REPORT 2275

MATERIALS PROPERTIES DATA BOOK

REVISION OF 15 JULY 1970

VOLUME 3

NONMETALLICS AND APPENDICES

30 AUGUST 1970

CONTRACT SNP-1

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A DIVISION OF AEROJET - GENERAL

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DATE 15 JULY 1970

SUPERSEDES 15 MAR 1970

FOREWORD

This Data Book was prepared in partial fulfillment of Contract SNP-1 of the Space Nuclear Propulsion Office, a joint office of the National Aeronautics and Space Administration and the Atomic Energy Commission, with the Aerojet Nuclear Systems Company. Guidance of the work was the responsibility of the Cleveland Extension of SNPO.

Sheets based either wholly or in part on technical contributions by the Westinghouse Astro-nuclear Laboratory are identified by WANL's insignia.

Contributions of data from persons or organizations are solicited, and if included in the Data Book, proper acknowledgment will be made. Communications relevant to such contributions or for related matters should be addressed to the Manager, Materials and Processes Section, Aerojet Nuclear Systems Company, Sacramento, California, under whose supervision the work is being accomplished.

DATE 15 MAR 1970**SUPERSEDES** 30 SEPT 1969**AUTHORIZATION FOR USE**

This Materials Properties Data Book has been previously established, and continues in effect, as the basic design criterion for materials usage within the NERVA Program, subject to interpretation or extrapolation by the Aerojet Nuclear Systems Company, Materials and Processes Section.

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DATE 15 JULY 1970

SUPERSEDES 15 MAR 1970

VOLUME 1
VOLUME 1
INTRODUCTION

<u>A. GENERAL</u>	<u>Page</u>	<u>B. LIST OF REFERENCES</u>	<u>Page</u>
	3		21
1. Organization	4	Reference Presentation	22
2. Data Presentation	6	1970	23
a. Adjustment of Data	6	1969	25
b. Identification of Primary Strength Properties	6	1968	27
c. Categories of Primary Strength Properties	7	1967	29
d. Design Properties	8	1966	32
e. Statistical Analysis of Material Test Data	9	1965	36
f. Symbology	10	1964	41
3. Bearing Properties	12	1963	46
4. Modulus of Elasticity	12	1962	50
5. Thermal Emissivity and Emittance	13	1961	54
6. Goodman Diagrams	14	1960	56
7. Appendices	15	1959	59
8. Data Sources	15	1958	61
		1957	62
		1956	63
		1955	64
		1954	65
		1953	66
		1952	66
		1951	67
		1950	67
		1949	68
		1948	68
		1947	69
		1946	69
		1939	70
		1938	70

DATE 15 JULY 1970

SUPERSEDES 15 MAR 1970

See Pages 4 and 5 of Introduction for Numerical Code

VOLUME 1
VOLUME 1
MATERIALS DATA
I. LIGHT METAL ALLOYS

	<u>Code</u>	<u>Page</u>
<u>Aluminum Alloys</u>	I-A	41
356	I-A-01	43
A356	I-A-02	51
2014	I-A-20	57
2024	I-A-24	61
2219	I-A-26	71
5083	I-A-52	79
5454	I-A-54	81
5456	I-A-56	83
6061	I-A-61	Vol. 1, Page 301
7039	I-A-74	97
7075	I-A-75	107
7079	I-A-77	119
7178	I-A-78	125
<u>Titanium Alloys</u>	I-B	127
Ti-5Al-2.5 Sn (A-110 AT)	I-B-10	129
Ti-5Al-2.5 Sn (A-110 AT)-ELI	I-B-11	Vol. 1, Page 471
Ti-6Al-4V (C-120 AV)	I-B-30	149
Ti-6Al-4V (C-120 AV)-ELI	I-B-31	163

DATE	15 JULY 1970
SUPERSEDES	30 SEPT 1969

See Pages 4 and 5 of Introduction for Numerical Code

VOLUME 1-A
VOLUME 1-A
MATERIALS DATA
II. NICKEL-BASE ALLOYS

	<u>Code</u>	<u>Page</u>
<u>Solution-Hardening Alloys</u>	II-A	169
Hastelloy C	II-A-13	171
Hastelloy N (INOR-8)	II-A-14	181
AISI 680 (Hastelloy X)	II-A-15	189
Inconel 625	II-A-17	197
<u>Precipitation-Hardening Alloys</u>	II-B	207
AISI 683 Rene' 41	II-B-10	209
AISI 684 Udimet 500	II-B-11	211*
AISI 685 Waspaloy	II-B-12	213
AISI 687 Udimet 700	II-B-14	215
AISI 688 Inconel X-750	II-B-15	217
Alloy 718	II-B-17	223
Udimet 630	II-B-28	231*
<u>Dispersion-Hardening Alloys</u>	II-C	235
TD Nickel	II-C-10	237

III. REFRACTORY METALS AND ALLOYS

	<u>Code</u>	<u>Page</u>
<u>Molybdenum and Molybdenum Alloys</u>	III-A	243
Molybdenum	III-A-10	245
TZM Molybdenum	III-A-11	257
<u>Tantalum and Tantalum Alloys</u>	III-B	263
Tantalum	III-B-10	265
<u>Tungsten and Tungsten Alloys</u>	III-C	273
Tungsten	III-C-10	275
Tungsten-25 Rhenium	III-C-20	283

IV. OTHER NONFERROUS METALS AND ALLOYS

	<u>Code</u>	<u>Page</u>
<u>Cobalt Alloys</u>	IV-A	289
AISI 670 Cobalt Alloy (Haynes 25)	IV-A-11	291
<u>Copper Alloys</u>	IV-B	303
Oxygen-Free, High-Conductivity	IV-B-10	305
<u>Zirconium Alloys</u>	IV-C	313

*To be published

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

See Pages 4 and 5 of Introduction for Numerical Code

VOLUME 2
VOLUME 2
MATERIALS DATA
V. FERROUS ALLOYS

	<u>Code</u>	<u>Page</u>
<u>Carbon and Low-Alloy Steels</u>	V-A	315
AISI 1025	V-A-10	317
AISI 4340	V-A-43	319
<u>Austenitic Stainless Steels</u>	V-B	321
AISI 301	V-B-01	323
AISI 303	V-B-03	341
AISI 304	V-B-04	349
AISI 310	V-B-10	361
AISI 316	V-B-16	371
AISI 321	V-B-21	379
AISI 347	V-B-47 Vol. 2, Page 261	
<u>Martensitic Stainless Steels</u>	V-C	401
AISI 440C (also, AISI 617)	V-C-29	403
<u>Precipitation-Hardening</u>	V-D	407
<u>Stainless</u>		
AISI 630 (17-4 PH)	V-D-10	409
AISI 631 (17-7 PH)	V-D-11	411
AISI 632 (PH-15-7 Mo)	V-D-12	421
AISI 633 (AM 350)	V-D-13	425
<u>Iron-Nickel-Chromium Alloys</u>	V-E	429
AISI 660 (A-286)	V-E-10	431
AISI 664 (D-979)	V-E-14	445
Incoloy 800	V-E-16	454-A
Ni-SPAN-C902	V-E-20	455
<u>Bolt Materials</u>	V-F	463

DATE	30 SEPT 1969
SUPERSEDES	30 JUNE 1968

See Pages 4 and 5 of Introduction for Numerical Code

VOLUME 3
VOLUME 3
MATERIALS DATA
VI. NUCLEAR MATERIALS

	<u>Code</u>	<u>Page</u>
<u>Nuclear Fuel Materials</u>	VI-A	465
NERVA Fueled Elements	VI-A-10	467
NERVA Non-Fueled Elements	VI-A-11	471
<u>Neutron Control Materials</u>	VI-B	475
AISI 304 + Gd	VI-B-11	477
Lithium Hydride	VI-B-13	481
<u>Moderator Materials</u>	VI-C	485
Beryllium (S-200 grade)	VI-C-12	Vol. 3, Page 41
Beryllium (1-400 grade)	VI-C-14	495

VII. GRAPHITES

	<u>Code</u>	<u>Page</u>
<u>Structural Graphites</u>	VII-A	499
Graphitite G	VII-A-10	501
MHLM (H4LM)	VII-A-11	509
P-03	VII-A-12	515
ATJ	VII-A-13	521
ZTA	VII-A-14	527
Carb-I-Tex 500	VII-A-15	529
Carb-I-Tex 700	VII-A-16	532-A
Carb-I-Tex 715	VII-A-17	532-E
TS-699	VII-A-18	533
<u>High-Expansion</u>	VII-B	534-A
<u>Structural Graphites</u>		
L-56	VII-B-10	535
EP-192	VII-B011	537
EP-192C	VII-B-12	539
EP-192C-H	VII-B-13	540-A
SX-5	VII-B-14	540-C
<u>Pyrolytic Graphite</u>	VII-C	541
Pyrolytic graphite	VII-C-10	543
Pyrolytic graphite foil (Pyrofoil)	VII-C-20	548
<u>Other Graphites</u>	VII-D	549

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

See Pages 4 and 5 of Introduction for Numerical Code

VOLUME 3
VOLUME 3
MATERIALS DATA
VIII. REFRACTORY CERAMICS

	<u>Code</u>	<u>Page</u>
<u>Oxides</u>	VIII-A	551
Beryllium oxide	VIII-A-10	553
Magnesium oxide	VIII-A-11	561
Thorium oxide	VIII-A-12	567
Zirconium oxide	VIII-A-13	575
<u>Carbides</u>	VIII-B	583
Boron carbide	VIII-B-10	585
Tantalum carbide	VIII-B-11	589
<u>Nitrides</u>	VIII-C	593
Boron nitride	VIII-C-10	595

IX. ADHESIVES

	<u>Code</u>	<u>Page</u>
<u>Epoxies</u>	IX-A	601
Epon 929 (Ep.)	IX-A-10	603
Epon 934 (Ep.)	IX-A-11	607
FM 1000 (Ep. -Nylon)	IX-A-12	609
HT 424 (Ep. -Phen.)	IX-A-13	611
Aerobond 430 (Ep. -Phen.)	IX-A-14	615
C-7 (Ep. -Resin)	IX-A-15	619
Epoxy-Patch 0151 (Ep. -Resin)	IX-A-16	621
Epy-150 (Ep. -Resin)	IX-A-17	623
Epy-400 (Ep. -Resin)	IX-A-18	625
<u>Phenolics</u>	IX-B	631
Metlbond 402 (Phen. -Nit.)	IX-B-10	633
FM-47 (Vinyl-Phen.)	IX-B-11	637
<u>Polyurethanes</u>	IX-C	641
Apco 1202	IX-C-10	643*
<u>Silicones</u>	IX-D	651
Silastic 140 (Silicone)	IX-D-10	653
RTV 891 (Silicone)	IX-D-11	655
<u>Ceramics (Cements)</u>	IX-E	
National Carbon No. 14	IX-E-10	663
DW-30	IX-E-11	665
P-514	IX-E-12	667

*To be published

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

See Pages 4 and 5 of Introduction for Numerical Code

VOLUME 3
VOLUME 3
MATERIALS DATA
X. PLASTICS

	<u>Code</u>	<u>Page</u>
Armalon	X-A-10	673
Teflon	X-A-11	677
SP-3	X-A-12	687
Kapton (H-Film)	X-A-13	689

APPENDICES
A. PLASTIC BENDING MODULUS

	<u>Page</u>
Foreword and Nomenclature	703
1 Basic Relationships	704
2 Ultimate Bending Strength	705
3 Yield Bending Strength	707
4 General Stress Level	708
5 Example	710

B. EFFECTS OF RADIATION ON STRUCTURAL MATERIALS *

*To be published

DATE 30 JUNE 1968

SUPERSEDES 1 MAY 1966

NUCLEAR MATERIALS

MATERIALS DATA

**VI
NUCLEAR MATERIALS**

**C.
MODERATOR MATERIALS**

DATE 1 MAY 1966

SUPERSEDES

NUCLEAR MATERIALS

MATERIALS DATA

**VI
NUCLEAR MATERIALS**

**A.
NUCLEAR FUEL ELEMENTS**

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

THIS MATERIAL IS USED IN THE FUEL ELEMENTS OF THE NERVA REACTOR.

THE INFORMATION HEREIN IS UNCLASSIFIED

THE MECHANICAL PROPERTIES LISTED ARE COMPARABLE TO EXTRUDED STRUCTURAL GRAPHITE. THEY SHOULD BE USED WITH CAUTION FOR NERVA FUEL ELEMENTS.

B. COMMERCIAL DESIGNATIONS

NONE

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

WESTINGHOUSE ASTRONUCLEAR LABORATORY
PITTSBURGH, PA.
Y12 PLANT, ORNL, OAK RIDGE, TENN.

D. CHEMICAL COMPOSITION (%)

ELEMENT	MAXIMUM	MINIMUM

SOURCE

E. ROOM TEMPERATURE PROPERTIES (AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
TENSILE ULTIMATE STRENGTH F_{TU}				PSI
	3300		3500	
		2000-4600		2150-4900
COMP. ULTIMATE STRENGTH F_{CU}				PSI
	8300		-	
		5600-11000		-
SHEAR STRENGTH F_{SU}				PSI
FLEXURAL STRENGTH F_B				PSI
			4000	
				3670-4330
ELONGATION e				%
MODULUS OF ELASTICITY E				10^6 PSI
COMP. MOD. OF ELASTICITY E_C				10^6 PSI
MODULUS OF RIGIDITY G				
HARDNESS				

THE PROPERTIES OF GRAPHITES DIFFER WIDELY, NOT ONLY BETWEEN DIFFERENT GRADES, BUT BETWEEN DIFFERENT LOTS, ADDITIONAL VARIATIONS IN PROPERTIES MAY BE FOUND BETWEEN DIFFERENT PIECES IN A GIVEN LOT AS WELL AS BETWEEN LOCATIONS AND ORIENTATIONS WITHIN A SINGLE BLOCK. THIS WIDE VARIATION IS DUE TO THE SENSITIVITY OF GRAPHITE PROPERTIES TO MANY VARIABLES. THESE VARIABLES INCLUDE DIFFERENCES IN STARTING MATERIALS, PARTICLE SIZE, FORMING METHOD, CONDITION OF THE FIRST BAKE, AND GRAPHITIZING CONDITIONS. IN SHORT, THE PROPERTIES AND UNIFORMITY OF THE FINAL GRAPHITE PRODUCT ARE GREATLY INFLUENCED BY MANUFACTURING AND MATERIAL VARIABLES.

2. PHYSICAL PROPERTIES

	LB/IN ³		g/cc	
	MEAN	RANGE	MEAN	RANGE
DENSITY ρ				
Code *	-3	2.11	2.06-2.13	.0763
	-4	2.17	2.15-2.19	.0783
	-5	2.22	2.15-2.27	.0801
	-6	2.22	2.17-2.27	.0801
	-7	2.23	2.20-2.26	.0805
	-8	2.26	2.22-2.31	.0816
	-9	2.34	2.28-2.40	.0846
* NRX-A3 ELEMENTS				
	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
SPECIFIC HEAT C				BTU/LB - °F
	-	-	-	-
THERMAL CONDUCTIVITY k				BTU - FT HR - FT ² - °F
(77°F)	-	-	90	82-95
MEAN COEFF. LINEAR THERMAL EXPANSION α				10^{-6} IN. IN. - °F
(212°F)	-	-	1.50	1.01-1.85
ELECTRICAL RESISTIVITY R				MICROHM - IN.
	610	-	-	-

** REPRESENTATIVE OF NRX-A2 COATED ELEMENTS

F. THERMOPHYSICAL EFFECTS

SUBLIMATION TEMPERATURE

THERMAL CONDUCTIVITY VS TEMPERATURE ***

TEMPERATURE (°F)	MEAN	RANGE
77	90	82-95
2012	18	16-20
2912	14	12-15

*** REPRESENTATIVE OF NRX-A-2 COATED ELEMENTS
ACROSS-THE-GRAIN DIRECTION, TUBULAR SPECIMEN
VALUES CORRECTED FOR GEOMETRY. VALUES NOT
CALCULATED WITH FUEL LOADING

G. THERMOPHYSICAL EFFECTS (CONTINUED)

EMITTANCE VS TEMPERATURE

G. CHEMICAL PROPERTIES

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

THIS SECTION IS INCLUDED TO PROVIDE A BRIEF SURVEY OF DEFECTS COMMONLY FOUND IN CONVENTIONAL EXTRUDED GRAPHITES, TO CLARIFY THEIR NATURE FOR THOSE NOT ALREADY COGNIZANT WITH GRAPHITE TECHNOLOGY.

PORE - A SPACE BETWEEN THE COKE PARTICLES NOT FILLED WITH SOLID MATERIAL. IT RESULTS FROM PARTIAL VAPORIZATION OF THE ORIGINAL PITCH BINDER. PORE DIMENSION IS GENERALLY SMALLER THAN THE PARTICLE SIZE. NOT A DEFECT.

VOID - A SPACE IN THE MATRIX NOT FILLED WITH SOLID MATERIAL. ITS SIZE IS MUCH LARGER THAN THE PARTICLE SIZE. A TRUE DEFECT.

(THE COMMON DISTINCTION BETWEEN PORES AND VOIDS IS THAT INDIVIDUAL PORES CANNOT BE DETECTED RADIOGRAPHICALLY. THE PRESENCE OF PORES IS A NORMAL FEATURE OF EXTRUDED AND MOLDED GRAPHITES, AND THEY CANNOT BE, THEREFORE, REGARDED AS DEFECTS EXCEPT IN FUNDAMENTAL CONSIDERATIONS. VOIDS, ON THE OTHER HAND, ARE TRUE DEFECTS BECAUSE THEY MAY BE ELIMINATED THROUGH PROPER LEVEL OF QUALITY CONTROL BY THE MANUFACTURER AND THE USER.)

INCLUSION - ANY FOREIGN (NON-CARBONACEOUS) MATERIAL IN GRAPHITE. GENERALLY DETECTABLE BY RADIOGRAPHIC INSPECTION BECAUSE OF ITS GREATER ABSORPTION FOR X-RAYS THAN THAT OF THE GRAPHITE MATRIX. INCLUSIONS ARE PREDOMINANTLY IMPURE IRON CARBIDES.

FLOW LINE - AN EXTENDED ARRAY OF LARGE PORES OR SMALL VOIDS, ALIGNED PARALLEL TO THE AXIS OF EXTRUSION, AND BRIDGED BY CONNECTING GRAPHITE STRUCTURE. SUCH FEATURES ARE CHARACTERISTIC OF EXTRUDED GRAPHITES, AND CAN BE TRACED TO THE EXTRUSION OF "GREEN MIX".

FLOW "LINES" ARE USUALLY NOT LINES, BUT CIRCUMFERENTIALLY CURVED PLANAR AGGREGATES OF OVERSIZE PORES. THEIR DETECTION BY RADIOGRAPHY IS NOT FEASIBLE UNLESS THE X-RAY BEAM IS PARALLEL TO THE PLANE. IF AN EXTRUDED LOG IS RADIOGRAPHED PERPENDICULAR TO THE AXIS, THE SENSITIVITY DROPS BECAUSE OF THE DECREASED BUILD-UP EFFECTS; THIS IS PARTICULARLY TRUE FOR EXTRUSIONS AS LARGE AS FIVE INCHES IN DIAMETER.

CRACK - AN EXTENDED VOID STRUCTURE HAVING NO CONNECTING MATERIAL BETWEEN OPPOSITE FACES. CRACKS ARE GENERALLY DUE TO EXCESSIVE OUT-GASSING DURING THE CARBONIZATION OF THE BINDER, OR TO THERMAL STRESS CAUSED BY EXCESSIVELY RAPID COOLING.

SPONGY AREA - PORTION OF THE GRAPHITE MATRIX WITH ABNORMALLY LOW DENSITY.

AG = ACROSS GRAIN
WG = WITH GRAIN
REP = REPRESENTATIVE OF

J. SERVICE LIMITS
K. PROCESSING
SURFACE TREATMENT
THERMAL TREATMENT
K. PROCESSING (CONTINUED)
JOINING
FORMING
MACHINABILITY
L. REFERENCES

NP-65-14
NP-65-15
NP-65-16
NP-65-17
NP-64-11

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

0.40
0.30
0.20
0.10
0
BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

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J. SERVICE LIMITS
K. PROCESSING
SURFACE TREATMENT
THERMAL TREATMENT
K. PROCESSING (CONTINUED)
JOINING
FORMING
MACHINABILITY
L. REFERENCES

NP-65-14
NP-65-16
NP-64-15
NP-65-17
NP-64-11

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

POISSON'S RATIO

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES

NUCLEAR MATERIALS

MATERIALS DATA

**VI
NUCLEAR MATERIALS**

**B.
NEUTRON CONTROL MATERIALS**

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

THIS ALLOY IS USED IN NUCLEAR REACTORS FOR CONTROL RODS AND SHIELDING. ITS PROPERTIES, OTHER THAN NUCLEAR, ARE VERY SIMILAR TO THE STANDARD AISI 304 STAINLESS STEEL. THE ADDITION OF GADOLINIUM (Gd) PROVIDES A MUCH HIGHER THERMAL NEUTRON ABSORPTION CROSS-SECTION THAN OTHER AUSTENITIC STAINLESS STEELS.

THE PROPERTIES GIVEN IN SECTION E-1, HEREIN, ARE AVERAGES EXCEPT FOR TENSILE ULTIMATE STRENGTH, TENSILE YIELD STRENGTH, ELONGATION, AND REDUCTION OF AREA WHICH ARE ALL 80% OF AVERAGE.

THE PROPERTIES GIVEN IN SECTIONS E-2 AND F ARE THOSE FOR CONVENTIONAL AISI 304 STAINLESS STEEL. WORK DONE TO DATE INDICATES THAT THE ADDITION OF GADOLINIUM IN THE RANGE SPECIFIED HAS LITTLE EFFECT ON THESE PROPERTIES.

B. COMMERCIAL DESIGNATIONS

AIISI 304 WITH GADOLINIUM

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BAR AND STRIP, HOT ROLLED AND ANNEALED	PURCHASED BY WESTINGHOUSE ASTRONUCLEAR LABORATORY TO THEIR SPECIFICATION: WANL - PDS - 30057

SUPPLIERS

CARPENTER STEEL COMPANY
READING, PENNSYLVANIA

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Mn	P	S	Si	Cr	Ni	Gd	Fe
MAXIMUM	0.08	2.0	0.04	0.03	1.0	20.0	12.0	1.0	BAL
MINIMUM	-	-	-	-	-	17.0	8.0	0.8	-

SOURCE WESTINGHOUSE ASTRONUCLEAR LABORATORY
SPECIFICATION: WANL-PDS-30057

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

HOT-ROLLED AND
ANNEALED STRIP

TENSILE ULTIMATE STRENGTH F_{TU} PSI
75,000

TENSILE YIELD STRENGTH F_{TY} PSI
28,000

COMP. YIELD STRENGTH F_{CY} PSI

ULTIMATE SHEAR STRENGTH F_{SU} PSI

SHEAR YIELD STRENGTH F_{SY} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

e/D = 1.5
e/D = 2.0

YIELD BEARING STRENGTH F_{BRY} PSI

e/D = 1.5
e/D = 2.0

ELONGATION
(LONGITUDINAL) 50 %
(TRANSVERSE) 48

REDUCTION OF AREA RA %

(DIRECTION NOT GIVEN) 41

MODULUS OF ELASTICITY E 10^6 PSI

26

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

MODULUS OF RIGIDITY G 10^6 PSI

(DYNAMIC) 13

POISSON'S RATIO

HARDNESS R_B

80

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³

0.287

SPECIFIC HEAT C BTU/LB - °F

0.12

THERMAL CONDUCTIVITY k BTU - FT
HR - FT² - °F

9.4

MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN.
IN. - °F

9.2

ELECTRICAL RESISTIVITY R MICROHM - IN.

