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Metals and Ceramics Division

CERAMIC TECHNOLOGY PROJECT DATABASE: SEPTEMBER 1990 SUMMARY REPORT

B. L. P. Keyes

June 1992

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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CONTENTS

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B. L. P. Keyes

ABSTRACT

Data generated within the Ceramic Technology Project (CTP) represent a very valuable resource for both research and industry. The CTP database was created to provide easy access to this information in electronic and hardcopy forms by using a computerized database and by issuing periodic hardcopy reports on the database contents. This report is the sixth in a series of semiannual database summaries and covers recent additions to the database, including joined brazed specimen test data.

1. INTRODUCTION

Data generation is an ongoing process in research. New materials are constantly developed, tested, modified, then retested, producing a vast quantity of information that should be archived and made available to other interested parties. The responsible researchers publish reports on their work, but these are not always easy to obtain, or even to find, several years after publication. Unless the work was well documented and archived, its usefulness will be limited to only a few individuals. Years later, the same work may be done again, with the same results, if no reference to the previous work exists. "Reinventing the wheel" is a waste of valuable resources. Such wastefulness must be avoided.

The CTP database was created to help avoid unnecessary testing redundancy by making available the work on material characterization and mechanical properties data generated within the CTP. Data are collected and stored in a timely manner using dBASE IV™ on an IBM PC/AT microcomputer. Users may access the data electronically by requesting information on specific materials or by requesting the entire database from the data base administrator. The data will be sent on floppy disks in the user's requested format. Direct access to the master files is limited to avoid accidental data contamination, or deletions, and to reduce the opportunity for exposure to computer viruses and other diseases. Hardcopy reports, like this one, are issued semiannually to inform the user community of the latest additions to the database and to give a system status update.

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2. SYSTEM STATUS REPORT

The database presently contains about 6,093 test results on over 360 different batches of ceramic materials. Approximately 47.8% of these are on zirconia-based ceramics, 7.1% are on silicon carbides, 21.8% are on silicon nitrides, 6.4% are on whisker-reinforced silicon nitrides, 15.3% are on alumina-based ceramics (including whisker-reinforced aluminas and mullites), and 1.6% are on other ceramics. Table 1 provides an overview of the data presently stored in the system in more detail.

Test data files on brazed-specimen torsion strength and torsion fatigue were added to the database during this summary period. Although the testing procedures for unjoined and joined specimens may be the same, additional information is needed to characterize the joint and all the materials used to create it. Often, dissimilar materials are brazed together, as in the case of the MS–PSZ and nodular cast-iron joints made by M. L. Santella at Oak Ridge National Laboratory (ORNL). To characterize such a joint requires information on all the materials involved, the actual joining process, and the test results. Detailed information on a given joint may be found in a separate file referenced by the joint code included in each joined-specimen test record. The JOINTEXT file is in text form and contains all the information about the brazing process and materials that could be found.

3. DATA SUMMARY

The data in this report cover 1 silicon carbide, 34 silicon nitrides, 10 whisker-reinforced silicon nitrides, 2 zirconia-toughened aluminas, 8 zirconias, and 34 joints. The data were taken from the CTP semiannual and bimonthly progress reports, contributions by K. C. Liu and M. L. Santella of ORNL, and a report prepared by GTE Laboratories, *Analytical and Experimental Evaluation of Joining Silicon Nitride to Metal and Silicon Carbide to Metal for Advanced Heat Engine Applications,* ORNL/Sub/87-SB047C/1, dated April 1990.

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 test 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 when such information becomes available. It is the policy for this database 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 and funding permit.

Some of the plots in this report compare properties of several materials by using bar charts. This was necessary because only one test temperature was used for many tests, thus providing no temperature range for an X-Y plot.

All Weibull analyses shown in this report were performed using the rank regression method, in which a least-squares fit to the data was used to estimate the modulus. Specifically, the data were sorted and the X-Y coordinates, ln [modulus of rupture (MOR) strength] and lnln [1/(1-F)], were calculated using Microsoft EXCEL™ (version 2.0) on an Apple Macintosh computer. 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.

Tracking down background information for a specific batch of a material is a time-consuming experience, which is often necessary to confirm the validity of the data. Keeping assigned batch numbers with the material as it goes through testing appears to be neglected in some cases. Some of the data in this report include the original batch codes assigned to the materials by the fabricators, but when no batch identifier is mentioned, a code is assigned by database personnel based upon the source (report code) and the company, laboratory, or individual who reported the data. In the case of materials with locally assigned batch codes, the possibility exists that the same material is also reported elsewhere in the database with the original fabricator's code.

4. SYSTEM ACCESS

Direct access to the master database is very limited to protect the integrity of the master files. Past experience has shown that major disasters often occur when too many people have direct access to unprotected files at the 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 consuming and hazardous to the integrity of the data being transmitted. This database was designed as a repository, not a full-function analytical tool.

Access to the data is attained by calling the database administrator and requesting all files or just those pertaining to certain materials or test types. The CTP database is a microcomputer-based system of files organized in dBASE IV™ structure. 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, then sent to the user. At this time, no plans are being considered for direct access from outside systems. Direct transfer is available by special arrangement but may be time consuming due to the sizes and numbers of files. No guarantee is given for the validity of data transmitted directly because of possible phone line problems. Until a computerized interface becomes available, the *CTP Database User's Guide* will be sent to all first-time users when the document becomes available.

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 1.44 MB). When requesting information from the database, users should indicate disk size, disk density, and file type.

Macintosh file types available are Microsoft EXCEL™, FOXBASE+™, SYLK, and plain, printable ASCII. IBM file types are Lotus 1-2-3, Microsoft EXCEL™, DIF, SDF, SYLK, plain ASCII, delimited ASCII, dBASE IV™, and dBASE III+™. Other formats may be available by special arrangement.

With computer diseases becoming so rampant, users should be aware that precautions are taken to ensure that the disks they receive from the database 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 425, 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 carefully screens incoming software to avoid contamination of either system. Information is not downloaded from public bulletin boards to either system. Both systems have virus detection software installed, and all efforts are made to ensure that both systems remain disease free. If users have problems with disks received from the database, they should inform database personnel immediately so that steps can be taken to correct the problems.

5. FUTURE PLANS

Plans are being made to write a computerized user interface using the dBASE IV™ programming language and to have the initial version completed some time in 1992. The interface will link the database's many files together, providing better access to information in the system. This interface will be available to all users of the database who request it.

The next hardcopy update is scheduled for draft completion in September 1992.

6. PREVIOUS DATABASE SUMMARY REPORTS

1. M. K. Booker, *Ceramics Technology for Advanced Heat Engines Project Data Base: A Summary Report*, ORNL/M-462, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab.

2. B. L. P. Booker, *Ceramics Technology for Advanced Heat Engines Project Data Base: September 1988 Summary Report*, ORNL/M-755, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., March 1989.

3. B. L. P. Keyes, *Ceramics Technology for Advanced Heat Engines Project Data Base: March 1989 Summary Report*, ORNL/M-1098, Martin Marietta Energy Systems Inc., Oak Ridge Natl. Lab., April 1990.

4. B. L. P. Keyes, *Ceramics Technology for Advanced Heat Engines Project Database: September 1989 Summary Report*,"ORNL/M-1286, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., October 1990.

5. B. L. P. Keyes, *Ceramics Technology Project Data Base: March 1990 Summary Report*, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., in publication.

7. ACKNOWLEDGMENTS

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TABLE 1. CTP DATABASE SUMMARY AS OF SEPTEMBER 30, 1990
(Numbers indicate quantity of records in each category)

Material Class	Thermal Contraction	Thermal Diffusivity	Thermal Expansion	Thermal Shock	Torsion	X-Ray Diffraction	Wear & Friction	Material Char.	Chemistry
Alumina			1	2				13	14
Alumina + reinforcing fibers		18	4	6				94	
Alumina + Zirconia	23		21					8	
Mullite								2	
Mullite + reinforcing fibers								24	
Silicon Carbide			23			17		9	57
Silicon Nitride		10	44		3	49	2	50	6
Silicon Nitride + reinforcing fibers		17	14					52	
Zirconia						72		37	44
Zirconia + reinforcing fibers								5	
Other					4			18	2
Total Records	23	45	107	8	7	138	2	312	123
Grand Total Records (test data only)	6093								

TABLE 1. CTP DATABASE SUMMARY AS OF SEPTEMBER 30, 1990
(Numbers indicate quantity of records in each category)

Material Class	Brazed Specimens: MOR 4	Brazed Specimens: Shear Str.	Brazed Specimens: Toughness	Brazed Specimens: Torsion	Brazed Specimens: Tor. Fatigue	Creep	Cyclic Fatigue	Density	Dynamic Fatigue	Elasticity
Alumina							15		9	28
Alumina + reinforcing fibers								7		
Alumina + Zirconia										
Mullite										2
Mullite + reinforcing fibers										11
Silicon Carbide		12						10	13	15
Silicon Nitride	69	48		15	7	37	19	28	16	24
Silicon Nitride + reinforcing fibers							15	2		16
Zirconia	160	58	2				51	158		119
Zirconia + reinforcing fibers										
Other										
Total Records	229	118	2	15	7	37	100	205	38	215

Material Class	Fracture Toughness	Hardness	Interrupted Fatigue	MOR 3 Pt Bend	MOR 4 Pt Bend	Oxidation Rate	Poisson's Ratio	Shear Modulus	Tensile	Thermal Conductivity
Alumina	39	4			411				28	3
Alumina + reinforcing fibers	39				144				11	34
Alumina + Zirconia					7					
Mullite				1	4					
Mullite + reinforcing fibers	16			9	22					
Silicon Carbide	24	27			235					
Silicon Nitride	94	112		10	647	1	2	1	73	9
Silicon Nitride + reinforcing fibers	53				144	3	17	16	86	9
Zirconia	347	24	239		1554				50	
Zirconia + reinforcing fibers					2				36	
Other	3	25			59					
Total Records	615	192	239	20	3229	4	19	17	284	55

(CONTINUED)

TABLE 1. CTP DATABASE SUMMARY AS OF SEPTEMBER 30, 1990
(Numbers indicate quantity of records in each category)

Material Class	Thermal Contraction	Thermal Diffusivity	Thermal Expansion	Thermal Shock	Torsion	X-Ray Diffraction	Wear & Friction	Material Char.	Chemistry
Alumina			1	2				13	14
Alumina + reinforcing fibers		18	4	6				94	
Alumina + Zirconia	23		21					8	
Mullite								2	
Mullite + reinforcing fibers								24	
Silicon Carbide			23			17		9	57
Silicon Nitride		10	44		3	49	2	50	6
Silicon Nitride + reinforcing fibers		17	14					52	
Zirconia						72		37	44
Zirconia + reinforcing fibers								5	
Other					4			18	2
Total Records	23	45	107	8	7	138	2	312	123
Grand Total Records (test data only)	6093								

APPENDIX A. MATERIAL CHARACTERISTICS AND BACKGROUND INFORMATION

SECTION 1. MATERIAL BACKGROUND INFORMATION

MATERIAL	BATCH CODE	MATERIAL CLASS	FABRICATOR	MATRIX	ADDITIVES	SOURCE REFERENCE
ALUMINAS						
BN-70	KYOFELD1989/MTL	ALO-ZTA	Kyocera-Feldmuhle	Al2O3, ZrO2 toughened		BM08/1989, p.58
CZA-600	CERAM1989/MTL	ALO-ZTA	Ceramatec	Al2O3, ZrO2 toughened		BM03/1989, p.58
METALS						
30Au-34Pd-36Ni	GTEL/BRAZE	BRAZE		30Au, 34Pd, 36Ni		ORNL/SUB/87-SB047C/1
Au-5Pd-2Ni	GTEL/BRAZE	BRAZE		93Au, 5Pd, 2Ni		ORNL/SUB/87-SB047C/1
INCOLOY 909	GTEL/CARTECH	METAL	Carpenter Technology	See Chemistry		ORNL/SUB/87-SB047C/1
INCONEL 718	GTEL/HUNTALLOY	METAL	Huntington Alloys	See Chemistry		ORNL/SUB/87-SB047C/1
MOLYBDENUM	GTEL/INTERLAYER	METAL		Mo		ORNL/SUB/87-SB047C/1
NICKEL	GTEL/INTERLAYER	METAL		Ni		ORNL/SUB/87-SB047C/1
SILICON NITRIDES						
AC8	GTEL/UBE-E10	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	8.3w%CeO,1.5AlO	BM4/88, p.94
AC8	GTEL/UBE-E10/88	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	8.3w%CeO2+1.5w%Al2O	ORNL/TM-11239,p55-56
AC8	GTEL/UBE10/688A	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	8.3w%CeO2+1.5w%Al2O3	BM06/88, p.131
AC8	GTEL/UBE10/688B	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	8.3w%CeO2+1.5w%Al2O3	BM06/88, p.131
AM4	GTEL/UBE-E10	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	4.4w%MgO,1.5AlO	BM4/88, p.94
AM4	GTEL/BM0889	SIN	GTE Laboratories	Si3N4	4.4w%MgO+1.5w%Al2O	BM10/89, p.116
AM4	GTEL/BM0889	SIN	GTE Laboratories	Si3N4	4.4w%MgO+1.5w%Al2O	BM10/89, p.116
AM4	GTEL/UBE-E10/88	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	4.4w%MgO+1.5w%Al2O	ORNL/TM-11239,p55-56
AM4	GTEL/UBE10/688A	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	4.4w%MgO+1.5w%Al2O3	BM06/88, p.131
AM4	GTEL/UBE10/688B	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	4.4w%MgO+1.5w%Al2O3	BM06/88, p.131
AM4	GTEL/UBE10/688C	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	4.4w%MgO+1.5w%Al2O3	BM06/88, p.131
AM4	GTEL/UBE10/688D	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	4.4w%MgO+1.5w%Al2O3	BM06/88, p.131
AM4+Si3N4(30v)	GTEL/BM0889	SIN	GTE Laboratories	Si3N4+30v% Si3N4 extra powder	4.4w%MgO+1.5w%Al2O	BM10/89, p.116
AY6	GTEL/UBE-E03	SIN HP	GTE Laboratories	Si3N4 (UBE-E3 powder base)	6w%Y2O3,1.5AlO	BM4/88, p.96
AY6	GTEL/UBE-E10	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	6w%Y2O3,1.5AlO	BM4/88, p.94
AY6	GTEL/UBE-E10-2	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	6w%Y2O3,1.5AlO	BM4/88, p.96
AY6	GTEL/UBE-E3&10	SIN HP	GTE Laboratories	Si3N4(UBE-E3&E10 powder base)	6w%Y2O3,1.5AlO	BM4/88, p.96
AY6	GTEL/BM0889	SIN	GTE Laboratories	Si3N4	6.0w%Y2O3+1.5w%Al2O	BM10/89, p.116
AY6	GTEL/UBE-E10/88	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	6w%Y2O3+1.5W%Al2O3	ORNL/TM-11239,p55-56
AY6	GTEL/UBE10/688A	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	6.0w%Y2O3+1.5w%Al2O3	BM06/88, p.131
AY6	GTEL/UBE10/688B	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	6.0w%Y2O3+1.5w%Al2O3	BM06/88, p.131
AY6	GTEL/UBE10/688C	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	6.0w%Y2O3+1.5w%Al2O3	BM06/88, p.131
AY6	GTEL/UBE10/688D	SIN HP	GTE Laboratories	Si3N4 (UBE-E10 powder base)	6.0w%Y2O3+1.5w%Al2O3	BM06/88, p.131
AY6+Si3N4(30v)	GTEL/BM0889	SIN	GTE Laboratories	Si3N4+30V% Si3N4 extra powder	6.0w%Y2O3+1.5w%Al2O	BM10/89, p.116
GTE PY6	GTEL/87-SB047C	SIN HP	GTE Laboratories	Si3N4	6w%Y2O3	ORNL/SUB/87-SB047C/1

SECTION 1. MATERIAL BACKGROUND INFORMATION, CONTINUED

MATERIAL	BATCH CODE	MATERIAL CLASS	FABRICATOR	MATRIX	ADDITIVES	INFORMATION SOURCE
SILICON NITRIDES						
GTE PY6	GTEL/BASELINE90	SIN	GTE Laboratories	Si3N4	6w%Y2O3	BM04/89, p.112
NT-154	NORTON/ORNL/1	SIN	Norton/TRW	Si3N4		BM12/88, p.19
Si3N4/Si3N4 JNT	NRTN/NCX-5100B	SIN/JOINT	Norton Company	Si3N4	4w%Y2O3	BM04/89, p.112
WHISKER-REINFORCED SILICON NITRIDES						
AM4+SiCw30v	GTEL/BM0889	SIN/SICW	GTE Laboratories	Si3N4+30v% SiC whiskers	4.4w%MgO+1.5w%Al2O	BM10/89, p.116
AY6+SiCw30v	GTEL/UBE-E10	SIN/SICW	GTE Laboratories	Si3N4+30v% SiC whiskers	6.0w%Y2O3+1.5w%Al2O	ORNL/TM-10705, p.235
AY6+SiCw30v	GTEL/BM0889	SIN/SICW	GTE Laboratories	Si3N4+30v% SiC whiskers	6.0w%Y2O3+1.5w%Al2O	BM10/89, p.116
AY6+SiCw30v	GTEL/SN502/0688	SIN/SICW	GTE Laboratories	Si3N4+SILAR SC-9 SiC whiskers	6.0w%Y2O3+1.5w%Al2O	BM06/88, p. 131
AY6+SiCw30v	GTEL/SN502/H88	SIN/SICW	GTE Laboratories	Si3N4+SILAR SC-9 SiC whiskers	6.0w%Y2O3+1.5w%Al2O	ORNL/TM-11239,p55-56
AY6+SiCw30v	GTEL/SN502/IH88	SIN/SICW	GTE Laboratories	Si3N4+SILAR SC-9 SiC whiskers	6.0w%Y2O3+1.5w%Al2O	ORNL/TM-11239,p55-56
AY6+SiCw30v	GTEL/UBE10/0688	SIN/SICW	GTE Laboratories	Si3N4+SILAR SC-9 SiC whiskers	6.0w%Y2O3+1.5w%Al2O	BM06/88, p. 131
AY6+SiCw30v	GTEL/UBE2/H88	SIN/SICW	GTE Laboratories	Si3N4+SILAR SC-9 SiC whiskers	6.0w%Y2O3+1.5w%Al2O	ORNL/TM-11239,p55-56
AY6+SiCw30v	GTEL/UBE2/IH88	SIN/SICW	GTE Laboratories	Si3N4+SILAR SC-9 SiC whiskers	6.0w%Y2O3+1.5w%Al2O	ORNL/TM-11239,p55-56
ZIRCONIAS						
1985	HIT1985/MTL	ZRO-TZP/Y	Hitachi	ZrO2	Y2O3	ORNL/TM-10308,p217
1986H	KOR1986H/MTL	ZRO-TZP/Y	Koransha	ZrO2	Y2O3	ORNL/TM-10308,p217
1986S	KOR1986S/MTL	ZRO-TZP/Y	Koransha	ZrO2	Y2O3	ORNL/TM-10308,p217
CZ-203	CER1987/MTL	ZRO-TZP/CE	Ceramatec	ZrO2		AMTLPKG-1/88
MS-PSZ*	NILCRA/UDRI/1	ZRO-PSZ	Nilcra Ceramics	ZrO2	3w%MgO	ORNL/TM-10308,p256
TASZIC	TOS1985/MTL	ZRO-TZP/Y	Toshiba Ceramics	ZrO2	Y2O3	ORNL/TM-10308,p217
TS-PSZ*	NILCRA/UDRI/1	ZRO-PSZ	Nilcra Ceramics	ZrO2	3w%MgO	ORNL/TM-10308,p256
TZP-110	ACS1985/MTL	ZRO-TZP/Y	AC Sparkplug	ZrO2	Y2O3	ORNL/TM-10308,p217
Z-191	NGK1985/MTL	ZRO-TZP/Y	NGK-Locke	ZrO2	Y2O3	ORNL/TM-10308,p217
Z-201	KYO1985/MTL	ZRO-TZP/Y	Kyocera	ZrO2	Y2O3	ORNL/TM-10308,p217
Z-701	KYO1988/MTL	ZRO-TZP/Y	Kyocera	ZrO2		AMTL-PKG1/88

* This information, although from a different batch, is provided for guidance only.

SECTION 2. MATERIAL CHARACTERISTICS AT ROOM TEMPERATURE

MATERIAL	BATCH CODE	VINTAGE	DENSITY g/cm^3	THEO. DENSITY %	MOE GPa	MOR MPa	TYPE OF HARDNESS TEST	HARDNESS VALUE	THERMAL EXPANS. COEFF. 1.E-06/°C	POISSONS RATIO	TYPE OF TOUGHNESS TEST	KIC MPa*m^2
ALUMINAS												
BN-70	KYOFELD1989/MTL	1989	3.94		353.0	512	VICKERS	17.1 GPa				
CZA-600	CERAM1989/MTL	1989	4.17			441	VICKERS	18.5 GPa				
METALS												
30Au-34Pd-36Ni	GTEL/BRAZE				32.4				14.200			
Au-5Pd-2Ni	GTEL/BRAZE				28.3				15.500			
INCOLOY 909	GTEL/CARTECH				158.6					0.337		
INCONEL 718	GTEL/HUNTALLOY				200.0					0.294		
MOLYBDENUM	GTEL/INTERLAYER				328.2				14.200			
NICKEL	GTEL/INTERLAYER				214.0				13.400			
SILICON NITRIDES												
AC8	GTEL/UBE-E10		3.30		284.0	879						5.100
AC8	GTEL/UBE-E10/88	1988		98.4	294.4		KNOOP	13.8GPa+-.4				4.200
AC8	GTEL/UBE10/688A	1988		98.4	294.4		KNOOP	13.8GPa+-.4			INDENTATION	4.2+-.3
AC8	GTEL/UBE10/688B	1988		98.3	292.3							
AM4	GTEL/UBE-E10		3.12		251.0	706						3.600
AM4	GTEL/BM0889	1988	3.12	98.5	251.0	706						3.600
AM4	GTEL/BM0889	1988	3.12	98.5	251.0	706						3.600
AM4	GTEL/UBE-E10/88	1988		98.6	306.1		KNOOP	14.1GPa+-.2				3.200
AM4	GTEL/UBE10/688A	1988		98.6	306.1		KNOOP	14.1+-.2GPa			INDENTATION	3.2+-.2
AM4	GTEL/UBE10/688B	1988		98.4	310.3							
AM4	GTEL/UBE10/688C	1988		98.5	309.6		KNOOP	14.0+-.3GPa			INDENTATION	4.0+-.5
AM4	GTEL/UBE10/688D	1988		98.5	299.9							
AM4+Si3N4(30v)	GTEL/BM0889	1988		98.5								
AY6	GTEL/UBE-E03		3.25			995						4.100
AY6	GTEL/UBE-E10		3.25		293.0	983						5.000
AY6	GTEL/UBE-E10-2		3.25			845						4.700
AY6	GTEL/UBE-E3&10		3.25			932						4.700
AY6	GTEL/BM0889	1988		98.5								
AY6	GTEL/UBE-E10/88	1988		99.4	301.3		KNOOP	14.2GPa+-.3				4.600
AY6	GTEL/UBE10/688A	1988		99.6	301.3		KNOOP	14.2+-.3GPa			INDENTATION	4.6+-.3
AY6	GTEL/UBE10/688B	1988		99.4	300.6							
AY6	GTEL/UBE10/688C	1988		99.4	308.9		KNOOP	14.3+-.4GPa			INDENTATION	4.8+-.2
AY6	GTEL/UBE10/688D	1988		99.3	301.3							

SECTION 2. MATERIAL CHARACTERISTICS AT ROOM TEMPERATURE, CONTINUED

MATERIAL	BATCH CODE	VINTAGE	DENSITY g/cm^3	THEO. DENSITY %	MOE GPa	MOR MPa	TYPE OF HARDNESS TEST	HARDNESS VALUE	THERMAL EXPANS. COEFF. 1.E-06/°C	POISSONS RATIO	TYPE OF TOUGHNESS TEST	KIC MPa*m^2
WHISKER-REINFORCED SILICON NITRIDES												
AY6+Si3N4(30v)	GTEL/BM0889	1988		98.5								
GTE PY6	GTEL/87-SB047C				296.5	703			3.500		INDENTATION	4.500
AY6+SiCw30v	GTEL/BM0889	1988		98.5								
AY6+SiCw30v	GTEL/SN502/0688	1988		99.6								
AY6+SiCw30v	GTEL/SN502/H88	1988										6.400
AY6+SiCw30v	GTEL/SN502/IH88	1988										4.200
AY6+SiCw30v	GTEL/UBE10/0688	1988		99.9								
AY6+SiCw30v	GTEL/UBE2/H88	1988										7.300
AY6+SiCw30v	GTEL/UBE2/IH88	1988										6.900
ZIRCONIAS												
1985	HIT1985/MTL		6.04		213.0	1169	KNOOP.3Kg	12.4 kg/mm2				
1986H	KOR1986H/MTL		6.04		214.0	1261						
1986S	KOR1986S/MTL		5.97		210.0	640	KNOOP.3Kg	10.8 kg/mm2				
CZ-203	CER1987/MTL											
MS-PSZ*	NILCRA/UDRI/1		5.69				VICKER	1099 kg/mm2	10.300			7.600
TASZIC	TOS1985/MTL	1985	5.88		200.0	633	KNOOP.3Kg	10.1 kg/mm2				
TS-PSZ*	NILCRA/UDRI/1		5.78				VICKER	1025 kg/mm2	9.500			6.000
TZP-110	ACS1985/MTL	1985	5.84		204.0	753	KNOOP.3Kg	11.1 kg/mm2				
Z-191	NGK1985/MTL		5.87		208.0	873	KNOOP.3Kg	10.9 kg/mm2				
Z-201	KYO1985/MTL		5.85		201.0	745	KNOOP.3Kg	10.5 kg/mm2				
Z-701	KYO1988/MTL											

* This information, although from a different batch, is provided for guidance only.

