCI/1												
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC3-CD2	25	4138.5	4.730	35.56	3.63	17.78	ANG1 = 0.0, ANG2 = 4.4
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC3-CD3	25	6630.5	3.670	35.56	3.69	16.00	ANG1 = 15.0, ANG2 = 64.8
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC4-CD1	25	6764.0	7.820	35.56	3.59	17.78	ANG1 = 0.0, ANG2 = 4.4
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC4-CD4	25	6408.0	7.330	35.56	3.63	17.78	ANG1 = 0.0, ANG2 = 4.4
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC5-CD3	25	6319.0	5.460	35.56	3.61	17.78	ANG1 = 10., ANG2 = 47.0
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC5-CD6	25	8544.0	2.180	35.56	3.62	16.51	ANG1 = 20., ANG2 = 80.4
Mg-PSZ	ZIRCOAZZYCRON-L	Incusil-ABA	NCI	SANDIA/BCL/1	LMC5-CD7	25	8588.5	3.440	35.56	3.63	14.99	ANG1 = 18, ANG2 = 72.3

NOTE: ANG1 is the angle between true vertical and the center line of the joint.
 ANG2 is the phase angle measuring the degree of mode I fracture toughness mixity.

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