28.0

MAGNETIC PROPERTIES

NON-MAGNETIC IN ANNEALED CONDITION

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2550° - 2650°F

PHASE CHANGES

WHEN PROPERLY ANNEALED, THE STRUCTURE IS PRIMARILY AUSTENITIC, WITH SMALL QUANTITIES OF FERRITE BEING PRESENT. WHEN SLOWLY COOLED THROUGH, OR HELD WITHIN THE TEMPERATURE RANGE OF 800°-1500°F, CARBIDES ARE PRECIPITATED, AND THE STRUCTURE THEN CONSISTS OF AUSTENITE PLUS CARBIDES. THIS MATERIAL, HOWEVER, IS LESS SUSCEPTIBLE TO CARBIDE PRECIPITATION THAN ARE OTHER AUSTENITIC STAINLESS STEELS.

THERMAL CONDUCTIVITY VS TEMPERATURE

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSION VS. TEMPERATURE

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE

GENERAL CORROSION RESISTANCE TO VARIOUS ATMOSPHERES, MOST ACIDS, STEAM, AND COMBUSTION GASES, IS VERY GOOD.

THE FOLLOWING MATERIALS HAVE NO CORROSIVE EFFECT ON TYPE 304 STAINLESS STEEL: ACETONE, BENZOL, ETHYL ALCOHOL, ETHYL CHLORIDE, ETHYL ETHER, FURFURAL, METHYL ALCOHOL, METHYL CHLORIDE, MINERAL OILS, VEGETABLE OILS, NITRIC ACID, PHOSPHORIC ACID, CONCENTRATED SULPHURIC ACID, ALUMINUM SULFATE, COPPER CYANIDE, COPPER SULFATE AND SODIUM NITRATE.

CARBIDE PRECIPITATION REDUCES CORROSION RESISTANCE. PASSIVATING IS NECESSARY TO DEVELOP BEST CORROSION RESISTANCE.

OXIDATION RESISTANCE IS GOOD UP TO 1700°F FOR CONTINUOUS SERVICE, AND TO 1600°F FOR INTERMITTENT SERVICE.

INTERGRANULAR CORROSION AFTER WELDING OR HEATING MAY OCCUR IN TYPE 304 (SEE PHASE CHANGES, SECTION F)

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

J. SERVICE LIMITS

CRYOGENIC TEMPERATURES:
TO -423°F

ELEVATED TEMPERATURE:
INTERMITTENT SERVICE TO 1600°F
CONTINUOUS SERVICE TO 1700°F

K. PROCESSING

SURFACE TREATMENT

CLEANING
ORGANIC SOLVENTS (CHLORIDE FREE PREFERRED), PICKLING,
SAND BLASTING

THERMAL TREATMENT

NOT HARDENABLE BY THERMAL TREATMENT.
HEAT TREATMENTS ARE USED MAINLY TO SOFTEN, RELIEVE
STRESSES AND DISSOLVE CARBIDES. THERMAL TREATMENT
RANGES ARE:

PARTIAL STRESS RELIEF 500 - 800°F

ANNEALING 1850 - 1950°F

HOLDING TIMES DEPEND ON SECTION SIZE

CARBIDE PRECIPITATION RANGE (TO BE AVOIDED):
800 - 1500°F

K. PROCESSING (CONTINUED)

JOINING

SEE V-8-04/2

FORMING

MACHINABILITY

L. REFERENCES

NP-56-3
NP-60-20
NP-65-17

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

BASIC DATA

A. GENERAL

LITHIUM HYDRIDE IS A WHITE, TRANSLUCENT, CRYSTALLINE SOLID. IT IS USED IN ORGANIC SYNTHESIS, AS A RAW MATERIAL FOR THE PRODUCTION OF OTHER, MORE COMPLEX HYDRIDES, AND AS A CHEMICAL REDUCING AGENT. ITS APPLICATION TO NERVA IS FOR NUCLEAR SHIELDING. LITHIUM HYDRIDE IS STABLE WITH RESPECT TO THERMAL DISSOCIATION AND WILL NOT DECOMPOSE WHEN MELTED. IT HAS GOOD ELECTRICAL CONDUCTIVITY AND CAN BE ELECTROLYZED IN ITS FUSED STATE. THERE IS SOME CONTAMINATION IN SPITE OF CLOSE CONTROL DURING MANUFACTURE. IT IS A HAZARDOUS MATERIAL ESPECIALLY IN WATER OR MOIST AIR.

THE VALUES IN SECTION E ARE AVERAGES OF THE AVAILABLE DATA.

B. COMMERCIAL DESIGNATIONS

LITHIUM HYDRIDE (LIH)

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
CLASS I	1 1/2 IN & SMALLER (INCLUDING FINES)
CLASS II	THROUGH 1 1/2 IN., RETAINED ON 1/4 IN. MESH
CLASS III	THROUGH 1/4 IN., RETAINED ON 8 MESH
CLASS IV	THROUGH 8 MESH, RETAINED ON 35 MESH
CLASS VI	THROUGH 35 MESH ± 100% " 60 " ± 90% " 100 " ± 80% " 150 " ± 65% " 200 " ± 45%
SHAPES	

SUPPLIERS

FOOTE MINERAL CO. PHILADELPHIA, PA.
LITHIUM CORPORATION OF AMERICA
MINNEAPOLIS, MINN.

D. CHEMICAL COMPOSITION (%)

ELEMENT	LIH	Na	K			
NOMINAL	96	0.09	0.02			

SOURCE NP-58-6

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI

TENSILE YIELD STRENGTH F_{TY} PSI

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

ELONGATION e %

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI

MODULUS OF RIGIDITY G 10^6 PSI

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³
0.0245 -- 0.027

SPECIFIC HEAT C BTU/LB - °F
0.65

THERMAL CONDUCTIVITY k BTU - FT / HR - FT² - °F
CAST 8
COMPACTED 4.3

MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN. / IN. - °F
17

ELECTRICAL RESISTIVITY R MICROHM - IN.

MAGNETIC PROPERTIES

DIAMAGNETIC

F. THERMOPHYSICAL EFFECTS

MELTING TEMPERATURE

1256°F

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE (°F)	k (BTU - FT / HR - FT ² - °F)	
	CAST	COMPACTED
100	7.5	4.1
200	6	3.9
300	5.4	3.7
400	4.4	3.5
600	3	3
800	2.4	2.6
900	2	2.4

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSION VS. TEMPERATURE

G. CHEMICAL PROPERTIES

COMPATIBILITY:

SOLUBLE IN POLAR ORGANIC SOLVENTS SUCH AS ETHER. NO APPRECIABLE SOLUBILITY IN INERT SOLVENTS. DECOMPOSES IN WATER. COMPATIBLE WITH NITROGEN, HYDROGEN, ARGON, AND HELIUM.

CORROSION:

CORROSIVE EFFECT OF MOLTEN LITHIUM HYDRIDE INCREASES AS THE IMPURITIES INCREASE. HIGH PURITY MATERIAL HAS NO APPARENT EFFECT ON ARMCO IRON OR AISI 321 AND 347 STAINLESS STEELS AT TEMPERATURES BELOW 1328°F.

H. NUCLEAR PROPERTIES
(SEE ALSO APPENDIX B)

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS
K. PROCESSING (CONTINUED)
JOINING
FORMING

CAN BE CAST OR COMPACTED. COMPACTION IS THE MORE PRACTICAL METHOD OF PRODUCING PELLETS AND SMALLER SLABS.

PROCESSING TECHNIQUES MUST GIVE DUE CONSIDERATION TO THE REACTIVITY OF LITHIUM HYDRIDE IN AIR AND WATER.

MACHINABILITY

CAN BE MACHINED TO A TOLERANCE OF $\pm 1/16$ INCH.

L. REFERENCES

NP-57-4
NP-58-6
NP-58-7
NP-59-10
NP-62-38

DATE 1 MAY 1966
SUPERSEDES

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

BLANK

DATE 1 MAY 1966

SUPERSEDES

NUCLEAR MATERIALS

MATERIALS DATA

**VI
NUCLEAR MATERIALS
C.
MODERATOR MATERIALS**

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

BERYLLIUM IS USED AS A STRUCTURAL MATERIAL, FOR HEAT SINKS, AND FOR NUCLEAR MODERATORS AND REFLECTORS. IT HAS GOOD RATIOS OF STRENGTH-TO-WEIGHT AND MODULUS OF ELASTICITY-TO-WEIGHT. THIS MATERIAL IS NOTCH-SENSITIVE AND SUBJECT TO CATASTROPHIC POST-BUCKLING FAILURE. BERYLLIUM IS A POTENTIALLY TOXIC MATERIAL TO LUNG TISSUE.

THE DATA GIVEN IN SECTION E-1 ARE MINIMA PER THE AMS SPECIFICATION VALUES FOR F_{TU} , F_{TY} , e , AND RA .

DATA FOR F_{TU} , F_{TY} AND e IN SECTION E-1 WHICH ARE FOLLOWED BY ** ARE STATISTICAL ANALYSIS VALUES OF BRUSH S-200 BERYLLIUM SHEET, FOR A POPULATION OF 99% WITH 95% CONFIDENCE

B. COMMERCIAL DESIGNATIONS

HOT PRESSED BERYLLIUM BLOCK, ROLLED BERYLLIUM SHEET, HOT PRESSED BERYLLIUM SHEET, EXTRUDED BERYLLIUM.

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
BARS, RODS AND SHAPES, VIRGIN BERYLLIUM (98.20% Be MIN)	AMS 7900
BARS, RODS AND SHAPES (98.00% Be MIN.)	AMS 7901
SHEET AND PLATE (98.00% Be MIN.)	AMS 7902

SUPPLIERS

GENERAL ASTROMETALS, YONKERS, N.Y.
BERYLLIUM CORP., READING, PA.
BRUSH BERYLLIUM CORP., CLEVELAND, OHIO

D. CHEMICAL COMPOSITION (%)

ELEMENT	BeO	Fe	Al	C	Si	Mg	*	Be
MAXIMUM	2.00	0.20	0.20	0.15	0.12	0.08		-
MINIMUM	-	-	-	-	-	-	-	98.00

* IMPURITIES, EACH, 0.04 MAXIMUM
SOURCE AMS 7901

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

AMS 7900	AMS 7901	AMS 7902	BLOCK POWDER MET.	CROSS ROLLED	SHEET HOT UPSET
TENSILE ULTIMATE STRENGTH F_{TU} PSI					
35,000	40,000	65,000*			
LONG			73,700**		
TRANS			73,500**		

TENSILE YIELD STRENGTH F_{TY} PSI					
27,000	30,000	45,000*			
LONG			47,700**		
TRANS			49,500**		
COMP. YIELD STRENGTH F_{CY} PSI					
			40,500	58,000	50,000

SHEAR STRENGTH F_{SU} PSI					
			50,800	70,000	

ULTIMATE BEARING STRENGTH F_{BRU} PSI					
			128,000	144,000	

BEARING YIELD STRENGTH F_{BRY} PSI					
			120,000	130,000	

ELONGATION e %					
1.0	1.0	5.0*			
LONG			4.6**		
TRANS			4.6**		

REDUCTION OF AREA RA %					
--	--	--	--	--	--

MODULUS OF ELASTICITY E 10^6 PSI					
			44.0	43.5	42.0

MODULUS OF RIGIDITY G 10^6 PSI					
			20		

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI					
			42.0	42.5	45.0

PLASTIC BENDING MODULUS (SEE APPENDIX A)					
---	--	--	--	--	--

* THICKNESS UNDER 0.25 INCHES

2. PHYSICAL PROPERTIES

DENSITY ρ LB/IN³	0.066
--	-------

SPECIFIC HEAT C BTU/LB - °F	0.445
---	-------

THERMAL CONDUCTIVITY k BTU - FT / HR - FT² - °F	104
--	-----

MEAN COEFF. LIN. THERMAL EXPANS. α 10^{-6} IN. / IN. - °F	6.7*
(75° TO 100°F)	

ELECTRICAL RESISTIVITY R MICROHM - IN.	2.0
--	-----

MAGNETIC PROPERTIES	NON-MAGNETIC
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F. THERMOPHYSICAL EFFECTS

MELTING RANGE	2340° - 2360°F
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PHASE CHANGES	HCP TO BCC AT 2280°F
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TEMPERATURE (°F)	k (BTU - FT / HR - FT ² - °F)
RT	104
200	98
400	89
600	80
800	71
1000	62
1200	55
1400	48
1600	41
1800	38
2000	32
2200	29

* AVERAGE OF 0.9% AND 2.0% BeO CONTENTS

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSIONITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

BERYLLIUM IS RESISTANT TO OXIDATION AT TEMPERATURES TO 1300°F.

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

THERMAL NEUTRON ABSORPTION CROSS-SECTION RANGES FROM 0.0085 TO 0.0095 BARN PER ATOM.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
J. SERVICE LIMITS

RT TO 1300°F IN AIR.

RT TO 1600°F IN H₂ OR INERT GAS

STRESS LIMITED BY CREEP

K. PROCESSING
SURFACE TREATMENT
PICKLING:

2% HF, 40% HNO₃, BALANCE H₂O AT ROOM TEMPERATURE FOR 1 - 2 MIN.

METAL REMOVAL:

10.3% H₃PO₄, 0.6% H₂SO₄, 15.6% CrO₃, 73.5% H₂O AT 81° - 90°F. THIS SOLUTION REMOVES ABOUT 1/2 MIL PER MINUTE AND LEAVES A SATIN-FINISH ALMOST FREE OF PITS.

ELECTROPLATING:

ANY COMMONLY USED PLATING METAL CAN BE APPLIED TO BERYLLIUM.

THERMAL TREATMENT
STRESS-RELIEF:

1350° - 1450°F, 30 MIN. - 1 HOUR VACUUM OR INERT GAS ATMOSPHERE.

ANNEALING:

1850°F VACUUM OR INERT-GAS ATMOSPHERE.

K. PROCESSING (CONTINUED)
JOINING
MECHANICAL:

FASTENING OTHER THAN RIVETING IS PREFERRED. UP TO 1200°F, THE JOINT-STRENGTH REDUCTION WITH INCREASE IN TEMPERATURE IS MAINLY DUE TO LOSS OF FASTENER STRENGTH. ABOVE 1200°F, LOSS OF STRENGTH IS IN THE BERYLLIUM. USE OF ADHESIVES SHOULD BE CONSIDERED.

WELDING:

FUSION, LIMITED TO LOW-STRESS APPLICATIONS TO 1000°F AND WHERE PRESSURE WELDING CANNOT BE USED, SHOULD BE PRE-HEATED IN THE 800° - 1200°F RANGE.

PRESSURE WELDING RECOMMENDED FOR APPLICATIONS WHERE PROPER JIGGING CAN BE USED.

BRAZING:

WIDELY USED, PREPLACEMENT OF SILVER (Ag-0.5% Li) BRAZE ALLOY IS DESIRABLE.

SOFT-SOLDERING:

EFFECTIVE WHEN PRESS-FIT JOINT IS USED.

FORMING:

HOT FORGING AT 1950°F. SPINNING, BENDING, AND DEEP DRAWING CAN BE DONE TO SOME DEGREE. CAN BE EXTRUDED, CROSS-ROLLED, AND HOT UPSET.

MACHINABILITY

SIMILAR TO CAST IRON, BUT MORE BRITTLE AND ABRASIVE. CARBIDE TOOLS ARE PREFERRED. RIGIDLY SUPPORT PARTS VULNERABLE TO DISTORTION AND VIBRATION, THE USE OF CUTTING FLUID CONTROLS DUST AND REDUCES TOXICITY HAZARD.

L. REFERENCES

NP-62-31
NP-64-8
NP-65-6
NP-65-39

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 1 MAY 1966

SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
TIME**

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

IMPACT STRENGTH

ROCKWELL HARDNESS

DATE 15 SEPT. 1967
SUPERSEDES 1 MAY 1966

**REDUCTION OF AREA
ELONGATION**

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

**POISSON'S RATIO
DENSITY**

ELECTRICAL RESISTIVITY

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
1

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

BASIC DATA

A. GENERAL

BERYLLIUM, A LIGHT-WEIGHT, HIGH-MODULUS METAL, IS USED AS A STRUCTURAL MATERIAL, FOR HEAT SINKS, AND FOR NUCLEAR MODERATORS AND REFLECTORS. IT HAS GOOD RATIOS OF STRENGTH TO WEIGHT AND MODULUS OF ELASTICITY TO WEIGHT. THIS MATERIAL IS NOTCH-SENSITIVE AND SUBJECT TO CATASTROPHIC POST-BUCKLING FAILURE. BERYLLIUM IS A POTENTIALLY TOXIC MATERIAL TO LUNG TISSUE, SO SPECIAL PRECAUTIONS MUST BE TAKEN TO PREVENT INHALATION.

THE DATA GIVEN IN SECTION E-1 ARE MIL-HNDBK-5A OR SPECIFICATION MINIMA VALUES FOR F_{TU} , F_{TY} , e , AND RA ; EXCEPT THAT THOSE VALUES WHICH ARE FOLLOWED BY *** ARE STATISTICAL ANALYSIS VALUES OF BRUSH S-200 BERYLLIUM SHEET OR BLOCK, FOR A POPULATION OF 99% WITH 95% CONFIDENCE.

B. COMMERCIAL DESIGNATIONS

(SEE "SUPPLIERS")

BLOCK: S-100 (A), HP-12 (B), GB-1 (C)

C.R. SHEET: SR-200 (A), HPS-20 (B)

INGOT SHEET: IS-2 (B)

(SEE "NOMENCLATURE" ON PAGE 1A)

C. FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
(SEE FOURTH COLUMN THIS PAGE)	

SUPPLIERS

- (A) BRUSH BERYLLIUM CO., CLEVELAND, OHIO
(B) THE BERYLLIUM CORP., READING, PENNA.
(C) GENERAL ASTROMETALS CORP., YONKERS, N.Y.

D. CHEMICAL COMPOSITION (%)

ELEMENT *	BeO	Fe	Al	C	Si	Mg	Be
AVERAGE	2.00	0.18	0.15	0.15	0.08	0.08	-
MINIMUM	-	-	-	-	-	-	98.0

SOURCE: REF. 66-43

* IMPURITIES,
EACH, 0.04 MAXIMUM

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	AMS 7900	M-H 5A *	BLOCK 7902	VAC. H-P	CROSS ROLLED	SHEET HOT UPSET
ULTIMATE TENSILE STRENGTH F_{TU}						KSI.
	35	-	65 **	35.9 ***	-	-
L_e	-	40	-	-	73.7 ***	-
T_e	-	43	-	-	73.5 ***	-

TENSILE YIELD STRENGTH F_{TY}						KSI.
	27	27	45 **	26.9 ***	-	-
L_e	-	-	-	-	47.7 ***	-
T_e	-	-	-	-	49.5 ***	-

COMP. YIELD STRENGTH F_{CY}						KSI.
	-	27	-	40.5	58	50

ULTIMATE SHEAR STRENGTH F_{SU}						KSI.
	-	33	-	50.8	70	-

ULTIMATE BEARING STRENGTH F_{BRU}						KSI.
$e/D=1.5$	-	88	-	-	-	-
$e/D=2.0$	-	110	-	128	144	-

BEARING YIELD STRENGTH F_{BRY}						KSI.
$e/D=1.5$	-	-	-	-	-	-
$e/D=2.0$	-	-	-	120	130	-

ELONGATION e						%
	1.0	1.0	5.0 **	-	5.0	-
L_e	-	-	-	1.3 ***	4.6 ***	-
T_e	-	-	-	1.8 ***	4.6 ***	-

REDUCTION OF AREA RA						%
------------------------	--	--	--	--	--	---

MODULUS OF ELASTICITY E						10^6 PSI.
	-	42.5	-	42.5	42.5	42.0

MODULUS OF RIGIDITY G						10^6 PSI.
	-	20	-	-	20	-

* MIL-HNDBK-5A (AMS 7901 MATERIAL, "A" BASIS DATA)
** THICKNESS UNDER 0.25 INCHES
*** SEE PARAGRAPH A, SECOND SUBPARAGRAPH

1. MECHANICAL PROPERTIES (CONTINUED)

	AMS 7900	M-H 5A *	AMS 7902	POWDER MET.	CROSS ROLLED	SHEET HOT UPSET
COMP. MOD. OF ELASTICITY E_C						10^6 PSI.
	-	42.5	-	42.0	42.5	45.0

POISSON'S RATIO

AVERAGE 0.085

HARDNESS BHN

106

2. PHYSICAL PROPERTIES

DENSITY ρ						
LB/IN ³						0.067
g/cc						1.85

SPECIFIC HEAT C						BTU/LB - °F
(AT 77° F)						0.445

THERMAL CONDUCTIVITY k						$\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$
(AT 212° F)						91
(AT 45° F)						116 ($\pm 1\%$)

MEAN COEFF. LIN. THERMAL EXPAN. α						$\frac{10^{-6} IN.}{IN. \cdot ^\circ F}$
77° TO 212° F						6.4

ELECTRICAL RESISTIVITY R						MICROHM - IN
(AT 45° F)						1.76 ($\pm 0.05\%$)

ELECTRICAL CONDUCTIVITY						% IACS.
						35 TO 42

MAGNETIC PROPERTIES
NON-MAGNETIC

C. FORMS, SPECIFICATIONS, SUPPLIERS

(CONTINUED FROM FIRST COLUMN)

FORMS AND CONDITIONS	SPECIFICATIONS *
BARS, RODS, AND SHAPES, VIRGIN BERYLLIUM, 1.50% BeO MAX.	AMS 7900 (-200 MESH VIRGIN POWDER) (AS-HOT PRESSED)
BARS, RODS, AND SHAPES, BLEND OF VIRGIN AND RECYCLED POWDER, 2.00% BeO MAX.	AMS 7901 (-200 MESH POWDER) (AS-HOT PRESSED)
BAR, EXTRUDED	PDS-30034 (WANL)
BLOCK, VACUUM HOT PRESSED	PDS-30018 (WANL)
SHEET AND PLATE, BLEND OF VIRGIN AND RECYCLED POWDER, 2.00% BeO MAX.	AMS 7209 (-200 MESH POWDER) (HOT ROLLED AND ANNEALED)
CROSS-ROLLED SHEET	
STRIP, PLATE	
WIRE	
FOIL (MIN. THICKNESS 0.0005-IN.)	
EXTRUSION	
FORGINGS	

* SEE ALSO S-100C, S-200C OR S-R-200, S-300C, I-400C, "NOMENCLATURE", PAGE VI-C-12/1A

THE PROPERTIES OF BERYLLIUM DIFFER WIDELY, NOT ONLY BETWEEN DIFFERENT GRADES, BUT BETWEEN DIFFERENT LOTS. ADDITIONAL VARIATIONS IN PROPERTIES MAY BE FOUND BETWEEN DIFFERENT PIECES IN A GIVEN LOT, AS WELL AS BETWEEN LOCATIONS AND ORIENTATIONS WITHIN A SINGLE PIECE. THIS WIDE VARIATION IS DUE TO THE SENSITIVITY OF BERYLLIUM PROPERTIES TO MANY VARIABLES. THESE VARIABLES INCLUDE DIFFERENCES IN STARTING MATERIALS, BERYLLIUM OXIDE CONTENT, GRAIN SIZE, AND FORMING METHODS. IN SUMMARY, THE PROPERTIES AND UNIFORMITY OF THE FINAL PRODUCT ARE GREATLY INFLUENCED BY MANUFACTURING AND MATERIAL VARIABLES.