SECTION 3. GENERAL MATERIAL TEXT INFORMATION

MATERIAL	BATCH CODE	REFERENCE CODE	CATEGORY	INFORMATION
AC8	GTEL/UBE-E10/88	SA12GTEL55	PROCESS	Densification treatments were: HOT PRESSED = 90 minutes at 1725C, 34.4MPa; ANNEAL = cooling from HOT PRESS at 60C/min to 1200C, held for 4 hours(240 minutes), then cooled to room temperature. No room temp. cool between hot pressing and anneal. Basic Si3N4 powder used was Ube-E10.
AM4	GTEL/UBE-E10/88	SA12GTEL55	PROCESS	Densification treatments were: HOT PRESSED = 90 minutes at 1725C, 34.4MPa; ANNEAL = cooling from HOT PRESS at 60C/min to 1200C, held for 4 hours(240 minutes), then cooled to room temperature. No room temp. cool between hot pressing and anneal. Basic Si3N4 powder used was Ube-E10.
AY6	GTEL/UBE-E10/88	SA12GTEL55	PROCESS	Densification treatments were: HOT PRESSED = 90 minutes at 1725C, 34.4MPa; ANNEAL = cooling from HOT PRESS at 60C/min to 1200C, held for 4 hours(240 minutes), then cooled to room temperature. No room temp. cool between hot pressing and anneal. Basic Si3N4 powder used was Ube-E10.
AY6+SiCw30v	GTEL/SN502/HP88	SA12GTEL57	PROCESS	SN502 powder was mixed with 30v% ACMC Silar SC-9 SiC whiskers using Advanced Composites Materials Corporation's (ACMC) proprietary processing. The blended powders were then hot-pressed at 1725C at 25.1MPa max pressure for 400 minutes. All densities were greater than 99.5% of theoretical density. X-ray analysis showed only beta-Si3N4 and SiC in the resulting materials. Whiskers were beneficiated for the MOR=975(+-39) batch, but not for the other batches.
AY6+SiCw30v	GTEL/UBE2/IH88	SA12GTEL57	PROCESS	80%Ube-E3 and 20%Ube-E10 Si3N4 powders were milled with 30v% Silar SC-9 SiC whiskers, mixed with a plasticizerless binder and injected into a single-side gate mold. After molding and binder burnout, the resulting bars were HIP'ed at varying temperatures and varying times (see CYCLE definitions) as a processing and densification study(effects of HIPing times and temperatures on densification.Cycle 1 = baseline. Cycle 2 = cycle1 + 30 minutes and 75C. Cycle 3 = cycle cycle 2 + 30 more minutes. Cycle 4 = cycle 3 + 75C more. Unfortunately, no baseline definitions were to be found in this literature except that cycle 2 is the standard HIPing cycle for this material. The pressure was constant at 207MPa for all cycles.
GTE PY6	GTEL/87-SB047C/1	ORNL87SB047C	GENERAL	MOR 4pt bend strength at 1200C=668.8MPa.

MATERIAL	BATCH CODE	REFERENCE CODE	CATEGORY	INFORMATION
GTE PY6	GTEL/BASELINE90	BM0690GTE109	PROCESS	Si3N4 baseline powder was batched with Molycorp Grade 1600, Lot#1862 Y2O3 powder in a SWECO mill(in 20Kg batches), then milled and discharged. Three batches were made up using randomly selected material(unriffled), yielding a total of 63Kg of PY6. This material was compounded with the binders in smaller batches of 10Kg each.The MOR bars reported in BM0690 were taken from batches 900223, 900327 and 900330; however the literature didn't indicate which specimen went with which batch.Other batches were milled from riffled material using the same process as for the unriffled material. The slurry was then injection molded into dies for either ASCERA rods or dogbone specimens, dried, HIP'ed then machined into test specimens (MOR bars were cut from both types for comparison). Specimens from the ASCERA mold are prefixed "ASC-" in the specimen ID; those from dog-bone molds are prefixed "DOG-". Work performed by A.E.Pasto and N.Natansohn at GTE Lab.
HEXALOY SA	GTEL/SOHIO87SB	ORNL87SB047C	GENERAL	MOR 4pt bend strength at 1000C=599.9MPa, at 1200C=406.8MPa.
INCOLOY 909	GTEL/CARTECH	ORNL87SB047C	GENERAL	MOE at 650C=155.8GPa, at 950C=126.9GPa. Tensile strength: 25C=1275.6MPa, 540C= 1158.4MPa, 650C=1034.2MPa. Yield Strength (.2%): 25C=1034.2, 540C=861.9MPa, 650C =861.9MPa. Poisson's ratio: 650C=0.352, 950C=.354, 1100C=0.401 . Smooth bar rupture strength in air at 650C = 517.12MPa at 100 hrs, 344.8MPa at 1000 hrs, 241.3MPa at 3500 hrs.
INCONEL 718	GTEL/HUNTALLOY	ORNL87SB047C	GENERAL	MOE: 650C=163.4GPa, 950C=124.8GPa, 1100C=98.6GPa. Tensile strength: 25C=1344.5MP a, 540C=1179.0MPa, 650C=999.8MPa. Yield strength (.2%): 25C=1130.8MPa, 540C= 979.1MPa, 650C=861.9MPa. Poisson's ratio: 650C=.283, 950C=.337, 1100C=.402 . Smooth bar rupture strength in ar at 650C: 100hrs = 737.8MPa, 1000hrs = 599.9MPa Stress to produce .2% plastic creep after 100hrs at 650C=620.6MPa, at 760C=96MPa
MOLYBDENUM	GTEL/87SB047C/1	ORNL87SB047C	GENERAL	Yield strengths in MPa: 20C=560.6, 200C=124.11, 300C=206.85, 800C=68.95, 1000C= 55.16MPa. Tensile strength given at RT is 665.00MPa. MOE in GPa at other temps: 200C=319.48, 300C=309.68, 800C=294.00, 1000C=269.50GPa. This material was used as an interlayer between the Ti-coated ceramic and the braze in a ceramic-to-metal joint. Test conducted at GTE Laboratories by S. Kang, J.H. Selverian, H. Kim, D. O'Niel, and K. Kim.

SECTION 3. GENERAL MATERIAL TEXT INFORMATION, CONTINUED

MATERIAL	BATCH CODE	REFERENCE CODE	CATEGORY	INFORMATION
30Au-34Pd-36Ni	GTEL/BRAZE	ORNL87SB047C	GENERAL	Liquidus temperature = 1169C, solidus temperature = 1135C. Tensile strength of fully annealed material = 827.4MPa. Yield strength (.2%) = 626.1MPa.Elongation in 50.8mm gage length <17%. Strain hardening coefficient = 0.249.This is a braze material.
Au-5Pd-2Ni	GTEL/BRAZE	ORNL87SB047C	GENERAL	Liquidus temperature = 1131C, solidus temperature = 1100C. Tensile strength of fully annealed material = 188.2MPa. Yield strength(.2%)=1297.6MPa. Elongation in in 50.8mm gage section = 28%. This is a braze material.

SECTION 4. CHEMISTRY

MATERIAL	BATCH CODE	SOURCE CODE	MATERIAL CONDITION	UNITS	CHEMISTRY
INCONEL 718*	GTEL/HUNTALLOY	ORNL87SB047C	AS RECEIVED	wt%	Fe:16, Ni+Co:50-55, Cr:17-21, Nb+Ta:4.75-5.5, Ti:0.65-1.15, Mo:2.8-3.3, Al:0.2-0.8
INCOLOY 909	GTEL/CARTECH	ORNL87SB047C	AS RECEIVED	wt%	Fe:42.17, Ni:38.2, Co:13.0, Nb:4.7, Ti:1.5, Al:0.03
POWDER ANALYSES:					
Si3N4	SN502/GTE SN185	BM288GTE96	AS RECEIVED	PPM	Al:<100, C:none detected, Ca:none detected, Cr:none detected, Fe:<50, Mg:none detected, Ni:none detected, O:1.5
Si3N4	UBE-E05 (B20208)	BM288GTE96	AS RECEIVED	PPM	Al:<5, C:none detected, Ca:<10, Cr:10, Fe:60, Mg:<5, Ni:<10, O:0.65
Si3N4	UBE-E05 (F610074)	BM288GTE96	AS RECEIVED	PPM	Al:<5, C:none detected, Ca:<10, Cr:10, Fe:60, Mg:<5, Ni:<10, O:0.80
Si3N4	UBE-E10 (A610342)	BM288GTE96	AS RECEIVED	PPM	Al:<5, C:none detected, Ca:<10, Cr:10, Fe:60, Mg:<5, Ni:<10, O:1.37

* This chemistry is the general specification for Inconel 718.

SECTION 5. JOINT DESCRIPTIONS

JOINT CODE	REFERENCE CODE	DESCRIPTION
GTEL/PY6-INC718	ORNL87SB047C	Joint consisted of a 12.7mm diameter GTE PY6 rod brazed into a cup-ended 19.5mm Inconel 718 shaft with Au-5Pd-2Ni. An interlayer of molybdenum was used between the Inconel 718 and PY6 to minimize thermal stresses. The PY6 was coated by electron beam (300C, 1E-5 to 1E-6 torr) with titanium to 3 micrometers thick in the metal contact region.
GTEL/PY6-INC909	ORNL87SB047C	Joint consisted of a GTE PY6 rod (12.7mm diameter) coated with titanium, brazed to an Incoloy 909 shaft with Au-5Pd-2Ni. The metal shaft was cupped on one end to hold the PY6 rod. An interlayer of nickel was used between the rod and the shaft-cup to minimize thermal stresses.The PY6 was coated using an electron beam at 300C, 1E-5 to 1E-6 torr to deposit 3 micrometers of titanium.
GTEL/PY6-TI-MO/1	ORNL87SB047C	Joint consisted of a GTE PY6 coupon coated with titanium, overlapped and brazed with Au+5Pd+2Ni to a molybdenum coupon. Overlap area was 1 sq. cm.
GTEL/PY6-TI-MO/2	ORNL87SB047C	Joint consisted of a GTE PY6 coupon coated with titanium, overlapped and brazed with 30Au+34Pd+36Ni to a molybdenum coupon. Overlap area was 1 sq. cm.
GTEL/PY6-TI-NI/2	ORNL87SB047C	Joint consisted of a GTE PY6 coupon coated with titanium, overlapped and brazed with 30Au-34Pd-36Ni to a nickel coupon. Overlap area was 1 square centimeter.
GTEL/PY6-ZR-MO/1	ORNL87SB047C	Joint consisted of a GTE PY6 coupon coated with zirconium, overlapped and brazed with 30Au-34Pd-36Ni to a molybdenum coupon. Overlap area was 1 sq. cm.
GTEL/PY6-ZR-MO/2	ORNL87SB047C	Joint consisted of a GTE PY6 coupon coated with zirconium, overlapped and brazed with 30Au+34Pd+36Ni to a molybdenum coupon. Overlap area was 1 sq. cm.
GTEL/SIC-HF-MO/3	ORNL87SB047C	Joint consisted of a Hexaloy SA coupon coated with hafnium, overlapped and brazed with Au-18Ni to a molybdenum coupon. Overlapped area was about 1. sq.cm.

SECTION 5. JOINT DESCRIPTIONS, CONTINUED

JOINT CODE	REFERENCE CODE	DESCRIPTION
GTEL/SIC-HF-SIC	ORNL87SB047C	Joint consisted of two Hexaloy SA coupons coated with hafnium, overlapped and brazed with Au-18Ni. Overlapped area was about 1 square centimeter.
GTEL/SIC-INC718	ORNL87SB047C	Joint consisted of a 12.7mm diameter Hexaloy SA rod brazed into the cupped end of a 19.5mm Inconel 718 shaft with 30Au-34Pd-36Ni. The ceramic rod was coated with 3 micrometers of titanium using electron beam deposition at 300C, 1.E-05 to 1E-6 torr. An interlayer of molybdenum was used between the ceramic rod and the metal shaft to minimize thermal stresses.
GTEL/SIC-INC909	ORNL87SB047C	Joint consisted of a 12.7mm diameter Hexaloy SA rod brazed into the cupped end of a 19.5mm diameter Incoloy 909 shaft with Au-5Pd-2Ni. The Hexaloy SA was coated with 3 micrometers of titanium in the metal contact region using electron beam deposition at 300C, 1E-5 to 1E-6 torr. An interlayer of molybdenum was used between the ceramic shaft and the metal rod to minimize thermal stresses
GTEL/SIC-TA-MO/3	ORNL87SB047C	Joint consisted of a Hexaloy SA coupon coated with tantalum, overlapped and brazed with Au-18Ni to a molybdenum coupon. Overlapped area was about 1 sq. cm.
GTEL/SIC-TI-MO/1	ORNL87SB047C	Joint consisted of a Hexaloy SA coupon coated with titanium, overlapped and brazed with Au-5Pd-2Ni to a molybdenum coupon. Overlap area was 1 square cm.
GTEL/SIC-TI-MO/2	ORNL87SB047C	Joint consisted of a Hexaloy SA coupon coated with titanium, overlapped and brazed with 30Au-34Pd-36Ni to a molybdenum coupon. Overlap area was 1 sq. cm.
GTEL/SIC-TI-MO/3	ORNL87SB047C	Joint consisted of a Hexaloy SA coupon coated with titanium, overlapped and brazed with Au-18Ni to a molybdenum coupon. Overlap area was 1 sq. cm.
GTEL/SIC-ZR-MO/3	ORNL87SB047C	Joint consisted of a Hexaloy SA coupon coated with zirconium, overlapped and brazed to a molybdenum coupon with Au-18Ni. Overlapped area was about 1 sq.cm.

SECTION 5. JOINT DESCRIPTIONS, CONTINUED

JOINT CODE	REFERENCE CODE	DESCRIPTION
GTEL/SIN-HF-ME/3	ORNL87SB047C	Joint consisted of an SNW-1000 coupon coated with hafnium, overlapped and brazed with Au-18Ni to an Incoloy 909 coupon. Overlapped area was about 1 sq. cm.
GTEL/SIN-HF-MO/3	ORNL87SB047C	Joint consisted of an SNW-1000 coupon coated with hafnium, overlapped and brazed with Au-18Ni to a molybdenum coupon. Overlapped area was about 1 sq. cm.
GTEL/SIN-TA-SIN	ORNL87SB047C	Joint consisted of an SNW-1000 coupon coated with tantalum, overlapped and brazed to another SNW-1000/Ta coupon with Au-18Ni. Overlap area was 1 sq. cm.
GTEL/SIN-TI-ME/3	ORNL87SB047C	Joint consisted of SNW-1000 coated with titanium, overlapped and brazed with Au-18Ni to an Incoloy 909 coupon. Overlap area was about 1 sq. cm.
GTEL/SIN-TI-MO/3	ORNL87SB047C	Joint consisted of an SNW-1000 coupon coated with titanium, overlapped and brazed with Au-18Ni to a molybdenum coupon. Overlapped area was 1 sq. cm.
GTEL/SIN-TI-SIN	ORNL87SB047C	Joint consisted of an SNW-1000 coupon coated with titanium, overlapped and brazed to another SNW-1000/Ti coupon with Au-18Ni. Overlapped area was 1 sq.cm.
GTEL/SIN-ZR-ME/3	ORNL87SB047C	Joint consisted of SNW-1000 coated with zirconium, overlapped and brazed with Au-18Ni to an Incoloy 909 coupon. Overlapped area was 1 square centimeter.
GTEL/SIN-ZR-MO/3	ORNL87SB047C	Joint consisted of an SNW-1000 coupon coated with zirconium, overlapped and brazed with Au-18Ni to a molybdenum coupon. Overlapped area was about 1 sq. cm.
GTEL/SIN-ZR-SIN	ORNL87SB047C	Joint consisted of an SNW-1000 coupon coated with zirconium, overlapped and brazed to another SNW-1000/Zr coupon with Au-18Ni. Overlapped area was 1 sq.cm.

SECTION 5. JOINT DESCRIPTIONS, CONTINUED

JOINT CODE	REFERENCE CODE	DESCRIPTION
ORNL/MS890/SNA1	BM1289ORNL10	Kyocera SN220 Si3N4 was vapor coated with Ti and brazed with Au-25Ni-25Pd at 1030C in a vacuum. The joint surfaces were left as ground (no polishing) prior to vapor-coating with Ti to 1 micrometer thick.
ORNL/MS890/SNG1	BM1289ORNL10	Kyocera SN220 was vapor coated with Ti and brazed with Au-25Ni-25Pd in a vacuum at 1030C. The joint surfaces were polished to a 1-micrometer diamond surface finish prior to vapor coating with Ti to 1-micrometer thick.
ORNL/MS890/SNG2	BM1289ORNL10	Kyocera SN220 Si3N4 was vapor coated with Ti and brazed with Au-25Ni-25Pd in vacuum at 1030C. Joint surfaces were polished to a 3-micrometer diamond finish prior to vapor coating with Ti to 1 micrometer thick.
ORNL/MS890/ZRFE	SA9ORNL184	Nilcra grade MS partially stabilized zirconia was vapor coated with titanium prior to brazing. Cummins Engine Grade 8003 nodular cast iron was electroplated with copper then brazed to the MS-PSZ/Ti material with 60Ag+30Cu+10Sn braze (BR 604) in a vacuum at 735°C.
ORNL/MS890/ZRZR	SA9ORNL187	Nilcra grade MS partially stabilized zirconia was vapor coated with titanium prior to brazing, then brazed to another MS-PSZ/Ti plate with 60Ag+30Cu+10Sn at 735°C in a vacuum.

APPENDIX B. TEST RESULTS

SECTION 1. TEST BACKGROUND INFORMATION

REFERENCE CODE	TEST TYPE	TEST BACKGROUND INFORMATION
KCLIU-9/90	CREEP	Specimen geometry: buttonhead tensile rods with a 6.3mm diameter, 32mm long uniform gage section. All circumferential marks in gage section were removed by final longitudinal grinding to a 0.4 micrometer (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. Work performed by K.C. Liu, H. Pih, and C.O. Stevens, ORNL.
AMTLPKG-6/90	FRACTURE TOUGHNESS	Microindentation tests were performed using a Vickers indenter on a "B" 4-point bend specimen, then breaking it immediately after (in a standard 4-point fixture to avoid environmental effects) using MIL STD-1942 specs. Bars polished to 2 microinch RMS or better c.1 a 4mmx50mm face. A 10mm moment arm was used. "B" specimens are 3mm x 4mm x 50mm. Testing was done by Jeff Swab and Tom Stefanick at the Army Materials Technology Laboratory
BM0889GTE123	FRACTURE TOUGHNESS	Heat treatment details: HOT PRESS = 400 minutes @1800C, 34.4MPa in N2; HOT PRESS/HT = HOT PRESS + 240 minutes at1200C in N2. Knoop indenter used on specimens. Indentation strength method referenced to G.R. Anstis, et al. J. AM. Cer. Soc.,64(9), p. 533 (1981). Work performed at GTE Laboratories by Buljan and Baldoni.

SECTION 1. TEST BACKGROUND INFORMATION, CONTINUED

REFERENCE CODE	TEST TYPE	TEST BACKGROUND INFORMATION
AMTLPKG-6/90	MOR4PTB	Standard "B" bars (3x4x50mm) were machined from billets of all materials except TZP-110. Due to material limitations the TZP-110 specimens were made into "A" bars (1.5x2x30mm). Heat treatments were done in air at lab ambient humidity in an unstressed condition, with bars on SiC knife edges. The knife edges were outside of the test area. All testing and preparations were done by MIL-STD-1942. Inner span for the tests was 20mm, outer span was 40mm, crosshead speed was 0.5 mm/minute, chart speed was 100mm/minute. "A" bars had inner span of 10mm, outer span of 20mm. Characteristic strength values were not corrected for volume and surface effects. Fracture surfaces were examined with a low magnification microscope and/or a SEM to determine flaw type. Testing was done by Jeff Swab and Tom Stefanick at the Army Materials Technology Laboratory. Summary of results can be found in MTL TR 89-21, "PROPERTIES OF YTTRIA-TETRAGONAL ZIRCONIA POLYCRYSTAL (Y-TZP) MATERIALS AFTER LONG-TERM EXPOSURE TO ELEVATED TEMPERATURES", Jeffery J. Swab, March 1989.
BM0889GTE123	MOR4PTB	Heat treatment HOT PRESS = 400 minutes at1800C, 34.4MPa in N2, HOT PRESS/HT = HOT PRESS(previous) + 240 minutes at 1200C in N2. Work performed at GTE Laboratories by Buljan and Baldoni.
BM0889GTE126	MOR4PTB	Heat treatment key: IM= injection molded (single side gate mold), HIP cycle information is proprietary. HP = hot pressed. IH = injection molded and hot pressed.
SA12GTEL55	MOR4PTB	GTEL std. 4 pt. fixture: 22mm inner span, 9.8mm outer span, 6.1mm load pt. diam. Densification treatments were: HOT PRESSED = 90 minutes at 1725C, 34.4MPa; ANNEAL = cooling from HOT PRESS at 60C/min to 1200C, held for 4 hours(240 minutes), then air cooled to room temperature. No room temp cooling between hot press and anneal. Specimens were 1.3x2.5x25mm bars, the GTEL standard.
ORNL87SB047C	TORSION	See entry under BRAZTORQ for testing details. Specimens in the TORSION file were monolithics with a 25.4 mm gage length, 12.7mm to 6.35mm diameters.

SECTION 1. TEST BACKGROUND INFORMATION, CONTINUED

REFERENCE CODE	TEST TYPE	TEST BACKGROUND INFORMATION
SANTELLA8/90	BRAZMOR4	Specimens were 3mm x 2.5mm x 30mm, with joint in the middle and tensile faces polished to a 1 micrometer-diamond finish. The test fixture used an inner span of 6.35mm, outer span of 19.05mm, and a cross-head speed of .25 mm/sec. No joints fractured through the metallic layer. Work performed by M. L. Santella,ORNL.
ORNL87SB047C	BRAZSHER	Lapped coupon samples were used in the shear tests. The lower coupon was the metal and the top was the coated ceramic. The two coupons were brazed together forming an overlapped area of about 1 sq. cm. Tests were run in an Instron 1320 in compression mode. Failure loads were recorded at the point of first load drop to avoid inflated strength values due to scraping during the shear tests.
ORNL87SB047C	BRAZTORQ	Torsion testing was performed on an MTS model 646/25S hydraulic axial/torsion machine. Maximum torque for the machine was 2260 newton-meters, with a maximum axial load of 245N. The machine's hydraulic grips could accommodate 12.7mm samples. Gripping pressure was adjusted to 10.3MPa to prevent cracking in the ceramic part of the specimen. Tests were run at 0.2 degress theta/sec. Axial load was controlled to +-4.448 Newtons of zero. An induction furnace was used for high temperature tests. A SiC susceptor was used for heating ceramic-metal joints. All specimens were equilibrated at test temperature before starting the actual tests. Work was performed at GTE Laboratories by S. Kang, J.H. Selverian, H. Kim, D. O'Niel, and K. Kim.
ORNL87SB047C	BRAZTORFT	Torsional fatigue tests used the same MTS model 646/25S hydraulic axial/torsion machine used for torsion testing from this data source. The tests were run under torque control, between 4 and 15.2 newton meters, with a mean torque level of 12.4Nm. A 1 Hz loading frequency was used. Maximum cycle time was .333 seconds. Target cycles for this study was 1000. Work performed at GTE Laboratories by S. Kang, J.H. Selverian, H. Kim, D. O'Niel, and H. Kim.

SECTION 2. CREEP DATA

MATERIAL	BATCH CODE	SOURCE CODE	TYPE OF CREEP TEST	SPECIMEN NUMBER	TEMP. °C	STRESS MPa	CREEP RATE /second	RUPTURE TIME hours	TEST NOTES	COMMENTS
NT-154	NORTON/ORNL-20S	KCLIU-9/90	STD LEVER ARM	20-29	1200	150.0	2.00E-10		Y	BROKE OUTSIDE GAGE
NT-154	NORTON/ORNL-20S	KCLIU-9/90	STD LEVER ARM	20-06	1300	120.0	6.69E-10			
NT-154	NORTON/ORNL-20S	KCLIU-9/90	STD LEVER ARM	20-13	1300	120.0	4.32E-10		Y	PRECYCLED
NT-154	NORTON/ORNL-20S	KCLIU-9/90	STD LEVER ARM	20-09	1370	100.0	8.14E-10	3200	Y	PRECYCLED
NT-154	NORTON/ORNL-20S	KCLIU-9/90	STD LEVER ARM	20-07	1370	100.0	8.12E-10	1300		TOTAL STRN=1.12%
NT-154	NORTON/ORNL-20S	KCLIU-9/90	STD LEVER ARM	20-17	1370	120.0	1.55E-09			
NT-154	NORTON/ORNL-CP	KCLIU-9/90	STD LEVER ARM	CP-28	1300	150.0	2.12E-09		Y	PRECYCLED, TEST DISC.
NT-154	NORTON/ORNL-CP	KCLIU-9/90	STD LEVER ARM	CP-30	1300	180.0	1.59E-08			
NT-154	NORTON/ORNL-CP	KCLIU-9/90	STD LEVER ARM	CP-34	1370	90.0	7.30E-09		Y	TEST DISCONTINUED
NT-154	NORTON/ORNL-CP	KCLIU-9/90	STD LEVER ARM	CP-31	1370	120.0	4.25E-08	50		

TEST NOTES

SPECIMEN NUMBER	NOTES:
ALL	All test specimens were buttonheaded tensile rods, tested in air.
20-09 20-09 20-09 20-09	Prior to testing, specimen was precycled from 158 to 220MPa in 14 steps with a total accumulation of 500,000 cycles in 150 hours. Specimen was then loaded to 100MPa, 1370C and run to 3200 hours. A power outage occurred at 1400 hours,after which the specimen was reloaded and the test continued. Showed good recovery.
20-13 20-13 20-13 20-13 20-13	Prior to testing, the specimen was precycled from 158 to 222MPa in 14 steps with a total accumulation of 500,000 cycles in 150 hours. Specimen was then reheated to 1300C and 120MPa. In-test strain measurements were lost 2 hours into the test due to poor bonding at the fiducial marks. Creep deformation was measured outside the furnace using a mechanical dial gage. Test completed after 2415 hours.
20-29	Specimen fractured at the shank due to weather-related power outage at 280 hrs.
CP-28 CP-28	Specimen heated to 1300C, then step-loaded by 7MPa to 150MPa. Specimen ruptured at 700 hours after accidentally being disturbed.
CP-34 CP-34 CP-34	Test was shut down at 500 hours by a power outage, then restarted under the same loading conditions and run for 300 hours, until shut down by another power outage. Specimen ruptured during attempt to reload for another restart.

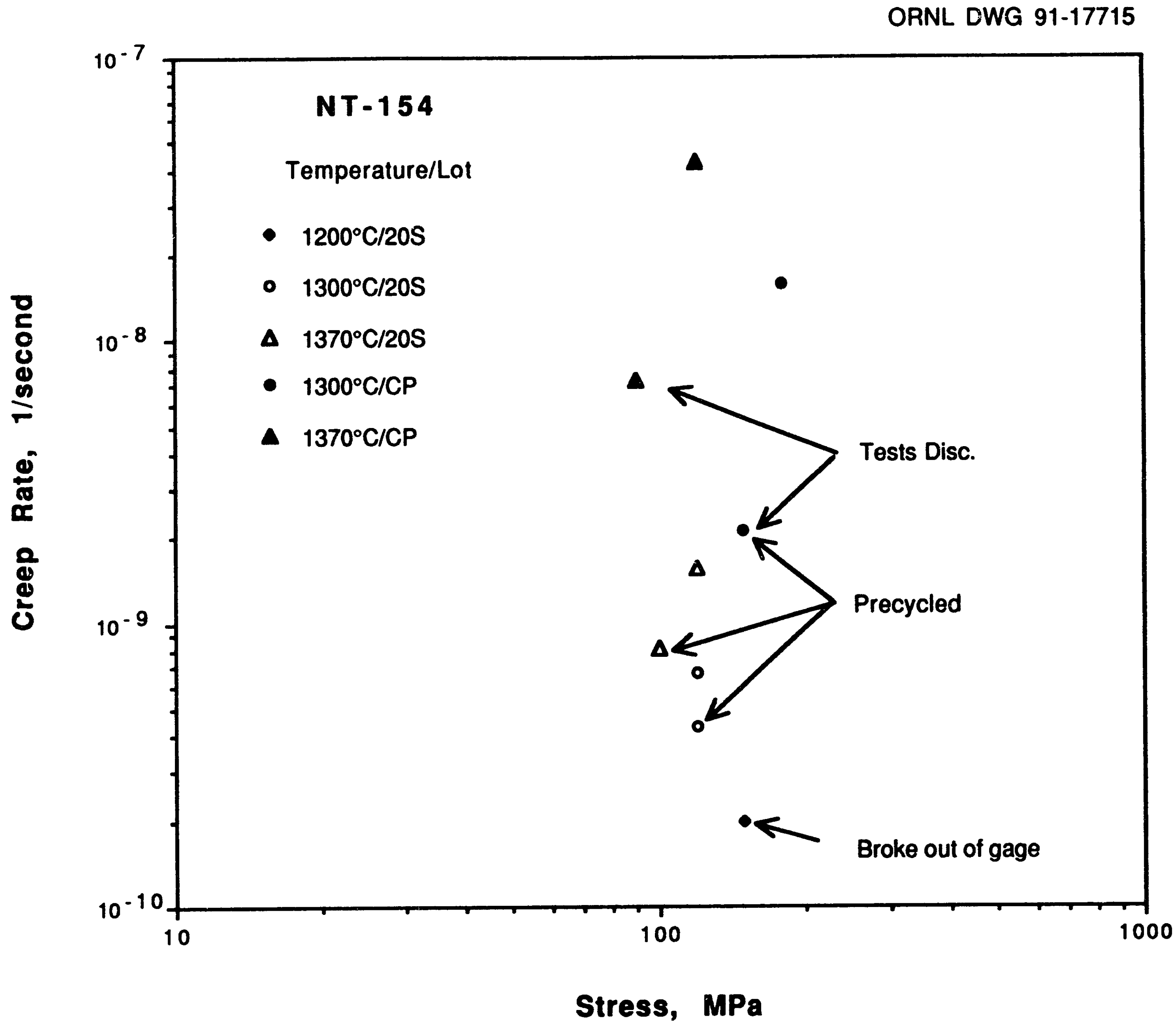

Figure 1. A comparison of creep rates of two lots of NT-154.

SECTION 3. FRACTURE TOUGHNESS

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	--SPECIMEN-- WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
ALUMINAS														
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	KF-11	MICROINDENTATION	25	3.996	2.996	219	10	183	4.33	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	KF-13	MICROINDENTATION	25	3.996	2.998	218	10	182	4.31	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	KF-14	MICROINDENTATION	25	3.995	2.994	230	10	193	4.49	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	KF-15	MICROINDENTATION	25	4.001	3.002	234	10	195	4.53	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	KF-26	MICROINDENTATION	25	3.999	2.996	203	10	170	4.03	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	KF-27	MICROINDENTATION	25	4.001	3.000	199	10	166	3.96	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	KF-28	MICROINDENTATION	25	3.995	2.995	200	10	167	3.99	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	KF-29	MICROINDENTATION	25	4.003	2.998	186	10	155	3.77	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	KF-30	MICROINDENTATION	25	3.998	2.996	191	10	160	3.85	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	CZA-26	MICROINDENTATION	25	3.981	2.987	218	10	184	4.29	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	CZA-27	MICROINDENTATION	25	3.988	3.000	205	10	171	4.07	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	CZA-28	MICROINDENTATION	25	3.986	2.949	206	10	172	4.09	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	CZA-29	MICROINDENTATION	25	3.986	3.008	205	10	171	4.05	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR	CZA-30	MICROINDENTATION	25	3.982	3.004	192	10	160	3.87	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	CZA-11	MICROINDENTATION	25	3.987	3.002	239	10	200	4.48	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	CZA-12	MICROINDENTATION	25	3.974	3.004	205	10	171	4.00	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	CZA-13	MICROINDENTATION	25	3.982	3.004	212	10	177	4.10	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	CZA-14	MICROINDENTATION	25	3.987	2.990	207	10	174	4.05	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR	CZA-15	MICROINDENTATION	25	3.982	2.992	198	10	167	3.92	
SILICON NITRIDES														
AM4	GTEL/BM0889	BM0889GTE123	HOT PRESSED	AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			7.10	
AM4	GTEL/BM0889	BM0889GTE123	HOT PRESSED/HT	AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			8.30	KIC+-0.3
AM4+Si3N4(30v)	GTEL/BM0889	BM0889GTE123	HOT PRESSED	AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			7.30	KIC+-0.2
AY6	GTEL/051888A	BM0889GTE122		AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3				4.90	KIC+-0.2
AY6	GTEL/051888A	BM0889GTE122		AIR	SUMMARY	MOD.INDENT TUFF	25	2.5	1.3	49			7.20	KIC+-0.4
AY6	GTEL/051888A	BM0889GTE122		AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			6.30	KIC+-0.1
AY6	GTEL/BM0889	BM0889GTE123	HOT PRESSED	AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			7.40	KIC+-0.1
AY6	GTEL/BM0889	BM0889GTE123	HOT PRESSED/HT	AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			5.80	KIC+-0.1
AY6+Si3N4(30v)	GTEL/BM0889	BM0889GTE123	HOT PRESSED	AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			5.50	KIC+-0.2
WHISKER-REINFORCED SILICON NITRIDES														
AY6+SiCw30v	GTEL/040188P	BM0889GTE122		AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3				6.0	KIC+-0.2
AY6+SiCw30v	GTEL/040188P	BM0889GTE122		AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			7.8	KIC+-0.4
AY6+SiCw30v	GTEL/040188P	BM0889GTE122		AIR	SUMMARY	MOD.INDENT TUFF	25	2.5	1.3	49			8.7	KIC+-0.6
AY6+SiCw30v	GTEL/BM0889	BM0889GTE123	HOT PRESSED	AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			8.0	KIC+-0.1
AY6+SiCw30v	GTEL/BM0889	BM0889GTE123	HOT PRESS/HT	AIR	SUMMARY	INDENT STRENGTH	25	2.5	1.3	49			8.3	KIC+-0.3

SECTION 3. FRACTURE TOUGHNESS, CONTINUED

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	—SPECIMEN— WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
WHISKER-REINFORCED SILICON NITRIDES														
AY6+SiCw30v	GTEL/SN502/0688	BM0688GTE129	HOT PRESS/1725C	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			5.800	KIC+-0.1	
AY6+SiCw30v	GTEL/SN502/0688	BM0688GTE129	HOT PRESS/1725C	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			6.100	KIC+-0.6	
AY6+SiCw30v	GTEL/SN502/0688	BM0688GTE129	HOT PRESS/1800C	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			5.900	KIC+-0.9	
AY6+SiCw30v	GTEL/SN502/0688	BM0688GTE129	HOT PRESS/1800C	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			6.000	KIC+-0.6	
AY6+SiCw30v	GTEL/SN502/HP88	SA12GTEL57	HOT PRESSED	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			6.400	KIC+-0.5	
AY6+SiCw30v	GTEL/SN502/IH88	SA12GTEL57	IM/HIP	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			4.200		
AY6+SiCw30v	GTEL/UBE10/0688	BM0688GTE129	HOT PRESS/1725C	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			5.000	KIC+-0.4	
AY6+SiCw30v	GTEL/UBE10/0688	BM0688GTE129	HOT PRESS/1800C	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			6.900	KIC+-0.9	
AY6+SiCw30v	GTEL/UBE10/0688	BM0688GTE129	HOT PRESS/1800C	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			6.900	KIC+-0.3	
AY6+SiCw30v	GTEL/UBE2/HP88	SA12GTEL57	HOT PRESSED	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			7.300	KIC+-0.6	
AY6+SiCw30v	GTEL/UBE2/IH88	SA12GTEL57	IM/HIP	AIR	SUMMARY	CONTROLLED FLAW	25	2.5	1.3			6.900	KIC+-0.4	
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 1	AIR	SUMOF5	INDENT STRENGTH	25	0.0				5.100	KIC=+-0.5	
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP-CYCLE 2	AIR	SUMOF5	INDENT STRENGTH	25	0.0				6.500	KIC=+-0.2	
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP-CYCLE 3	AIR	SUMOF5	INDENT STRENGTH	25	0.0				6.400	KIC=+-0.4	
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP-CYCLE 4	AIR	SUMOF5	INDENT STRENGTH	25	0.0				6.200	KIC=+-0.2	
ZIRCONIAS														
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-192*	MICROINDENTATION	25	3.996	2.980	856	2.5	724		
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-193	MICROINDENTATION	25	3.996	2.962	370	2.5	317	4.46	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-194	MICROINDENTATION	25	4.000	2.954	384	2.5	33	4.60	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-195	MICROINDENTATION	25	4.008	2.958	372	2.5	318	4.47	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-189	MICROINDENTATION	25	3.998	2.980	288	5	243	4.35	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-190	MICROINDENTATION	25	4.000	2.966	276	5	235	4.24	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-191	MICROINDENTATION	25	4.008	2.958	274	5	234	4.23	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-186	MICROINDENTATION	25	3.996	2.970	222	10	189	4.28	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-187	MICROINDENTATION	25	3.990	2.966	222	10	190	4.29	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-188	MICROINDENTATION	25	4.000	2.980	230	10	194	4.37	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-261	MICROINDENTATION	25	3.979	2.934	230	10	201	4.49	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-262	MICROINDENTATION	25	3.983	2.947	233	10	202	4.50	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-263	MICROINDENTATION	25	3.977	2.931	230	10	202	4.50	
1985	HIT1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(40% H2O)	HIT-264	MICROINDENTATION	25	3.978	2.950	232	10	201	4.48	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-159	MICROINDENTATION	25	3.998	2.956	508	2.5	436	5.67	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-160	MICROINDENTATION	25	3.998	2.960	746	2.5	639	7.55	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-161	MICROINDENTATION	25	4.002	2.952	594	2.5	511	6.38	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-162	MICROINDENTATION	25	3.998	2.990	482	2.5	405	5.36	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-156	MICROINDENTATION	25	3.994	2.964	272	5	233	4.21	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-157	MICROINDENTATION	25	3.992	2.962	272	5	233	4.21	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-158	MICROINDENTATION	25	4.000	2.958	292	5	250	4.44	

* Specimen broke outside of indention.

SECTION 3. FRACTURE TOUGHNESS, CONTINUED

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	--SPECIMEN-- WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
ZIRCONIAS														
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-153	MICROINDENTATION	25	3.998	2.968	226	10	193	4.34	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-154	MICROINDENTATION	25	3.996	2.960	224	10	192	4.33	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-155	MICROINDENTATION	25	3.995	2.960	234	10	201	4.48	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-265	MICROINDENTATION	25	3.985	2.945	236	10	205	4.55	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-266	MICROINDENTATION	25	3.977	2.935	235	10	206	4.56	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-267	MICROINDENTATION	25	3.977	2.935	233	10	204	4.53	
1985	HIT1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(40% H2O)	HIT-268	MICROINDENTATION	25	3.987	2.946	235	10	204	4.53	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-222	MICROINDENTATION	25	4.024	2.972	530	2.5	447	5.76	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-223	MICROINDENTATION	25	4.020	2.966	344	2.5	292	4.18	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-224	MICROINDENTATION	25	4.022	2.960	534	2.5	455	5.83	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-225	MICROINDENTATION	25	4.014	2.974	402	2.5	340	4.69	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-219	MICROINDENTATION	25	4.024	2.966	308	5	261	4.57	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-220	MICROINDENTATION	25	4.024	2.970	270	5	228	4.14	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-221	MICROINDENTATION	25	4.024	2.964	288	5	244	4.35	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-216	MICROINDENTATION	25	4.024	2.968	272	10	230	4.95	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-217	MICROINDENTATION	25	4.026	2.968	254	10	215	4.70	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-218	MICROINDENTATION	25	4.020	2.972	224	10	189	4.27	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-257	MICROINDENTATION	25	3.976	2.952	223	10	193	4.34	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-258	MICROINDENTATION	25	3.970	2.948	221	10	192	4.32	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-259	MICROINDENTATION	25	3.970	2.950	274	10	238	5.08	
1985	HIT1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(30% H2O)	HIT-260	MICROINDENTATION	25	3.980	2.948	223	10	193	4.35	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-146	MICROINDENTATION	25	4.016	2.990	592	2.5	495	6.27	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-147	MICROINDENTATION	25	4.020	2.998	666	2.5	557	6.85	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-148	MICROINDENTATION	25	4.018	2.982	694	2.5	583	7.09	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-149	MICROINDENTATION	25	4.026	2.986	724	2.5	601	7.25	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-143	MICROINDENTATION	25	4.016	2.988	332	5	278	4.84	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-144	MICROINDENTATION	25	4.006	2.982	344	5	290	4.99	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-145	MICROINDENTATION	25	4.024	2.994	350	5	291	5.01	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-140	MICROINDENTATION	25	4.020	2.988	266	10	222	4.87	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-141	MICROINDENTATION	25	4.016	2.990	268	10	224	4.89	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-142	MICROINDENTATION	25	4.020	2.988	264	10	221	4.84	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-298	MICROINDENTATION	25	4.005	2.973	448	10	380	7.27	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-299	MICROINDENTATION	25	4.007	2.971	405	10	344	6.74	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-345	MICROINDENTATION	25	3.982	2.959	535	10	460	8.40	
1986H	KOR1986H/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38-52% H20)	KH-346	MICROINDENTATION	25	3.998	2.974	861	10	730	11.80	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-215	MICROINDENTATION	25	4.000	2.962	1165	2.5	998	10.60	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-216	MICROINDENTATION	25	4.002	2.964	920	2.5	785	8.87	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-217	MICROINDENTATION	25	3.996	2.964	860	2.5	735	8.44	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-218	MICROINDENTATION	25	4.000	2.960	722	2.5	618	7.41	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-212	MICROINDENTATION	25	3.982	2.954	542	5	468	7.16	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-213	MICROINDENTATION	25	3.998	2.966	504	5	430	6.71	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-214	MICROINDENTATION	25	3.994	2.968	535	5	456	7.02	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-209	MICROINDENTATION	25	4.014	2.972	344	10	291	5.96	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-210	MICROINDENTATION	25	4.016	2.958	380	10	324	6.46	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-211	MICROINDENTATION	25	3.982	2.968	388	10	332	6.58	

SECTION 3. FRACTURE TOUGHNESS, CONTINUED

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	—SPECIMEN— WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
ZIRCONIAS														
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-347	MICROINDENTATION	25	3.993	2.958	350	10	301	6.10	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-348	MICROINDENTATION	25	3.984	2.950	279	10	241	5.18	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-349	MICROINDENTATION	25	3.990	2.957	279	10	240	5.16	
1986H	KOR1986H/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38-60% H20)	KH-350	MICROINDENTATION	25	3.980	2.946	276	10	240	5.15	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-280	MICROINDENTATION	25	4.020	2.990	956	2.5	798	8.97	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-281	MICROINDENTATION	25	4.022	2.982	582	2.5	488	6.21	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-282	MICROINDENTATION	25	4.022	2.968	588	2.5	498	6.30	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-283	MICROINDENTATION	25	4.010	2.980	562	2.5	473	6.07	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-284	MICROINDENTATION	25	4.028	2.972	596	2.5	503	6.34	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-166	MICROINDENTATION	25	4.020	2.978	330	5	278	4.84	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-167	MICROINDENTATION	25	4.016	2.970	332	5	281	4.88	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-168	MICROINDENTATION	25	4.020	2.980	314	5	264	4.65	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-169	MICROINDENTATION	25	4.014	2.966	334	5	284	4.91	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-170	MICROINDENTATION	25	4.014	2.996	340	5	283	4.91	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-161	MICROINDENTATION	25	3.982	2.970	256	10	219	4.81	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-162	MICROINDENTATION	25	4.022	2.984	276	10	231	5.01	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-163	MICROINDENTATION	25	3.994	2.970	250	10	213	4.71	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-164	MICROINDENTATION	25	4.004	2.976	252	10	213	4.72	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-165	MICROINDENTATION	25	3.998	2.966	256	10	218	4.80	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-296	MICROINDENTATION	25	4.002	2.970	270	10	229	4.98	
1986H	KOR1986H/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(53.5% H20)	KH-297	MICROINDENTATION	25	4.004	2.970	367	10	310	6.24	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-146*	MICROINDENTATION	25	4.010	2.960	698	2.5	596		
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-147	MICROINDENTATION	25	4.010	2.964	684	2.5	582	7.10	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-148	MICROINDENTATION	25	4.008	2.954	668	2.5	573	7.01	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-149	MICROINDENTATION	25	4.016	2.962	746	2.5	635	7.57	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-143	MICROINDENTATION	25	4.010	2.966	360	5	306	5.21	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-144	MICROINDENTATION	25	4.010	2.962	338	5	288	4.98	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-145	MICROINDENTATION	25	4.012	2.966	338	5	287	4.97	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-140	MICROINDENTATION	25	4.014	2.968	292	10	248	5.29	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-141	MICROINDENTATION	25	4.010	2.970	280	10	237	5.12	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-142	MICROINDENTATION	25	4.010	2.968	266	10	226	4.93	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-244	MICROINDENTATION	25	3.995	2.977	274	10	232	5.04	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-245	MICROINDENTATION	25	3.995	2.977	417	10	353	6.90	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-246	MICROINDENTATION	25	4.006	2.991	358	10	300	6.10	
1986S	KOR1986S/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&67% H2O)	KS-247	MICROINDENTATION	25	3.996	2.982	402	10	339	6.69	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-168	MICROINDENTATION	25	4.006	2.966	618	2.5	526	6.61	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-169	MICROINDENTATION	25	4.010	2.962	570	2.5	436	6.23	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-170	MICROINDENTATION	25	4.020	2.968	620	2.5	525	6.60	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-164	MICROINDENTATION	25	4.010	2.954	334	5	286	4.98	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-165	MICROINDENTATION	25	4.004	2.964	318	5	271	4.78	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-166	MICROINDENTATION	25	4.004	2.952	336	5	289	5.01	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-161	MICROINDENTATION	25	4.016	2.968	296	10	251	5.37	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-162	MICROINDENTATION	25	4.008	2.954	274	10	235	5.11	

* Specimen broke outside of indention.

SECTION 3. FRACTURE TOUGHNESS, CONTINUED

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	—SPECIMEN— WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
ZIRCONIAS														
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-163	MICROINDENTATION	25	4.014	2.970	256	10	217	4.81	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-139	MICROINDENTATION	25	3.990	2.984	282	10	238	5.16	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-241	MICROINDENTATION	25	3.986	2.982	536	10	454	8.36	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-242	MICROINDENTATION	25	4.004	2.958	280	10	240	5.18	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-243	MICROINDENTATION	25	3.998	2.994	302	10	253	5.39	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-157*	MICROINDENTATION	25	4.008	2.956	684	2.5	586	0.00	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-158	MICROINDENTATION	25	4.010	2.966	750	2.5	638	7.60	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-159	MICROINDENTATION	25	4.008	2.958	756	2.5	647	7.68	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-160	MICROINDENTATION	25	4.012	2.962	622	2.5	530	6.61	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-154	MICROINDENTATION	25	4.008	2.966	558	5	475	7.24	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-155	MICROINDENTATION	25	4.010	2.966	488	5	415	6.55	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-156	MICROINDENTATION	25	4.014	2.968	504	5	428	6.69	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-151	MICROINDENTATION	25	4.006	2.956	370	10	317	6.36	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-152	MICROINDENTATION	25	4.010	2.962	360	10	307	6.21	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-153	MICROINDENTATION	25	4.010	2.962	302	10	258	5.44	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-248	MICROINDENTATION	25	3.993	2.975	287	10	244	5.22	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-249	MICROINDENTATION	25	3.992	2.978	494	10	419	7.83	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-250	MICROINDENTATION	25	4.002	2.983	321	10	270	5.65	
1986S	KOR1986S/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27&42% H2O)	KS-251	MICROINDENTATION	25	3.999	2.973	295	10	250	5.33	
CZ-203	CER1987/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(27% H2O)	CER-21	MICROINDENTATION	25	3.998	2.950	514	10	443	8.26	
CZ-203	CER1987/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(27% H2O)	CER-22*	MICROINDENTATION	25	3.986	2.934	623	10	547		
CZ-203	CER1987/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(27% H2O)	CER-23*	MICROINDENTATION	25	3.989	2.960	673	10	578		
CZ-203	CER1987/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(27% H2O)	CER-24*	MICROINDENTATION	25	3.988	2.938	603	10	526		
CZ-203	CER1987/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(27% H2O)	CER-25	MICROINDENTATION	25	3.988	2.954	619	10	534	9.50	
CZ-203	CER1987/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(27% H2O)	CER-46	MICROINDENTATION	25	3.998	2.944	556	10	481	8.82	
CZ-203	CER1987/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(27% H2O)	CER-47*	MICROINDENTATION	25	4.006	2.954	590	10	506		
CZ-203	CER1987/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(27% H2O)	CER-48	MICROINDENTATION	25	3.996	2.964	645	10	551	9.76	
CZ-203	CER1987/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(27% H2O)	CER-49	MICROINDENTATION	25	3.994	2.956	582	10	500	9.08	
CZ-203	CER1987/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(27% H2O)	CER-50	MICROINDENTATION	25	3.990	2.950	540	10	467	8.62	
CZ-203	CER1987/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27% H2O)	CER-71*	MICROINDENTATION	25	3.994	2.904	649	10	578		
CZ-203	CER1987/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27% H2O)	CER-72	MICROINDENTATION	25	3.996	2.934	655	10	571	10.03	
CZ-203	CER1987/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27% H2O)	CER-73	MICROINDENTATION	25	4.006	2.944	631	10	545	9.68	
CZ-203	CER1987/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27% H2O)	CER-74	MICROINDENTATION	25	3.998	2.914	607	10	536	9.57	
CZ-203	CER1987/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(27% H2O)	CER-75	MICROINDENTATION	25	3.998	2.916	593	10	523	9.39	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-143*	MICROINDENTATION	25	4.030	2.984	654	5	547		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-144	MICROINDENTATION	25	4.032	2.984	558	5	466	7.20	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-145*	MICROINDENTATION	25	4.032	2.994	626	5	520		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-149*	MICROINDENTATION	25	4.026	2.980	656	5	550		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-140*	MICROINDENTATION	25	4.030	2.992	652	10	542		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-141	MICROINDENTATION	25	4.026	2.984	510	10	427	8.02	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-142	MICROINDENTATION	25	4.022	2.984	562	10	471	8.63	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-120	MICROINDENTATION	25	4.025	2.985	668	10	559	9.81	