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
1A

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

BASIC DATA

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

2340°-2360° F

BOILING POINT

AT 1 ATMOSPHERE 5378° F

PHASE CHANGES (TRANSFORMATION TEMP.)

HEXAGONAL CLOSE PACKED TO BODY-CENTERED CUBIC AT 2280° F.

RECRYSTALLIZATION TEMPERATURES

TYPE	TOTAL REDUCTION IN THICKNESS %	TEMP °F
SR CAST	50 - 100	1346
	180 - 225	1292
SR POWDER	8 - 235	1472
	50 - 225	1472
QMV CAST	50 - 100	1427
	180 - 225	1400
QMV POWDER	50 - 250	1490

THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE °F	k $\left(\frac{\text{BTU-FT}}{\text{HR-FT}^2-\text{°F}} \right)$
-320	126
-260	154
-200	157
-151	151
-100	142
9	122
45	116
200	98
400	89
600	80
800	71
1000	62
1200	55
1400	48
1600	41
1800	38
2000	32
2200	29

ACCURACY
± 1%

F. THERMOPHYSICAL EFFECTS (CONTINUED)

VAPOR PRESSURE

TEMPERATURE °F	PRESSURE, ATMOSPHERES
1600	1.7×10^{-8}
1800	1.7×10^{-7}
2000	1.6×10^{-6}
2200	1.1×10^{-5}
2400	6.0×10^{-5}
2600	3.0×10^{-4}
2800	1.2×10^{-3}
3000	4.4×10^{-3}

G. CHEMICAL PROPERTIES

OXIDATION

BERYLLIUM IS RESISTANT TO OXIDATION AT TEMPERATURES TO 1290° F.

IT IS PROTECTED BY A VERY THIN OXIDE FILM AT ROOM TEMPERATURE IN AIR, WHEN HEATED IN AIR FOR 1 HOUR, A BARELY PERCEPTIBLE TEMPER COLOR APPEARS AT 1290° F, A WHITE FILM AT 1470° F, AND A HEAVY WHITE SCALE AT 1832° F. OXIDATION DAMAGE IN THE FORM OF GRAIN BOUNDARY ATTACK OCCURS AFTER 1 HOUR AT 1650° F.

CAUTION - OPERATIONS PRODUCING FUMES OR FINE PARTICLES MUST BE WELL VENTED, SINCE INHALATION OF Be MUST BE AVOIDED, BOTH THE METAL AND ITS OXIDE BEING TOXIC. SEE NOTE UNDER "MACHINABILITY".

ISOTROPY

HOT-PRESSED BLOCK IS MORE ISOTROPIC THAN IS COLD-PRESSED BLOCK

H. NUCLEAR PROPERTIES

THERMAL NEUTRON ABSORPTION CROSS-SECTION RANGES FROM 0.0085 TO 0.0095 BARNS PER ATOM.

I. NOMENCLATURE

THE FOLLOWING NOMENCLATURE IS PECULIAR TO BERYLLIUM TECHNOLOGY (PARTICULARLY THAT PRODUCED BY THE BRUSH BERYLLIUM CO.).*

PROCESS Q - A METHOD BY WHICH RAW Be, MADE AS PEBBLE BY REDUCTION OF BeF₂ WITH Mg, IS VACUUM MELTED, AND CAST INTO INGOTS FOR POWDERING. THE CAST Be INGOTS ARE COMMUNUTED INTO POWDER, (AEC GENERAL SPECIFICATION FOR BERYLLIUM, FABRICATED BY POWDER METALLURGY, CALLS FOR ATTRITION TO -100 MESH) WHICH IS CONSOLIDATED BY HOT-PRESSING INTO FINE GRAINED BILLETS.

QT - POWDER OBTAINED FROM Be AS ABOVE, WITHOUT ANY SPECIAL PROCESS TO ELIMINATE SLAG.

QMV - POWDER MADE BY CASTING QT PEBBLE UNDER VACUUM INTO 50-LB INGOTS, AND POWDERING CHIPS MACHINED FROM THESE INGOTS.

FLAKE - Be PRODUCED BY ELECTROLYSIS OF A MOLTEN BeCl₂-NaCl MIXTURE, USUALLY IN EUTECTIC PROPORTIONS.

I. NOMENCLATURE (CONTINUED)

VACUUM HOT-PRESSED (OR HOT-PRESSED) - SHAPES PREPARED FROM QMV POWDER BY LOW PRESSURE (100 TO 200 PSI) HOT PRESSED UNDER VACUUM AT 1922 TO 2012° F, TO PRODUCE A FINE-GRAINED, RELATIVELY ISOTROPIC PRODUCT.

WARM PRESSED - PROCESSED AT 752 TO 842° F.

WARM EXTRUDED - EXTRUDED AT 752 TO 842° F.

HOT EXTRUDED - EXTRUDED AT 1832 TO 2012° F.

CROSS-ROLLED SHEET - SHEET ROLLED BOTH PARALLEL AND NORMAL TO THE LENGTH, PRODUCING A MODERATE DUCTILITY IN THESE TWO DIRECTIONS, AND A RELATIVELY HIGH LEVEL OF STRENGTH, DUE (IN PART) TO RESIDUAL COLD WORK FROM THE FABRICATION PROCESS.

HOT-UPSET SHEET - SHEET PRODUCED BY AN UPSET-FORGING PROCESS, CONSOLIDATING CANNED Be POWDERS OR INGOTS BY UPSET-FORGING AT 1850 TO 1950° F, THUS ORIENTING THE BASAL AND PRISM SLIP PLANES MORE FAVORABLY TO ACCOMMODATE COMPLEX STRESSING WITHOUT FRACTURE.

INGOT SHEET - SHEET WHICH (GENERALLY) IS EXTRUDED AND THEN CROSS ROLLED.

POWDER SHEET - SHEET OBTAINED BY CROSS-ROLLING HOT-PRESSED BERYLLIUM SLABS.

S-100 C, S-200 C OR S-R-200, S-300 C, I-400 C - BRUSH BERYLLIUM CO. SPECIFICATIONS FOR GRADES OF Be, DESIGNATING, RESPECTIVELY, THE INCLUSION OF 1%, 2%, 3% AND 4% BeO. GRADES S-100 AND S-300 ARE NOT CURRENTLY IN PRODUCTION.

L, OR LONG. - PARALLEL TO PRESSING DIRECTION.

T, OR TRANS. - NORMAL TO PRESSING DIRECTION.

EXT. - EXTRUDED

C.R. - CROSS-ROLLED

H.P. - HOT-PRESSED

* SEE ALSO ASTM B 243, "DEFINITION OF TERMS USED IN POWDER METALLURGY"

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
2

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

BASIC DATA

J. SERVICE LIMITS

RT TO 1300°F IN AIR

RT TO 1600°F IN H₂ OR INERT GAS

CREEP PROPERTIES SHOULD BE SERIOUSLY CONSIDERED IF HIGH STRESS-OPTIONS ARE TO BE MAINTAINED ABOVE 1000°F.

K. PROCESSING

SURFACE TREATMENT

A SURFACE TREATMENT TO REMOVE THE EXTREME OUTER SURFACE OF METAL IS RECOMMENDED TO INSURE THE PROPERTIES SPECIFIED. ALL DESIGN ALLOWABLES ARE FOR MATERIAL SO PREPARED. THIS IS ESPECIALLY IMPORTANT WHEN IT IS TO BE MECHANICALLY JOINED.

PICKLING

2% HF, 50% HNO₃, BALANCE H₂O AT ROOM TEMPERATURE FOR 1 TO 2 MINUTES.

METAL REMOVAL

10.3% H₃PO₄, 0.6% H₂SO₄, 15.6% CrO₃, 73.5% H₂O AT 81 TO 90°F. THIS SOLUTION REMOVES ABOUT 1/2 MIL PER MINUTE AND LEAVES A SATIN-FINISH ALMOST FREE OF PITS.

ELECTROPLATING

ANY COMMONLY USED PLATING METAL CAN BE APPLIED TO BERYLLIUM.

K. PROCESSING (CONTINUED)

THERMAL TREATMENT

STRESS-RELIEF

1350-1450°F. 30 MIN TO 1 HOUR, IN VACUUM OR INERT GAS ATMOSPHERE. STRESS RELIEVING TIME MUST BE HELD TO A MINIMUM TO AVOID REDUCTION IN STRENGTH.

ANNEALING

1850°F IN VACUUM OR INERT-GAS ATMOSPHERE.

JOINING

MECHANICAL

FASTENING OTHER THAN RIVETING IS AVAILABLE, UP TO 1200°F, THE JOINT STRENGTH REDUCTION WITH INCREASE IN TEMPERATURE IS MAINLY DUE TO LOSS OF FASTENER STRENGTH. ABOVE 1200°F, LOSS OF STRENGTH IS IN THE BERYLLIUM. USE OF ADHESIVES SHOULD BE CONSIDERED.

WELDING

FUSION WELDING IS LIMITED TO LOW-STRESS APPLICATIONS TO 1000°F AND WHERE PRESSURE WELDING CANNOT BE USED WELD AREAS SHOULD BE PRE-HEATED IN THE 800-1200°F RANGE.

PRESSURE WELDING IS RECOMMENDED FOR APPLICATIONS WHERE PROPER JIGGING CAN BE USED.

BRAZING

WIDELY USED, AT 1700°F IN ARGON, MINIMIZE EXPOSURE TIME OVER 1500°F TO HOLD DOWN GRAIN GROWTH. PRE-PLACEMENT OF SILVER (Ag-0.5% Li) BRAZE ALLOY IS DESIRABLE (SEE "SOLDERING" NOTE).

SOFT-SOLDERING

EFFECTIVE WHEN PRESS-FIT JOINT IS USED. SOLDERING AND TORCH BRAZING REQUIRE AN ACTIVE FLUX TO REMOVE THE SURFACE OXIDE.

K. PROCESSING (CONTINUED)

FORMING

EXTREMELY LIMITED FORMABILITY AT ROOM TEMPERATURE; A FORMING RANGE BETWEEN 1000° AND 1400°F IS RECOMMENDED TO MINIMIZE RESIDUAL STRESSES AND TO PERMIT MAXIMUM DEFORMATION.

THE INFLUENCE OF FORGING TEMPERATURE ON ROOM TEMPERATURE TENSILE STRENGTH AND ELONGATION IS ILLUSTRATED BY THE FOLLOWING GRAPH:

HOT FORGING AT 1950°F, PARTICULARLY FOR RELATIVELY SIMPLE CONFIGURATION.

SPINNING, BENDING, AND DEEP DRAWING CAN BE DONE TO SOME DEGREE. CAN BE EXTRUDED, CROSS-ROLLED, AND HOT UPSET.

PARTS NOT FORMED AT A SLOW RATE MUST BE STRESS-RELIEVED.

K. PROCESSING (CONTINUED)

MACHINABILITY

BERYLLIUM IS BEST WORKED WHEN ITS SURFACES ARE KEPT UNDER COMPRESSION.

IT IS SIMILAR TO CAST IRON, BUT IS MORE BRITTLE AND ABRASIVE. CARBIDE TOOLS ARE PREFERRED. RIGIDLY SUPPORT PARTS VULNERABLE TO DISTORTION AND VIBRATION. THE USE OF CUTTING FLUID CONTROLS DUST AND REDUCES TOXICITY HAZARDS.

CARE MUST BE USED IN CUTTING OPERATIONS TO AVOID FRACTURE, DAMAGE, OR SPALLING AT POINTS OF BREAK OUT.

FABRICATORS SHOULD FOLLOW APPROVED PRACTICES FOR PROTECTION OF PERSONNEL.

L. REFERENCES

69- 7	66-10	64- 8	62-75
68-12	66-27	63- 2	62-82
68-34	66-37	63- 6	62-84
67-20	66-43	63-56	60- 1
67-21	65- 6	63-86	59- 6
67-22	65-34	62-30	58- 1
67-25	65-39	62-31	58- 4
67-29	64- 7	62-74	54- 6

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
3

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

TENSILE STRENGTHS

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
3A

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

TENSILE STRENGTHS

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

TENSILE STRENGTHS

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
3C

DATE 30 SEPT 1969
SUPERSEDES 1 MAY 1966

TENSILE STRENGTHS

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
3D

DATE 30 SEPT 1969

SUPERSEDES

TENSILE STRENGTHS

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

**VI-C-12
3E**

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

TENSILE STRENGTHS

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL**

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

VI-C-12
4A

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL

DATE 30 JUNE 1968
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL**

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12

DATE	30 SEPT 1969
SUPERSEDES	

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MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
5

DATE 30 JUNE 1968
SUPERSEDES

FATIGUE STRENGTH

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

**VI-C-12
5A**

DATE 30 JUNE 1968
SUPERSEDES

FATIGUE STRENGTH

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

**VI-C-12
5B**

DATE 30 JUNE 1968
SUPERSEDES

FATIGUE STRENGTH

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

**VI-C-12
5C**

DATE 30 JUNE 1968
SUPERSEDES

FATIGUE STRENGTH

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

**VI-C-12
6**

DATE 30 JUNE 1968
SUPERSEDES

**STRESS TO RUPTURE
AND CREEP
AS FUNCTION OF TEMPERATURE**

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
7

DATE 30 JUNE 1968
SUPERSEDES 1 MAY 1966

STRESS TO RUPTURE
AND CREEP
AS FUNCTION OF TEMPERATURE

DATE 30 JUNE 1968
SUPERSEDES 15 SEPT 1967

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
8A

DATE 30 JUNE 1968

SUPERSEDES 15 SEPT 1967

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
8B

DATE 30 SEPT 1969
SUPERSEDES

STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

**VI-C-12
8C**

DATE 30 JUNE 1968
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF TEMPERATURE**

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12

9

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

IMPACT STRENGTH
HARDNESS

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
10

DATE 30 JUNE 1968
SUPERSEDES

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
10A

DATE 30 JUNE 1968
SUPERSEDES 15 SEPT 1967

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
10B

DATE 30 SEPT 1969

SUPERSEDES

REDUCTION OF AREA
ELONGATION

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

**VI-C-12
10C**

DATE 30 JUNE 1968
SUPERSEDES 15 SEPT 1967

**REDUCTION OF AREA
ELONGATION**

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIALVI-C-12
10D

DATE 30 SEPT 1969

SUPERSEDES 30 JUNE 1968

ELONGATION
(AFTER IRRADIATION)

DESIGN VALUES,
80 % OF AVERAGE

EFFECTS OF IRRADIATION ON ELONGATION OF

S-200 BERYLLIUM

UNLESS OTHERWISE NOTED
E $\geq$ 1.0 MEV.

FORM AND CONDITION	GAGE LENGTH (IN.)	TEMPERATURES (°F)			PRE- IRRADIATION CONTROL VALUES	POST-IRRADIATION VALUES DOSAGES GIVEN AS INTEGRATED NEUTRON FLUX (NVT) IN TERMS OF NEUTRONS/CM ²										NO. OF IRRADIATION SPECIMENS	REFERENCE	COMMENTS
		IRRADIATION	POST- IRRADIATION ANNEAL	POST- IRRADIATION TEST		10 ¹⁵		10 ¹⁶		10 ¹⁷		10 ¹⁸		10 ¹⁹				
						ELONG, - %	DOSAGE	ELONG, - %	DOSAGE	ELONG, - %	DOSAGE	ELONG, - %	DOSAGE					
VAC, H.P. BLK, VAC, H.P. BLK, VAC, H.P. BLK, VAC, H.P. BLK, VAC, H.P. BLK, VAC, H.P. BLK, VAC, H.P. BLK		-320 -320 -320 -320 -320 -320		-320 -286 -200 -128 -100 -10	0,4 0,6 0,96 1,0 1,0 1,0					0 0 0 0 0,16 0,92	5 × 10 ¹⁷ 5 × 10 ¹⁷ 5 × 10 ¹⁷ 5 × 10 ¹⁷ 5 × 10 ¹⁷ 5 × 10 ¹⁷					67-22 67-22 67-22 67-22 67-22 67-22		
VAC, H.P. BLK,		-320		70	1,0					0,92	5 × 10 ¹⁷						67-22	
VACCUM HOT-PRESSED BLOCK; SPECIMENS IMMERSED IN LIQUID NITROGEN DURING IRRADIATION AND UNTIL TESTED

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

MODULUS OF ELASTICITY
MODULUS OF RIGIDITY

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
12

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

VALUES OF MEAN COEFFICIENT ARE FROM
ROOM TEMPERATURE TO INDICATED TEMPERATURES

THERMAL EXPANSION

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
13

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

THERMAL CONDUCTIVITY
SPECIFIC HEAT

MATERIALS DATA BOOK

**S-200 BERYLLIUM
NUCLEAR MATERIAL**

**VI-C-12
14**

DATE 30 SEPT 1969
SUPERSEDES

**THERMAL DIFFUSIVITY
EMITTANCE**

MATERIALS DATA BOOK

S-200 BERYLLIUM
NUCLEAR MATERIAL

VI-C-12
16

DATE 30 SEPT 1969
SUPERSEDES 30 JUNE 1968

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES

GRAPHITES

MATERIALS DATA

**VII
GRAPHITES**

**A.
STRUCTURAL GRAPHITES**

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

GRAPHITITE G IS PRODUCED BY EXTRUSION. IT IS FINE GRAINED AND DENSE, AND ALL LARGE AND ACCESSIBLE PORES ARE FILLED WITH A FINE CARBONACEOUS DUST BY MEANS OF A PROPRIETARY DENSIFICATION TREATMENT, THEREFOR GIVING LOW GAS PERMEABILITY.

ALTHOUGH GRAPHITITE G IS BRITTLE, IT HAS THE ADVANTAGES OF HIGH DENSITY, LOW PERMEABILITY, GOOD RESISTANCE TO THERMAL SHOCK, AND GOOD STRENGTH TO 5000°F. IT HAS A MATRIX FREE OF RADIOGRAPHICALLY DETECTABLE INCLUSIONS. THE HIGHEST STRENGTH IS OBTAINED WITH STOCK LESS THAN 2-IN. DIAMETER.

B. COMMERCIAL DESIGNATIONS

GRAPHITITE G.

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
EXTRUDED RODS	WANL-PDS - 30020
TUBES	

SUPPLIERS

BASIC CARBON CORP.,
DIVISION OF CARBORUNDUM CORP.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	OTHER, INCL. ASH							
AVERAGE	99.75	0.25							

SOURCE

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
TENSILE ULTIMATE STRENGTH E_{TU}				PSI
MANUFACTURER'S VALUE	2900			
WANL AVERAGES	2480	1600-3310		
COMP. YIELD STRENGTH E_{CY}				PSI
(ORIENTATION NOT GIVEN)			10,000	
SHEAR STRENGTH E_{SU}				PSI
FLEXURAL STRENGTH F_B				PSI
			1880	
ELONGATION e				%
			NEGLIGIBLE	
MODULUS OF ELASTICITY E				10^6 PSI
(AT RT)		1.5		
(AT 4200°F)		2.7		
COMP. MOD. OF ELASTICITY E_C				10^6 PSI
			1.5	
MODULUS OF RIGIDITY G				
POISSON'S RATIO				
			0.12	

THE PROPERTIES OF GRAPHITES DIFFER WIDELY, NOT ONLY BETWEEN DIFFERENT GRADES, BUT BETWEEN DIFFERENT LOTS. ADDITIONAL VARIATIONS IN PROPERTIES MAY BE FOUND BETWEEN DIFFERENT PIECES IN A GIVEN LOT AS WELL AS BETWEEN LOCATIONS AND ORIENTATIONS WITHIN A SINGLE BLOCK. THIS WIDE VARIATION IS DUE TO THE SENSITIVITY OF GRAPHITE PROPERTIES TO MANY VARIABLES. THESE VARIABLES INCLUDE DIFFERENCES IN STARTING MATERIALS, PARTICLE SIZE, FORMING METHOD, CONDITION OF THE FIRST BAKE, AND GRAPHITIZING CONDITIONS. IN SHORT, THE PROPERTIES AND UNIFORMITY OF THE FINAL GRAPHITE PRODUCT ARE GREATLY INFLUENCED BY MANUFACTURING AND MATERIAL VARIABLES.

2. PHYSICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
DENSITY ρ				
LB/IN ³			0.068	
g/cc			1.88	
SPECIFIC HEAT C				BTU/LB - °F
			0.26	
THERMAL CONDUCTIVITY k				$\frac{BTU - FT}{HR - FT^2 - °F}$
AT RT		92		
AT 4200°F		9		
MEAN COEFF. LINEAR THERMAL EXPANSION α				$\frac{10^{-6} IN.}{IN. - °F}$
			1.2	2.2
ELECTRICAL RESISTIVITY R				MICROHM - IN.
			300-350	

F. THERMOPHYSICAL EFFECTS

SUBLIMATION TEMPERATURE

AT ATM PRESSURE 6600°F

THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE °F	WITH GRAIN k	ACROSS GRAIN k
-423	-	0
-320	-	40
-100	-	78
0	107	74
75	104	73
100	102	71
500	83	56
900	66	43
1300	51	32
1700	40	23
2100	34	16
2500	32	14
2900	30	12
3300	28	11
3700	26	10
4100	25	9
4500	27	7

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMITTANCE VS TEMPERATURE

G. CHEMICAL PROPERTIES

REACTS WITH HYDROGEN AT HIGH TEMPERATURES UNLESS PROTECTED BY A SUITABLE COATING

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

GOOD NEUTRON MODERATOR

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

THIS SECTION IS INCLUDED TO PROVIDE A BRIEF SURVEY OF DEFECTS COMMONLY FOUND IN CONVENTIONAL EXTRUDED GRAPHITES, TO CLARIFY THEIR NATURE FOR THOSE NOT ALREADY COGNIZANT WITH GRAPHITE TECHNOLOGY.

PORE - A SPACE BETWEEN THE COKE PARTICLES NOT FILLED WITH SOLID MATERIAL. IT RESULTS FROM PARTIAL VAPORIZATION OF THE ORIGINAL PITCH BINDER. PORE DIMENSION IS GENERALLY SMALLER THAN THE PARTICLE SIZE. NOT A DEFECT.

VOID - A SPACE IN THE MATRIX NOT FILLED WITH SOLID MATERIAL. ITS SIZE IS MUCH LARGER THAN THE PARTICLE SIZE. A TRUE DEFECT.

(THE COMMON DISTINCTION BETWEEN PORES AND VOIDS IS THAT INDIVIDUAL PORES CANNOT BE DETECTED RADIOGRAPHICALLY. THE PRESENCE OF PORES IS A NORMAL FEATURE OF EXTRUDED AND MOLDED GRAPHITES, AND THEY CANNOT BE, THEREFORE, REGARDED AS DEFECTS EXCEPT IN FUNDAMENTAL CONSIDERATIONS. VOIDS, ON THE OTHER HAND, ARE TRUE DEFECTS BECAUSE THEY MAY BE ELIMINATED THROUGH PROPER LEVEL OF QUALITY CONTROL BY THE MANUFACTURER AND THE USER.)

INCLUSION - ANY FOREIGN (NON-CARBONACEOUS) MATERIAL IN GRAPHITE. GENERALLY DETECTABLE BY RADIOGRAPHIC INSPECTION BECAUSE OF ITS GREATER ABSORPTION FOR X-RAYS THAN THAT OF THE GRAPHITE MATRIX. INCLUSIONS ARE PREDOMINANTLY IMPURE IRON CARBIDES.

FLOW LINE - AN EXTENDED ARRAY OF LARGE PORES OR SMALL VOIDS, ALIGNED PARALLEL TO THE AXIS OF EXTRUSION, AND BRIDGED BY CONNECTING GRAPHITE STRUCTURE. SUCH FEATURES ARE CHARACTERISTIC OF EXTRUDED GRAPHITES, AND CAN BE TRACED TO THE EXTRUSION OF "GREEN MIX".

FLOW "LINES" ARE USUALLY NOT LINES, BUT CIRCUMFERENTIALLY CURVED PLANAR AGGREGATES OF OVERSIZE PORES. THEIR DETECTION BY RADIOGRAPHY IS NOT FEASIBLE UNLESS THE X-RAY BEAM IS PARALLEL TO THE PLANE. IF AN EXTRUDED LOG IS RADIOGRAPHED PERPENDICULAR TO THE AXIS, THE SENSITIVITY DROPS BECAUSE OF THE DECREASED BUILD-UP EFFECTS; THIS IS PARTICULARLY TRUE FOR EXTRUSIONS AS LARGE AS FIVE INCHES IN DIAMETER.

CRACK - AN EXTENDED VOID STRUCTURE HAVING NO CONNECTING MATERIAL BETWEEN OPPOSITE FACES. CRACKS ARE GENERALLY DUE TO EXCESSIVE OUT-GASSING DURING THE CARBONIZATION OF THE BINDER, OR TO THERMAL STRESS CAUSED BY EXCESSIVELY RAPID COOLING.

SPONGY AREA - PORTION OF THE GRAPHITE MATRIX WITH ABNORMALLY LOW DENSITY.

J. SERVICE LIMITS

EXCESSIVE VAPORIZATION NEAR 6000°F

K. PROCESSING
SURFACE TREATMENT

NO TYPE OF CLEANING SOLVENT SHOULD BE USED.

THERMAL TREATMENT

NOT APPLICABLE

K. PROCESSING (CONTINUED)
JOINING

MAY BE JOINED BY BRAZING. BRAZED JOINTS DEVELOP STRENGTHS EQUAL TO OR GREATER THAN THE PARENT MATERIAL. JOINING BY A CARBONACEOUS PROCESS RESULTS IN JOINTS WEAKER THAN THE PARENT MATERIAL. ORGANIC OR CARBONACEOUS CEMENTS ARE USED.

BRAZING CAN BE ACCOMPLISHED BY USING FILLER METALS THAT ARE GOOD CARBIDE FORMERS. THREE ALLOYS THAT ARE EFFECTIVE IN THE 1700°-1950°F RANGE ARE:

1. Ti CORED, 72% Ag - 28% Cu WIRE, BRAZE AT 1700°F
2. 72% Au - 22% Ni - 6% Cr WIRE, BRAZE AT 1950°F
3. 48% Ti - 48% Zr - 4% Be, 100-MESH POWDER, BRAZE AT 1950°F. (USED EXTENSIVELY BECAUSE OF ITS LINEAR THERMAL EXPANSION TO GRAPHITE).

FORMING

NOT APPLICABLE

MACHINABILITY

EXCELLENT

L. REFERENCES

NP-65-12
NP-64-11

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL**

DATE 1 MAY 1966

SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
10⁻⁶ IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

DATE 1 MAY 1966
SUPERSEDES

DENSITY

ELECTRICAL RESISTIVITY

BLANK

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

THIS GRAPHITE IS A COARSE-GRAINED EXTRUSION. IT IS AVAILABLE IN LARGE SIZES AND IS THEREFORE USED FOR LARGE REFRACTORY STRUCTURES AND CYLINDERS. IT TENDS TO BE BRITTLE AND TO CONTAIN RADIOGRAPHIC FLAWS. THE STRENGTH VARIES WITH GRAIN DIRECTION. IT MAY BE DENSIFIED INTO A STRONGER, MORE IMPERVIOUS MATERIAL BY THE MANUFACTURER'S PROPRIETARY PROCESS, AND IS THEN DESIGNATED H-249.

THE ROOM TEMPERATURE PROPERTIES GIVEN IN SECTION E ARE AVERAGE VALUES.

B. COMMERCIAL DESIGNATIONS

MHLM, H4LM, H-249

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
H4LM	WANL-PDS - 30073

SUPPLIERS

GREAT LAKES CARBON CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Fe	Other, Incl. Ash				
AVERAGE	99.5	0.125	0.375				
MINIMUM							

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
TENSILE ULTIMATE STRENGTH E_{TU}				
	1700		1500	
COMP. YIELD STRENGTH E_{CY}				
ORIENTATION NOT GIVEN				
	5800			
SHEAR STRENGTH E_{SU}				
FLEXURAL STRENGTH E_B				
ELONGATION e				
MODULUS OF ELASTICITY E				
ORIENTATION NOT GIVEN				
	1.3			
COMP. MOD. OF ELASTICITY E_C				
ORIENTATION NOT GIVEN				
	1.0			
MODULUS OF RIGIDITY G				
HARDNESS				

THE PROPERTIES OF GRAPHITES DIFFER WIDELY, NOT ONLY BETWEEN DIFFERENT GRADES, BUT BETWEEN DIFFERENT LOTS. ADDITIONAL VARIATIONS IN PROPERTIES MAY BE FOUND BETWEEN DIFFERENT PIECES IN A GIVEN LOT AS WELL AS BETWEEN LOCATIONS AND ORIENTATIONS WITHIN A SINGLE BLOCK. THIS WIDE VARIATION IS DUE TO THE SENSITIVITY OF GRAPHITE PROPERTIES TO MANY VARIABLES. THESE VARIABLES INCLUDE DIFFERENCES IN STARTING MATERIALS, PARTICLE SIZE, FORMING METHOD, CONDITION OF THE FIRST BAKE, AND GRAPHITIZING CONDITIONS. IN SHORT, THE PROPERTIES AND UNIFORMITY OF THE FINAL GRAPHITE PRODUCT ARE GREATLY INFLUENCED BY MANUFACTURING AND MATERIAL VARIABLES.

2. PHYSICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
DENSITY ρ				
LB/IN ³	0.063	-	0.063	-
g/cc	1.75	-	-	-
SPECIFIC HEAT C				
	0.26	-	0.26	-
THERMAL CONDUCTIVITY k				
	80	-	80	-
MEAN COEFF. LINEAR THERMAL EXPANSION α				
	1.4	-	1.9	-
ELECTRICAL RESISTIVITY R				

F. THERMOPHYSICAL EFFECTS
SUBLIMATION TEMPERATURE

AT ATM. PRESSURE 6600°F

THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE (°F)	$k \left(\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F} \right)$	
	AVERAGE	RANGE *
	MIN.	MAX.
-423	0	-
-300	40	-
-150	78	-
75	70	112
300	60	99
600	49	83
900	40	68
1200	30	58
1500	26	50
2000	18	40
2500	13	34
3000	11	33
3500	9	32
4000	8	30
4456	6	28

* AVERAGE RANGE FOR MOLDED STOCK, COMMERCIAL GRADE

F. THERMOPHYSICAL EFFECTS (CONTINUED)
EMITTANCE VS TEMPERATURE
G. CHEMICAL PROPERTIES
COMPATIBILITY

COMPATIBLE WITH COLLOIDAL SILICA TO AT LEAST 572°F

CORROSION RESISTANCE

REACTS WITH HYDROGEN AT HIGH TEMPERATURES

HYDROGEN PERMEABILITY

DARCY = 0.36 DETERMINED WITH HELIUM, BUT CONSIDERED REPRESENTATIVE OF HYDROGEN

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

GOOD NEUTRON MODERATOR

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

THIS SECTION IS INCLUDED TO PROVIDE A BRIEF SURVEY OF DEFECTS COMMONLY FOUND IN CONVENTIONAL EXTRUDED GRAPHITES, TO CLARIFY THEIR NATURE FOR THOSE NOT ALREADY COGNIZANT WITH GRAPHITE TECHNOLOGY.

PORE - A SPACE BETWEEN THE COKE PARTICLES NOT FILLED WITH SOLID MATERIAL. IT RESULTS FROM PARTIAL VAPORIZATION OF THE ORIGINAL PITCH BINDER. PORE DIMENSION IS GENERALLY SMALLER THAN THE PARTICLE SIZE, NOT A DEFECT.

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INCLUSION - ANY FOREIGN (NON-CARBONACEOUS) MATERIAL IN GRAPHITE. GENERALLY DETECTABLE BY RADIOGRAPHIC INSPECTION BECAUSE OF ITS GREATER ABSORPTION FOR X-RAYS THAN THAT OF THE GRAPHITE MATRIX. INCLUSIONS ARE PREDOMINANTLY IMPURE IRON CARBIDES.

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SPONGY AREA - PORTION OF THE GRAPHITE MATRIX WITH ABNORMALLY LOW DENSITY.

J. SERVICE LIMITS

EXCESSIVE VAPORIZATION NEAR 6000°F

K. PROCESSING
SURFACE TREATMENT

NO TYPE OF CLEANING SOLVENT SHOULD BE USED.

THERMAL TREATMENT

NOT APPLICABLE

K. PROCESSING (CONTINUED)
JOINING

MAY BE JOINED BY BRAZING. BRAZED JOINTS DEVELOP STRENGTHS EQUAL TO OR GREATER THAN THE PARENT MATERIAL. JOINING BY A CARBONACEOUS PROCESS RESULTS IN JOINTS WEAKER THAN THE PARENT MATERIAL. ORGANIC OR CARBONACEOUS CEMENTS ARE USED.

BRAZING CAN BE ACCOMPLISHED BY USING FILLER METALS THAT ARE GOOD CARBIDE FORMERS. THREE ALLOYS THAT ARE EFFECTIVE IN THE 1700°-1950°F RANGE ARE:

1. Ti CORED, 72% Ag - 28% Cu WIRE. BRAZE AT 1700°F
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3. 48% Ti - 48% Zr - 4% Be, 100-MESH POWDER, BRAZE AT 1950°F. (USED EXTENSIVELY BECAUSE OF ITS LINEAR THERMAL EXPANSION TO GRAPHITE).

FORMING

NOT APPLICABLE

MACHINABILITY

EXCELLENT, EASILY ABRADED

L. REFERENCES

NP-61-13
NP-61-14
NP-65-13

DATE 1 MAY 1966

SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

P-03 GRAPHITE IS A FINE-GRAINED AND DENSE GRAPHITE. ITS ADVANTAGES INCLUDE HIGH DENSITY, HIGH STRENGTH TO 4500°F, AND FREEDOM FROM RADIOGRAPHIC FLAWS. IT IS AVAILABLE AS REGULARLY MOLDED STOCK, AND AS SEMI-COMMERCIAL ISOSTATICALLY MOLDED STOCK, BOTH WITH A HIGH AND RELATIVELY UNIFORM DENSITY. IT IS LIMITED BY ITS BRITTLINESS AND THE SMALL SIZES GENERALLY AVAILABLE. IT CAN BE FABRICATED IN LARGE SIZES BY ISOSTATIC-PRESSING TECHNIQUES.

THE ROOM TEMPERATURE PROPERTIES GIVEN IN SECTION E ARE AVERAGES FOR REGULARLY MOLDED STOCK.

B. COMMERCIAL DESIGNATIONS
C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
SMALL SHAPES	WANL-PDS - 30086

SUPPLIERS

PURE CARBON CO.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	OTHER, INCL. ASH					
AVERAGE	99.75	0.25					
MINIMUM							

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

		WITH GRAIN		ACROSS GRAIN	
		MEAN	RANGE	MEAN	RANGE
TENSILE ULTIMATE STRENGTH	F_{TU}				PSI
(ORIENTATION NOT GIVEN)	4500				
(ORIENTATION NOT GIVEN)	3700-6200				
COMP. YIELD STRENGTH	F_{CY}				PSI
(ORIENTATION NOT GIVEN)	20,000				
SHEAR STRENGTH	F_{SU}				PSI
FLEXURAL STRENGTH	F_B				PSI
(4-POINT TEST)	8080				
(4-POINT TEST)	7655-8370				
ELONGATION	e				%
	NEGLECTIBLE				
MODULUS OF ELASTICITY	E				10^6 PSI
	1.8				
COMP. MOD. OF ELASTICITY	E_C				10^6 PSI
	1.8				
MODULUS OF RIGIDITY	G				
HARDNESS					

THE PROPERTIES OF GRAPHITES DIFFER WIDELY, NOT ONLY BETWEEN DIFFERENT GRADES, BUT BETWEEN DIFFERENT LOTS. ADDITIONAL VARIATIONS IN PROPERTIES MAY BE FOUND BETWEEN DIFFERENT PIECES IN A GIVEN LOT AS WELL AS BETWEEN LOCATIONS AND ORIENTATIONS WITHIN A SINGLE BLOCK. THIS WIDE VARIATION IS DUE TO THE SENSITIVITY OF GRAPHITE PROPERTIES TO MANY VARIABLES. THESE VARIABLES INCLUDE DIFFERENCES IN STARTING MATERIALS, PARTICLE SIZE, FORMING METHOD, CONDITION OF THE FIRST BAKE, AND GRAPHITIZING CONDITIONS. IN SHORT, THE PROPERTIES AND UNIFORMITY OF THE FINAL GRAPHITE PRODUCT ARE GREATLY INFLUENCED BY MANUFACTURING AND MATERIAL VARIABLES.

2. PHYSICAL PROPERTIES

		WITH GRAIN		ACROSS GRAIN	
		MEAN	RANGE	MEAN	RANGE
DENSITY	ρ				
LB/IN ³	(NO ORIENTATION)			0.064	-
g/cc	(NO ORIENTATION)			1.85	1.82-1.89
SPECIFIC HEAT	C				BTU/LB - °F
(NO ORIENTATION)				0.26	
THERMAL CONDUCTIVITY	k				BTU - FT HR - FT ² - °F
	35.8	-	-	-	
MEAN COEFF. LINEAR THERMAL EXPANSION	α				10^{-6} IN. IN. - °F
(RT-212°F)	2.4	-	-	2.9	-
ELECTRICAL RESISTIVITY	R				MICROHM - IN.
	175	-	-	195	-

F. THERMOPHYSICAL EFFECTS
SUBLIMATION TEMPERATURE

AT ATM PRESSURE 6600°F

THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE °F	k $\left(\frac{\text{BTU} - \text{FT}}{\text{HR} - \text{FT}^2 - ^\circ\text{F}} \right)$	
	WITH GRAIN	ACROSS GRAIN
77	35.8	
178	38.2	
279	40.9	
406	41.4	
536	38.2	
658	37.7	
795	36.3	

F. THERMOPHYSICAL EFFECTS (CONTINUED)
EMITTANCE VS TEMPERATURE
G. CHEMICAL PROPERTIES
CORROSION RESISTANCE

REACTS WITH HYDROGEN AND OXYGEN AT HIGH TEMPERATURES UNLESS PROTECTED BY SUITABLE COATINGS.

RESISTANT TO MOST CHEMICALS

HYDROGEN PERMEABILITY

DARCY = 0.010. NOTE, DETERMINED WITH HELIUM, BUT CONSIDERED REPRESENTATIVE OF HYDROGEN

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

GOOD NEUTRON MODERATOR

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

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INCLUSION - ANY FOREIGN (NON-CARBONACEOUS) MATERIAL IN GRAPHITE. GENERALLY DETECTABLE BY RADIOGRAPHIC INSPECTION BECAUSE OF ITS GREATER ABSORPTION FOR X-RAYS THAN THAT OF THE GRAPHITE MATRIX. INCLUSIONS ARE PREDOMINANTLY IMPURE IRON CARBIDES.

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SPONGY AREA - PORTION OF THE GRAPHITE MATRIX WITH ABNORMALLY LOW DENSITY.

J. SERVICE LIMITS

EXCESSIVE VAPORIZATION NEAR 6000°F

K. PROCESSING
SURFACE TREATMENT

NO TYPE OF CLEANING SOLVENT SHOULD BE USED.

THERMAL TREATMENT

NOT APPLICABLE

K. PROCESSING (CONTINUED)
JOINING

MAY BE JOINED BY BRAZING. BRAZED JOINTS DEVELOP STRENGTHS EQUAL TO OR GREATER THAN THE PARENT MATERIAL. JOINING BY A CARBONACEOUS PROCESS RESULTS IN JOINTS WEAKER THAN THE PARENT MATERIAL. ORGANIC OR CARBONACEOUS CEMENTS ARE USED.

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3. 48% Ti - 48% Zr - 4% Be, 100-MESH POWDER, BRAZE AT 1950°F. (USED EXTENSIVELY BECAUSE OF ITS LINEAR THERMAL EXPANSION TO GRAPHITE).

FORMING

NOT APPLICABLE

MACHINABILITY

EXCELLENT, EASILY ABRADED

L. REFERENCES

NP-65-23
NP-65-24
NP-65-25

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

DENSITY

ELECTRICAL RESISTIVITY

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

ATJ GRAPHITE IS A MOLDED GRAPHITE WITH A FINE GRAIN HAVING GOOD STRENGTH UP TO 5000°F. ITS DISADVANTAGES ARE THAT IT IS BRITTLE, ANISOTROPIC, AND SHOWS LARGE DENSITY VARIATIONS IN A SINGLE PIECE. ITS USES ARE FOR REFRACTORY STRUCTURES, BLOCKS, STRIPS, AND SLEEVES.

B. COMMERCIAL DESIGNATIONS

ATJ GRAPHITE

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
9 X 20 X 24-IN.	WANL-PDS-30008
13-IN. DIA X 14-IN. LG	
14-IN. DIA X 15-IN. LG	
16.5-IN. DIA X 14-IN. LG	
8 X 17 X 4.9-IN.	

SUPPLIERS

CARBON PRODUCTS DIVISION
UNION CARBIDE CORP.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Other, Incl. Ash				
AVERAGE	99.75	0.25				
MINIMUM						

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
TENSILE ULTIMATE STRENGTH F_{TU}				
	4100		2900	
COMP. YIELD STRENGTH F_{CY}				
	8270		8540	
SHEAR STRENGTH F_{SU}				
	1448		1200	
FLEXURAL STRENGTH F_B				
	4200 - 4560		3425-3700	

ELONGATION e	%
	NEGLECTIBLE

MODULUS OF ELASTICITY E	10^6 PSI
	1.45 1.131-1.187

COMP. MOD. OF ELASTICITY E_C	10^6 PSI
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MODULUS OF RIGIDITY G	
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HARDNESS	ROCKWELL R-71
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THE PROPERTIES OF GRAPHITES DIFFER WIDELY, NOT ONLY BETWEEN DIFFERENT GRADES, BUT BETWEEN DIFFERENT LOTS. ADDITIONAL VARIATIONS IN PROPERTIES MAY BE FOUND BETWEEN DIFFERENT PIECES IN A GIVEN LOT AS WELL AS BETWEEN LOCATIONS AND ORIENTATIONS WITHIN A SINGLE BLOCK. THIS WIDE VARIATION IS DUE TO THE SENSITIVITY OF GRAPHITE PROPERTIES TO MANY VARIABLES. THESE VARIABLES INCLUDE DIFFERENCES IN STARTING MATERIALS, PARTICLE SIZE, FORMING METHOD, CONDITION OF THE FIRST BAKE, AND GRAPHITIZING CONDITIONS. IN SHORT, THE PROPERTIES AND UNIFORMITY OF THE FINAL GRAPHITE PRODUCT ARE GREATLY INFLUENCED BY MANUFACTURING AND MATERIAL VARIABLES.

2. PHYSICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
DENSITY ρ				
LB/IN ³	0.063		0.063	
g/cc	1.73		1.73	
SPECIFIC HEAT C				
	0.25		0.25	
THERMAL CONDUCTIVITY k				
	68		52	
MEAN COEFF. LINEAR THERMAL EXPANSION α				
	(75° - 100°F)	1.2	1.9	

ELECTRICAL RESISTIVITY R	MICROHM - IN.
	110 145

F. THERMOPHYSICAL EFFECTS

SUBLIMATION TEMPERATURE

(AT ATMOSPHERIC PRESSURE) 6600°F

THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE °F	$k \left(\frac{\text{BTU} \cdot \text{FT}}{\text{HR} \cdot \text{FT}^2 \cdot ^\circ\text{F}} \right)$	
	WITH GRAIN	ACROSS GRAIN
150	-	47
200	68	-
500	59	42
700	52	39
1000	42	35
1100	40	-
1500	35	25
2000	28	21
2250	27	20
4000	22	17

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMITTANCE

SPECTRAL, 6500 Å
DULL SURFACE = 0.90
POLISHED SURFACE = 0.77

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE:

REACTS WITH HYDROGEN AT HIGH TEMPERATURES UNLESS PROTECTED BY COATING

HYDROGEN PERMEABILITY:

DARCY - WITH GRAIN, 0.018
DARCY - ACROSS GRAIN, 0.015

DETERMINED WITH HELIUM, BUT CONSIDERED REPRESENTATIVE OF HYDROGEN.

OXIDATION THRESHOLD TEMPERATURE

(APPROXIMATE RANGE) 940°-1000°F

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

SUITABLE AS A MODERATOR, REFLECTOR, THERMAL COLUMN, OR STRUCTURAL COMPONENT.

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE

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PORE - A SPACE BETWEEN THE COKE PARTICLES NOT FILLED WITH SOLID MATERIAL. IT RESULTS FROM PARTIAL VAPORIZATION OF THE ORIGINAL PITCH BINDER. PORE DIMENSION IS GENERALLY SMALLER THAN THE PARTICLE SIZE. NOT A DEFECT.

VOID - A SPACE IN THE MATRIX NOT FILLED WITH SOLID MATERIAL. ITS SIZE IS MUCH LARGER THAN THE PARTICLE SIZE. A TRUE DEFECT.

(THE COMMON DISTINCTION BETWEEN PORES AND VOIDS IS THAT INDIVIDUAL PORES CANNOT BE DETECTED RADIOGRAPHICALLY. THE PRESENCE OF PORES IS A NORMAL FEATURE OF EXTRUDED AND MOLDED GRAPHITES, AND THEY CANNOT BE, THEREFORE, REGARDED AS DEFECTS EXCEPT IN FUNDAMENTAL CONSIDERATIONS. VOIDS, ON THE OTHER HAND, ARE TRUE DEFECTS BECAUSE THEY MAY BE ELIMINATED THROUGH PROPER LEVEL OF QUALITY CONTROL BY THE MANUFACTURER AND THE USER.)

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CRACK - AN EXTENDED VOID STRUCTURE HAVING NO CONNECTING MATERIAL BETWEEN OPPOSITE FACES. CRACKS ARE GENERALLY DUE TO EXCESSIVE OUT-GASSING DURING THE CARBONIZATION OF THE BINDER, OR TO THERMAL STRESS CAUSED BY EXCESSIVELY RAPID COOLING.

SPONGY AREA - PORTION OF THE GRAPHITE MATRIX WITH ABNORMALLY LOW DENSITY.

J. SERVICE LIMITS

EXCESSIVE VAPORIZATION OCCURS NEAR 6000°F

K. PROCESSING
SURFACE TREATMENT

NO TYPE OF CLEANING SOLVENT SHOULD BE USED

THERMAL TREATMENT

NOT APPLICABLE

K. PROCESSING (CONTINUED)
JOINING

MAY BE JOINED BY BRAZING. BRAZED JOINTS DEVELOP STRENGTHS EQUAL TO OR GREATER THAN THE PARENT MATERIAL. JOINING BY A CARBONACEOUS PROCESS RESULTS IN JOINTS WEAKER THAN THE PARENT MATERIAL. ORGANIC OR CARBONACEOUS CEMENTS ARE USED.