* Specimen broke outside of indention

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	--SPECIMEN-- WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
ZIRCONIAS														
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-192*	MICROINDENTATION	25	4.026	2.988	658	10	549		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-193*	MICROINDENTATION	25	4.024	2.984	648	10	543		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-194	MICROINDENTATION	25	4.026	2.973	648	10	546	9.65	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-195	MICROINDENTATION	25	4.032	2.996	658	10	545	9.64	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-146	MICROINDENTATION	25	4.028	2.986	436	15	364	7.88	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-147	MICROINDENTATION	25	4.030	2.984	372	15	311	7.00	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38% H2O)	TOSH-148	MICROINDENTATION	25	4.030	2.982	528	15	442	9.11	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-152*	MICROINDENTATION	25	4.032	2.980	790	5	662		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-153*	MICROINDENTATION	25	4.026	2.992	734	5	611		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-151	MICROINDENTATION	25	4.030	2.994	606	10	503	9.03	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-154*	MICROINDENTATION	25	4.030	2.986	562	10	469		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-155*	MICROINDENTATION	25	4.032	2.988	572	10	477		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-160*	MICROINDENTATION	25	44.024	2.968	522	10	442		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-196*	MICROINDENTATION	25	3.996	2.962	526	10	450		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-197	MICROINDENTATION	25	3.981	2.938	700	10	611	10.44	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-198	MICROINDENTATION	25	4.030	2.993	700	10	582	10.06	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-199*	MICROINDENTATION	25	4.021	2.992	689	10	574		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-200*	MICROINDENTATION	25	4.030	2.998	764	10	633		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-201*	MICROINDENTATION	25	4.029	2.998	742	10	615		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-202*	MICROINDENTATION	25	3.992	2.962	618	10	529		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-203	MICROINDENTATION	25	3.993	2.962	521	10	446	8.25	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-156	MICROINDENTATION	25	4.026	2.984	638	10	534	10.44	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-157	MICROINDENTATION	25	4.026	2.986	492	10	411	8.59	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-158	MICROINDENTATION	25	4.012	2.998	532	15	443	9.07	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38% H2O)	TOSH-159	MICROINDENTATION	25	4.026	2.992	452	15	376	8.03	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-168*	MICROINDENTATION	25	4.026	2.982	654	2.5	548		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-169*	MICROINDENTATION	25	4.026	2.992	668	2.5	556		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-161*	MICROINDENTATION	25	4.030	2.970	646	5	545		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-162	MICROINDENTATION	25	4.024	2.992	610	5	508	7.67	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-163	MICROINDENTATION	25	4.022	2.994	654	5	544	8.08	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-164	MICROINDENTATION	25	4.030	2.988	580	10	484	8.79	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-165	MICROINDENTATION	25	4.022	2.984	450	10	377	7.30	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-170	MICROINDENTATION	25	4.028	2.986	458	10	383	7.38	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-116	MICROINDENTATION	25	4.016	3.002	569	10	472	8.63	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-117	MICROINDENTATION	25	4.014	2.992	570	10	476	8.69	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-118	MICROINDENTATION	25	4.016	2.988	711	10	595	10.27	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-229*	MICROINDENTATION	25	4.026	2.992	697	10	580		
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-166	MICROINDENTATION	25	4.026	2.982	370	15	310	6.97	
TASZIC	TOS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(46&55% H2O)	TOSH-167	MICROINDENTATION	25	4.028	2.984	356	15	298	6.77	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(33% H2O)	AC-56	MICROINDENTATION	25	4.000	2.980	347	10	293	5.99	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(33% H2O)	AC-59	MICROINDENTATION	25	3.994	2.966	387	10	330	6.56	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(33% H2O)	AC-60	MICROINDENTATION	25	3.994	2.972	346	10	294	6.01	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(33% H2O)	AC-128	MICROINDENTATION	25	3.994	2.972	329	10	280	5.79	

* Specimen broke outside of indention

SECTION 3. FRACTURE TOUGHNESS, CONTINUED

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	--SPECIMEN-- WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
ZIRCONIAS														
TZP-110	ACS1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(33% H2O)	AC-129	MICROINDENTATION	25	3.990	2.970	332	10	283	5.84	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(33% H2O)	AC-25	MICROINDENTATION	25	3.998	2.970	529	10	450	8.28	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(33% H2O)	AC-29	MICROINDENTATION	25	4.000	2.986	546	10	459	8.41	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(33% H2O)	AC-30*	MICROINDENTATION	25	3.998	2.970	622	10	529		
TZP-110	ACS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(33% H2O)	AC-126	MICROINDENTATION	25	3.995	2.964	460	10	393	7.49	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(33% H2O)	AC-127	MICROINDENTATION	25	3.994	2.964	413	10	353	6.91	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(60% H2O)	AC-83	MICROINDENTATION	25	4.000	2.968	327	10	278	5.76	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(60% H2O)	AC-C84	MICROINDENTATION	25	3.994	2.966	318	10	272	5.85	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(60% H2O)	AC-85	MICROINDENTATION	25	3.996	2.968	314	10	268	5.59	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(60% H2O)	AC-89	MICROINDENTATION	25	3.996	2.968	316	10	269	5.62	
TZP-110	ACS1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(60% H2O)	AC-90	MICROINDENTATION	25	4.000	2.970	298	10	254	5.38	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-143	MICROINDENTATION	25	4.014	2.980	742	2.5	624	7.46	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-144*	MICROINDENTATION	25	4.016	2.980	906	2.5	762		
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-145	MICROINDENTATION	25	4.008	2.970	862	2.5	731	8.40	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-146*	MICROINDENTATION	25	4.008	2.970	808	2.5	686		
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-140	MICROINDENTATION	25	4.010	2.968	644	5	547	8.03	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-141	MICROINDENTATION	25	4.012	2.968	594	5	504	7.56	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-14	MICROINDENTATION	25	4.010	2.978	542	5	457	7.02	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-147	MICROINDENTATION	25	4.008	2.982	436	10	367	7.08	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-148	MICROINDENTATION	25	4.010	2.980	384	10	324	6.44	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-149	MICROINDENTATION	25	4.010	3.000	550	10	457	8.34	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-270	MICROINDENTATION	25	4.000	2.954	332	10	285	5.86	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-271	MICROINDENTATION	25	4.000	2.969	356	10	303	6.13	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-272	MICROINDENTATION	25	3.998	2.970	447	10	380	7.27	
Z-191	NGK1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(38&42% H2O)	NGK-273	MICROINDENTATION	25	3.988	2.953	518	10	447	8.21	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-158	MICROINDENTATION	25	4.016	2.990	712	2.5	595	7.27	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-159*	MICROINDENTATION	25	4.008	2.982	830	2.5	699		
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-160*	MICROINDENTATION	25	4.006	2.988	830	2.5	696		
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-154	MICROINDENTATION	25	0.012	3.002	538	5	446	6.97	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-155*	MICROINDENTATION	25	4.008	2.974	744	5	630		
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-156	MICROINDENTATION	25	4.008	2.980	618	5	517	7.79	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-157	MICROINDENTATION	25	4.006	3.008	562	5	465	7.19	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-151	MICROINDENTATION	25	4.008	2.974	432	10	366	7.14	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-152	MICROINDENTATION	25	4.010	2.980	378	10	318	6.44	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-153	MICROINDENTATION	25	4.012	3.000	374	10	311	6.32	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-274	MICROINDENTATION	25	3.999	2.969	423	10	360	7.06	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-275	MICROINDENTATION	25	3.996	2.963	607	10	519	9.29	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-276	MICROINDENTATION	25	3.992	2.960	387	10	332	6.64	
Z-191	NGK1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(38&46% H2O)	NGK-277	MICROINDENTATION	25	3.995	2.953	560	10	481	8.76	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-161*	MICROINDENTATION	25	4.004	2.970	876	2.5	744		
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-162*	MICROINDE¨ITATION	25	4.012	2.972	808	2.5	684		
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-163*	MICROINDENTATION	25	4.006	2.986	858	2.5	721		
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-164	MICROINDENTATION	25	4.008	2.992	516	5	431	6.76	

* Specimen broke out of indention.

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	--SPECIMEN-- WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
ZIRCONIAS														
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-165	MICROINDENTATION	25	4.000	2.968	692	5	589	8.54	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-166*	MICROINDENTATION	25	4.010	2.970	830	5	704		
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-170	MICROINDENTATION	25	4.004	2.966	624	5	531	7.90	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-167	MICROINDENTATION	25	4.006	2.982	400	10	337	6.67	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-168	MICROINDENTATION	25	4.010	2.968	308	10	262	5.52	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-169	MICROINDENTATION	25	4.008	2.972	348	10	295	6.04	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-266	MICROINDENTATION	25	4.000	2.980	470	10	397	7.55	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-267	MICROINDENTATION	25	3.989	2.958	664	10	571	9.91	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-268	MICROINDENTATION	25	3.990	2.974	544	10	462	8.47	
Z-191	NGK1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52&55% H2O)	NGK-269	MICROINDENTATION	25	4.008	2.964	464	10	421	7.89	
Z-201	KYO1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(34% H2O)	KY-212†	MICROINDENTATION	25	4.042	3.008	293	2.5	240	3.72	
Z-201	KYO1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(34% H2O)	KY-213†	MICROINDENTATION	25	4.028	2.958	420	2.5	358	5.01	
Z-201	KYO1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(34% H2O)	KY-211	MICROINDENTATION	25	4.044	2.998	246	5	203	3.90	
Z-201	KYO1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(34% H2O)	KY-214	MICROINDENTATION	25	4.018	2.996	520	5	433	6.88	
Z-201	KYO1985/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(34% H2O)	KY-217	MICROINDENTATION	25	4.032	3.008	280	5	230	4.29	
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-149	MICROINDENTATION	25	4.048	2.998	293	2.5	242	3.74	
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-191*	MICROINDENTATION	25	4.028	2.988	287	2.5	239		
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-193*	MICROINDENTATION	25	4.010	2.994	408	2.5	341		
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-194*	MICROINDENTATION	25	4.042	3.018	305	2.5	249		
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-195	MICROINDENTATION	25	3.998	2.964	695	2.5	594	7.24	
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-148	MICROINDENTATION	25	4.046	3.014	282	5	230	4.29	
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-192*	MICROINDENTATION	25	4.024	2.990	540	5	450		
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-196*	MICROINDENTATION	25	4.045	3.000	195	5	161		
Z-201	KYO1985/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(34% H2O)	KY-198	MICROINDENTATION	25	4.020	2.988	705	5	589	8.68	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-181	MICROINDENTATION	25	4.018	2.980	688	2.5	578	7.08	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-185	MICROINDENTATION	25	4.022	2.980	762	2.5	640	7.64	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-188	MICROINDENTATION	25	4.018	2.980	650	2.5	547	6.74	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-189	MICROINDENTATION	25	4.016	2.976	725	2.5	612	7.38	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-190	MICROINDENTATION	25	4.018	2.978	663	2.5	558	6.90	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-182	MICROINDENTATION	25	4.018	2.986	555	5	465	7.15	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-183	MICROINDENTATION	25	4.018	2.984	498	5	418	6.60	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-184	MICROINDENTATION	25	4.018	2.986	520	5	435	6.81	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-186	MICROINDENTATION	25	4.018	2.978	503	5	423	6.67	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-187	MICROINDENTATION	25	4.010	2.984	615	5	517	7.74	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-225	MICROINDENTATION	25	4.006	2.996	417	10	348	6.84	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-226	MICROINDENTATION	25	4.008	2.994	448	10	374	7.22	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-227	MICROINDENTATION	25	4.002	2.996	432	10	361	7.03	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-228	MICROINDENTATION	25	4.002	2.980	448	10	378	7.28	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-229	MICROINDENTATION	25	4.000	2.996	425	10	355	6.95	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-230	MICROINDENTATION	25	4.000	3.000	411	10	343	6.76	
Z-201	KYO1985/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(34&55% H2O)	KY-231	MICROINDENTATION	25	4.008	2.994	403	10	337	6.67	

* Specimen broke out of indention.
† Specimen warped prior to testing

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TYPE OF TOUGHNESS TEST	TEMP. °C	--SPECIMEN-- WIDTH mm	THICK mm	LOAD N	INDENT LOAD kg	FRACT. STRESS MPa	KIC MPa√m	COMMENTS
ZIRCONIAS														
Z-701	KYO1988/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(23% H2O)	KY7-111	MICROINDENTATION	25	4.007	3.002	274	10	228	4.94	
Z-701	KYO1988/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(23% H2O)	KY7-112	MICROINDENTATION	25	4.008	3.005	273	10	228	4.92	
Z-701	KYO1988/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(23% H2O)	KY7-113	MICROINDENTATION	25	4.008	3.001	277	10	230	4.98	
Z-701	KYO1988/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(23% H2O)	KY7-114	MICROINDENTATION	25	4.006	3.002	345	10	287	5.87	
Z-701	KYO1988/MTL	AMTLPKG-6/90	100HRS @ 1000C	AIR(23% H2O)	KY7-115	MICROINDENTATION	25	4.010	3.008	273	10	228	4.91	
Z-701	KYO1988/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(23% H2O)	KY7-21	MICROINDENTATION	25	4.002	2.983	282	10	238	5.05	
Z-701	KYO1988/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(23% H2O)	KY7-22	MICROINDENTATION	25	4.002	2.985	287	10	240	5.12	
Z-701	KYO1988/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(23% H2O)	KY7-23	MICROINDENTATION	25	4.001	2.989	363	10	303	6.08	
Z-701	KYO1988/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(23% H2O)	KY7-24	MICROINDENTATION	25	4.002	2.985	281	10	235	5.04	
Z-701	KYO1988/MTL	AMTLPKG-6/90	500HRS @ 1000C	AIR(23% H2O)	KY7-25	MICROINDENTATION	25	4.002	2.984	284	10	237	5.08	
Z-701	KYO1988/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(23% H2O)	KY7-81	MICROINDENTATION	25	4.009	3.002	270	10	224	4.87	
Z-701	KYO1988/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(23% H2O)	KY7-82	MICROINDENTATION	25	4.010	3.003	336	10	279	5.73	
Z-701	KYO1988/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(23% H2O)	KY7-83	MICROINDENTATION	25	4.008	3.002	333	10	277	5.70	
Z-701	KYO1988/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(23% H2O)	KY7-84	MICROINDENTATION	25	4.009	3.000	284	10	220	4.79	
Z-701	KYO1988/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(23% H2O)	KY7-85	MICROINDENTATION	25	4.007	3.006	285	10	220	4.79	

* Specimen broke out of indention.

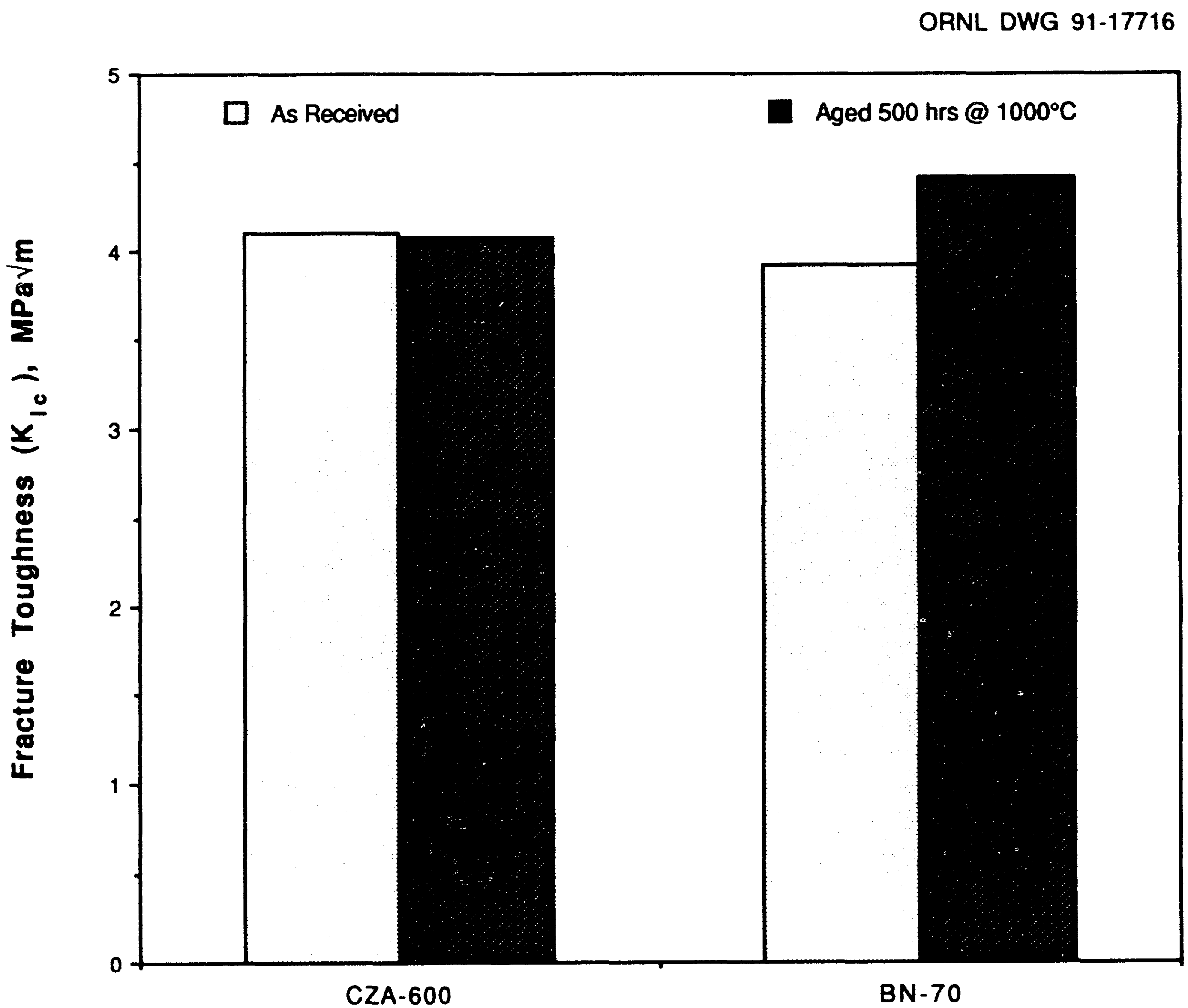

Figure 2. A comparison of fracture toughnesses for two conditions of zirconia-toughened aluminas tested at 25°C.

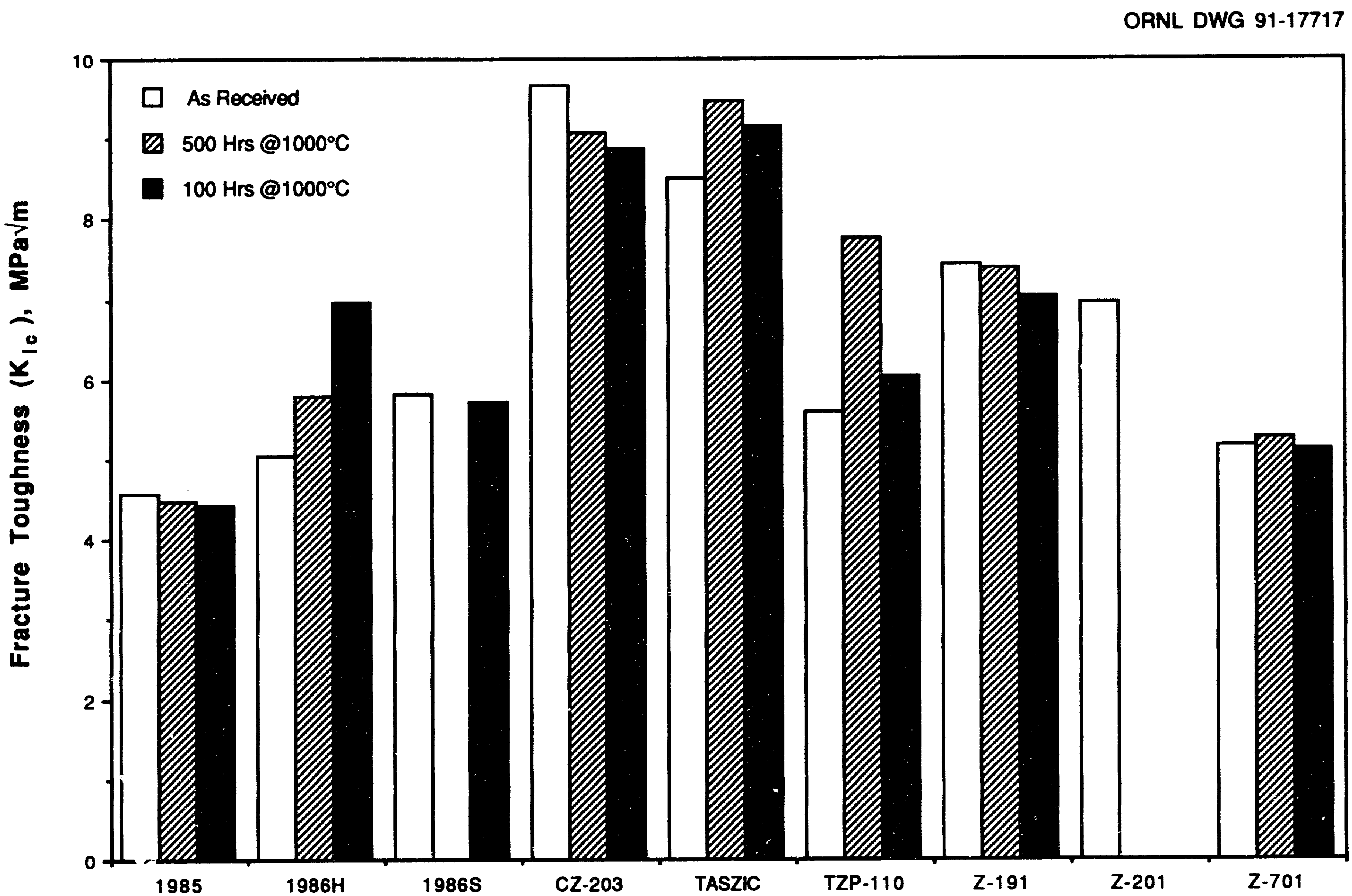

Figure 3. Effects of aging on the fracture toughness of various zirconias tested at 25°C. Indentation load was 10kg.

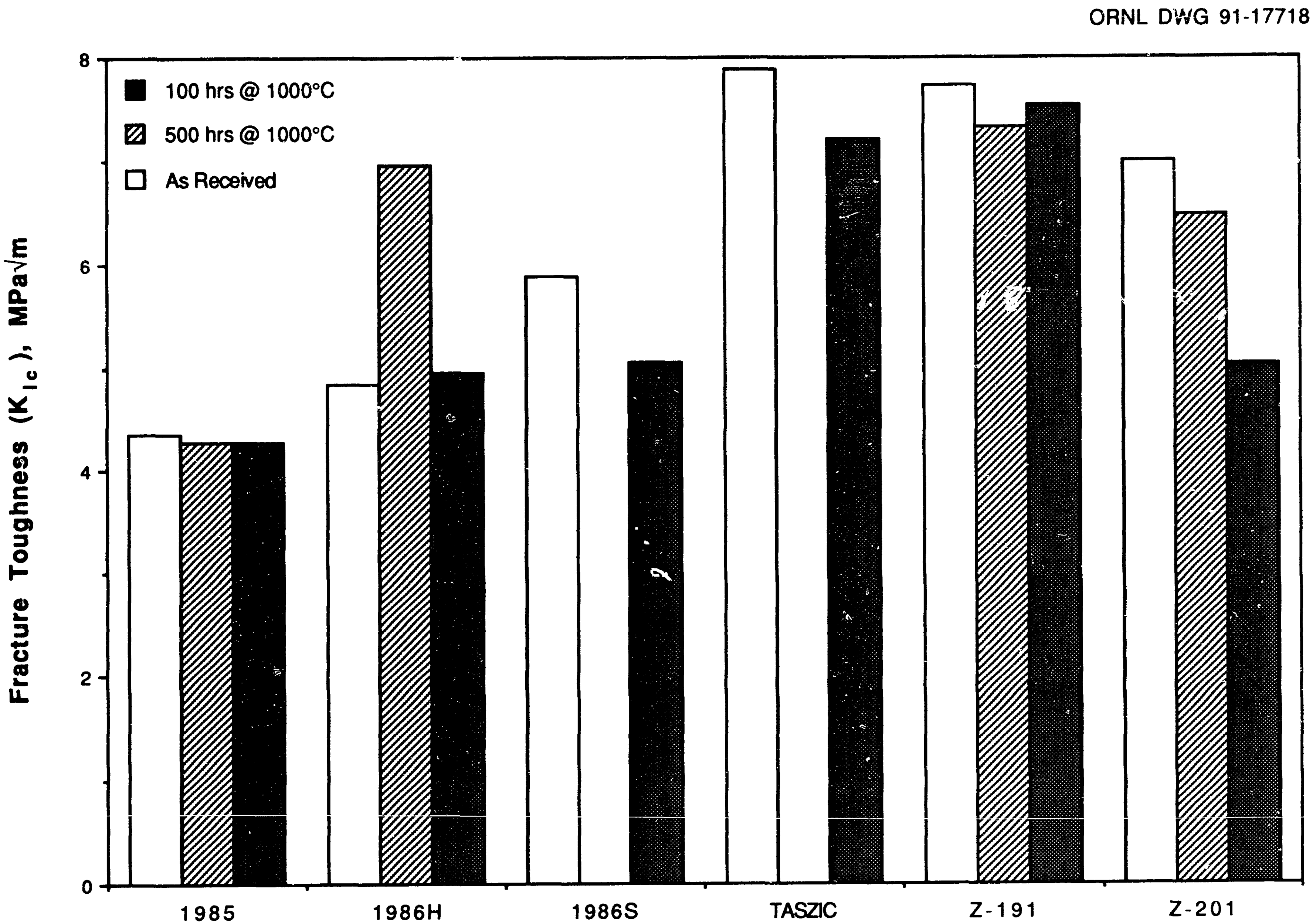

Figure 4. Effects of aging on the fracture toughness of several zirconia -based ceramics tested at 25°C with an indentation load of 5 kg.