BRAZING CAN BE ACCOMPLISHED BY USING FILLER METALS THAT ARE GOOD CARBIDE FORMERS. THREE ALLOYS THAT ARE EFFECTIVE IN THE 1700°-1950°F RANGE ARE:

1. Ti CORED, 72% Ag - 28% Cu WIRE. BRAZE AT 1700°F
2. 72% Au - 22% Ni - 6% Cr WIRE. BRAZE AT 1950°F
3. 48% Ti - 48% Zr - 4% Be, 100-MESH POWDER, BRAZE AT 1950°F. (USED EXTENSIVELY BECAUSE OF ITS LINEAR THERMAL EXPANSION TO GRAPHITE).

FORMING

NOT APPLICABLE

MACHINABILITY

GOOD

L. REFERENCES

NP-65-13
NP-61-19

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

SPECIFIC HEAT, STRUCTURAL GRAPHITE
REF. NP-64-30

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

DENSITY

ELECTRICAL RESISTIVITY

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

ZTA GRAPHITE IS A HOT-PRESSED GRAPHITE. IT HAS THE ADVANTAGES OF HIGH DENSITY AND LOW PERMEABILITY. ITS LIMITATIONS ARE BRITTLENESS AND ANISOTROPY. IT HAS HIGH WITH-GRAIN THERMAL CONDUCTIVITY AND FLEXURAL AND TENSILE STRENGTHS (TO 4892°F) AND EXCELLENT EROSION RESISTANCE. IT IS CAPABLE OF TAKING A FINE SURFACE FINISH TO CLOSE TOLERANCES. ALL PROPERTIES ARE DENSITY DEPENDENT.

THE ROOM TEMPERATURE PROPERTIES GIVEN IN SECTION E ARE AVERAGE VALUES

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
8-IN. DIA. X 11 IN. LONG	WANL-PDS-30019
14-IN. DIA. X 8-IN. LONG	

SUPPLIERS

CARBON PRODUCTS DIVISION
UNION CARBIDE CORP.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Other, Incl. Ash				
AVERAGE	99.75	0.25				

E. ROOM TEMPERATURE PROPERTIES (AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
TENSILE ULTIMATE STRENGTH F_{TU}				PSI
	4000		1200	
COMP. YIELD STRENGTH F_{CY}				PSI
	7240		12020	
SHEAR STRENGTH F_{SU}				PSI
FLEXURAL STRENGTH F_B				PSI
	5300-6000		2000-3000	
ELONGATION e				%
	NEGLECTIBLE			
MODULUS OF ELASTICITY E				10^6 PSI
	2.65		0.80	
COMP. MOD. OF ELASTICITY E_C				10^6 PSI
MODULUS OF RIGIDITY G				
HARDNESS				

THE PROPERTIES OF GRAPHITES DIFFER WIDELY, NOT ONLY BETWEEN DIFFERENT GRADES, BUT BETWEEN DIFFERENT LOTS. ADDITIONAL VARIATIONS IN PROPERTIES MAY BE FOUND BETWEEN DIFFERENT PIECES IN A GIVEN LOT AS WELL AS BETWEEN LOCATIONS AND ORIENTATIONS WITHIN A SINGLE BLOCK. THIS WIDE VARIATION IS DUE TO THE SENSITIVITY OF GRAPHITE PROPERTIES TO MANY VARIABLES. THESE VARIABLES INCLUDE DIFFERENCES IN STARTING MATERIALS, PARTICLE SIZE, FORMING METHOD, CONDITION OF THE FIRST BAKE, AND GRAPHITIZING CONDITIONS. IN SHORT, THE PROPERTIES AND UNIFORMITY OF THE FINAL GRAPHITE PRODUCT ARE GREATLY INFLUENCED BY MANUFACTURING AND MATERIAL VARIABLES.

2. PHYSICAL PROPERTIES

	WITH GRAIN		ACROSS GRAIN	
	MEAN	RANGE	MEAN	RANGE
DENSITY ρ				
LB./IN. ³	0.070		0.070	
g/cc	1.945			
SPECIFIC HEAT C				BTU/LB - °F
	0.26		0.26	
THERMAL CONDUCTIVITY k				BTU - FT HR - FT ² - °F
	85		48	
MEAN COEFF. LINEAR THERMAL EXPANSION α				10^{-6} IN. IN. - °F
	0.7		8.2	
ELECTRICAL RESISTIVITY R				MICROHM - IN.
	710		1990	

F. THERMOPHYSICAL EFFECTS

SUBLIMATION TEMPERATURE	
(AT ATMOSPHERIC PRESSURE)	6600°F
THERMAL CONDUCTIVITY VS TEMPERATURE	

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMITTANCE

SPECTRAL EMISSIVITY AT 6500° A
DULL SURFACE = 0.90
POLISHED SURFACE = 0.77

G. CHEMICAL PROPERTIES

CORROSION RESISTANCE

REACTS WITH HYDROGEN AT HIGH TEMPERATURES UNLESS PROTECTED BY A SUITABLE COATING

OXIDATION THRESHOLD TEMPERATURES

APPROXIMATE RANGE: 940 - 1000°F

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

SUITABLE AS MODERATOR, REFLECTOR, THERMAL COLUMN, AND STRUCTURAL COMPONENT.

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

I. NOMENCLATURE

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SPONGY AREA - PORTION OF THE GRAPHITE MATRIX WITH ABNORMALLY LOW DENSITY.

J. SERVICE LIMITS

EXCESSIVE VAPORIZATION OCCURS NEAR 6000°F

K. PROCESSING

SURFACE TREATMENT

NO TYPE OF CLEANING SOLVENT SHOULD BE USED.

THERMAL TREATMENT

NOT APPLICABLE

K. PROCESSING (CONTINUED)

JOINING

MAY BE JOINED BY BRAZING. BRAZED JOINTS DEVELOP STRENGTHS EQUAL TO OR GREATER THAN THE PARENT MATERIAL. JOINING BY A CARBONACEOUS PROCESS RESULTS IN JOINTS WEAKER THAN THE PARENT MATERIAL. ORGANIC OR CARBONACEOUS CEMENTS ARE USED.

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3. 48% Ti - 48% Zr - 4% Be, 100-MESH POWDER, BRAZE AT 1950°F. (USED EXTENSIVELY BECAUSE OF ITS LINEAR THERMAL EXPANSION TO GRAPHITE).

FORMING

NOT APPLICABLE

MACHINABILITY

CAN BE MACHINED TO VERY CLOSE TOLERANCES AND SHARP DETAIL WITH FINE SURFACE FINISH.

L. REFERENCES

NP-65-13
NP-62-43

DATE 1 MAY 1966

SUPERSEDES

GRAPHITES

MATERIALS DATA

**VII
GRAPHITES**

**B.
PYROLYTIC GRAPHITE**

BLANK

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

THIS TYPE OF GRAPHITE IS PYROLYTICALLY DEPOSITED FROM A CARBONACEOUS VAPOR PHASE. IT IS USED AS A THERMAL INSULATOR AND AN IMPERVIOUS COATING. ITS LIMITATIONS ARE THAT IT IS VERY ANISOTROPIC AND TENDS TO DELAMINATE. IN ADDITION, THE AVAILABLE MAXIMUM THICKNESS IS NORMALLY LESS THAN 0.50-IN. THE RANGE OF PROPERTIES VARIES BETWEEN WIDE LIMITS DEPENDING ON DEPOSITION PARAMETERS AND MICROSTRUCTURE (REFER TO MANUFACTURERS' LITERATURE).

THE PLANES PARALLEL TO THE SURFACE OF DEPOSITION ARE CALLED THE "A-B" OR BASAL PLANES. THE "C" DIRECTION IS NORMAL TO THE BASAL PLANES.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGE ROOM TEMPERATURE VALUES

B. COMMERCIAL DESIGNATIONS

PYROLYTIC GRAPHITE

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
TUBE	WANL-PDS - 30014
FREE STANDING SHAPES	WANL-PDS - 30015
BLANKS	WANL-PDS - 30016
CUPS	WANL-PDS - 30017

SUPPLIERS

GENERAL ELECTRIC CO.
HIGH TEMPERATURE MATERIALS, INC.
PYROGENICS, INC.
SUPER TEMP CORP.

D. CHEMICAL COMPOSITION (%)

ELEMENT	C	Ash	Other						
AVERAGE VALUE	99.99	0.003	0.009						
RANGE		0.001	0.007						

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	PLANES (SEE SECT. A)	
	"A-B"	"C"
TENSILE ULTIMATE STRENGTH F_{TU}	PSI	
	14,000	1500

COMP. ULTIMATE STRENGTH F_{CU}	PSI
	14,000 68,000

SHEAR STRENGTH F_{SU}	PSI
-------------------------	-----

FLEXURAL STRENGTH F_B	PSI
-------------------------	-----

ELONGATION e	%
	NEGLIGIBLE

MODULUS OF ELASTICITY E	10^6 PSI
	4.4 1.7

COMP. MOD. OF ELASTICITY E_C	10^6 PSI
	10 16

MODULUS OF RIGIDITY G	
	0.2 2.7

HARDNESS	
----------	--

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2. PHYSICAL PROPERTIES

	PLANES	
	"A-B"	"C"
DENSITY ρ		
LB/IN ³ (AS DEPOSITED, UN-DELAMINATED)	0.079-0.081	
g/cc	2.20 -2.23	

SPECIFIC HEAT C	BTU/LB - °F
	0.26

THERMAL CONDUCTIVITY k	$\frac{BTU - FT}{HR - FT^2 - °F}$
(@ 500°F)	200 1.00

MEAN COEFF. LINEAR THERMAL EXPANSION α	$\frac{10^{-6} IN.}{IN. - °F}$
(@ 500°F)	0.2 10.8

ELECTRICAL RESISTIVITY R	MICROHM - IN.
	180 190,000

F. THERMOPHYSICAL EFFECTS

SUBLIMATION TEMPERATURE	
(AT ATMOSPHERIC PRESSURE)	6600°F

PHASE CHANGES

SINGLE PHASE UNDER LOW PRESSURES.

EMISSIONITY VS. TEMPERATURE

TOTAL EMISSIONITY = 0.845 (AT 2400°F)

F. THERMOPHYSICAL EFFECTS (CONTINUED)
THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	$k \left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$	A*	"C" **
		DIRECTION	DIRECTION
- 423	0 EST.		0.04
- 320	21 EST.		0.13
- 280	50 EST.		
- 110			0.40
- 100	132 EST.		
- 50	150 EST.		
0	167 EST.		0.68
100	200 EST.		1.06
110	202		
150	215		
200			1.26
300	229		
500			1.12
510	213		
670	200		
700			1.00
900			0.89
930	175		
1000	170		
1210	150		
1500	129		0.76
1810	109		
2000	97		0.72
2330	80 EST.		
2500			0.68
2700	60 EST.		
3000	50 EST.		0.66
3320	40 EST.		
3500			0.62
3840	35 EST.		
4000	34 EST.		0.59
4500	29 EST.		0.55
5000	27 EST.		
5500	24 EST.		

* REF. NP-62-49

** REF. NP-63-14

G. CHEMICAL PROPERTIES
CORROSION RESISTANCE

GREATER RESISTANCE TO MOST CHEMICALS THAN MOST COMMERCIAL GRADES OF GRAPHITE. REACTIVE WITH OXYGEN AND HYDROGEN AT RATE DEPENDING ON TEMPERATURE AND PRESSURE.

HYDROGEN PERMEABILITY

ESSENTIALLY ZERO

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
H. NOMENCLATURE

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SPONGY AREA - PORTION OF THE GRAPHITE MATRIX WITH ABNORMALLY LOW DENSITY.

SUBSTRATE SURFACE - THAT SURFACE DEPOSITED DIRECTLY ADJACENT TO THE MANDREL DURING DEPOSITION.

CLEAVED SURFACE - THAT PORTION OF A DE-LAMINATED SURFACE ON WHICH RE-NUCLEATION HAS OCCURRED IN A REGULAR PLANE, RESULTING IN A REGULAR SURFACE.

SPALLED SURFACE - THAT PORTION OF A DE-LAMINATED SURFACE ON WHICH RE-NUCLEATION HAS OCCURRED IN AN IRREGULAR MANNER, RESULTING IN AN IRREGULAR SURFACE.

DE-LAMINATION - A SEPARATION OF MATERIAL PARALLEL TO THE PLANE OF DEPOSITION, EXCEPT WHEN LIMITED TO A SINGLE NODULE OR CLUSTER OF NODULES.

SOOTING - AN IRREGULAR GRAPHITE DEPOSIT, GENERALLY FERN-LIKE IN APPEARANCE (ON THE LAST DEPOSITED SURFACE), IN WHICH THERE IS NO NODULAR STRUCTURE.

NODULE - AN ISOLATED AND ABNORMALLY LARGE GROWTH CONE EMBEDDED IN THE MATRIX OF A COMPONENT.

I. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

LITTLE DATA AVAILABLE

J. SERVICE LIMITS

DEPENDS ON SPECIFIC ENVIRONMENT

K. PROCESSING
SURFACE TREATMENT

NO TYPE OF CLEANING SOLVENT SHOULD BE USED.

THERMAL TREATMENT

PROPERTIES CHANGE WITH HIGH TEMPERATURE ANNEALING

K. PROCESSING (CONTINUED)
JOINING

MAY BE JOINED WITH ORGANIC OR CARBONACEOUS CEMENT, BUT JOINT IS WEAKER THAN PARENT MATERIAL. LITTLE DATA ARE AVAILABLE ON BRAZING.

FORMING

NOT APPLICABLE

MACHINABILITY

GOOD

L. REFERENCES

NP-62-49
NP-63- 8
NP-63-14
NP-64-25

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966

SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

THERMAL EXPANSION

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

SPECIFIC HEAT

SPECIFIC HEAT
BTU/LB-°F

TEMPERATURES IN 100° F

DATE 1 MAY 1966
SUPERSEDES

THERMAL CONDUCTIVITY

BLANK

DATE 1 MAY 1966

SUPERSEDES

GRAPHITES

MATERIALS DATA

**VII
GRAPHITES**

**C.
OTHER GRAPHITES**

BLANK

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

**REFRACTORY
CERAMICS**

MATERIALS DATA

**VIII
REFRACTORY CERAMICS**

**A.
OXIDES**

BLANK

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
A. GENERAL

BERYLLIUM OXIDE IS POLYCRYSTALLINE IN FORM AND COLORLESS. WHEN SUFFICIENTLY DENSE IT IS TRANSLUCENT. ITS NUCLEAR PROPERTIES ARE GOOD, AND IT IS HIGHLY REFRACTORY. RESISTANCE TO THERMAL SHOCK IS GOOD. IT LACKS DUCTILITY. WATER VAPOR AT TEMPERATURES ABOVE 2000°F WILL CORRODE BERYLLIUM OXIDE, WHILE IMPURITIES TEND TO DEGRADE NUCLEAR PROPERTIES. IT IS HIGHLY TOXIC IN POWDERED FORM, ESPECIALLY DUST GENERATED FROM ABRASION CONDITIONS, SUCH AS GRINDING, MACHINING, CUTTING, OR DRILLING. ORDINARY HANDLING AND USAGE OF CURED SYSTEMS WILL NOT RESULT IN DEVELOPMENT OF A TOXIC CONDITION.

BERYLLIUM OXIDE IS USED AS A MODERATOR, REFLECTOR, OR FUEL DILUENT, AND FOR STRUCTURAL PARTS, ELECTRICAL INSULATORS, ETC. IT INSULATES ELECTRICALLY LIKE A CERAMIC, BUT CONDUCTS HEAT LIKE A METAL.

THE ROOM TEMPERATURE PROPERTIES IN SECTION E ARE AVERAGE FOR SEVERAL FORMS AND DENSITIES UNLESS OTHERWISE NOTED. IN ADDITION, THE F_{TU} IS 80% OF SUCH AN AVERAGE.

B. COMMERCIAL DESIGNATIONS

BERYLLIUM OXIDE (BeO)

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
POWDER - FROM 80 MESH DOWN TO 325 MESH	
COLD PRESSED AND SINTERED FORMS	
HOT PRESSED FORMS	
SLIP CAST	

SUPPLIERS

BERYLLIUM CORP., READING, PENNA.

NATIONAL BERYLLIA CORP., HASKELL, N.J.

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE
E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI.
14,800

TENSILE YIELD STRENGTH F_{TY} PSI.

COMP. YIELD STRENGTH F_{CY} PSI.
180 - 200,000

FLEXURAL STRENGTH F_B PSI.
27,000

ULTIMATE SHEAR STRENGTH F_{SU} PSI.

ULTIMATE BEARING STRENGTH F_{BRU} PSI.
e/D=1.5
e/D=2.0

BEARING YIELD STRENGTH F_{BRY} PSI.
e/D=1.5
e/D=2.0

ELONGATION e %

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI.
STATIC 41
DYNAMIC 55

MODULUS OF RIGIDITY G 10^6 PSI.
STATIC 14
DYNAMIC 21

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI.

I. MECHANICAL PROPERTIES (CONTINUED)

POISSON'S RATIO
SLIP CAST 0.34

HARDNESS

2. PHYSICAL PROPERTIES

DENSITY ρ
LB/IN³ (THEORETICAL) 0.108
g/cc (THEORETICAL) 3.008
COMMERCIAL 2.85 - 2.90

SPECIFIC HEAT C BTU/LB - °F
(SINTERED OR HOT PRESSED) 0.240

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$
144

MEAN COEFF. LIN. THERMAL EXPAN. α $\frac{10^{-6} IN.}{IN. - °F}$
4.2

ELECTRICAL RESISTIVITY R MICROHM - IN.
 7.88×10^{19}

MAGNETIC PROPERTIES

DIAMAGNETIC

F. THERMOPHYSICAL EFFECTS

BOILING POINT
7030°F

MELTING RANGE
4580 - 4660°F
PURE BeO 4650°F

F. THERMOPHYSICAL EFFECTS (CONTINUED)
PHASE CHANGES

RECRYSTALLIZATION OCCURS ABOVE 3700°F (ISOTROPIC TO ABOUT 3100°F, AND ANISOTROPIC ABOVE 3700°F)

THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE °F	k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
-458	0.048
-420	8.47
-294	213.0
68	157.3
212	121.0
392	92.0
752	58.0
1112	31.46
1832	16.94
2912	9.68

EMISSIVITY VS TEMPERATURE (SPECTRAL POLISHED)*

(0.665 WAVELENGTHS)

TEMPERATURE °F	EMISSIVITY
1740	0.212
1880	0.209
2060	0.210
2240	0.213
2420	0.217
2600	0.222
2780	0.229
2960	0.235

REF. NP-66-26

* DENSITY 2.778 gm/cm³

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
G. CHEMICAL PROPERTIES

CONSIDERABLE CHEMICAL INERTNESS. A BASIC COMPOUND IN ITS BEHAVIOR TOWARDS ACIDS. DISSOLVES READILY IN ALL CONCENTRATED ACIDS FORMING READILY SOLUBLE BERYLLIUM SALTS. RELATIVELY STABLE TO THE ACTION OF ALKALINE SOLUTIONS (DEGREE OF REACTION DEPENDS ON THE PREVIOUS TREATMENT OF THE OXIDE). STABLE TO ACTION OF NaK AND LIQUID K TO 1100°F.

COMPATIBILITY

GOOD RESISTANCE TO REDUCING ATMOSPHERE AND MOST RESISTANT OF ALL OXIDES TO REDUCTION BY CARBON AT EL-EVATED TEMPERATURES. ABOVE 3270°F, HOWEVER, CARBON REACTS WITH BeO TO FORM Be₂C WHICH DECOMPOSES AT 3990°F WITH VOLATILIZATION OF Be. STABLE IN NITROGEN, HYDROGEN, AND HELIUM UP TO 3632°F.

CORROSION RESISTANCE

RELATIVELY LOW VAPOR PRESSURE, AND CAN BE USED IN VACUUM UP TO ABOUT 3600°F. READILY VOLATILIZED HOW-EVER BY WATER VAPOR ABOVE 3000°F, AND BODIES HEATED IN THE ATMOSPHERE OF GAS-FIRED FURNACES MAY LOSE CONSIDERABLE WEIGHT.

H. NUCLEAR PROPERTIES

GOOD NUCLEAR CORE MATERIAL BECAUSE OF ITS HIGH REFRACTORY PROPERTIES, HIGH THERMAL CONDUCTIVITY, AND THERMAL STRESS RESISTANCE. IT HAS A HIGH SCATTERING CROSS SEC-TION AND A LARGE NEUTRON ENERGY EXCHANGE PER COLLI-SION, BUT ONE OF THE SMALLEST NEUTRON ABSORPTION CROSS SECTIONS PER UNIT VOLUME AND A LOW SLOWING-DOWN-LENGTH.

I. NOMENCLATURE
J. SERVICE LIMITS

DOES NOT SUFFER MAJOR RADIATION DAMAGE BELOW 10²⁰ NVT EXCEPT FOR SOME LOSS IN THERMAL CONDUCTIVITY. ANY DAMAGE OCCURRING MAY BE REMOVED BY ANNEALING AT TEMPERATURES FROM 1832°F TO 2732°F. SOME SERI-
OUS DAMAGE APPEARS TO OCCUR AFTER LONG EXPOSURE ABOVE 10²¹ NVT AT TEMPERATURES BELOW 1832°F.

MAY BE USED AT NO-LOAD CONDITIONS, IN NON-IRRADIATION ENVIRONMENT, TO 3270°F. (COORS DATA).

K. PROCESSING
SURFACE TREATMENT
THERMAL TREATMENT

SINTERED AT 3100 TO 3600°F

K. PROCESSING (CONTINUED)
JOINING
FORMING

CASTING, STAMPING, SPINNING, AND SEMI DRY PRESSING BY USUAL CERAMIC METHODS, FOLLOWED BY SINTERING, HOT PRESSING. FABRICATION DEPENDS ON ELIMINATING PORES BETWEEN AND IN THE POWDER PARTICLES.

MACHINABILITY
L. REFERENCES

NP-67-9	NP-64-18	NP-62-33
NP-67-3	NP-63-38	NP-62-32
NP-66-14	NP-63-36	NP-60-19
NP-64-49	NP-63-35	

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

ELECTRICAL RESISTIVITY

BLANK

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
A. GENERAL

MAGNESIUM OXIDE IS A REFRACTORY CERAMIC AND MAY BE OBTAINED IN EITHER THE SINGLE-CRYSTAL OR POLY-CRYSTALLINE (TRANSLUCENT) FORM. IT IS SIMILAR TO OTHER OXIDES, BUT IS LESS STABLE UNDER REDUCING CONDITIONS. IT HAS A HIGH MELTING TEMPERATURE, GOOD FABRICABILITY, AND IS QUITE STABLE UNDER NEUTRAL OR OXIDIZING CONDITIONS.

THIS MATERIAL IS OF LIMITED USE IN VACUUM. IT HAS FAIR THERMAL SHOCK RESISTANCE, AND POOR STABILITY UNDER REDUCING CONDITIONS. IT IS SUSCEPTIBLE TO BRITTLE FAILURE, BUT THIS CAN BE IMPROVED BY PRESTRESSING. THE PROPERTIES OF MAGNESIUM OXIDE ARE QUITE DEPENDENT ON FORM, PURITY, AND DENSITY.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGE, EXCEPT FOR F_{TU} , WHICH IS 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

SINGLE CRYSTAL OR POLY-CRYSTALLINE MAGNESIUM OXIDE (MAGNESIA)

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORM AND CONDITION	SPECIFICATIONS
POWDER	
CAST, ISOSTATIC, OR COLD PRESSED, THEN SINTERED.	
HOT-PRESSED	
PRESSED AND PRE- STRESSED	

SUPPLIERS

NORTON CO., WORCESTER, MASS.
CARBORUNDUM CO., NIAGARA FALLS, N.Y.
GENERAL ELECTRIC CO., PITTSFIELD, MASS.

D. CHEMICAL COMPOSITION (%)

ELEMENT	MgO	CaO	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃
TYPICAL	96.39	1.91	1.21	0.23	0.26

SOURCE NP-62-35

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI.
SLIP-CAST AND SINTERED 8,960
HOT-PRESSED 12,000

TENSILE YIELD STRENGTH F_{TY} PSI.

COMP. YIELD STRENGTH F_{CY} PSI.

ULTIMATE SHEAR STRENGTH F_{SU} PSI.

ULTIMATE BEARING STRENGTH F_{BRU} PSI.

$e/D=1.5$
 $e/D=2.0$

YIELD BEARING STRENGTH F_{BRY} PSI.

$e/D=1.5$
 $e/D=2.0$

ELONGATION e %

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI.

(DEPENDING ON FORM, PURITY,
AND DENSITY) 16-51

MODULUS OF RIGIDITY G 10^6 PSI.

(DEPENDING ON FORM, PURITY,
AND DENSITY) 11.25-16.75

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI.

HARDNESS KHN.

2. PHYSICAL PROPERTIES

DENSITY ρ
LB/IN³ 0.136
g/cc 3.6

SPECIFIC HEAT C BTU/LB-°F

MEAN OF LITERATURE RANGE 0.224

THERMAL CONDUCTIVITY k $\frac{BTU-FT}{HR-FT^2-°F}$

POLY-CRYSTALLINE 20.0
SINGLE-CRYSTAL 42.0

MEAN COEFF. LIN. THERMAL EXPAN. α 10^{-6} IN.
IN.-°F

(R.T. TO 1000°F) 7.0

ELECTRICAL RESISTIVITY R MICROHM-IN.

$> 3.9 \times 10^{20}$

MAGNETIC PROPERTIES
F. THERMOPHYSICAL EFFECTS
MELTING POINT

5070°F

PHASE CHANGES
THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k $\left(\frac{BTU-FT}{HR-FT^2-°F} \right)$ (POLY-CRYSTALLINE)
RT	23.0
330	15.12
660	9.12
1000	5.87
1500	3.87
2000	2.87
2500	2.5
3000	3.0
3500	2.5

F. THERMOPHYSICAL EFFECTS (CONTINUED)
EMISSIVITY VS. TEMPERATURE (TOTAL NORMAL)

TEMPERATURE °F	EMISSIVITY
-423	0.7
200	0.71
600	0.63
1000	0.52
1400	0.42
1800	0.32
2200	0.27
2600	0.28
3000	0.32
3400	0.42
3800	0.6

REF. NP-66-26

G. CHEMICAL PROPERTIES

GOOD STABILITY UNDER NEUTRAL OR OXIDIZING CONDITIONS TO $>3630^\circ\text{F}$. LESS STABLE UNDER REDUCING CONDITIONS AT 3090°F . HIGH VAPOR PRESSURE LIMITS USE IN VACUUM TO $2900-3100^\circ\text{F}$. SOLUBLE IN WATER.

H. NUCLEAR PROPERTIES

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

4000 TO 4500° F IN AIR (SEE ALSO SECTIONS F AND G)

K. PROCESSING (CONTINUED)
JOINING
K. PROCESSING
SURFACE TREATMENT
FORMING

USUALLY BY SLIP-CASTING, ISOSTATIC PRESSING, OR COLD PRESSING, FOLLOWED BY SINTERING; OR BY HOT PRESSING.

THERMAL TREATMENT
MACHINABILITY
L. REFERENCES

NP-66-14	NP-64-19	NP-62-35
NP-65-12	NP-64-18	NP-61-18
NP-64-20	NP-63-37	

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

TENSILE STRENGTHS

DATE 15 SEPT 1967
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 15 SEPT 1967
SUPERSEDES

**IMPACT STRENGTH
ROCKWELL HARDNESS**

DATE 1 MAY 1966

SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF ELASTICITY
 10^6 PSI

MODULUS OF RIGIDITY

MODULUS OF RIGIDITY
 10^6 PSI

TEMPERATURES IN 100° F

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

DATE 1 MAY 1966
SUPERSEDES

ELECTRICAL RESISTIVITY

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

BASIC DATA

A. GENERAL

THIS IS A FUSED OXIDE OF THORIUM. ITS CRYSTALLINE STRUCTURE IS CUBIC, AND IT DOES NOT INVERT AT ELEVATED TEMPERATURES AS IN THE CASE OF OTHER OXIDES, SUCH AS ZrO_2 . THORIA HAS ONE OF THE HIGHEST MELTING POINTS OF ALL OF THE REFRACTORY CERAMICS, BUT IT IS SENSITIVE TO THERMAL SHOCK, AND IS BRITTLE AT NORMAL TEMPERATURES.

THORIA SHOULD BE USED ONLY IN COMPRESSION OR IN TENSION IN COMBINATION WITH OTHER MATERIALS, WHERE THE LOAD IS DISTRIBUTED IN SUCH A WAY AS TO ELIMINATE HIGH STRESS CONCENTRATIONS. IT IS ALSO USED IN VERY HIGH TEMPERATURE APPLICATIONS, AND IN THE ELECTRONIC FIELD.

VALUES IN SECTION E ARE AVERAGES, EXCEPT F_{TU} , WHICH IS A DESIGN VALUE; 80% OF AVERAGE.

B. COMMERCIAL DESIGNATION

OXIDE OF THORIUM, OR THORIA

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
AVAILABLE AS POWDER IN A WIDE RANGE OF MESH SIZES; AVAILABLE IN MANY FORMS AND SHAPES BY PROCESSES OF PRESSING, EXTRUDING, RAMMING AND CASTING, AND SLIP CASTING	

SUPPLIERS

NORTON CO., WORCESTER, MASSACHUSETTS
ZIRCONIUM CORP. OF AMERICA, SOLON, OHIO
CERAC, INC., BUTLER, WISCONSIN

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

E. ROOM TEMPERATURES PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU}	PSI.	11,200
TENSILE YIELD STRENGTH F_{TY}	PSI.	
COMP. YIELD STRENGTH F_{CY}	PSI.	217,000
SHEAR YIELD STRENGTH F_{SY}	PSI.	
AT 2012°F		3,500
ULTIMATE BEARING STRENGTH F_{BRU}	PSI.	
e/D=1.5 e/D=2.0		
YIELD BEARING STRENGTH F_{BRY}	PSI.	
e/D=1.5 e/D=2.0		
ELONGATION e	%	
REDUCTION OF AREA RA	%	
MODULUS OF ELASTICITY E	10^6 PSI.	34.7
MODULUS OF RIGIDITY G	10^6 PSI.	14.5
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI.	
HARDNESS KHN		
KNOOP, 100g		945

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³ (THEORETICAL BULK) g/cc	0.35
SPECIFIC HEAT C	BTU/LB - °F	> 95% DENSE 0.065
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F	8.7
MEAN COEFF. LIN. THERMAL EXPAN. α	10^{-6} IN. IN. - °F	(RT TO 270°F) 95% DENSE 3.72
ELECTRICAL RESISTIVITY R	MICROHM-IN.	(AT 750°F) 4×10^{13}
MAGNETIC PROPERTIES		
F. THERMOPHYSICAL EFFECTS		
MELTING RANGE		5792°F
PHASE CHANGES		NONE
THERMAL CONDUCTIVITY VS. TEMPERATURE		
TEMPERATURE °F	k $\left(\frac{BTU/FT}{HR - FT^2 - °F} \right)$	
RT	---	8.7
130	5.0	8.1
200	4.65	7.45
500	3.45	4.8
1000	2.05	3.3
1500	1.3	2.4
2000	0.9	1.85
2500	0.7	1.4
2830	0.65	1.2

DATA POINTS WERE READ FROM CURVE AND DO NOT NECESSARILY REPRESENT MEASURED VALUES AT INDICATED TEMP.

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMITTANCE VS. TEMPERATURE

G. CHEMICAL PROPERTIES

NEUTRAL, BUT VERY SLIGHTLY ATTACKED BY ACIDS AND BASES.

STARTS TO FORM CARBIDES AT HIGH TEMPERATURE WHEN IN CONTACT WITH CARBON; A FUNCTION OF TIME AND TEMPERATURE.

APPRECIABLY VOLATILE IN HELIUM AT 4172°F, AND HAS GOOD RESISTANCE TO HYDROGEN.

H. NUCLEAR PROPERTIES

THERMAL NEUTRON CAPTURE CROSS SECTION: $0.160 \text{ cm}^2/\text{cm}^3$

DATE 15 NOV. 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

4892°F IN AIR
3902°F IN OXYGEN

K. PROCESSING (CONTINUED)
JOINING
K. PROCESSING
SURFACE TREATMENT
FORMING
THERMAL TREATMENT
MACHINABILITY
L. REFERENCES

NP-65-49	NP-64-20	NP-61-29
NP-65-22	NP-63-38	NP-61-28
NP-64-37	NP-63-37	NP-61-18
NP-64-37	NP-62-36	NP-56-4

DATE 15 NOV. 1966
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 15 NOV. 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 15 NOV. 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 15 SEPT 1967

SUPERSEDES 15 NOV 1966

ELECTRICAL RESISTIVITY

DATE 15 NOV. 1966
SUPERSEDES

POISSON'S RATIO

DENSITY

BLANK

DATE 15 SEPT 1967

SUPERSEDES 15 NOV 1966

BASIC DATA
A. GENERAL

THIS IS A FUSED OXIDE OF ZIRCONIUM. IT IS PRODUCED IN TWO FORMS:

PURE ZIRCONIA WITH MONOCLINIC CRYSTAL STRUCTURE, STABILIZED ZIRCONIA WITH CUBIC CRYSTAL STRUCTURE.

THE MONOCLINIC CRYSTALS OF PURE ZrO_2 REVERT TO A TETRAGONAL SHAPE WHEN THE TEMPERATURE RISES ABOVE 1830°F, BUT STABILIZED ZrO_2 RETAINS ITS CUBIC STRUCTURE WITH REPEATED CYCLING TO ITS MELTING POINT.

ZrO_2 HAS CONSISTENTLY HIGH PURITY AND FINE PARTICLES OF UNIFORM SIZE. IT HAS LOW THERMAL CONDUCTIVITY, WITH LOW THERMAL SHOCK RESISTANCE, AND IS A FAIRLY GOOD ELECTRICAL INSULATOR AT LOW TEMPERATURES. WHEN HEATED TO 2400°F, HOWEVER IT BECOMES A CONDUCTOR. IT IS INERT TO ATTACK BY MANY METALS, HAS GREAT CHEMICAL STABILITY, AND WITHSTANDS EXTREMELY HIGH TEMPERATURES IN BOTH OXIDIZING AND REDUCING ATMOSPHERES.

VALUES IN SECTION E ARE AVERAGES, EXCEPT F_{TU} , WHICH IS 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

PURE ZIRCONIA, STABILIZED ZIRCONIA

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
AVAILABLE AS POWDER IN A WIDE RANGE OF MESH SIZES, AND IN MANY FORMS AND SHAPES BY PRESSING, EXTRUDING, RAMMING AND CASTING, AND SLIP CASTING	

SUPPLIERS

ZIRCONIUM CORP. OF AMERICA, SOLON, OHIO
NORTON CO., WORCESTER, MASS.
CERAC, INC., BUTLER, WISCONSIN

D. CHEMICAL COMPOSITION (%)

COMPOUND	CaO	SiO ₂	TiO ₂	Fe ₂ O ₃	HfO ₂	Al ₂ O ₃	ZrO ₂ + HfO ₂
PURE	0.25	0.7	0.3	0.2	<2.0	0.5	BAL. 98.65
STABILIZED	4.75	0.8	0.8	0.5	<3.0	1.0	BAL. 93.85

SOURCE NORTON CO.

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

PURE STABILIZED
TENSILE ULTIMATE STRENGTH* F_{TU} PSI.

16,000

TENSILE YIELD STRENGTH F_{TY} PSI.

COMP. YIELD STRENGTH* F_{CY} PSI.

295,000

ULTIMATE SHEAR STRENGTH F_{SU} PSI.

ULTIMATE BEARING STRENGTH F_{BRU} PSI.

e/D=1.5

e/D=2.0

YIELD BEARING STRENGTH F_{BRY} PSI.

e/D=1.5

e/D=2.0

ELONGATION e %

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10⁶ PSI.

14.0

27.5

COMP. MODULUS OF ELASTICITY E_C 10⁶ PSI.

MODULUS OF RIGIDITY* G 10⁶ PSI.

(AT 2372°F) 14.1

HARDNESS* KHN

KNOOP, 100g 1200

* FORM NOT GIVEN

2. PHYSICAL PROPERTIES

PURE STABILIZED
DENSITY* ρ

LB/IN³

0.22

g/cc

6.1

SPECIFIC HEAT C BTU/LB - °F

0.106

0.127

THERMAL CONDUCTIVITY* k $\frac{BTU - FT}{HR - FT^2 - °F}$

1.14

MEAN COEFF. LIN. THERMAL EXPAN. α $\frac{10^{-6} IN.}{IN. - °F}$

(RT TO 200°F)

-

4.1

ELECTRICAL RESISTIVITY R MICROHM - IN.

(AT 950°F)

-

4×10^{12}

MAGNETIC PROPERTIES

* FORM NOT GIVEN

F. THERMOPHYSICAL EFFECTS

MELTING POINT

4870°F

PHASE CHANGES

PURE MONOCLINIC CRYSTALS REVERT TO A TETRAGONAL SHAPE WHEN HEATED ABOVE 1830°F. THIS IS ACCOMPANIED BY A DIMENSIONAL CHANGE RESULTING IN CATASTROPHIC FAILURE.

STABILIZED NO PHASE CHANGES

F. THERMOPHYSICAL EFFECTS (CONTINUED)

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k $\left(\frac{BTU - FT}{HR - FT^2 - °F} \right)$
RT	1.14
400	1.15
1000	1.19
1500	1.26
2000	1.36
2500	1.40
2550	1.41

(DATA POINTS READ FROM CURVE AND DO NOT NECESSARILY REPRESENT MEASURED VALUES AT INDICATED TEMPERATURES)

EMITTANCE VS. TEMPERATURE (TOTAL EMISSIVITY)

TEMPERATURE °F	EMITTANCE
932	0.65
1112	0.50
1472	0.36
1832	0.33
2192	0.34
2552	0.38

G. CHEMICAL PROPERTIES

NEUTRAL, BUT VERY SLIGHTLY ATTACKED BY ACIDS AND BASES.

STARTS TO FORM CARBIDES AT 3000°F WHEN IN CONTACT WITH CARBON (A FUNCTION OF TIME AND TEMPERATURE).

IS GENERALLY INERT IN OXIDIZING AND REDUCING ATMOSPHERES.

VOLATILE IN HELIUM ABOVE 4172°F. STABLE IN HYDROGEN TO 3992°F.

STARTS TO FORM NITRIDES AT HIGH TEMPERATURES WHEN IN CONTACT WITH N_2 .

H. NUCLEAR PROPERTIES

THERMAL NEUTRON CAPTURE CROSS SECTION: 0.0571 cm²/cm³

DATE 15 SEPT 1967

SUPERSEDES 15 NOV 1966

BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

4400° F IN AIR (SEE SECTION G).
3992° F IN VACUUM.
3550 TO 3992° F IN REDUCING ATMOSPHERE.
CHANGES FROM AN ELECTRICAL INSULATOR TO A CONDUCTOR
AT 2400° F.

K. PROCESSING

SURFACE TREATMENT

THERMAL TREATMENT

K. PROCESSING (CONTINUED)

JOINING

FORMING

MACHINABILITY

FIRED SHAPES CAN BE ACCURATELY MACHINED BY WET DIAMOND GRINDING. GREEN BLANKS CAN BE MACHINED AND THEN FIRED FOR A MORE ECONOMICAL APPROACH TO PRODUCING COMPLEX SHAPES. CLOSE TOLERANCES CAN BE HELD.

L. REFERENCES

NP-67-11	NP-63-38	NP-61-29
NP-65-22	NP-63-37	NP-61-28
NP-64-37	NP-62-36	NP-61-18
NP-64-36		

DATE 15 SEPT 1967
SUPERSEDES 15 NOV 1966

TENSILE STRENGTHS

DATE 15 NOV. 1966

SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING**

DATE 15 NOV. 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 15 NOV. 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

BTU/LB-°F
SPECIFIC HEAT

THERMAL CONDUCTIVITY

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

TEMPERATURES IN 100° F

DATE 15 NOV. 1966
SUPERSEDES

ELECTRICAL RESISTIVITY

BLANK

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

**REFRACTORY
CERAMICS**

MATERIALS DATA

**VIII
REFRACTORY CERAMICS**

**B.
CARBIDES**

BLANK

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

BASIC DATA

A. GENERAL

BORON CARBIDE IS A CRYSTALLINE COMPOUND POSSESSING HIGH HARDNESS AND STRENGTH, LIGHT WEIGHT, LARGE CROSS-SECTION OF NEUTRON CAPTURE, AND GOOD RESISTANCE TO ABRASION. HOWEVER, BORON CARBIDE HAS LOW OXIDATION RESISTANCE, AND POOR RESISTANCE TO THERMAL SHOCK.

BORON CARBIDE IS USED AS A NEUTRON ABSORBER OR PARTICLE ACCELERATOR, IN ELECTRICAL AND ELECTRONIC APPLICATIONS, ETC.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGES, (EXCEPT FOR F_{TU} , WHICH IS 80% OF AVERAGE) FOR HOT-PRESSED MATERIAL.

B. COMMERCIAL DESIGNATION

HIGH BORON B_4C , TECHNICAL GRADE B_4C

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
POWDER (INDIVIDUAL MESH SIZES 8-800 CRUDE B_4C , 1-IN. AND FINER)	WANL-PDS-30036
HOT PRESSED SHAPES	
COLD PRESSED AND SINTERED SHAPES.	

SUPPLIERS

NORTON CO., WORCESTER, MASS.
BORIDE PRODUCTS, INC., FERNDALE, MICH.
CARBORUNDUM CO., NIAGARA FALLS, N.Y.
UNION CARBIDE METALS CO., NIAGARA FALLS, N.Y.
CERAC, INC., BUTLER, WISCONSIN
SHIELD ALLOY CORP., NEWFIELD, N.J.

D. CHEMICAL COMPOSITION (%)

ELEMENT	B	C	B_2O_3	Fe	Si	Al_2O_3
MAXIMUM	76.0	21.2	0.07	0.27	0.40	0.015
MINIMUM	—	—	—	—	—	—

SOURCE NP-64-22 * TECHNICAL GRADE

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI.
35,200

TENSILE YIELD STRENGTH F_{TY} PSI.

COMPRESSIVE STRENGTH F_{CY} PSI.
400,000

ULTIMATE SHEAR STRENGTH F_{SU} PSI.

ULTIMATE BEARING STRENGTH F_{BRU} PSI.

$e/D=1.5$
 $e/D=2.0$

BEARING YIELD STRENGTH F_{BRY} PSI.

$e/D=1.5$
 $e/D=2.0$

ELONGATION e %

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI.

(HOT PRESSED) 65

MODULUS OF RIGIDITY G 10^6 PSI.

27

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI.

POISSON'S RATIO

0.21

2. PHYSICAL PROPERTIES

DENSITY ρ
LB/IN³ 0.091
g/cc

SPECIFIC HEAT C BTU/LB - °F
0.215

THERMAL CONDUCTIVITY k $\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$

(HOT PRESSED) 25
(COLD PRESSED & SINTERED) 10

MEAN COEFF. LIN. THERMAL EXPAN. α $\frac{10^{-6} IN.}{IN. \cdot ^\circ F}$

(75 TO 1100°F) 2.63

ELECTRICAL RESISTIVITY R MICROHM - IN.
 2.4×10^5

MAGNETIC PROPERTIES

F. THERMOPHYSICAL EFFECTS

MELTING TEMPERATURE
4440°F

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k $\left(\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F} \right)$
RT	---
200	17
250	---
500	9.0
600	12
1000	---
1500	9
2000	8
3000	8
4000	10

** HOT PRESSED

*** COLD PRESSED AND SINTERED

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSIVITY VS. TEMPERATURE

SPECTRAL, $\eta = 0.65$

TEMPERATURE °F	EMITTANCE
1562	0.84
1742	0.85
2100	0.86
2462	0.87
2821	0.88

G. CHEMICAL PROPERTIES

COMPATIBILITY

UNAFFECTED BY ALL SOLUTIONS OF ACIDS AND ALKALIS AT ORDINARY TEMPERATURES

CORROSION RESISTANCE

GOOD RESISTANCE TO WATER AT 500°F, SLOWLY ETCHED BY HYDROGEN AROUND 2200°F, OXIDIZES RAPIDLY IN AIR OR OXIDIZING GASES ABOVE 1830°F.

H. NUCLEAR PROPERTIES

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

TEMPERATURE: OXIDIZING ATMOSPHERE = 1000° F
INERT ATMOSPHERE = 4100° F

K. PROCESSING
SURFACE TREATMENT
THERMAL TREATMENT

NEARLY PURE B₄C CAUSES EFFECTIVE SINTERING RANGE TO BE EXTREMELY NARROW. CONTROLLED VARIATION IN PARTICLE SIZE PRODUCES MOST ACCEPTABLE RESULTS, ALTHOUGH SMALLER PARTICLES ARE BETTER. SINTERING IS IMPROVED THROUGH USE OF VARIOUS COVER GASES OR VACUUM, AND BY THE ADDITION OF VARIOUS METALLIC ELEMENTS. SINTER AT 4037° F FOR SIX HOURS.

K. PROCESSING (CONTINUED)
JOINING
FORMING

USUALLY FORMED BY EXTRUDING OR PRESSING

MACHINABILITY
L. REFERENCES

NP-67-3	NP-64-18
NP-66-14	NP-63-36
NP-65-19	NP-62-35
NP-64-22	NP-61-18

DATE 15 SEPT 1967
SUPERSEDES

**STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL**

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

MEAN COEFFICIENT-LINEAR THERMAL EXPANSION
 10^{-6} IN./IN.-°F

THERMAL CONDUCTIVITY
BTU-FT/HR-FT²-°F

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
A. GENERAL

TANTALUM CARBIDE IS ONE OF THE GROUP 5A CARBIDES. IT HAS HIGH MELTING TEMPERATURE AND HARDNESS, GOOD CHEMICAL STABILITY, AND ABRASION RESISTANCE. HOWEVER, TANTALUM CARBIDE HAS POOR OXIDATION RESISTANCE AND POOR THERMAL SHOCK RESISTANCE, AND IS DIFFICULT TO FABRICATE.

MUCH OF THE DATA ARE INCOMPLETE, AND MANY OF THE REPORTED VALUES ARE STRONGLY DEPENDENT UPON SPECIFIC SAMPLE PREPARATION, GRAIN SIZE, GROWTH AND ORIENTATION, DENSITY, AND TYPE OF POROSITY.

THE PROPERTIES IN SECTION E ARE AVERAGES, EXCEPT FOR F_{TU} , WHICH IS 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

TANTALUM CARBIDE (TaC)

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
POWDER (3-6 MICRONS)	
POWDER (-200 TO +325 MESH)	WANL-PDS-30054
SIMPLE SHAPES	

SUPPLIERS

KAWECKI CHEMICAL CO., N.Y., N.Y.
SHIELD ALLOY CORP., NEWFIELD, N.J.
CERAC INC., BUTLER, WIS.
UNION CARBIDE METALS CO., NIAGARA FALLS
VR/WEISSON CO., WAUKEGAN, ILLINOIS
KENNAMETAL INC., LATROBE, PENNA.