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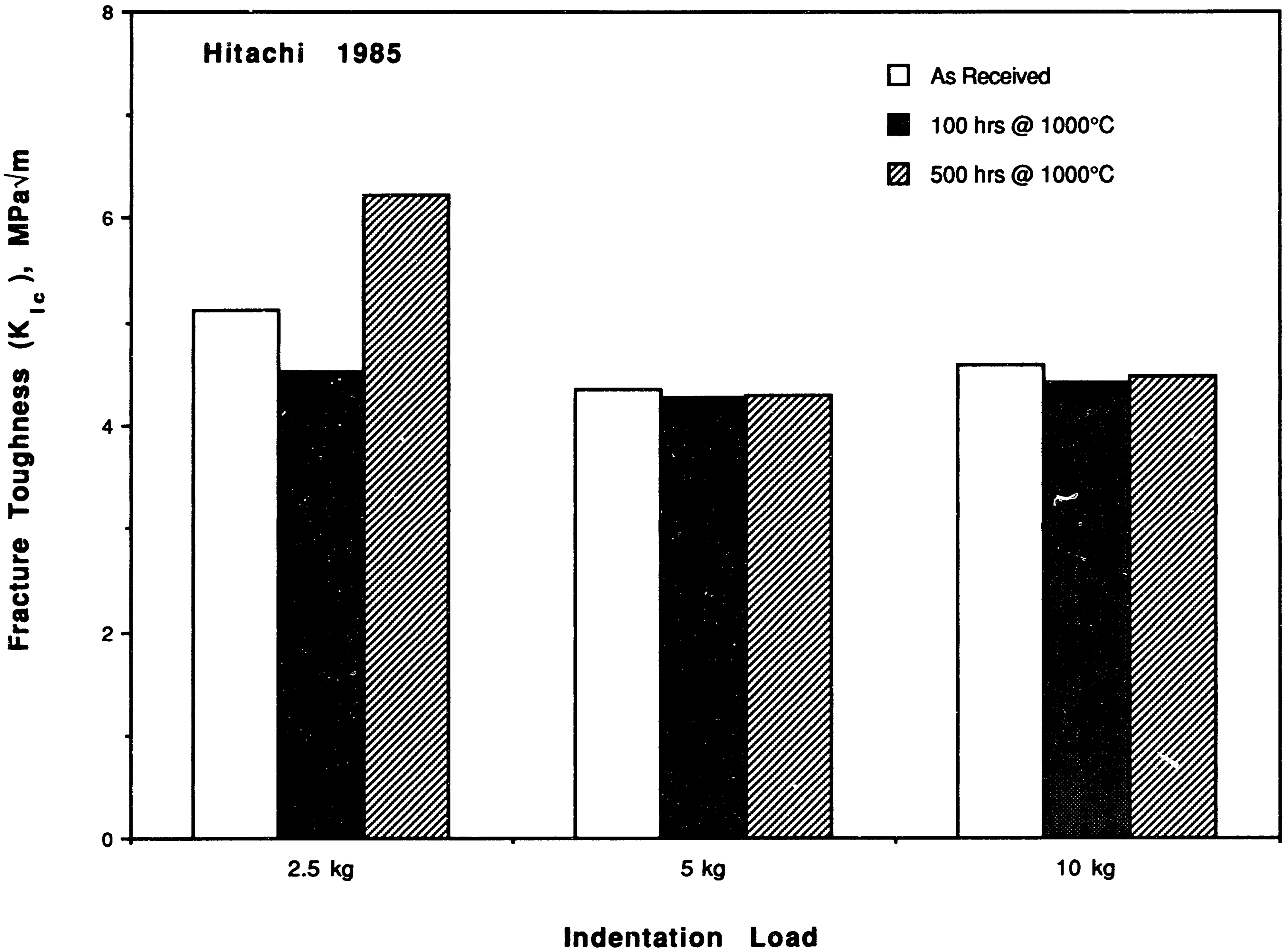

Figure 5. The effects of indentation load on the fracture toughness of zirconia-based Hitachi 1985 before and after aging.

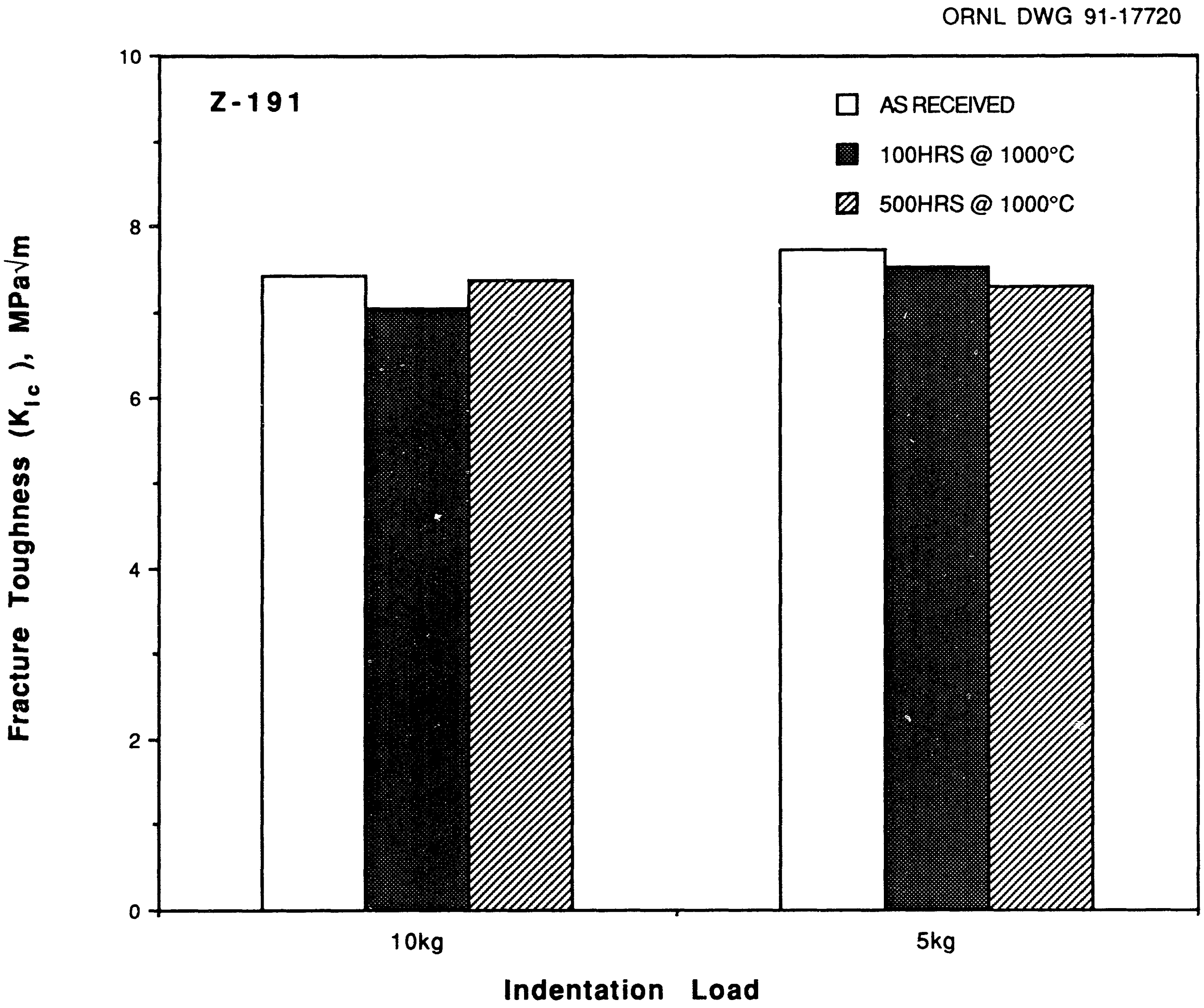

Figure 6. The effects of indentation load on fracture toughness of Z-191 tested at 25°C, before and after aging.

SECTION 4. MODULUS OF ELASTICITY

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	TYPE OF TEST	SPECIMEN NUMBER	TEMP °C	MOD. OF ELASTICITY GPA
ALUMINAS								
BN-70	KYOFELD1989/MTL	ATMLPKG-6/90	500H @ 1000C	AIR	SONIC	SUMMARY	25	355
BN-70	KYOFELD1989/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	353
CZA-600	CERAM1989/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	339
CZA-600	CERAM1989/MTL	ATMLPKG-6/90	500H @ 1000C	AIR	SONIC	SUMMARY	25	343
ZIRCONIAS								
1985	HIT1985/MTL	ATMLPKG-6/90	500H @ 1000C	AIR	SONIC	SUMMARY	25	214
1985	HIT1985/MTL	ATMLPKG-6/90	100H @ 1000C	AIR	SONIC	SUMMARY	25	213
1985	HIT1985/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	213
1986H	KOR1986H/MTL	ATMLPKG-6/90	500H @ 1000C	AIR	SONIC	SUMMARY	25	213
1986H	KOR1986H/MTL	ATMLPKG-6/90	100H @ 1000C	AIR	SONIC	SUMMARY	25	212
1986H	KOR1986H/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	214
1986S	KOR1986S/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	210
1986S	KOR1986S/MTL	ATMLPKG-6/90	100H @ 1000C	AIR	SONIC	SUMMARY	25	211
1986S	KOR1986S/MTL	ATMLPKG-6/90	500H @ 1000C	AIR	SONIC	SUMMARY	25	211
CZ-203	CER1987/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	200
CZ-203	CER1987/MTL	ATMLPKG-6/90	100H @ 1000C	AIR	SONIC	SUMMARY	25	201
CZ-203	CER1987/MTL	ATMLPKG-6/90	500H @ 1000C	AIR	SONIC	SUMMARY	25	200
TASZIC	TOS1985/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	200
TASZIC	TOS1985/MTL	ATMLPKG-6/90	100H @1000C	AIR	SONIC	SUMMARY	25	200
TASZIC	TOS1985/MTL	ATMLPKG-6/90	500H @1000C	AIR	SONIC	SUMMARY	25	200

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMNT	TYPE OF TEST	SPECIMEN NUMBER	TEMP °C	MOD. OF ELASTICITY GPA
ZIRCONIAS								
TZP-110	ACS1985/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	204
TZP-110	ACS1985/MTL	ATMLPKG-6/90	100H @ 1000C	AIR	SONIC	SUMMARY	25	206
TZP-110	ACS1985/MTL	ATMLPKG-6/90	500H @ 1000C	AIR	SONIC	SUMMARY	25	208
Z-191	NGK1985/MTL	ATMLPKG-6/90	100H @1000C	AIR	SONIC	SUMMARY	25	207
Z-191	NGK1985/MTL	ATMLPKG-6/90	500H @1000C	AIR	SONIC	SUMMARY	25	208
Z-191	NGK1985/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	208
Z-201	KYO1985/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	201
Z-201	KYO1985/MTL	ATMLPKG-6/90	100H @1000C	AIR	SONIC	SUMMARY	25	203
Z-201	KYO1985/MTL	ATMLPKG-6/90	500H @1000C	AIR	SONIC	SUMMARY	25	205
Z-701	KYO1988/MTL	ATMLPKG-6/90	500H @1000C	AIR	SONIC	SUMMARY	25	213
Z-701	KYO1988/MTL	ATMLPKG-6/90	100H @1000C	AIR	SONIC	SUMMARY	25	213
Z-701	KYO1988/MTL	ATMLPKG-6/90	AS RECEIVED	AIR	SONIC	SUMMARY	25	212

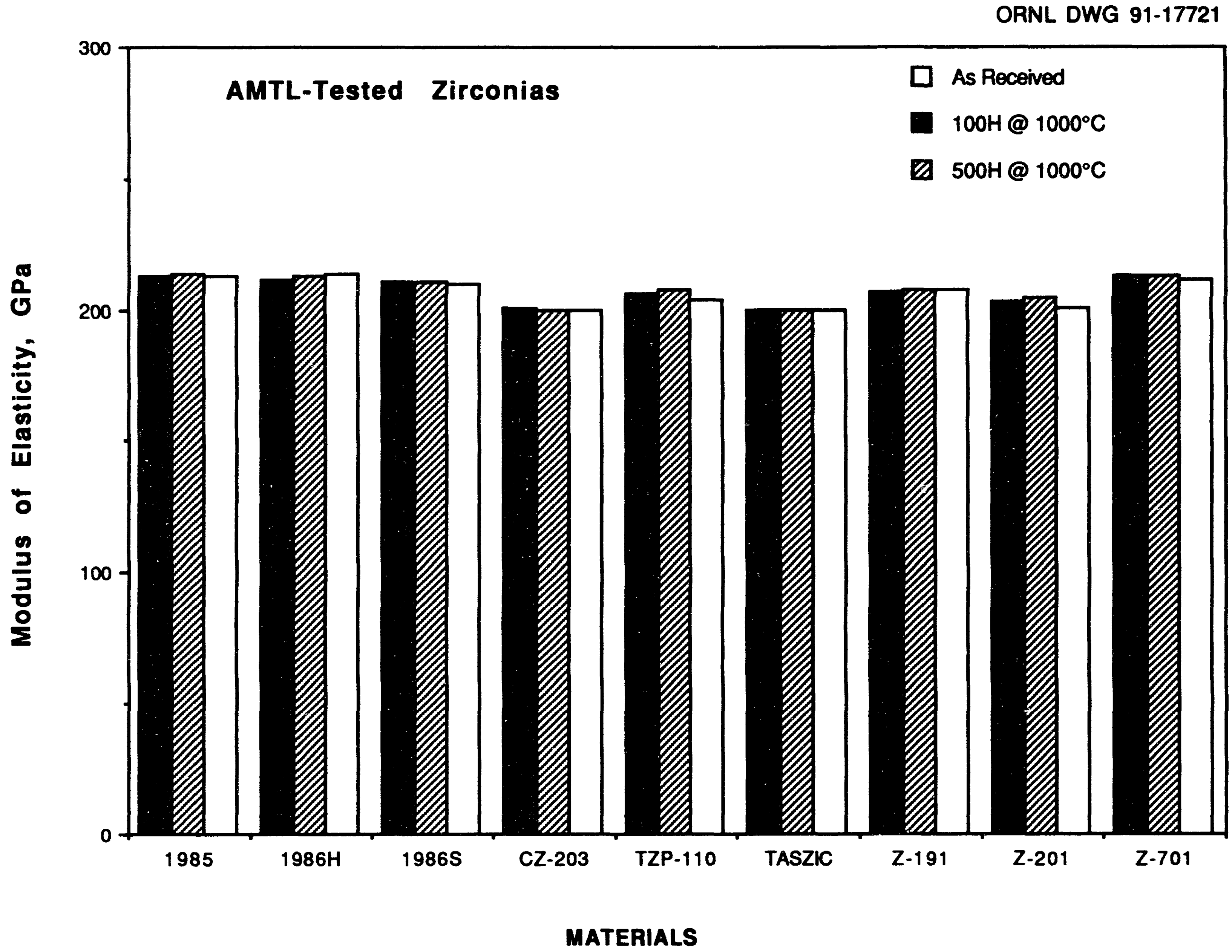

Figure 7. Aging heat treatments seem to have little effect on the elasticity of many zirconia-based ceramics.

SECTION 5. MODULUS OF RUPTURE - 4-POINT BEND

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TEMP. °C	LOAD N	WIDTH mm	THICK mm	MOR MPa	CROSSHEAD SPEED	COMMENTS
ALUMINAS												
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	20	25	560	4.003	3.009	464	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	18	25	566	3.997	3.002	471	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	25	25	571	3.999	3.003	475	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	19	25	611	3.996	3.002	509	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	23	25	625	4.002	3.008	518	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	22	25	622	3.997	3.001	518	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	17	25	629	4.001	3.004	523	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	21	25	629	3.997	3.002	524	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	16	25	659	3.948	3.003	555	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(48% H2O)	24	25	678	4.002	3.008	562	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	2	25	499	4.003	3.006	414	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	3	25	527	3.997	3.002	439	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	5	25	533	4.000	3.000	444	0.5mm/min	LLP BREAK
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	1	25	553	3.999	3.002	460	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	10	25	560	4.005	3.006	464	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	8	25	566	4.007	3.010	468	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	4	25	565	3.999	3.001	471	0.5mm/min	RLP BREAK
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	7	25	581	4.006	3.008	481	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	6	25	585	4.004	3.006	485	0.5mm/min	
BN-70	KYOFELD1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR(52% H2O)	9	25	591	4.006	3.010	489	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	16	25	505	3.976	2.999	424	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	25	25	505	3.974	2.998	424	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	22	25	509	3.999	3.000	424	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	17	25	504	3.949	2.999	426	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	19	25	507	3.987	2.987	428	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	18	25	521	3.987	2.999	436	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	20	25	520	3.975	2.999	436	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	24	25	533	3.986	3.002	445	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	23	25	557	3.988	3.002	465	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	500HRS@1000C	AIR	21	25	507	3.987	3.002	423	.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	4	25	345	3.962	3.006	289	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	9	25	446	3.987	3.008	371	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	8	25	532	3.967	3.006	445	0.5mm/min	RLP BREAK
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	3	25	536	3.967	3.009	448	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	10	25	549	3.984	3.009	457	0.5mm/min	

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TEMP. °C	LOAD N	WIDTH mm	THICK mm	MOR MPa	CROSSHEAD SPEED	COMMENTS
SILICON NITRIDES												
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	1	25	558	3.971	3.008	466	0.5mm/min	RLP BREAK
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	2	25	570	3.989	3.002	476	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	7	25	578	3.985	3.004	482	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	5	25	584	3.982	3.009	486	0.5mm/min	
CZA-600	CERAM1989/MTL	AMTLPKG-6/90	AS RECEIVED	AIR(52% H2O)	6	25	584	3.983	3.005	487	0.5mm/min	LLP BREAK
AC8	GTEL/UBE-E10/88	SA12GTEL55	HOT PRESS	AIR	SUMMARY	25		2.500	1.300	1006		MOR4=+-88MPa
AC8	GTEL/UBE-E10/88	SA12GTEL55	HOT PRESS	AIR	SUMMARY	1200		2.500	1.300	503		MOR4=+-12MPa
AC8	GTEL/UBE-E10/88	SA12GTEL55	HP+ANNEAL	AIR	SUMMARY	25		2.500	1.300	937		MOR4=+-124MPa
AC8	GTEL/UBE-E10/88	SA12GTEL55	HP+ANNEAL	AIR	SUMMARY	1200		2.500	1.300	509		MOR4=+-8MPa
AM4	GTEL/BM0689	BM0689GTE123	HOT PRESS	AIR	SUMMARY	25		1.300	2.500	590		MOR4=+-44MPa
AM4	GTEL/BM0689	BM0689GTE123	HOT PRESS/HT	AIR	SUMMARY	25		1.300	2.500	789		MOR4=+-208MPa
AM4	GTEL/UBE-E10/88	SA12GTEL55	HOT PRESS	AIR	SUMMARY	25		2.500	1.300	646		MOR4=+-97MPa
AM4	GTEL/UBE-E10/88	SA12GTEL55	HOT PRESS	AIR	SUMMARY	1200		2.500	1.300	617		MOR4=+-11MPa
AM4	GTEL/UBE-E10/88	SA12GTEL55	HP+ANNEAL	AIR	SUMMARY	25		2.500	1.300	838		MOR4=+-86MPa
AM4	GTEL/UBE-E10/88	SA12GTEL55	HP+ANNEAL	AIR	SUMMARY	1200		2.500	1.300	515		MOR4=+-7MPa
AM4+Si3N4(30v)	GTEL/BM0689	BM0689GTE123	HOT PRESS	AIR	SUMMARY	25		1.300	2.500	901		MOR4=+-102MPa
AY6	GTEL/BM0689	BM0689GTE123	HOT PRESS	AIR	SUMMARY	25		2.500	1.300	981		MOR4=+-44MPa
AY6	GTEL/BM0689	BM0689GTE123	HOT PRESS/HT	AIR	SUMMARY	25		2.500	1.300	847		MOR4=+-71MPa
AY6	GTEL/UBE-E10/88	SA12GTEL55	HOT PRESS	AIR	SUMMARY	25		2.500	1.300	1052		MOR4=+-80MPa
AY6	GTEL/UBE-E10/88	SA12GTEL55	HOT PRESS	AIR	SUMMARY	1200		2.500	1.300	773		MOR4=+-70MPa
AY6	GTEL/UBE-E10/88	SA12GTEL55	HP+ANNEAL	AIR	SUMMARY	25		2.500	1.300	991		MOR4=+-91MPa
AY6	GTEL/UBE-E10/88	SA12GTEL55	HP+ANNEAL	AIR	SUMMARY	1200		2.500	1.300	652		MOR4=+-50MPa
AY6+Si3N4(30v)	GTEL/BM0689	BM0689GTE123	HOT PRESS	AIR	SUMMARY	25		2.500	1.300	845		MOR4=+-127MPa
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-1	25				697.3		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-2	25				887.1		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-3	25				898.8		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-4	25				846.4		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-5	25				890.6		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-6	25				807.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-7	25				817		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-8	25				804.3		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-9	25				876.2		

SECTION 5. MODULUS OF RUPTURE - 4-POINT BEND, CONTINUED

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TEMP. °C	LOAD N	WIDTH mm	THICK mm	MOR MPa	CROSSHEAD SPEED	COMMENTS
SILICON NITRIDES												
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-10	25				736.9		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-11	25				920.8		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-12	25				817.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-13	25				827.2		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-14	25				873.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-15	25				924.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-16	1370				252.6		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-17	1370				227.2		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-18	1370				268.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-19	1370				249.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-20	1370				303.2		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	ASC-21	1370				320.2		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-1	25				774.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-2	25				768.7		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-3	25				839.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-4	25				625.7		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-5	25				612.9		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-6	25				537.2		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-7	25				665.3		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-8	25				683.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-9	25				711.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-10	25				684		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-11	25				799.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-12	25				670.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-13	25				652.4		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-14	25				634.6		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-15	25				688.6		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-16	25				722.1		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-17	25				704.1		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-18	25				778.3		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-19	25				779.1		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-20	25				684.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-21	25				738.2		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-22	25				735.8		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-23	25				561		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-24	25				696.5		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-25	25				695.3		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-26	25				615.6		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-27	25				696.6		
GTE PY6	GTEL/BASELINE90	BM0690GTE119		AIR	DOG-28	25				711.3		

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TEMP. °C	LOAD N	WIDTH mm	THICK mm	MOR MPa	CROSSHEAD SPEED	COMMENTS
SILICON NITRIDES												
GTE PY6	GTEL/BASELINE90	BM0890GTE119		AIR	DOG-29	25				640.6		
GTE PY6	GTEL/BASELINE90	BM0890GTE119		AIR	DOG-30	25				669.3		
GTE PY6	GTEL/BASELINE90	BM0890GTE119		AIR	DOG-31	1370				231.5		
GTE PY6	GTEL/BASELINE90	BM0890GTE119		AIR	DOG-32	1370				229.9		
GTE PY6	GTEL/BASELINE90	BM0890GTE119		AIR	DOG-33	1370				280.5		
GTE PY6	GTEL/BASELINE90	BM0890GTE119		AIR	DOG-34	1370				253		
GTE PY6	GTEL/BASELINE90	BM0890GTE119		AIR	DOG-35	1370				253.4		
WHISKER-REINFORCED SILICON NITRIDES												
AY6+SiCw30v	GTEL/BM0889	BM0889GTE123	HOT PRESS	AIR	SUMMARY	25		2.500	1.300	994		MOR4—+-73MPa
AY6+SiCw30v	GTEL/BM0889	BM0889GTE123	HOT PRESS/HT	AIR	SUMMARY	25		2.500	1.300	789		MOR4—+-208MPa
AY6+SiCw30v	GTEL/SN502/0688	BM0688GTE129	HOT PRESS/1725	AIR	SUMMARY	25		2.500	1.300	840		MOR4—+-30MPa
AY6+SiCw30v	GTEL/SN502/0688	BM0688GTE129	HOT PRESS/1725	AIR	SUMMARY	25		2.500	1.300	796		MOR4—+-40MPa
AY6+SiCw30v	GTEL/SN502/0688	BM0688GTE129	HOT PRESS/1800	AIR	SUMMARY	25		2.500	1.300	857		MOR4—+-6MPa
AY6+SiCw30v	GTEL/SN502/0688	BM0688GTE129	HOT PRESS/1800	AIR	SUMMARY	25		2.500	1.300	880		MOR4—+-101MPa
AY6+SiCw30v	GTEL/SN502/HP88	SA12GTEL58	HOT PRESS	AIR	SUMRY-5	25		2.500	1.300	975		MOR4—+-39MPa
AY6+SiCw30v	GTEL/SN502/HP88	SA12GTEL58	HOT PRESS	AIR	SUMOF3	1000		2.500	1.300	819		MOR4—+-64MPa
AY6+SiCw30v	GTEL/SN502/HP88	SA12GTEL58	HOT PRESS	AIR	SUMOF3	1200		2.500	1.300	597		MOR4—+-26MPa
AY6+SiCw30v	GTEL/SN502/HP88	SA12GTEL58	HOT PRESS	AIR	SUMOF3	1400		2.500	1.300	257		MOR4—+-25MPa
AY6+SiCw30v	GTEL/SN502/IH88	SA12GTEL57	IM/HIP	AIR	SUMMARY	25		2.500	1.300	818		MOR4—+-112MPa
AY6+SiCw30v	GTEL/UBE10/0688	BM0688GTE129	HOT PRESS/1725	AIR	SUMMARY	25		2.500	1.300	823		MOR4—+-13MPa
AY6+SiCw30v	GTEL/UBE10/0688	BM0688GTE129	HOT PRESS/1800	AIR	SUMMARY	25		2.500	1.300	919		MOR4—+-72MPa
AY6+SiCw30v	GTEL/UBE10/0688	BM0688GTE129	HOT PRESS/1800	AIR	SUMMARY	25		2.500	1.300	913		MOR4—+-47MPa
AY6+SiCw30v	GTEL/UBE2/HP88	SA12GTEL58	HOT PRESS	AIR	SUMOF5	25		2.500	1.300	1043		MOR4—+-50MPa
AY6+SiCw30v	GTEL/UBE2/HP88	SA12GTEL58	HOT PRESS	AIR	SUMOF3	1200		2.500	1.300	618		MOR4—+-27MPa
AY6+SiCw30v	GTEL/UBE2/HP88	SA12GTEL58	HOT PRESS	AIR	SUMOF3	1400		2.500	1.300	407		MOR4—+-62MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 1	AIR	SUMOF7	25		2.500	1.300	901		MOR4—+-102MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 1	AIR	SUMOF7	25		2.500	1.300	1053		MOR4—+-8.7MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 1	AIR	SUMOF1	1000		2.500	1.300	766		
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 1	AIR	SUMOF1	1200		2.500	1.300	465		MOR4—+-86MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 1	AIR	SUMOF3	1400		2.500	1.300	110		MOR4—+-2MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 2	AIR	SUMOF3	1400		2.500	1.300	386		MOR4—+-58MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 2	AIR	SUMOF3	1200		2.500	1.300	616		MOR4—+-105MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 2	AIR	SUMOF7	25		2.500	1.300	1209		MOR4—+-73MPa

SECTION 5. MODULUS OF RUPTURE - 4-POINT BEND, CONTINUED

MATERIAL	BATCH CODE	SOURCE CODE	HEAT TREATMENT	ENVIRONMENT	SPECIMEN NUMBER	TEMP. °C	LOAD N	WIDTH mm	THICK mm	MOR MPa	CROSSHEAD SPEED	COMMENTS
WHISKER-REINFORCED SILICON NITRIDES												
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 2	AIR	SUMOF1	1000		2.500	1.300	863		
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 3	AIR	SUMOF5	25		2.500	1.300	1155		MOR4=+-62MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 3	AIR	SUMOF3	1200		2.500	1.300	670		MOR4=+-75MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 3	AIR	SUMOF3	1400		2.500	1.300	365		MOR4=+-49MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 3	AIR	SUMOF1	1000		2.500	1.300	919		
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 4	AIR	SUMOF3	1400		2.500	1.300	460		MOR4=+-21MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 4	AIR	SUMOF3	1200		2.500	1.300	638		MOR4=+-51MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 4	AIR	SUMOF3	25		2.500	1.300	1120		MOR4=+-102MPa
AY6+SiCw30v	GTEL/UBE2/IH88	BM0889GTE126	IM/HIP CYCLE 4	AIR	SUMOF1	1000		2.500	1.300	986		
AY6+SiCw30v	GTEL/UBE2/IH88	SA12GTEL57	IM/HIP	AIR	SUMMARY	25		2.500	1.300	1143		MOR4=+-48MPa
AY6+SiCw30v	GTEL/UBE2/IH88	SA12GTEL58	IM/HIP	AIR	SUMOF7	25		2.500	1.300	1195		MOR4=+-71MPa

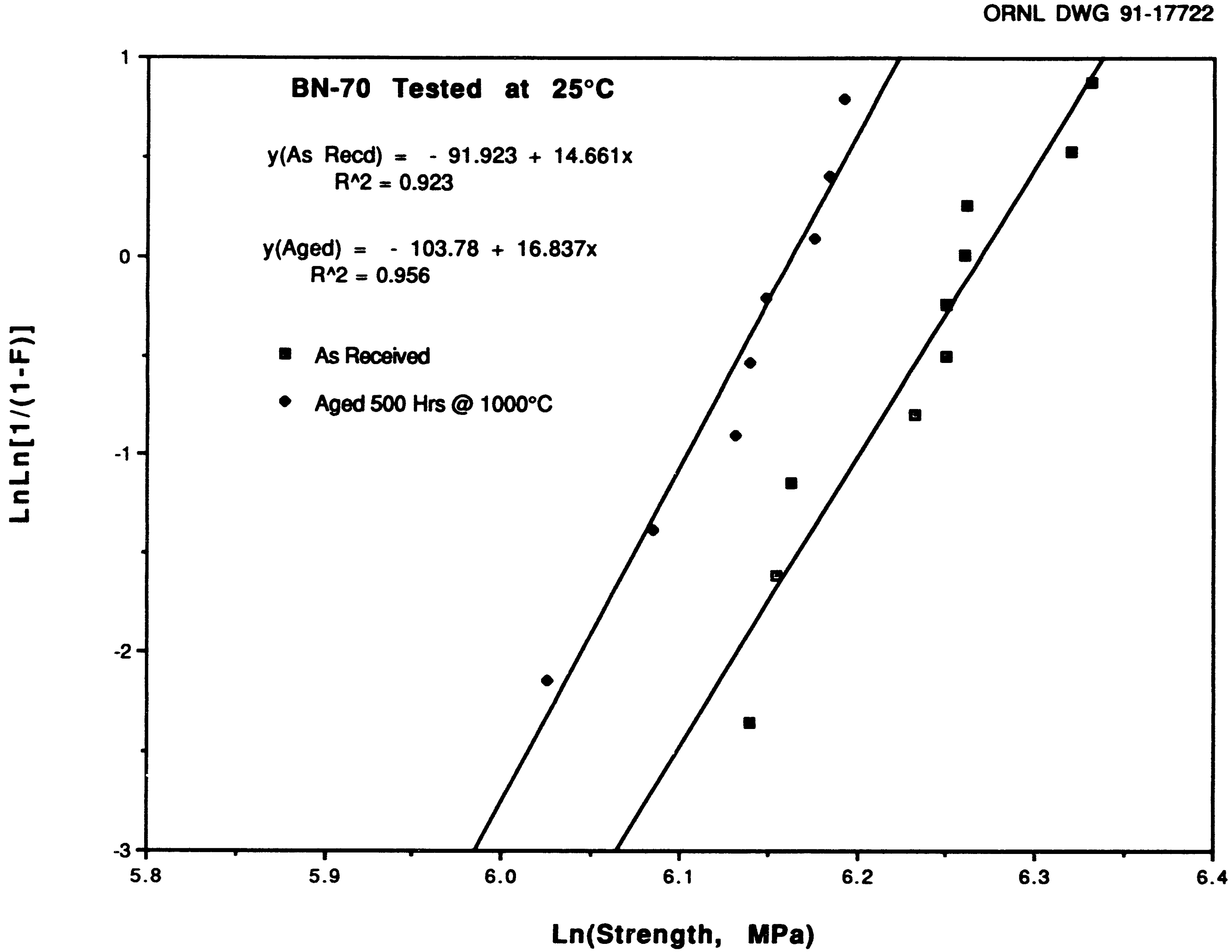

Figure 8. Weibull plot of BN-70 comparing as-received material to aged material. Test temperature was 25°C.

ORNL DWG 91-17723

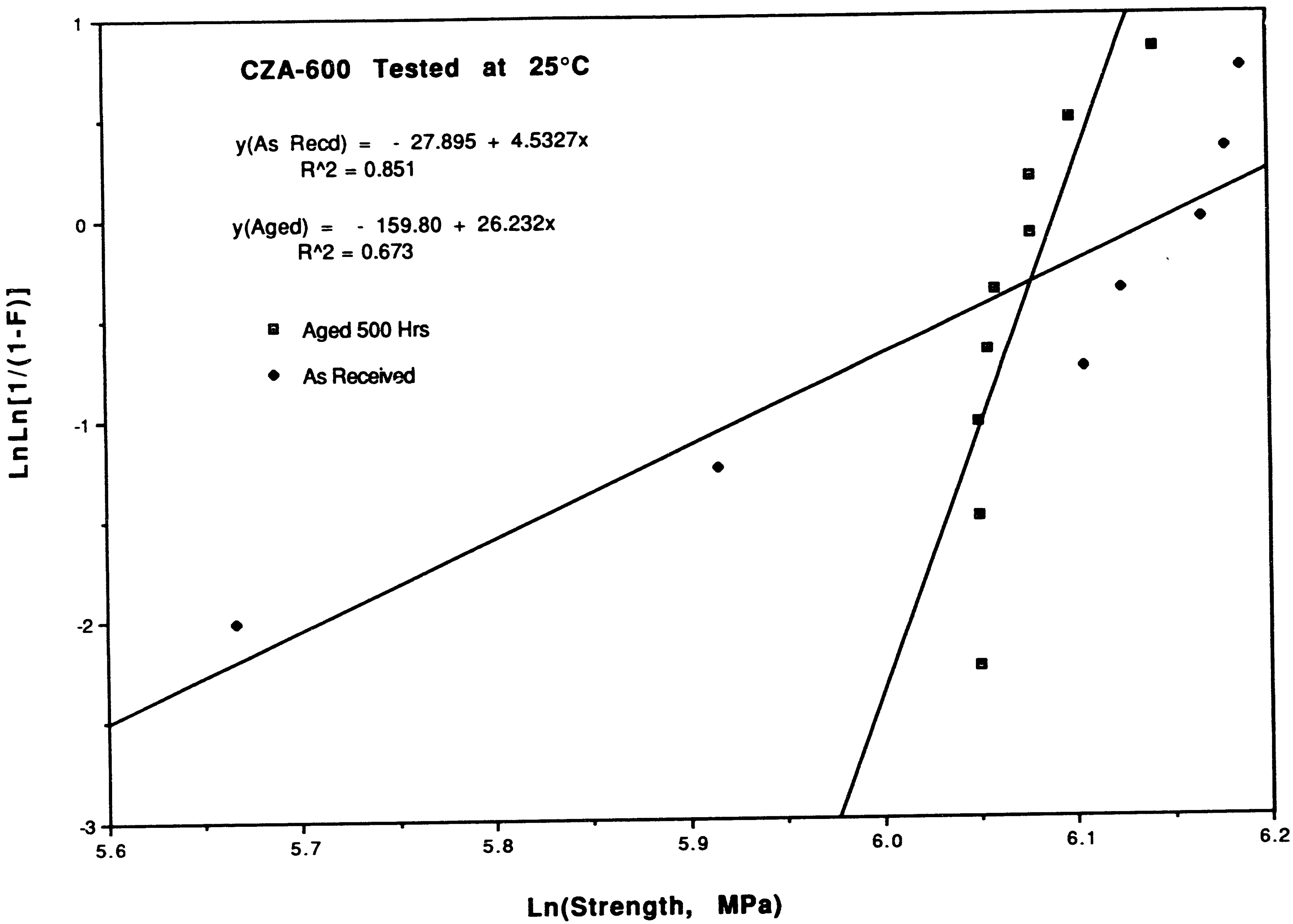

Figure 9. Weibull plot of CZA-600, a zirconia-toughened alumina, before and after aging. Test temperature was 25°C.

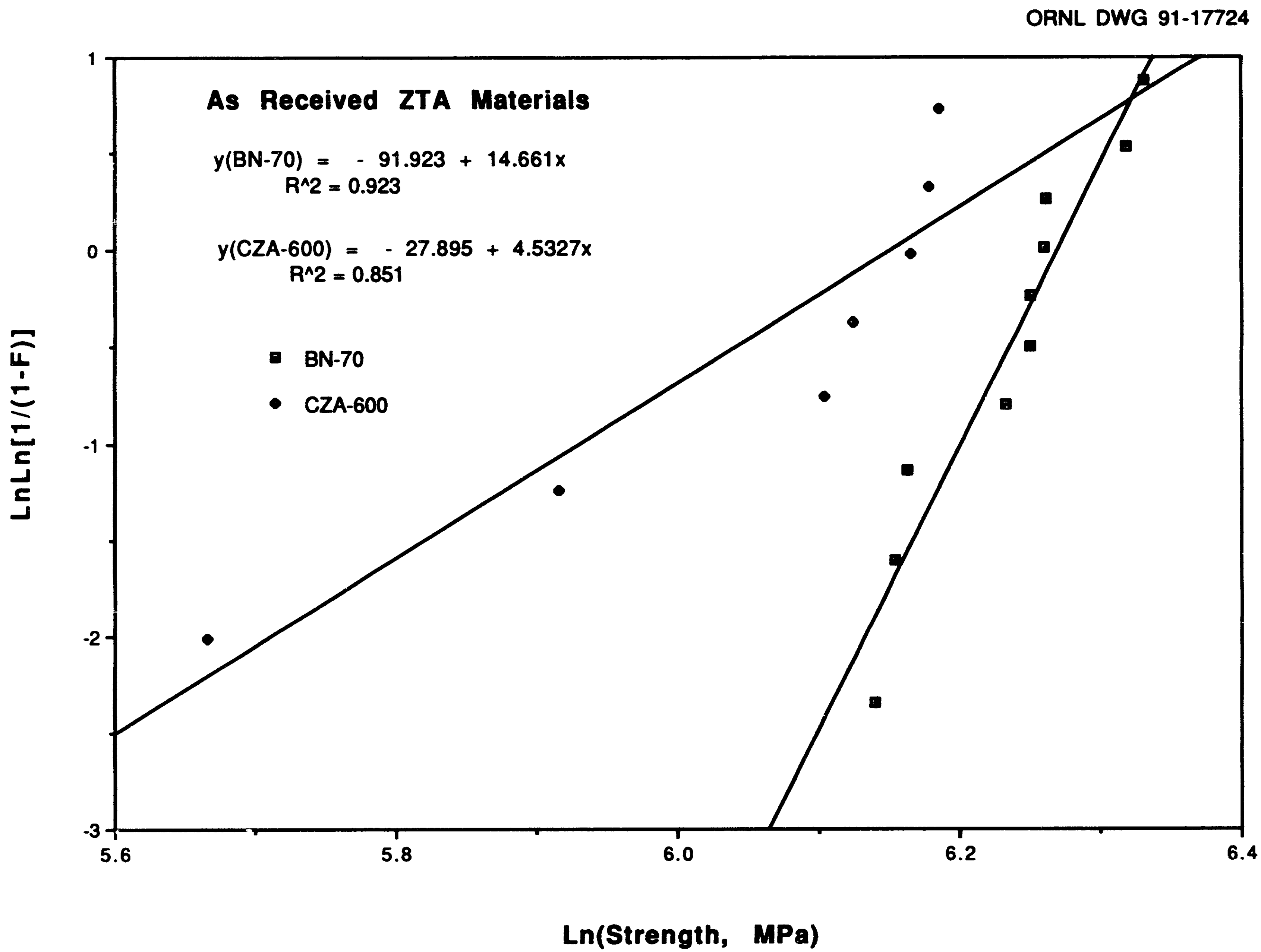

Figure 10. Weibull plot of the MOR 4-point bend strengths of BN-70 and CZA-600 in the as-received condition, tested at 25°C.

ORNL DWG 91-17725

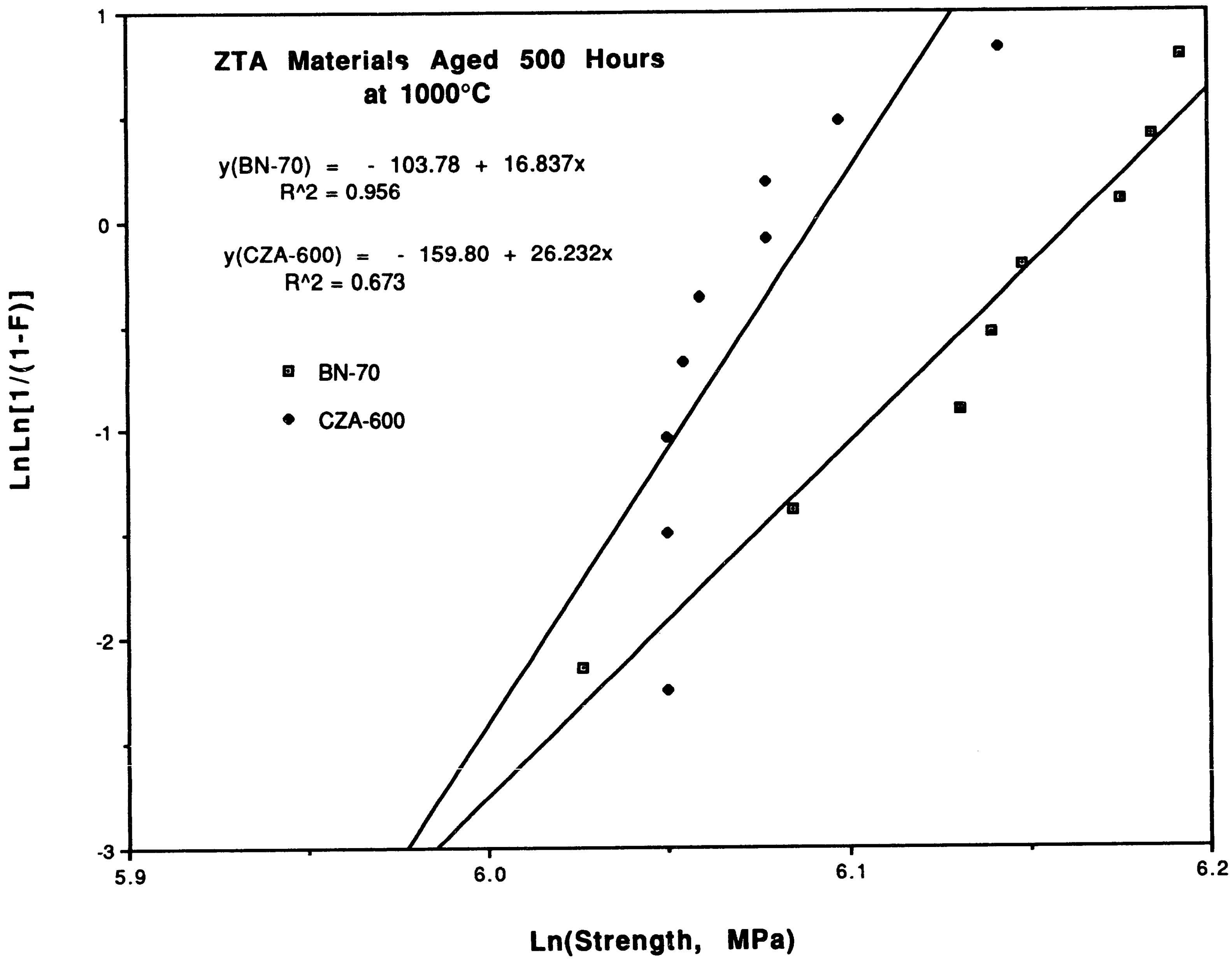

Figure 11. Weibull plot of the MOR 4-point bend strength at 25°C of BN-70 and CZA-600, after aging 500 hours at 1000°C.

ORNL DWG 91-17727

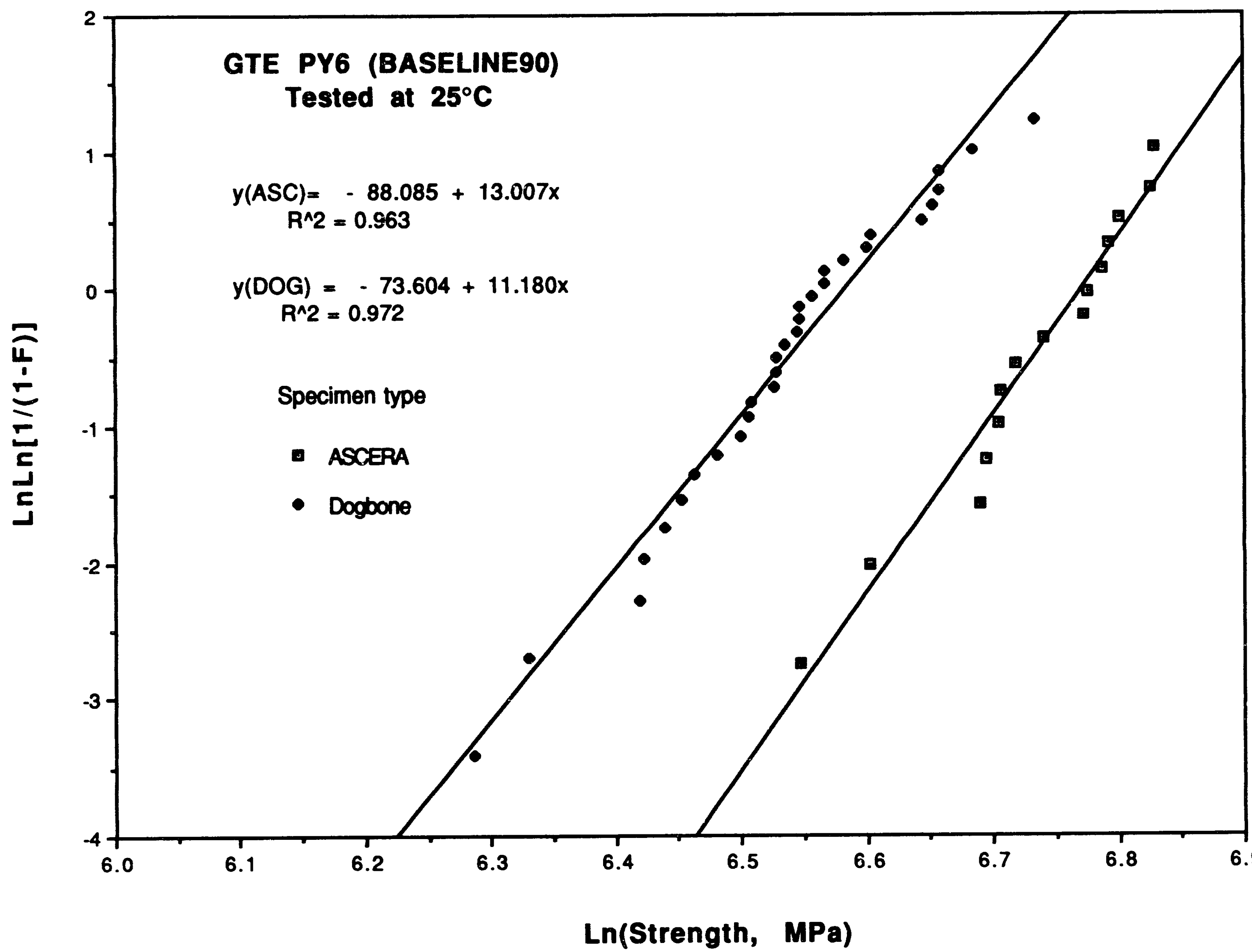

Figure 12. Weibull plot of GTE PY6 (BASELINE90) strength values from dogbone specimens and ASCERA specimens, both tested at 25°C

ORNL DWG 91-17726

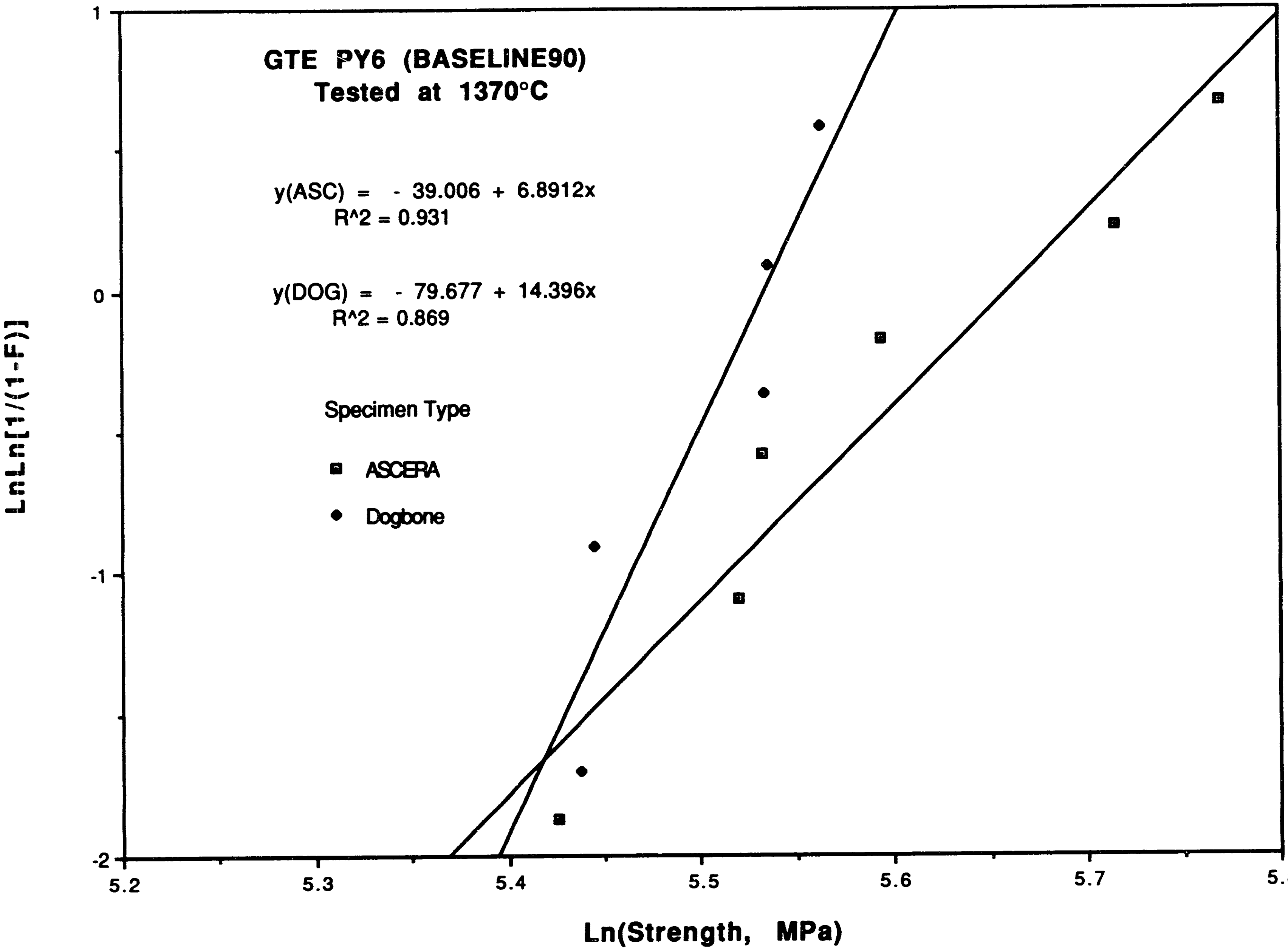

Figure 13. Weibull plot of GTE PY6 (BASELINE90) MOR 4-point bend strength values from dogbone and ASCERA-type specimens, tested at 25°C.