D. CHEMICAL COMPOSITION (%)

ELEMENT	TaC	C	C	B	Nb	Ti	Fe	Si	Zr
		total	free						
MAXIMUM	-	6.4	0.30	0.005	0.50	0.20	0.10	0.05	0.03
MINIMUM	99.3	6.1	-	-	-	-	-	-	-

SOURCE, WANL-PDS-30054 OTHER IMPURITIES - 0.02 MAX.

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI

3200

TENSILE YIELD STRENGTH F_{TY} PSI

COMP. YIELD STRENGTH F_{CY} PSI

SHEAR STRENGTH F_{SU} PSI

ULTIMATE BEARING STRENGTH F_{BRU} PSI

e/D=1.5
e/D=2.0

YIELD BEARING STRENGTH F_{BRY} PSI

e/D=1.5
e/D=2.0

ELONGATION e %

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI

41.5

MODULUS OF RIGIDITY G 10^6 PSI

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI

PLASTIC BENDING MODULUS (SEE APPENDIX A)

2. PHYSICAL PROPERTIES

DENSITY ρ

LB/IN³ (THEORETICAL) 0.52
g/cc

SPECIFIC HEAT C BTU/LB-°F

TaC WITH 1.5% Fe }
PRESENT AS Fe₃O₄ } 0.2

THERMAL CONDUCTIVITY k BTU-FT/HR-FT²-°F

13

MEAN COEFF. LIN. THERMAL EXPAN. α 10^{-6} IN./IN.-°F

(75° - 1820°F) 3.69

ELECTRICAL RESISTIVITY R MICROHM-IN.

7.3

MAGNETIC PROPERTIES

SUSCEPTIBILITY $< 0.45 \times 10^{-6}$ CPS UNITS

F. THERMOPHYSICAL EFFECTS
MELTING POINT

RANGE IN LITERATURE, 6310 - 7310°F
MOST PROBABLE VALUE OF MELTING POINT, 6940°F

PHASE CHANGES
THERMAL CONDUCTIVITY VS TEMPERATURE

TEMPERATURE °F	$k \left(\frac{\text{BTU-FT}}{\text{HR-FT}^2-\text{°F}} \right)$
RT	13
500	19.2
1000	20.75
1500	21.6
2000	22.3
2500	22.85
3000	23.35
3500	23.35
4000	22.85
4500	22.3

F. THERMOPHYSICAL EFFECTS (CONTINUED)
EMISSIVITY VS. TEMPERATURE

NORMAL TOTAL, POLISHED

TEMPERATURE °F	EMISSIVITY
2780	0.22
3500	0.25
4220	0.30
4940	0.33

G. CHEMICAL PROPERTIES
COMPATIBILITY:

CHEMICALLY INERT AT ORDINARY TEMPERATURES, RESISTS REDUCING ATMOSPHERES.

CORROSION RESISTANCE:

STABLE IN NITROGEN AND HYDROGEN ATMOSPHERES AT ELEVATED TEMPERATURES, BEGINS TO DECARBURIZE AND OXIDIZE IN AIR OR OXYGEN AT ABOUT 1500°F.

H. NUCLEAR PROPERTIES

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

SEE SECTION F, MELTING POINT, AND SECTION G

K. PROCESSING (CONTINUED)
JOINING
K. PROCESSING
SURFACE TREATMENT
FORMING

 FORMED BY HOT PRESSING, STEEL-DIE PRESSING, AND
SINTERING.

THERMAL TREATMENT
MACHINABILITY

 SHAPING MUST BE ACCOMPLISHED PRIOR TO FINAL SYNTHESIS
BECAUSE MACHINING IS DIFFICULT. GEOMETRICAL TOLERANCES
ARE OBTAINED ONLY AT GREATLY INCREASED EXPENSE.

L. REFERENCES

NP-64-19	NP-61-18
NP-64-18	NP-61-16
NP-63-36	NP-57-3

DATE 1 MAY 1966
SUPERSEDES

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

BLANK

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

**REFRACTORY
CERAMICS**

MATERIALS DATA

**VIII
REFRACTORY CERAMICS**

**C.
NITRIDES**

BLANK

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
A. GENERAL

BORON NITRIDE IS A WHITE, FINE-GRAINED, REFRACTORY CERAMIC. IT IS READILY MACHINABLE, HAS GOOD HEAT CONDUCTION, AND RESISTANCE TO MOISTURE PICK-UP. IT IS RESISTANT TO THERMAL SHOCK AND CORROSION. AS AN ELECTRICAL INSULATOR, IT IS RATED AS EXCELLENT. OF RELATIVELY LIGHT WEIGHT, IT ALSO POSSESSES A HIGH NEUTRON CAPTURE CROSS-SECTION. IT HAS DIRECTIONAL PROPERTIES.

BORON NITRIDE IS USABLE AS AN ENGINEERING MATERIAL ONLY IN THE COMPACTED AND SINTERED FORM.

THE VALUES FOR THE PROPERTIES IN SECTION E ARE AVERAGE, EXCEPT FOR F_{TU} , WHICH IS 80% OF AVERAGE.

VALUES IN SECTIONS E-1 AND E-2 ARE ARRANGED IN COLUMNS 1 AND 2, INDICATING (RESPECTIVELY), "PARALLEL TO PRESSING DIRECTION", AND "PERPENDICULAR TO PRESSING DIRECTION".

B. COMMERCIAL DESIGNATIONS

HOT PRESSED BORON NITRIDE

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
WIDE VARIETY OF SIZES AND SHAPES IN HOT PRESSED CONDITION	

SUPPLIERS

HIGH TEMPERATURE MATERIALS, LOWELL, MASS.
NATIONAL CARBON CO., N.Y., N.Y.
CARBORUNDUM CO., LATRODE, PENNA.
NORTON CO., WORCESTER, MASS.

D. CHEMICAL COMPOSITION (%)

ELEMENT	BN	N ₂	B	C	O ₂	OTHER METALLICS
MAXIMUM	97.0	—	—	—	—	—
TYPICAL	—	53.0	42.9	0.2	3.1	0.01
MINIMUM	95.5	—	—	—	—	—

SOURCE NP-65-21

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

(SEE A)
COL.-1 COL.-2

TENSILE ULTIMATE STRENGTH F_{TU} PSI.

4,600 7,200

TENSILE YIELD STRENGTH F_{TY} PSI.

COMP. YIELD STRENGTH F_{CY} PSI.

38,500 27,000

ULTIMATE SHEAR STRENGTH F_{SU} PSI.

ULTIMATE BEARING STRENGTH F_{BRU} PSI.

e/D=1.5
e/D=2.0

BEARING YIELD STRENGTH F_{BRY} PSI.

e/D=1.5
e/D=2.0

ELONGATION e %

REDUCTION OF AREA RA %

MODULUS OF ELASTICITY E 10^6 PSI.

12.36 4.91

MODULUS OF RIGIDITY G 10^6 PSI.

COMP. MODULUS OF ELASTICITY E_C 10^6 PSI.

HARDNESS KHN

2. PHYSICAL PROPERTIES

(SEE A)
COL.-1 COL.-2

DENSITY ρ

LB/IN³ 0.081

SPECIFIC HEAT C BTU/LB - °F

0.208

THERMAL CONDUCTIVITY k $\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$

MEAN COEFF. LIN. THERMAL EXPAN. α $\frac{10^{-6} IN.}{IN. \cdot ^\circ F}$

(75° F - 660° F) 5.64 0.33

ELECTRICAL RESISTIVITY R MICROHM - IN.

$3.15 - 3.94 \times 10^{18}$

MAGNETIC PROPERTIES

F. THERMOPHYSICAL EFFECTS

SUBLIMATION TEMPERATURE

> 5430° F

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

TEMPERATURE °F	k $\left(\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F} \right)$
600	10.6
819	10.2
1035	9.9
1311	9.3
1793	9.0

DATA FROM CARBORUNDUM COMPANY

* COL.-1 } (SEE A)
* COL.-2 }

F. THERMOPHYSICAL EFFECTS (CONTINUED)

EMISSION VS. TEMPERATURE

TOTAL NORMAL POLISHED (WEIGHTED AVERAGE)

TEMPERATURE °F	EMISSION
1225	0.720
1300	0.723
1400	0.726
1500	0.725
1600	0.737
1700	0.737
1800	0.750
1875	0.755

G. CHEMICAL PROPERTIES

COMPATIBILITY

FAIRLY INERT AND STABLE. RESISTS MOLTEN ALUMINUM, IRON, SILICON, BRONZE, AND HALIDE SALTS. ATTACKED BY MOLTEN CERUM AND BERYLLIUM.

CORROSION RESISTANCE

EXCELLENT CORROSION RESISTANCE AND RESISTANCE TO OXIDATION TO 1800° F.

MOISTURE PICKUP

2-IN. x 1/2-IN. x 1/4-IN. SAMPLE, EXPOSED TO 85% RELATIVE HUMIDITY AT 155° F FOR ONE WEEK = 0.6% OR LESS.

DATE 15 SEPT 1967

SUPERSEDES 1 MAY 1966

BASIC DATA
H. NUCLEAR PROPERTIES

HIGH NEUTRON CAPTURE CROSS-SECTION

I. NOMENCLATURE
J. SERVICE LIMITS

NOT FOR USE ABOVE 2500° F. DUE TO LACK OF MECHANICAL PROPERTIES DATA ABOVE THIS TEMPERATURE. POTENTIALLY USEFUL TO TEMPERATURES IN EXCESS OF 4000° F.

RADIATION

INSUFFICIENT DATA TO EVALUATE, BUT INDICATIONS ARE THAT LARGE AMOUNT OF HELIUM WOULD BE RELEASED WHEN IRRADIATED, RESULTING IN SEVERE DAMAGE. HIGH CONCENTRATION OF NITROGEN MAY BE UNDESIRABLE

K. PROCESSING
SURFACE TREATMENT
THERMAL TREATMENT

SPALLING DUE TO MOISTURE PICKUP MAY BE ELIMINATED BY HEATING TO 660° F.

K. PROCESSING (CONTINUED)
JOINING
FORMING
HOT PRESSING
MACHINABILITY

READILY MACHINED TO CLOSE TOLERANCES BY CONVENTIONAL METHODS WITHOUT LUBRICATION.

L. REFERENCES

NP-66-14	NP-64-18
NP-65-21	NP-63-37
NP-65-20	NP-63-36
NP-64-21	NP-61-18
NP-64-20	

DATE 15 SEPT 1967
SUPERSEDES

TENSILE STRENGTHS

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

STRENGTHS
COMPRESSIVE, SHEAR,
BEARING, FLEXURAL

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE 15 SEPT 1967
SUPERSEDES 1 MAY 1966

THERMAL EXPANSION VALUES ARE FROM
ROOM TEMPERATURE TO INDICATED TEMP.

**THERMAL EXPANSION
SPECIFIC HEAT**

THERMAL CONDUCTIVITY

DATE 1 MAY 1966
SUPERSEDES

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES

**OTHER NON-METALLIC
MATERIALS**

MATERIALS DATA

**IX
OTHER NON-METALLIC MATERIALS**

**A.
PLASTICS**

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

ARMALON IS A REINFORCED PLASTIC. THE PLASTIC ITSELF IS EITHER FEP OR TFE TEFLON. THE REINFORCEMENT IS FIBERGLASS OR TEFLON FIBER. FOR SPECIFIC PROPERTIES, A PARTICULAR DUPONT STOCK NUMBER MUST BE REFERENCED. PROPERTIES OF ARMALON VARY DEPENDING UPON CHARACTERISTICS OF REINFORCEMENT, CHEMISTRY OF PLASTIC AND PROCESSING.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGE.

B. COMMERCIAL DESIGNATIONS

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
TEFLON IMPREGNATED FELT TEFLON-COATED GLASS FABRICS AND LAMINATES, EITHER TFE OR FEP. CONSTRUCTION MAY BE EITHER SINGLE PLY OR MULTIPLE PLY.	

SUPPLIERS

E. I. DUPONT de NEMOURS & CO., INC.
FABRICS & FINISHES DEPARTMENT
WILMINGTON, DELAWARE

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

E. ROOM TEMPERATURE PROPERTIES (AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

	DUPONT * 405-116 TFE	DUPONT * 510-128 FEP
TENSILE ULTIMATE STRENGTH	FTU	PSI
	13,760	21,600

ELONGATION	e	%
	0.8	1.2

MODULUS OF ELASTICITY	E	10 ⁶ PSI
	2.09	1.94

HARDNESS	
	75 SHORE D

2. PHYSICAL PROPERTIES

DENSITY	p
LB/IN ³ g/cc	0.078 2.16

SPECIFIC HEAT	C	BTU/LB - °F
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THERMAL CONDUCTIVITY	k	BTU - FT HR - FT ² - °F
----------------------	---	---------------------------------------

MEAN COEFF. LIN. THERMAL EXPANS.	a	10 ⁻⁶ IN. IN. - °F
----------------------------------	---	----------------------------------

ELECTRICAL RESISTIVITY	R	MICROHM - IN.
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*THE 400 SERIES NUMBERS ARE ASSIGNED TO TFE TEFLON COMPOSITES. THE 500 SERIES NUMBERS ARE ASSIGNED TO FEP TEFLON. THE SECOND AND THIRD DIGITS OF THE 400 AND 500 NUMBERS INDICATE THE THICKNESS (IN MILS) OF THE PREPREG (PRE-IMPREGNATED GLASS CLOTH) USED FOR THE LAMINATE. THE NUMBERS AFTER THE HYPHEN ARE STANDARD DESIGNATIONS FOR TYPES OF GLASS CLOTH.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE
PHASE CHANGES
THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS

K. PROCESSING

L. REFERENCES

NP 65-26

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

BLANK

DATE 1 MAY 1966
SUPERSEDES

**IMPACT STRENGTH
HARDNESS**

ELONGATION

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

TEFLON AND TEFLON TFE ARE TETRAFLUORETHYLENE PLASTICS. THEY ARE WHITE AND, IN THICKNESSES GREATER THAN 1/16-IN., ARE OPAQUE. THE RESIN MANUFACTURER USUALLY FURNISHES THEM IN THE FORM OF MOLDING POWDERS. TEFLON CAN ALSO BE PURCHASED IN A WATER DISPERSION, AND TFE CAN BE PROCURED FROM PROCESSORS AS SHEET, ROD, TUBE, FILM, AND FABRICATED PARTS. WHEN ALLOWABLE CONTAMINATION LIMITS ARE LOW, IT IS USUALLY MORE ECONOMICAL TO PROCURE FINISHED PARTS. GENERAL INDUSTRY SPECIFICATIONS DO NOT PROVIDE SUFFICIENT CONTROL OVER QUALITY FOR MOST CRYOGENIC APPLICATIONS, AND WIDE VARIATIONS IN QUALITY RESULT FROM DIFFERENT MOLDING POWDERS, MOLDING METHODS, AND SINTERING CONDITIONS.

DATA SHOWN ARE TYPICAL FOR GOOD QUALITY TFE.

B. COMMERCIAL DESIGNATIONS

TEFLON TFE

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
POLYTETRAFLUORETHYLENE	
TEFLON	AMS 3651
TEFLON FILM	AMS 3652
EXTRUDED TUBING, ELECTRICAL INSULATION, STANDARD WALL (TEFLON)	AMS 3653
EXTRUDED TUBING, ELECTRICAL INSULATION, LIGHT WALL (TEFLON)	AMS 3654 MIL - I - 22129
EXTRUDED, TFE FLUOROCARBON RESIN, AS-SINTERED RODS AND TUBES (TEFLON)	AMS 3656

SUPPLIERS

E. I. DUPONT DE NEMOURS	(RESIN)
ALLIED CHEMICAL CO.	(RESIN)
FLUOROCARBON CO.	(PROCESSOR)
RAYBESTOS MANHATTAN	(PROCESSOR)

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

E. ROOM TEMPERATURE PROPERTIES

(AVERAGE UNLESS OTHERWISE NOTED)

I. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU}	PSI
MIN.	4000
TENSILE YIELD STRENGTH F_{TY}	PSI
MIN.	1750
COMP. YIELD STRENGTH F_{CY}	PSI
2% OFFSET	2000
ELONGATION e	%
	300
MODULUS OF ELASTICITY E	10^6 PSI
	0.1
MODULUS OF RIGIDITY G	10^6 PSI
MIN.	0.017
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
	0.06
POISSON'S RATIO	0.46
HARDNESS	60 SHORE D

2. PHYSICAL PROPERTIES

DENSITY ρ	LB/IN ³
	0.079
SPECIFIC HEAT C	BTU/LB - °F
	0.25
THERMAL CONDUCTIVITY k	BTU - FT HR - FT ² - °F
	0.14
MEAN COEFF. LIN. THERMAL EXPANS. α	10^{-6} IN. IN. - °F
(68° TO -238°F)	63.4
(68° TO -320°F)	53.8
(68° TO -423°F)	44.0
ELECTRICAL RESISTIVITY R	
MICROHM - IN.	$> 3.9 \times 10^{20}$
COEFFICIENT OF FRICTION (DEPENDING ON LOAD AND SLIDING SPEED)	0.015-0.10

F. THERMOPHYSICAL EFFECTS

MELTING RANGE	610-620°F
PHASE CHANGES	
THERMAL CONDUCTIVITY VS. TEMPERATURE	
EMISSIVITY VS. TEMPERATURE	

G. CHEMICAL PROPERTIES

WATER ABSORPTION: NONE
INERT TO ALL COMMON SOLVENTS AND REAGENTS
REACTS WITH MOLTEN ALKALI METALS AND HALOGENS UNDER CERTAIN CONDITIONS OF TEMPERATURE AND PRESSURE.
SWOLLEN BY N_2O_4 AND SOME HALOGENATED SOLVENTS

H. NUCLEAR PROPERTIES

(SEE ALSO APPENDIX B)

MODERATE DAMAGE BEGINNING AT 5×10^6 ERGS/GM(C)
SERIOUS DAMAGE AT 2.5×10^7 ERGS/GM(C)

A. GENERAL

TEFLON 100 IS A FLUORINATED-ETHYLENE-PROPYLENE (FEP) PLASTIC. IT IS MILKY IN COLOR AND TRANSLUCENT IN THE CURED FORM.

THE PROPERTY VALUES IN SECTION E ARE AVERAGE.

B. COMMERCIAL DESIGNATIONS

TEFLON FEP

E. ROOM TEMPERATURE PROPERTIES

I. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU}	PSI
	4000
ELONGATION e	%
	300
MODULUS OF ELASTICITY E	10^6 PSI
	0.10
MODULUS OF RIGIDITY G	10^6 PSI
COMP. MODULUS OF ELASTICITY E_C	10^6 PSI
HARDNESS	55 SHORE D

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
I. NOMENCLATURE
J. SERVICE LIMITS

-423° TO 500°F (FOR BOTH TFE & FEP TYPES)

K. PROCESSING
SURFACE TREATMENT

SODIUM ETCH FOR ADHESIVE BONDING

THERMAL TREATMENT

SLOW COOLING TO INCREASE CRYSTALLINITY

RAPID COOLING TO MINIMIZE CRYSTAL NUCLEATION AND GROWTH

K. PROCESSING (CONTINUED)
JOINING

ADHESIVE BONDING OF ETCHED SURFACES

HOT BONDING WITH FLUORINATED ETHYLENE PROPYLENE

FORMING

PRESSURE AND HOT FORMING

MACHINABILITY

FAIR

L. REFERENCES

NP-62-46
NP-65-1
NP-65-27

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

STRENGTHS
COMPRESSIVE, SHEAR,
BEARING

DATE 1 MAY 1966
SUPERSEDES

**STRESS VS STRAIN
AS FUNCTION OF
TEMPERATURE**

DATE 1 MAY 1966

SUPERSEDES

**IMPACT STRENGTH
HARDNESS**

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

MODULUS OF RIGIDITY

DATE	1 MAY 1966
SUPERSEDES	

BASIC DATA
A. GENERAL

VESPEL SP-3 IS A POLYIMIDE PLASTIC FILLED WITH 15% MOLYBDENUM DISULFIDE (MoS₂). IT IS BLACK IN COLOR.

THE PROPERTIES GIVEN IN SECTION E ARE AVERAGE.

B. COMMERCIAL DESIGNATIONS

VESPEL SP-3

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

E. I. DUPONT de NEMOURS & CO. INC.
PLASTICS DEPARTMENT
WILMINGTON, DELAWARE

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE
E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI

10,700

ELONGATION e %

5.0

MODULUS OF ELASTICITY E 10⁶ PSI

(DYNAMIC) 0.61

HARDNESS

85 SHORE D

2. PHYSICAL PROPERTIES

DENSITY ρ

LB/IN³ 0.057
g/cc

SPECIFIC HEAT C BTU/LB - °F

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES
H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

NO APPRECIABLE CHANGE IN PROPERTIES GIVEN IN SECTION E AFTER GAMMA DOSE OF 3×10^{10} ERGS/GRAM (C).

J. SERVICE LIMITS
K. PROCESSING

VESPEL SP-3 CAN BE MACHINED TO MANY DESIRED SHAPES.

L. REFERENCES

NP 63-41

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

KAPTON, FORMERLY KNOWN AS H-FILM, IS A PLASTIC LAMINATE OF THE POLYIMIDE TYPE.

THE VALUES GIVEN IN SECTION E ARE AVERAGES

B. COMMERCIAL DESIGNATIONS

KAPTON, H-FILM

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

E. I. DUPONT de NEMOURS & CO. INC.
FILM DEPARTMENT
WILMINGTON, DELAWARE

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

TENSILE ULTIMATE STRENGTH F_{TU} PSI

25,000

TENSILE YIELD STRENGTH F_{TY} PSI

(AT 3% OFFSET) 8,000

ELONGATION e %

56

MODULUS OF ELASTICITY E 10^6 PSI

0.43

HARDNESS

2. PHYSICAL PROPERTIES

DENSITY ρ

LB./IN.³ 0.051
g/cc

SPECIFIC HEAT C BTU/LB. - °F

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - ^\circ F}$

0.09

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - ^\circ F}$

36.0

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

NONE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

EFFECT OF NEUTRON EXPOSURE ON KAPTON*

$\frac{5 \times 10^{11}}{FILM DARKENED}$ ERGS/GM (C) $\frac{10^{12}}{FILM DARKENED AND TOUGH}$

* TEMP. 350°F., FLUX 5×10^{12} nvt
BROOKHAVEN PILE-MIXED NEUTRON AND GAMMA RADIATION

J. SERVICE LIMITS

-200° TO +500°F

TEMP. (°F)	TENSILE STRENGTH (PSI)	ELONGATION
-320	35,000	2%
+ 77	25,000	70%
+392	17,000	90%

L. REFERENCES

NP-65-28
NP-65-30

DATE 1 MAY 1966
SUPERSEDES

TENSILE STRENGTHS

DATE 1 MAY 1966
SUPERSEDES

IMPACT STRENGTH
HARDNESS

DATE 1 MAY 1966
SUPERSEDES

MODULUS OF ELASTICITY

DATE 1 MAY 1966
SUPERSEDES

ELECTRICAL RESISTIVITY

DATE 1 MAY 1966

SUPERSEDES

DIELECTRIC STRENGTH

DATE 1 MAY 1966

SUPERSEDES

**OTHER NON-METALLIC
MATERIALS**

MATERIALS DATA

**IX
OTHER NON-METALLIC MATERIALS**

**B.
ADHESIVES**

BLANK

DATE	1 MAY 1966
SUPERSEDES	

BASIC DATA

A. GENERAL

EPON 929 IS A STRUCTURAL EPOXY ADHESIVE. IT IS A ONE-PART PASTE SYSTEM AND IS YELLOW GREEN IN COLOR.