ORNL DWG 91-17728

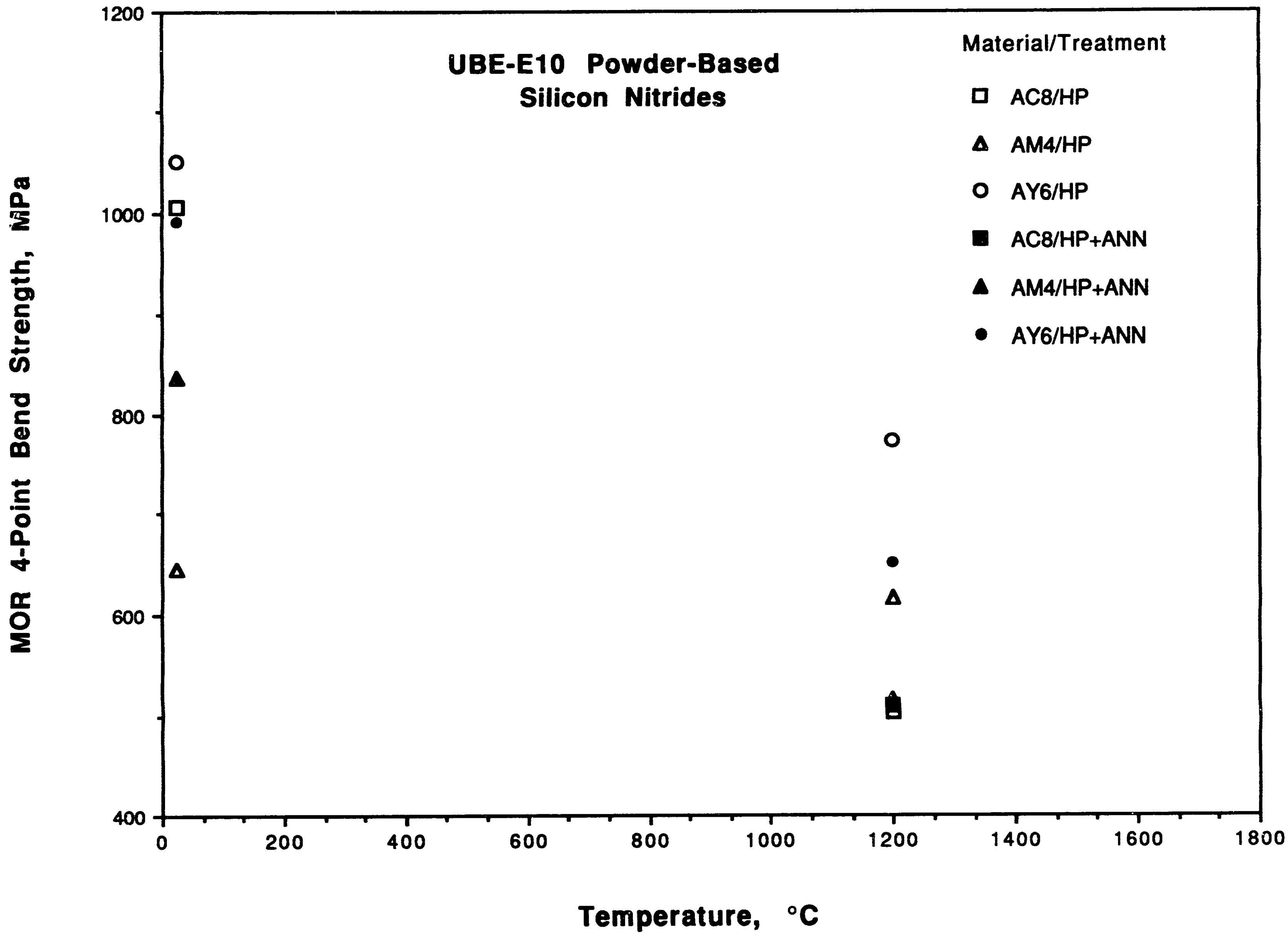

Figure 14. The effects of densification treatment and additives on average bend strength of silicon nitrides made with UBE-E10 powder.

SECTION 6. TORSION SHEAR STRENGTH

MATERIAL	BATCH CODE	SOURCE CODE	TEMP °C	TORQUE Nm	ROTATION degrees	GAGE AREA cm^2	COMMENTS
SILICON NITRIDES							
GTE PY6	GTEL/87-SB047C	ORNL87SB047C	25	59.88	1.83	6.35	
GTE PY6	GTEL/87-SB047C	ORNL87SB047C	25	238.40	0.04	12.70	
GTE PY6	GTEL/87-SB047C	ORNL87SB047C	650	59.32	1.84	6.35	
METALS USED IN BRAZED JOINTS							
INCONEL 909	GTEL/CARTECH	ORNL87SB047C	25	65.53	2.00	9.53	25.4MM GAGE SECTION
INCONEL 909	GTEL/CARTECH	ORNL87SB047C	650	45.19	2.30	9.53	25.4MM GAGE SECTION
INCONEL 718	GTEL/HUNTALLOY	ORNL87SB047C	25	62.14	2.50	9.53	25.4MM GAGE SECTION
INCONEL 718	GTEL/HUNTALLOY	ORNL87SB047C	650	54.23	2.30	9.53	25.4MM GAGE SECTION

SECTION 7. MODULUS OF RUPTURE- 4 POINT BEND OF BRAZED SPECIMENS

MATERIAL 1 = SN-220 coated with titanium, BATCH CODE = KYOCERA/MS890
MATERIAL 2 = SN-220 coated with titanium, BATCH CODE = KYOCERA/MS890
BRAZE = Au-25Ni-25Pd
SOURCE CODE = SANTELLA8/90
JOINT CODE = ORNL/MS890/SNA1

SPECIMEN NUMBER	BRAZING TREATMENT	SPECIMEN CONDITION	ENV.	TEMP °C	MOR MPa	LOAD N	WIDTH mm	THICK mm
1	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	441.3		2.5	2.0
2	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	419.4		2.5	2.0
3	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	457.5		2.5	2.0
4	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	414.9		2.5	2.0
5	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	444.8		2.5	2.0
6	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	387.1		2.5	2.0
7	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	385.6		2.5	2.0
8	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	373.9		2.5	2.0
9	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	438.3		2.5	2.0
10	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	347.4		2.5	2.0
11	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	340.3		2.5	2.0
12	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	352.7		2.5	2.0
13	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	344.8		2.5	2.0
14	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	495.8		2.5	2.0
15	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	414.9		2.5	2.0
16	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	465.2		2.5	2.0
17	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	474.9		2.5	2.0
18	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	292.8		2.5	2.0
MCB-451A	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	381.2	382.7	3.1064	2.4714
MCB-451B	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	392.3	391.5	3.1064	2.4790
MCB-451C	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	513.3	515.6	3.0607	2.4892
MCB-451D	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	360.7	360.0	3.0937	2.4841
MCB-451E	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	367.9	364.1	3.1191	2.4841
MCB-451F	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	375.9	381.4	3.0734	2.4714
MCB-452A	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	361.2	362.1	3.0734	2.4867
MCB-452B	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	448.4	446.7	3.0988	2.4841
MCB-452C	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	386.5	386.7	3.0988	2.4790
MCB-452D	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	440.4	416.4	3.2715	2.4816
MCB-452E	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	419.5	420.0	3.0861	2.4816
MCB-452F	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	382.1	385.5	3.0861	2.4765
MCB-453A	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	412.8	415.8	3.0963	2.4714
MCB-453B	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	255.3	259.5	3.0683	2.4714
MCB-453C	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	334.9	336.3	3.1064	2.4714
MCB-453D	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	312.3	310.3	3.1191	2.4790
MCB-453E	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	316.3	318.8	3.0810	2.4765
MCB-453F	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	318.9	320.2	3.1064	2.4714

SECTION 7. MODULUS OF RUPTURE- 4 POINT BEND OF BRAZED SPECIMENS, CONTINUED

MATERIAL 1 = SN-220 coated with titanium, BATCH CODE = KYOCERA/MS890
MATERIAL 2 = SN-220 coated with titanium, BATCH CODE = KYOCERA/MS890
BRAZE = 50Au-25Ni-25Pd
SOURCE CODE = SANTELLA8/90
JOINT CODE = ORNL/MS890/SNG1

SPECIMEN NUMBER	BRAZING TREATMENT	SPECIMEN CONDITION	ENV.	TEMP °C	MOR MPa	WIDTH mm	THICK mm
1	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	428.2	2.5	2.0
2	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	404.8	2.5	2.0
3	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	421.9	2.5	2.0
4	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	209.3	2.5	2.0
5	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	345.2	2.5	2.0
6	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	404.8	2.5	2.0
7	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	412.7	2.5	2.0
8	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	444.6	2.5	2.0
9	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	394.7	2.5	2.0
10	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	425.8	2.5	2.0
11	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	464.6	2.5	2.0
12	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	453.7	2.5	2.0
13	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	378.2	2.5	2.0
14	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	442.7	2.5	2.0
15	BRAZED IN VAC@1030C	AS BRAZED	AIR	25	425.0	2.5	2.0

MATERIAL 1 = SN-220 coated with titanium, BATCH CODE = KYOCERA/MS890
MATERIAL 2 = SN-220 coated with titanium, BATCH CODE = KYOCERA/MS890
BRAZE = 50Au-25Ni-25Pd
SOURCE CODE = SANTELLA8/90
JOINT CODE = ORNL/MS890/SNG2

SPECIMEN NUMBER	BRAZING TREATMENT	SPECIMEN CONDITION	ENV.	TEMP °C	MOR MPa	LOAD N	WIDTH mm	THICK mm
MCB-444A	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	336.7	330.7	3.099	2.502
MCB-444B	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	444.8	442.4	3.078	2.494
MCB-444C	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	390.5	382.8	3.099	2.504
MCB-444D	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	390.5	386.0	3.073	2.504
MCB-444E	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	289.6	292.1	3.061	2.484
MCB-444F	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	426.6	420.8	3.104	2.494
MCB-445A	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	401.2	400.4	3.068	2.494
MCB-445B	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	448.4	442.1	3.112	2.492
MCB-445C	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	440.4	436.4	3.096	2.492
MCB-445D	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	386.5	388.1	3.068	2.487
MCB-445E	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	203.3	204.9	3.081	2.477
MCB-445F	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	390.5	389.4	3.096	2.484
MCB-446A	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	433.2	440.6	3.086	2.464
MCB-446B	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	458.6	468.1	3.043	2.477
MCB-446C	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	446.6	459.8	3.086	2.449
MCB-446D	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	335.8	340.1	3.112	2.459
MCB-446E	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	473.7	486.8	3.112	2.441
MCB-446F	BRAZED IN VAC@1030C	AS BRAZED	AIR	600	414.6	394.9	3.343	2.446

SECTION 7. MODULUS OF RUPTURE- 4 POINT BEND OF BRAZED SPECIMENS, CONTINUED

MATERIAL 1 = MS-PSZ coated with titanium, BATCH CODE = NILSEN/ORNL/J1
MATERIAL 2 = NODULAR CAST IRON, BATCH CODE = CUMMINS GRADE 8003
BRAZE = Ag-30Cu-10Sn
SOURCE CODE = SANTELLA8/90
JOINT CODE = ORNL/MS890/ZRFE1

SPECIMEN NUMBER	BRAZING TREATMENT	SPECIMEN CONDITION	ENV.	TEMP °C	MOR MPa	WIDTH mm	THICK mm	LOAD RATE mm/sec
MCB-465C	BRAZED IN VAC@735C	AS BRAZED	AIR	25	91.7	2.50	2.00	22.70
MCB-461A	BRAZED IN VAC@735C	AS BRAZED	AIR	25	125.3	2.50	2.00	22.70
MCB-466C	BRAZED IN VAC@735C	AS BRAZED	AIR	25	129.2	2.50	2.00	22.70
MCB-455D	BRAZED IN VAC@735C	AS BRAZED	AIR	25	190.7	2.50	2.00	22.70
MCB-465D	BRAZED IN VAC@735C	AS BRAZED	AIR	25	208.7	2.50	2.00	22.70
MCB-459A	BRAZED IN VAC@735C	AS BRAZED	AIR	25	238.4	2.50	2.00	22.70
MCB-455B	BRAZED IN VAC@735C	AS BRAZED	AIR	25	299.7	2.50	2.00	22.70
MCB-465B	BRAZED IN VAC@735C	AS BRAZED	AIR	25	304.8	2.50	2.00	22.70
MCB-458A	BRAZED IN VAC@735C	AS BRAZED	AIR	25	306.9	2.50	2.00	22.70
MCB-455E	BRAZED IN VAC@735C	AS BRAZED	AIR	25	312.6	2.50	2.00	22.70
MCB-463B	BRAZED IN VAC@735C	AS BRAZED	AIR	25	317.8	2.50	2.00	22.70
MCB-466B	BRAZED IN VAC@735C	AS BRAZED	AIR	25	320.8	2.50	2.00	22.70
MCB-455A	BRAZED IN VAC@735C	AS BRAZED	AIR	25	323.2	2.50	2.00	22.70
MCB-466A	BRAZED IN VAC@735C	AS BRAZED	AIR	25	323.7	2.50	2.00	22.70
MCB-465A	BRAZED IN VAC@735C	AS BRAZED	AIR	25	327.5	2.50	2.00	22.70
MCB-455F	BRAZED IN VAC@735C	AS BRAZED	AIR	25	332.2	2.50	2.00	22.70
MCB-465E	BRAZED IN VAC@735C	AS BRAZED	AIR	25	337.8	2.50	2.00	22.70
MCB-463C	BRAZED IN VAC@735C	AS BRAZED	AIR	25	350.4	2.50	2.00	22.70
MCB-455C	BRAZED IN VAC@735C	AS BRAZED	AIR	25	370.3	2.50	2.00	22.70
MCB-456A	BRAZED IN VAC@735C	AS BRAZED	AIR	25	375.2	2.50	2.00	22.70
MCB-463A	BRAZED IN VAC@735C	AS BRAZED	AIR	25	377.0	2.50	2.00	22.70
MCB-463D	BRAZED IN VAC@735C	AS BRAZED	AIR	25	378.0	2.50	2.00	22.70

MATERIAL 1 = MS-PSZ coated with titanium, BATCH CODE = NILSEN/ORNL/J1
MATERIAL 2 = NODULAR CAST IRON, BATCH CODE = CUMMINS GRADE 8003
BRAZE = Ag-30Cu-10Sn
SOURCE CODE = SANTELLA8/90
JOINT CODE = ORNL/MS890/ZRFE2

SPECIMEN NUMBER	BRAZING TREATMENT	SPECIMEN CONDITION	ENV.	TEMP °C	MOR MPa	WIDTH mm	THICK mm	LOAD RATE mm/sec
MCB-462A	BRAZED IN VAC@735C	AS BRAZED	AIR	400	109.3	2.50	2.00	22.70
MCB-456B	BRAZED IN VAC@735C	AS BRAZED	AIR	400	117.5	2.50	2.00	22.70
MCB-460D	BRAZED IN VAC@735C	AS BRAZED	AIR	400	130.7	2.50	2.00	22.70
MCB-462D	BRAZED IN VAC@735C	AS BRAZED	AIR	400	143.0	2.50	2.00	22.70
MCB-460A	BRAZED IN VAC@735C	AS BRAZED	AIR	400	146.2	2.50	2.00	22.70
MCB-462C	BRAZED IN VAC@735C	AS BRAZED	AIR	400	150.3	2.50	2.00	22.70
MCB-460B	BRAZED IN VAC@735C	AS BRAZED	AIR	400	170.1	2.50	2.00	22.70
MCB-462B	BRAZED IN VAC@735C	AS BRAZED	AIR	400	177.2	2.50	2.00	22.70
MCB-460E	BRAZED IN VAC@735C	AS BRAZED	AIR	400	188.8	2.50	2.00	22.70
MCB-462E	BRAZED IN VAC@735C	AS BRAZED	AIR	400	191.2	2.50	2.00	22.70
MCB-460C	BRAZED IN VAC@735C	AS BRAZED	AIR	400	195.7	2.50	2.00	22.70
MCB-456E	BRAZED IN VAC@735C	AS BRAZED	AIR	400	213.2	2.50	2.00	22.70
MCB-456D	BRAZED IN VAC@735C	AS BRAZED	AIR	400	220.6	2.50	2.00	22.70
MCB-456C	BRAZED IN VAC@735C	AS BRAZED	AIR	400	227.1	2.50	2.00	22.70
MCB-458B	BRAZED IN VAC@735C	AS BRAZED	AIR	400	243.3	2.50	2.00	22.70

ORNL-DWG 91-17729

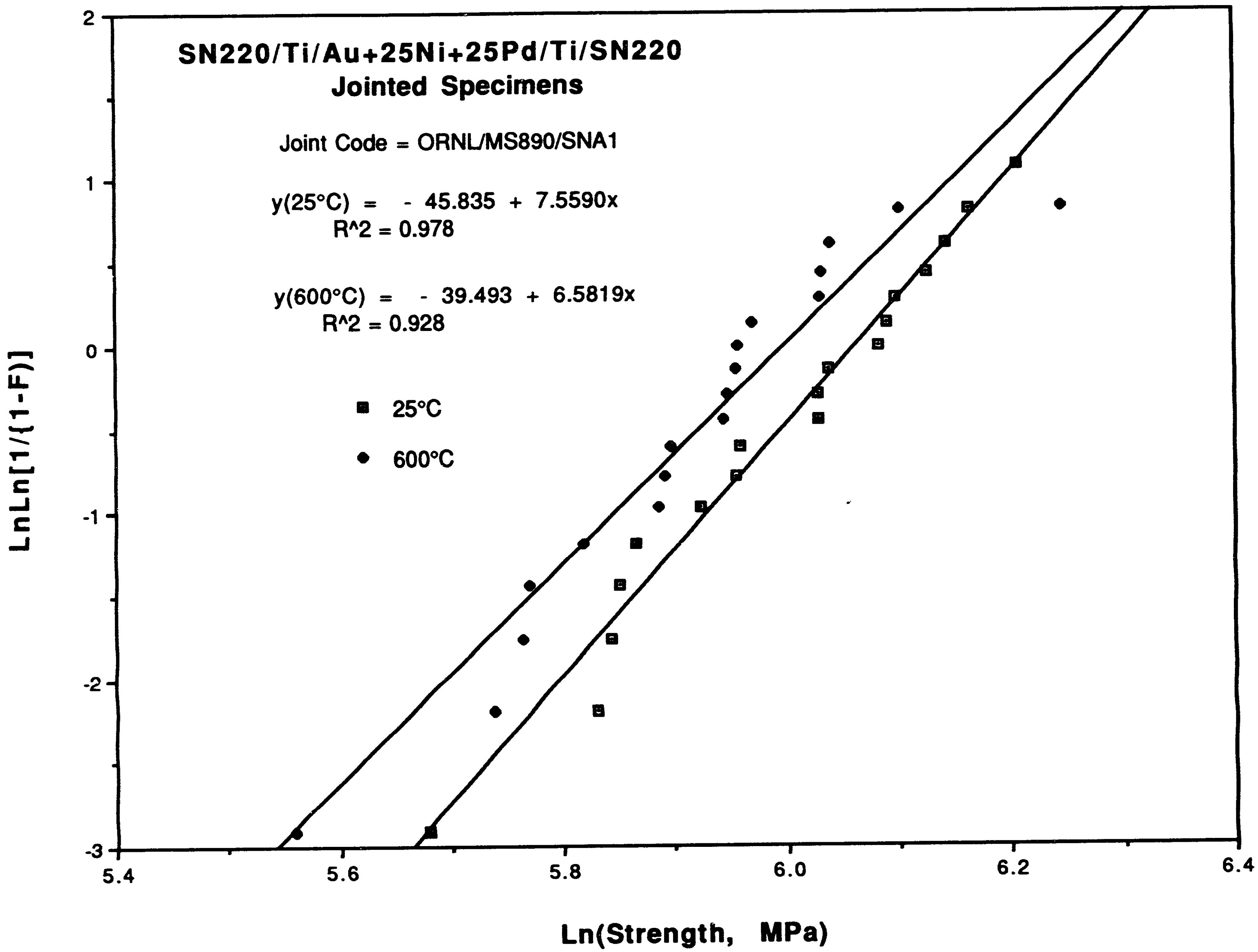

Figure 15. Weibull plot of the MOR 4-point bend strengths for (SN220/Ti/Au+25Ni+25Pd/Ti/SN220) joint tested at 25°C and 600°C.

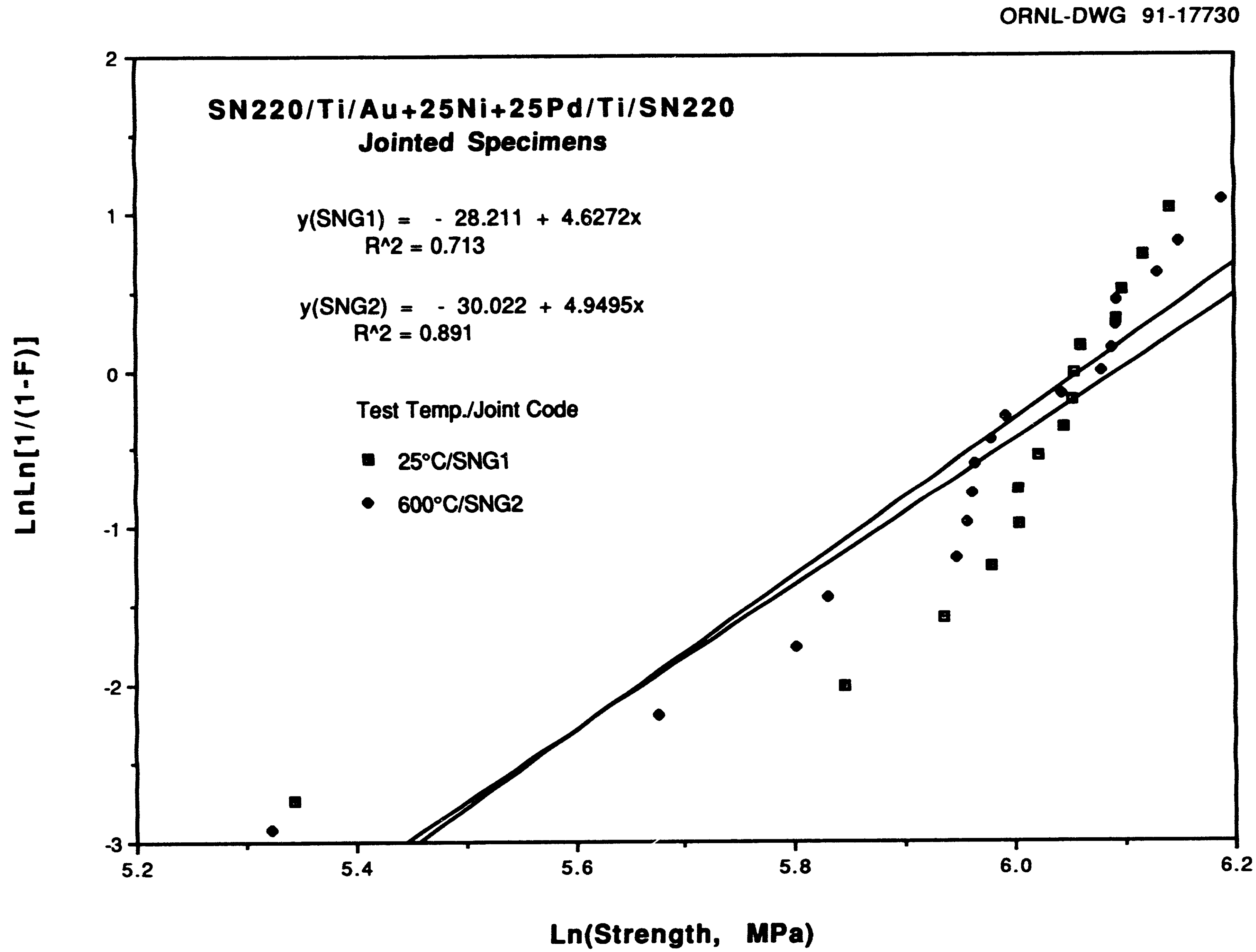

Figure 16. *Weibull plot of MOR 4-point bend strengths of SN220 brazed specimens (with ground joining surfaces) tested at 25°C and 600°C.*

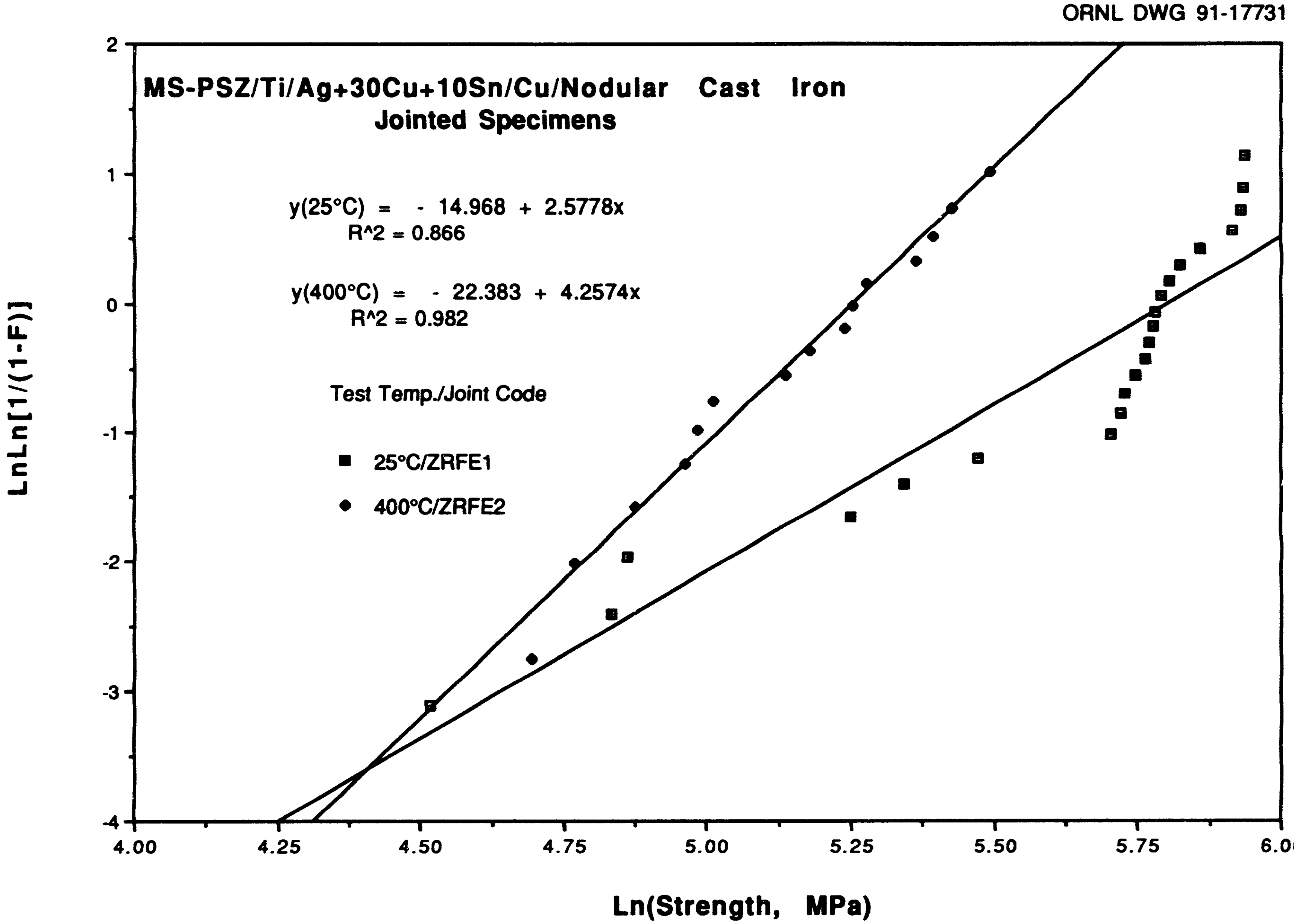

Figure 17. Weibull plot of MOR 4-point bend strengths of (MS-PSZ/Ti/ Ag+30Cu+10Sn/Cu/Nodular Cast Iron) tested at 25°C and 400°C.

SECTION 8. SHEAR STRENGTH OF BRAZED SPECIMENS

MATERIAL 1 = GTE PY6, BATCH CODE = GTEL/87-SB047C
SOURCE CODE = ORNL87SB047C

MATERIAL 1 COATING	MATERIAL 2	BATCH CODE 2	BRAZE MATERIAL	JOINT CODE	SPECIMEN NUMBER	TEMP °C	LOAD N	SHEAR STRESS MPa
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-TI-MO/1	SUMMARY	525	13344.0	135.1
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-TI-MO/1	SUMMARY	525	13010.0	131.7
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-TI-MO/1	SUMMARY	525	12899.0	143.4
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-TI-MO/1	SUMMARY	500	12054.0	141.4
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-TI-MO/1	SUMMARY	500	13589.0	171.0
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-TI-MO/1	SUMMARY	25	3402.7	42.1
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-TI-MO/1	SUMMARY	25	3936.4	40.7
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-TI-MO/1	SUMMARY	25	10453.0	108.3
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-TI-MO/2	SUMMARY	525	19238.0	215.8
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-TI-MO/2	SUMMARY	525	12232.0	126.2
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-TI-MO/2	SUMMARY	525	21906.0	251.0
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-TI-MO/2	SUMMARY	25	2891.2	30.3
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-TI-MO/2	SUMMARY	25	6049.2	64.1
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Pd-40Ni	GTEL/PY6-TI-MO/5	SUMMARY	525	9118.4	94.5
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Pd-40Ni	GTEL/PY6-TI-MO/5	SUMMARY	525	17970.0	204.8
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Pd-40Ni	GTEL/PY6-TI-MO/5	SUMMARY	525	9563.2	102.7
TITANIUM	NICKEL	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-TI-NI/2	SUMMARY	525	8117.6	80.0
TITANIUM	NICKEL	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-TI-NI/2	SUMMARY	525	5448.8	53.8
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-ZR-MO/1	SUMMARY	525	11387.0	137.9
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/PY6-ZR-MO/1	SUMMARY	525	12454.0	146.9
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-ZR-MO/2	SUMMARY	525	2001.6	19.3
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-ZR-MO/2	SUMMARY	525	9896.8	97.2
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/PY6-ZR-MO/2	SUMMARY	525	10008.0	101.4

SECTION 8. SHEAR STRENGTH OF BRAZED SPECIMENS, CONTINUED

MATERIAL 1 = SNW-1000, BATCH CODE = GTEL/87-SB047C
SOURCE CODE = ORNL87SB047C

MATERIAL 1 COATING	MATERIAL 2	BATCH CODE 2	BRAZE MATERIAL	JOINT CODE	BRAZE TREATMENT	SPECIMEN NUMBER	TEMP °C	SHEAR STRESS MPa	COMMENTS
HAFNIUM	INCOLOY 909	GTEL/CARTECH	Au-18Ni	GTEL/SIN-HF-ME/3	BRAZED @980C/10 MIN.	SUMMARY	25	26.2	
HAFNIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-HF-MO/3	BRAZED @980C/10 MIN.	SUMMARY	25	53.1	
TANTALUM	SNW-1000/TA	GTEL/87-SB047C	Au-18Ni	GTEL/SIN-TA-SIN	BRAZED @980C/10 MIN.	SUMMARY	25	189.6	
TITANIUM	INCOLOY 909	GTEL/CARTECH	Au-18Ni	GTEL/SIN-TI-ME/3	BRAZED @980C/10 MIN.	SUMMARY	25	4.8	
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-TI-MO/3	BRAZED @980C/10 MIN.	SUMMARY	25	49.0	
TITANIUM	NIOBIUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/SIN-TI-NB/2			525	51.0	
TITANIUM	NIOBIUM	GTEL/INTERLAYR	60Pd-40Ni	GTEL/SIN-TI-NB/5			525	84.8	
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	60Pd-40Ni	GTEL/SIN-TI-NB/5			525	42.7	
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	60Pd-40Ni	GTEL/SIN-TI-NB/5			525	33.1	
TITANIUM	SNW-1000/TI	GTEL/87-SB047C	Au-18Ni	GTEL/SIN-TI-SIN	BRAZED @980C/10 MIN.	SUMMARY	25	291.6	
ZIRCONIUM	INCOLOY 909	GTEL/CARTECH	Au-18Ni	GTEL/SIN-ZR-ME/3	BRAZED @980C/10 MIN.	SUMMARY	25	20.7	
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/SIN-ZR-MO/2			525	15.2	No failure at 104.8MPa
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @980C/10 MIN.	SUMMARY	25	79.3	
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @960C/3 MIN.		25	37.2	EXCELLENT BONDING
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @960C/3 MIN.		25	148.2	EXCELLENT BONDING
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @960C/3 MIN.		25	64.8	EXCELLENT BONDING
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @960C/3 MIN.		25	82.0	EXCELLENT BONDING
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @1100C/30MIN.		25	130.3	EXCELLENT BONDING
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @1100C/30MIN.		25	39.3	EXCELLENT BONDING
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @1100C/30MIN.		25	87.6	EXCELLENT BONDING
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIN-ZR-MO/3	BRAZED @1100C/30MIN.		25	74.5	EXCELLENT BONDING
ZIRCONIUM	SNW1000/ZR	GTEL/87-SB047C	Au-18Ni	GTEL/SIN-ZR-SIN	BRAZED @980C/10 MIN.	SUMMARY	25	311.0	

SECTION 8. SHEAR STRENGTH OF BRAZED SPECIMENS, CONTINUED

MATERIAL 1 = HEXALOY SA, BATCH CODE = GTEL/SOHIO-87SB
SOURCE CODE = ORNL87SB047C

MATERIAL 1 COATING	MATERIAL 2	BATCH CODE 2	BRAZE MATERIAL	JOINT CODE	BRAZING TREATMENT	SPECIMEN NUMBER	TEMP °C	LOAD N	SHEAR STRESS MPa
HAFNIUM	HEXALOY SA/Hf	GTEL/SOHIO-87SB	Au-18Ni	GTEL/SIC-HF-SIC	BRAZED @980C/10 MIN.	SUMMARY	25		95.8
HAFNIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIC-HF-MO/3	BRAZED @980C/10 MIN.	SUMMARY	25		11.0
TANTALUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIC-TA-MO/3	BRAZED @980C/10 MIN.	SUMMARY	25		16.5
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/SIC-TI-MO/1		SUMMARY	25	3758.5	44.1
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/SIC-TI-MO/1		SUMMARY	25	1423.3	14.5
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-5Pd-2Ni	GTEL/SIC-TI-MO/1		SUMMARY	25	3313.7	37.2
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/SIC-TI-MO/2		SUMMARY	500	2780.0	29.7
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/SIC-TI-MO/2		SUMMARY	25	3113.6	32.4
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/SIC-TI-MO/2		SUMMARY	25	520.4	5.5
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	30Au-34Pd-36Ni	GTEL/SIC-TI-MO/2		SUMMARY	25	2224.0	23.4
TITANIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIC-TI-MO/3	BRAZED @980C/10 MIN.	SUMMARY	25		20.0
ZIRCONIUM	MOLYBDENUM	GTEL/INTERLAYR	Au-18Ni	GTEL/SIC-ZR-MO/3	BRAZED @980C/10 MIN.	SUMMARY	25		24.1

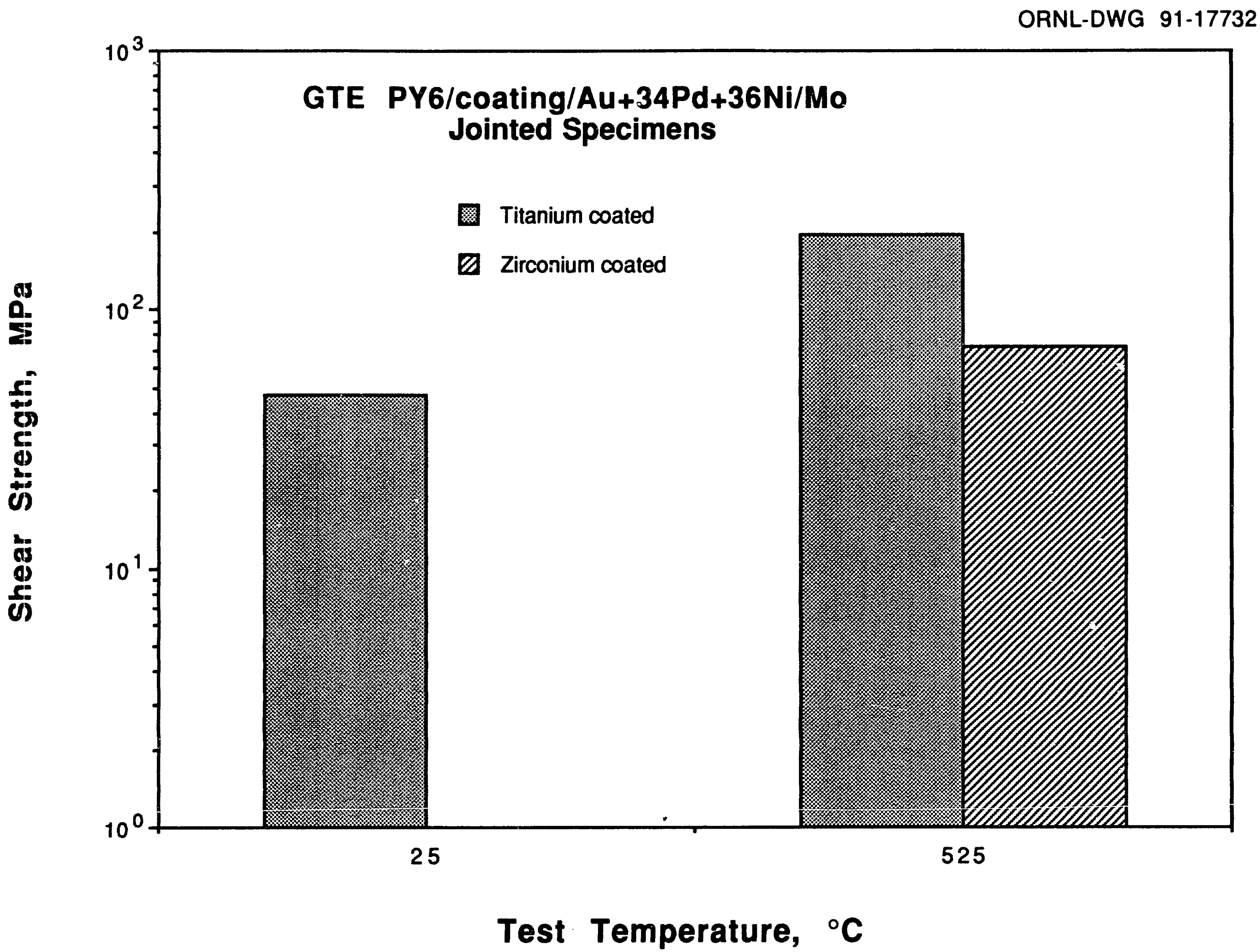

Figure 18. The effects of coating material on the shear strength of GTE PY6-molybdenum joints at 25°C and 525°C.

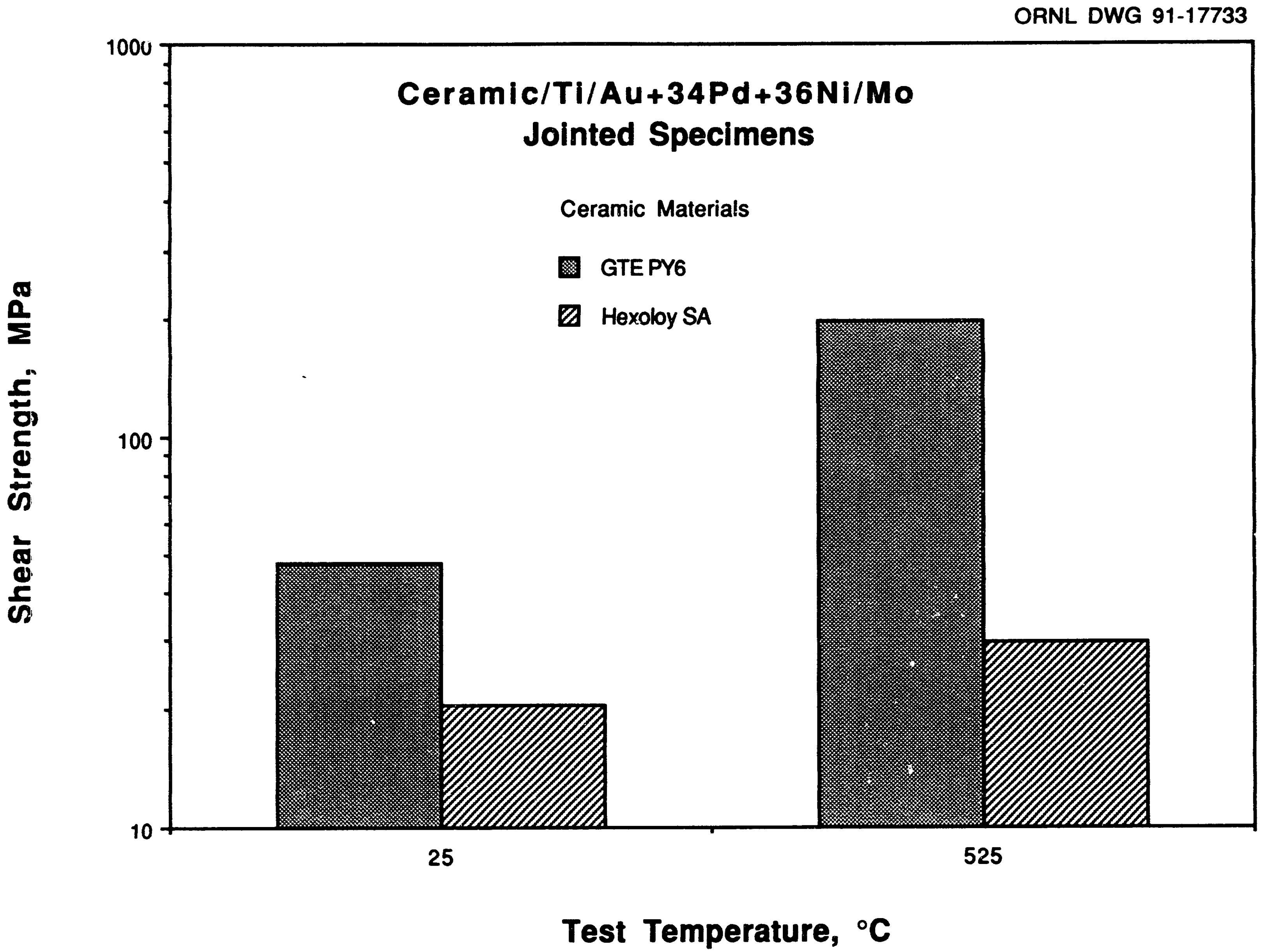

Figure 19. A comparison of GTE PY6-molybdenum to Hexoloy SA-molybdenum joint shear strength.

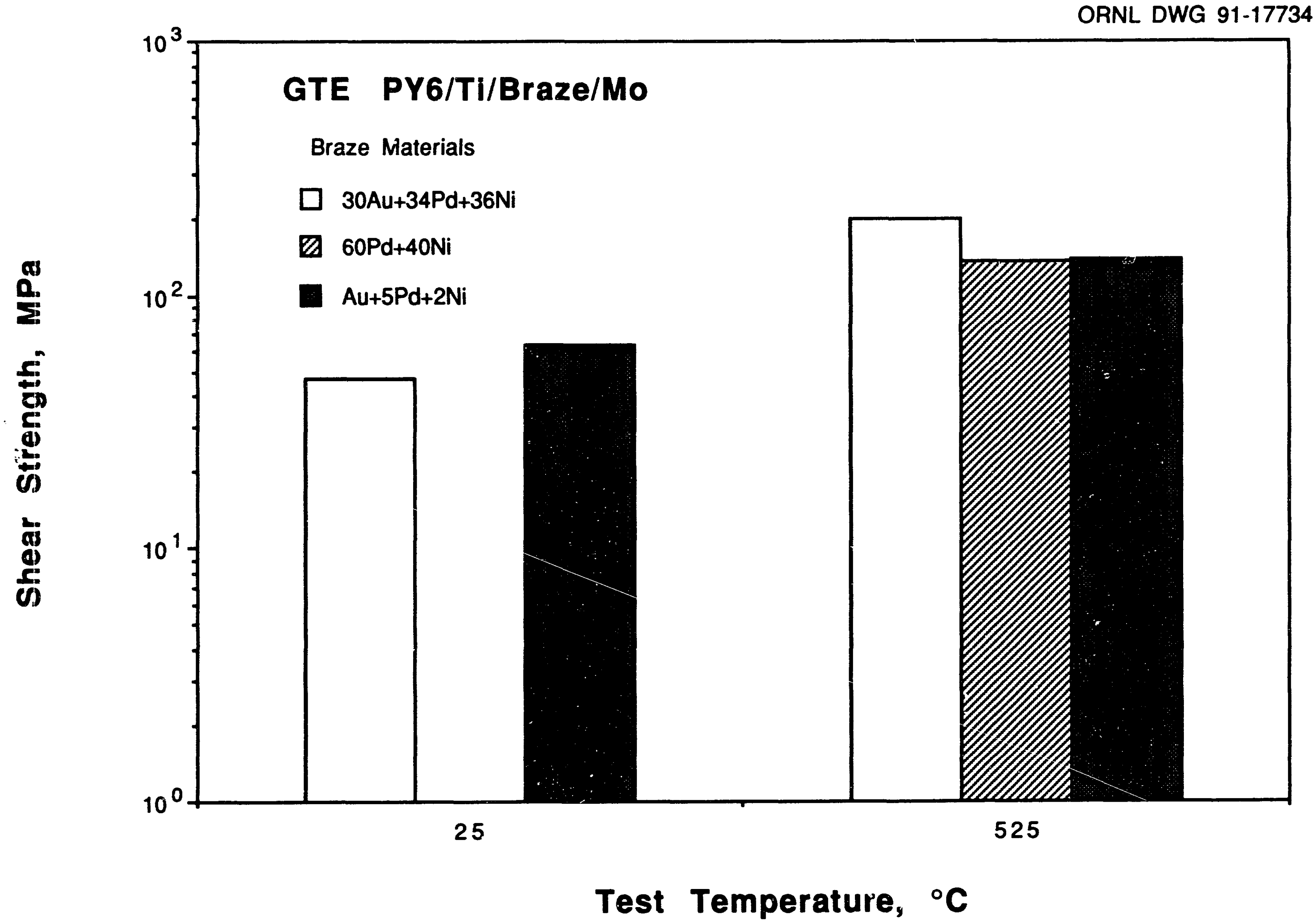

Figure 20. Effects of braze material on shear strength of titanium-coated GTE PY6 brazed to molybdenum.

SECTION 9. TORSION OF BRAZED SPECIMENS

MATERIAL 1 = HEXALOY SA coated with titanium, BATCH CODE = GTEL/SOHIO-87SB
MATERIAL 2 = INCOLOY 909, BATCH CODE = GTEL/CARTECH
BRAZE MATERIAL = Au-5Pd-2Ni
SOURCE CODE = ORNL87SB047C
JOINT CODE = GTEL/SIC-INC909

TEST TEMP °C	TORQUE Nm	BENDING MOMENT Nm	ROTATION DEGREES	COMMENTS
25	11.980	18.300	0.25	BROKE IN CERAMIC
25	7.910	6.100	0.25	BROKE IN CERAMIC
25	7.680	6.100	0.30	BROKE IN CERAMIC
650	1.130			SLIPPED AT BRZ/CER INTFC
650	2.820			SLIPPED AT BRZ/CER INTFC
650	4.520			SLIPPED AT BRZ/CER INTFC

MATERIAL 1 = GTE PY6 coated with titanium, BATCH CODE = GTEL/87-SB047C
MATERIAL 2 = INCOLOY 909, BATCH CODE = GTEL/CARTECH
BRAZE MATERIAL = Au-5Pd-2Ni
SOURCE CODE = ORNL87SB047C
JOINT CODE = GTEL/PY6-INC909

TEST TEMP °C	TORQUE Nm	BENDING MOMENT Nm	ROTATION DEGREES	COMMENTS
25	60.900	7.120	2.22	BROKE IN CERAMIC
25	97.390	14.240	3.52	BROKE IN CERAMIC
25	53.100	11.190	1.98	BROKE IN CERAMIC
25	30.170	13.220	1.15	BROKE IN CERAMIC
25	59.660	10.170	1.05	BROKE IN CERAMIC
650	4.630			SLIPPED AT BRZ/CER INTFC
650	1.580		0.10	SLIPPED AT BRZ/CER INTFC
650	7.010			SLIPPED AT BRZ/CER INTFC
650	4.860		0.21	SLIPPED AT BRZ/CER INTFC

MATERIAL 1 = GTE PY6 coated with titanium, BATCH CODE = GTEL/87-SB047C
MATERIAL 2 = INCONEL 718, BATCH CODE = GTEL/HUNTALLOY
BRAZE MATERIAL = Au-5Pd-2Ni
SOURCE CODE = ORNL87SB047C
JOINT CODE = GTEL/PY6-INC718

TEST TEMP °C	TORQUE Nm	BENDING MOMENT Nm	ROTATION DEGREES	COMMENTS
25	12.200	25.420	0.38	BROKE IN CERAMIC
25	39.540	13.220	1.19	BROKE IN CERAMIC
25	22.600	17.290	0.70	BROKE IN CERAMIC
25	51.180	16.270	0.80	BROKE IN CERAMIC
25	40.670	16.270	0.64	BROKE IN CERAMIC
950	0.340			SLIPPED AT BRZ/CER INTFC

SECTION 10. TORSION FATIGUE OF BRAZED SPECIMENS

MATERIAL 1 = GTE PY6 coated with titanium, BATCH CODE = GTEL/87-SB047C
MATERIAL 2 = INCOLOY 909, BATCH CODE = GTEL/CARTECH
BRAZE MATERIAL = Au-5Pd-2Ni
SOURCE CODE = ORNL87SB047C
JOINT CODE = GTEL/PY6-INC909

SPECIMEN NUMBER	TEMP °C	TORQUE Nm	BENDING MOMENT Nm	ROTATION DEGREES	CYCLES TO FAILURE
BZTRFT1*	25	4 TO 20.9	20.300	+-0.31	>1000
BZTRFT2*	25	4 TO 20.9	19.300	+-0.32	>1000
BZTRFT3*	25	4 TO 20.9	21.354	+-0.31	>1000
BZTRFT4†	25	4 TO 20.9	26.438	+-0.32	>1000
	25	4 TO 20.9	16.270	+-0.32	>1000000

TEST NOTES

* Specimen was heated to 650-700C, gripped in the MTS machine, then cooled before test to realign the specimen.

† Specimen was heated to 650-700C, gripped in the MTS machine, then cooled before testing to realign the specimen. This test was run until fracture, enduring more than 1,000,000 cycles with no signs of degradation. Parameters unchanged from beginning of the test.

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