SEE SECTION G FOR WARNING.

B. COMMERCIAL DESIGNATIONS

EPON 929

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

SHELL CHEMICAL CO.
ADHESIVES DEPARTMENT
PITTSBURGH, CALIFORNIA

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ADHESIVE ULTIMATE
SHEAR STRENGTH F_{SU} PSI
3500

ELONGATION e %

MODULUS OF ELASTICITY E 10^6 PSI

2. PHYSICAL PROPERTIES

DENSITY ρ
LB/IN³ (CURED) 0.051
g/cc

SPECIFIC HEAT C BTU/LB - °F

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

G. CHEMICAL PROPERTIES

EPON 929 IS A HIGHLY EXOTHERMIC POLYMER, BUT IT CAN BE WARMED TO 140°F. FOR HANDLING. THE MAXIMUM STRENGTH CURE IS 80 MINUTES MINIMUM AT 275°F.

WARNING:
CURING SHOULD BE DONE IN A HOODED ENCLOSURE, SINCE THE VOLATILES ARE NOXIOUS.

WARNING:
EPON 929 CANNOT BE CURED AT 250°F. OR ABOVE, IN THICKNESSES GREATER THAN 1/16 INCH WITHOUT LOSING THE BATCH IN AN EXOTHERMIC REACTION. THIS EXOTHERMIC REACTION CAUSES THE EVOLUTION OF NOXIOUS VAPORS.

VOLATILE CONTENT:
LESS THAN 1%

SHELF LIFE:
4 MONTHS MINIMUM AT 75°F.

VISCOSITY:
4000 POISE (THICK PASTE)

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS

-50° TO 450°F

STRENGTH LEVEL IS UNCHANGED FROM +300° TO -50°F. EPON 929 MAY BE USEFUL AT TEMPERATURES MUCH BELOW -50°F.

K. PROCESSING

CURES:
4 HOURS AT 250°F
80 MINUTES AT 275°F
40 MINUTES AT 400°F

(MAXIMUM THICKNESS OF ADHESIVE = 1/16 INCH)

L. REFERENCES

NP-63-42

DATE 1 MAY 1966
SUPERSEDES

ADHESIVE SHEAR

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

THIS MATERIAL IS A STRUCTURAL ADHESIVE OF THE EPOXY TYPE. IT IS A TWO-PART PASTE. PART A IS A GRAY PASTE, AND PART B IS AN AMBER LIQUID.

B. COMMERCIAL DESIGNATIONS

EPON 934

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

SHELL CHEMICAL CO.
ADHESIVES DEPARTMENT
PITTSBURG, CALIFORNIA

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE
E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ADHESIVE ULTIMATE
SHEAR STRENGTH F_{SU} PSI

3200

ELONGATION e %

MODULUS OF ELASTICITY E 10^6 PSI

HARDNESS SHORE

(CURED) 86 D

2. PHYSICAL PROPERTIES

DENSITY ρ

LB./IN.³ (CURED) 0.045
g/cc

SPECIFIC HEAT C BTU/LB - °F

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

VISCOSITY:

PART A 5000 POISE (THICK PASTE)
PART B 20 POISE (LIQUID)

VOLATILES:

LESS THAN 2%

SHELF LIFE:

PART A 6 MONTHS AT 70°F
PART B 4 YEARS AT 70°F

POT LIFE:

40 MINUTES AT 75°F

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS

-75° TO + 250°F.

STRENGTH AT -75°F IS 80% OF MAXIMUM, THEREFORE EPON 934 MAY BE USEFUL AT TEMPERATURES MUCH BELOW -75°F.

K. PROCESSING

CURES: 5 DAYS AT 70°F.
1 HOUR AT 180°F.
15 MINUTES AT 300°F.

L. REFERENCES

NP-63-42

DATE 1 MAY 1966
SUPERSEDES

ADHESIVE SHEAR

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

FM 1000 IS A STRUCTURAL ADHESIVE OF THE EPOXY-NYLON TYPE. IT IS USED AS AN UN-SUPPORTED FILM ITS COLOR IS OFF-WHITE AND IT IS LIQUID.

B. COMMERCIAL DESIGNATIONS

FM 1000

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

AMERICAN CYANAMID CO.
BLOOMINGDALE, DEPT.
TORRANCE, CALIF.

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE
E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ADHESIVE ULTIMATE
SHEAR STRENGTH F_{SU} PSI
(METAL TO METAL) 6,300

ELONGATION e %

MODULUS OF ELASTICITY E 10^6 PSI

HARDNESS SHORE D

(CURED) 60

2. PHYSICAL PROPERTIES

DENSITY ρ
LB/IN³ 0.042
g/cc

SPECIFIC HEAT C BTU/LB - °F

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

VOLATILES CONTENT: LESS THAN 2%

SHELF LIFE: 6 MONTHS MINIMUM AT 75°F

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS
K. PROCESSING

CURE:
60 MINUTES AT 350°F AND PRESSURE GREATER THAN
5 PSI

L. REFERENCES

BLANK

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

HT 424 IS A STRUCTURAL ADHESIVE OF THE EPOXY-PHENOLIC TYPE. IT IS USED AS A SUPPORTED FILM. ITS COLOR IS GRAY.

B. COMMERCIAL DESIGNATIONS

HT 424

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
	MIL-A-5090, TYPE III
	MIL-A-29463, CLASS F TYPE I & II

SUPPLIERS

AMERICAN CYANAMID CO.
BLOOMINGDALE DEPT.
SAN DIEGO, CALIF.

D. CHEMICAL COMPOSITION (%)

ELEMENT	MAXIMUM	MINIMUM

SOURCE

E. ROOM TEMPERATURE PROPERTIES (AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ADHESIVE ULTIMATE
SHEAR STRENGTH F_{SU} PSI
3600

ELONGATION e %

MODULUS OF ELASTICITY E 10^6 PSI

HARDNESS SHORE D
(CURED) 60

2. PHYSICAL PROPERTIES

DENSITY ρ
 LB/IN^3 0.058
 g/cc

SPECIFIC HEAT C BTU/LB - $^{\circ}F$

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - ^{\circ}F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - ^{\circ}F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

VOLATILE CONTENT: 10%

SHELF LIFE: 180 DAYS AT $-10^{\circ}F$

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS

K. PROCESSING

CURE:

40 MIN. AT $330^{\circ}F$.

L. REFERENCES

NP-61-26

DATE 1 MAY 1966

SUPERSEDES

ADHESIVE SHEAR

DATE	1 MAY 1966
SUPERSEDES	

BASIC DATA

A. GENERAL

AEROBOND 430 IS IN THE FORM OF A FILM SUPPORTED ON GLASS FABRIC. THE COLOR IS GRAY AND IT IS A ONE-PART SYSTEM.

THIS MATERIAL IS A STRUCTURAL ADHESIVE OF THE EPOXY-PHENOLIC TYPE.

B. COMMERCIAL DESIGNATIONS

AEROBOND 430

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS
FILM SUPPORTED ON GLASS FABRIC	

SUPPLIERS

ADHESIVE ENGINEERING CO.
SAN CARLOS, CALIF.

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

**E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)**

1. MECHANICAL PROPERTIES

ADHESIVE ULTIMATE
SHEAR STRENGTH F_{TU} PSI
2,600

ELONGATION e %

MODULUS OF ELASTICITY E 10^6 PSI

HARDNESS
(CURED) 80

2. PHYSICAL PROPERTIES

DENSITY ρ
LB/IN³ (BULK, CURED) 0.068
g/cc

SPECIFIC HEAT C BTU/LB - °F

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

SHELF LIFE:

2 DAYS AT 75°F. MUST BE REFRIGERATED FOR LONGER STORAGE.

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS

-400°F TO +500°F

K. PROCESSING

CURE:

60 MINUTES AT 75°F.

L. REFERENCES

NP-65-28

DATE 1 MAY 1966
SUPERSEDES

ADHESIVE SHEAR

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

METLBOND 402, TYPE 1, IS A STRUCTURAL ADHESIVE OF THE PHENOLIC-NITRILE TYPE. IT IS USED AS AN UNSUPPORTED FIBER. METLBOND 402 IS YELLOW.

METLBOND 402 IS FLEXIBLE IN THIN SECTIONS

B. COMMERCIAL DESIGNATIONS

METLBOND 402, TYPE 1

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

NARMCO MATERIALS DIV.
WHITTAKER CORP.
COSTA MESA, CALIF.

D. CHEMICAL COMPOSITION (%)

ELEMENT	MAXIMUM	MINIMUM

SOURCE

E. ROOM TEMPERATURE PROPERTIES (AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ADHESIVE ULTIMATE
SHEAR STRENGTH F_{SU} PSI
4000

ELONGATION e %

MODULUS OF ELASTICITY E 10^6 PSI

HARDNESS SHORE D
(CURED) 60

2. PHYSICAL PROPERTIES

DENSITY ρ
LB./IN.³ 0.035
g/cc

SPECIFIC HEAT C BTU/LB. - °F

THERMAL CONDUCTIVITY k $\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. \cdot ^\circ F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

VOLATILES CONTENT:

LESS THAN 2%

SHELF LIFE:

IF STORAGE TEMPERATURE DOES NOT EXCEED 75°F, SHELF LIFE WILL BE MORE THAN SIX MONTHS.

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS

-423° TO 300°F

K. PROCESSING

CURE:

60 MINUTES AT 335°F.

L. REFERENCES

NP-65-29

DATE 1 MAY 1966

SUPERSEDES

ADHESIVE SHEAR

DATE 1 MAY 1966

SUPERSEDES

BASIC DATA

A. GENERAL

FM 47 IS A STRUCTURAL ADHESIVE OF THE VINYL-PHENOLIC TYPE. IT IS USED IN BOTH SUPPORTED AND UNSUPPORTED FORMS. IT IS LIGHT BROWN IN COLOR. FM 47 IS A ONE-PART LIQUID SYSTEM.

B. COMMERCIAL DESIGNATIONS

FM 47

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

AMERICAN CYANAMID CO.
BLOOMINGDALE DEPT.
TORRANCE, CALIF.

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE

E. ROOM TEMPERATURE PROPERTIES (AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ADHESIVE ULTIMATE
SHEAR STRENGTH F_{SU} PSI
4300

ELONGATION e %

MODULUS OF ELASTICITY E 10^6 PSI

HARDNESS SHORE D
(CURED) 60

2. PHYSICAL PROPERTIES

DENSITY ρ
LB/IN³ 0.029
g/cc

SPECIFIC HEAT C BTU/LB - °F

THERMAL CONDUCTIVITY k $\frac{BTU \cdot FT}{HR \cdot FT^2 \cdot ^\circ F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. \cdot ^\circ F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

VOLATILE CONTENT

15%

SHELF LIFE

ONE YEAR MIN. AT 100°F.

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS

K. PROCESSING

CURES

100 MINUTES AT 275°F, UNDER 15 PSI PRESSURE
5 MINUTES AT 400°F, UNDER 15 PSI PRESSURE

L. REFERENCES

NP-61-24

BLANK

DATE 1 MAY 1966

SUPERSEDES
BASIC DATA
A. GENERAL

APCO 1252 IS A STRUCTURAL ADHESIVE OF THE POLYURETHANE TYPE. THE COLOR IS CLEAR TO CLOUDY. APCO 1252 IS A TWO-PART LIQUID SYSTEM.

THE VALUE FOR ADHESIVE ULTIMATE SHEAR STRENGTH IN SECTION E IS 80% OF AVERAGE.

B. COMMERCIAL DESIGNATIONS

APCO 1252

C. AVAILABLE FORMS, SPECIFICATIONS, SUPPLIERS

FORMS AND CONDITIONS	SPECIFICATIONS

SUPPLIERS

APPLIED PLASTICS CO., INC.
EL SEGUNDO, CALIF.

D. CHEMICAL COMPOSITION (%)

ELEMENT									
MAXIMUM									
MINIMUM									

SOURCE
E. ROOM TEMPERATURE PROPERTIES
(AVERAGE UNLESS OTHERWISE NOTED)

1. MECHANICAL PROPERTIES

ADHESIVE ULTIMATE
SHEAR STRENGTH F_{SU} PSI

2750

ELONGATION e %

MODULUS OF ELASTICITY E 10^6 PSI

HARDNESS SHORE D

2. PHYSICAL PROPERTIES

DENSITY ρ

LB/IN³ 0.038
g/cc

SPECIFIC HEAT C BTU/LB - °F

THERMAL CONDUCTIVITY k $\frac{BTU - FT}{HR - FT^2 - °F}$

MEAN COEFF. LIN. THERMAL EXPANS. α $\frac{10^{-6} IN.}{IN. - °F}$

ELECTRICAL RESISTIVITY R MICROHM - IN.

F. THERMOPHYSICAL EFFECTS

MELTING RANGE

PHASE CHANGES

THERMAL CONDUCTIVITY VS. TEMPERATURE

G. CHEMICAL PROPERTIES

SHELF LIFE:

1 YEAR MINIMUM

VISCOSITY:

15 POISE FOR PART A AND FOR PART B

POT LIFE:

6 HOURS AT 70°F.

H. NUCLEAR PROPERTIES (SEE ALSO APPENDIX B)

J. SERVICE LIMITS
K. PROCESSING

MIXING:

100 GRAMS OF PART A TO 5 GRAMS OF PART B

CURES:

18 DAYS AT 75°F. (USEFUL STRENGTH AFTER 8 HOURS)

6 HOURS AT 165°F.

45 MINUTES AT 300°F.

L. REFERENCES

NP-64-24

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DATE 1 MAY 1966

SUPERSEDES

**PLASTIC BENDING
MODULUS**

APPENDIX A

PLASTIC BENDING MODULUS

BY
RICHARD GAVALIS
LEAD ENGINEER, STRUCTURAL MECHANICS, RE-ENTRY SYSTEMS DEPT.
GENERAL ELECTRIC COMPANY

REPRODUCED BY COURTESY OF
MACHINE DESIGN MAGAZINE

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DATE

1 MAY 1966

SUPERSEDES
**PLASTIC BENDING
MODULUS**

In recent years, new structural materials have been appearing in ever-increasing numbers. In addition, structures are now being designed for a wide range of environmental temperatures.

Often, the yield and ultimate strength are the only characteristics available on a new material at the design temperature. This article shows how to determine, from this limited data, the bending strength of a material in the plastic range.

NOMENCLATURE

- $B_{a,k}$ = Bending modulus for any allowable stress and section factor, psi
- $B_{u,k}$ = Ultimate bending modulus for any section factor, psi
- $B_{y,k}$ = Yield bending modulus for any section factor, psi
- c = Distance from neutral axis to outer fiber, in.
- e = Strain at outer fiber of beam, in. per in.
- I = Moment of inertia of cross section about the neutral axis, in.⁴
- k = Section factor
= $2Qc/I$
- M = Applied bending moment, lb-in.
- M_a = Allowable moment, lb-in.
- Q = First moment about the neutral axis of the area between the neutral axis and the outer fiber, in.³
- Z_1 = Slope of bending-modulus curve between plasticity limit and yield tensile strength
- Z_2 = Slope of bending-modulus curve between yield and ultimate tensile strengths
- σ_a = Allowable stress at outer fiber, psi
- $\sigma_{o,a}$ = Trapezoidal intercept stress for any allowable stress, psi
- $\sigma_{o,u}$ = Ultimate trapezoidal intercept stress, psi
- $\sigma_{o,y}$ = Yield trapezoidal intercept stress, psi
- $\sigma_{p,l}$ = Plasticity limit stress, psi
- $\sigma_{t,u}$ = Ultimate tensile strength, psi
- $\sigma_{t,y}$ = Yield tensile strength, psi

DATE

1 MAY 1966

SUPERSEDES
**PLASTIC BENDING
MODULUS**

1. Basic Relationships

Classical bending theory ($\sigma = Mc/I$) assumes that when a bending moment M is applied to a beam, plane sections remain plane and the strain is proportional to the distance from the neutral axis, Fig. 1a. When the strain level at the outer fiber (point a) is below the elastic limit of the material, the stress variation across the section is linear, Fig. 1b, and the Mc/I bending-stress equation is exact. In the inelastic range, the strain distribution is still linear, but the stress distribution is nonlinear, Fig. 1c, due to plastic effects. Classical bending-stress equation does not apply.

It has been shown (Ref. 1) that the actual stress variation across the section can be replaced with a trapezoidal stress distribution, as shown by the dotted lines in Fig. 1c. The trapezoid must be chosen so that the stress at the outer fiber is the allowable stress, σ_a , and the moments taken about the neutral axis for the actual stress distribution and the assumed trapezoidal stress distribution are equal. The value of the stress at the neutral axis in the trapezoidal distribution is called the trapezoidal intercept stress, σ_o .

A fictitious ultimate bending stress, called the bending modulus of rupture, B , is used for convenience in establishing the bending strength of a material. Utilizing the trapezoidal stress distribution, the bending modulus of rupture can be found and, when combined with the section modulus, I/c , permits the allowable moment, M_a , to be calculated:

$$M_a = B_{a,k} \left(\frac{I}{c} \right) \quad (1)$$

where

$$B_a = \frac{Mc}{I} = \sigma_a + (k - 1)\sigma_{o,a} \quad (2)$$

FIGURE 1 - BASIC STRESS-STRAIN DISTRIBUTIONS:

- a, STRAIN DISTRIBUTION;
- b, STRESS DISTRIBUTION IN ELASTIC RANGE;
- c, STRESS DISTRIBUTION IN PLASTIC RANGE.

References are tabulated at end of this appendix.

DATE	1 MAY 1966
SUPERSEDES	

**PLASTIC BENDING
MODULUS**

2. Ultimate Bending Strength

When the extreme fiber of the cross section in bending (point a, Fig. 1a) can be stressed to the ultimate tensile strength, ($\sigma_{t,u}$), of the material, the bending modulus is, from Equation 2,

$$B_{u,k} = \sigma_{t,u} + (k - 1)\sigma_{o,u} \quad (3)$$

where section factor k is

$$k = \frac{2Qc}{I} \quad (4)$$

For a rectangular cross section, $k = 1.5$, and the ultimate bending modulus is

$$B_{u,1.5} = \sigma_{t,u} + 0.5 \sigma_{o,u} \quad (5)$$

The value of the ultimate trapezoidal intercept stress ($\sigma_{o,u}$) can be obtained from Fig. 2, or the ultimate bending modulus ($B_{u,1.5}$) can be obtained directly, and more accurately, from Fig. 3.

In general, for a cross section with any section factor k, the ultimate bending modulus can be found from Equation 3. However, a more accurate equation is

$$B_{u,k} = B_{u,1.5} + (k - 1.5)\sigma_{o,u} \quad (6)$$

which is found by equating $\sigma_{t,u}$ obtained from Equation 3 to that $\sigma_{t,u}$ from Equation 5. The rectangular section with $k = 1.5$ is used as a basis in plastic-bending theory (Ref. 2); therefore, the ultimate bending modulus ($B_{u,1.5}$) and yield bending modulus ($B_{y,1.5}$) are used in this article as reference values.

DATE 1 MAY 1966
SUPERSEDES

**PLASTIC BENDING
MODULUS**

FIGURE 2 - ULTIMATE AND YIELD TRAPEZOIDAL INTERCEPT STRESS

FIGURE 3 - ULTIMATE AND YIELD BENDING MODULUS
FOR RECTANGULAR CROSS SECTION ($k = 1.5$)

DATE	1 MAY 1966
SUPERSEDES	

PLASTIC BENDING MODULUS

3. Yield Bending Strength

Assuming that the extreme fiber is stressed to the yield strength, $\sigma_{t,y}$, of the material, the yield bending modulus is

$$B_{y,k} = \sigma_{t,y} + (k - 1)\sigma_{o,y} \quad (7)$$

For a rectangular cross section, $k = 1.5$; thus,

$$B_{y,1.5} = \sigma_{t,y} + 0.5\sigma_{o,y} \quad (8)$$

The yield trapezoidal-intersect stress, $\sigma_{o,y}$, is found from Fig. 2. This average curve gives a reasonably accurate value of yielding bending modulus. However, Fig. 3 gives more accurate values of $B_{y,1.5}$.

For the general cross section with any value of k , yield bending modulus is

$$B_{y,k} = B_{y,1.5} + (k - 1.5)\sigma_{o,y} \quad (9)$$

DATE 1 MAY 1966

SUPERSEDES
**PLASTIC BENDING
MODULUS**

4. General Stress Level

If the allowable stress at the extreme fiber lies between the plastic-limit stress and ultimate strength of the material, the allowable bending modulus is calculated by first obtaining the plastic-limit stress from Fig. 4. Below this stress, no appreciable plastic-bending occurs. If the proportional limit of the material is known and its value lies between the typical and lower-bound curves of Fig 4, the proportional limit stress should be used as the plastic-limit stress.

Next, the ultimate and yield bending modulus are calculated for the section factor desired, as explained in 2 and 3, above, "Ultimate Bending Strength", and "Yield Bending Strength", respectively. A curve is then constructed, Fig. 5, by plotting the allowable bending modulus against the allowable extreme-fiber stress for any section factor. Three points on the curve are available: Bending modulus at the yield strength, at the ultimate strength, and at the plastic-limit stress point.

A linear variation between these points is satisfactory. The actual variation is as shown by the dashed lines in Fig 5. A more accurate curve can be drawn by simulating the arcs in Fig. 5; this is done by using a rise (D) to arc-chord (A) ratio of 0.04. This D/A ratio holds for the upper and lower arc. A curve of this type can be used for any selected value of k. A complete bending-modulus curve is shown in Fig. 6. From this curve, the bending modulus can be found by interpolation for any stress level or section factor.

Equations based on the linear variation can be used instead of the plot shown in Fig. 6.

For $\sigma_{p,l} < \sigma_a < \sigma_{t,y}$

$$Z_1 = \frac{B_{y,k} - \sigma_{p,l}}{\sigma_{t,y} - \sigma_{p,l}} \quad (10)$$

and

$$B_{a,k} = (B_{y,k} - Z_1 \sigma_{t,y}) + Z_1 \sigma_a \quad (11)$$

For $\sigma_{t,y} < \sigma_a < \sigma_{t,u}$

$$Z_2 = \frac{B_{u,k} - B_{y,k}}{\sigma_{t,u} - \sigma_{t,y}} \quad (12)$$

and

$$B_{a,k} = (B_{u,k} - Z_2 \sigma_{t,u}) + Z_2 \sigma_a \quad (13)$$

DATE 1 MAY 1966
SUPERSEDES

PLASTIC BENDING MODULUS

FIGURE 4 - PLASTICITY LIMIT STRESS

FIGURE 5 - CONSTRUCTION OF PLASTIC BENDING CURVE FOR SPECIFIC k

DATE 1 MAY 1966

SUPERSEDES
**PLASTIC BENDING
MODULUS**

5. Example

- For section factor $k = 1.37$, what is the allowable ultimate and yield bending modulus for a 2014-T6 forging at room temperature: Known values $\sigma_{t,u} = 65,000$ psi, and $\sigma_{t,y} = 50,000$ psi. (For comparison, values in brackets are those obtained by more exact, though cumbersome, methods.) (Ref. 2).

For $k = 1.5$:

$$\begin{aligned}\sigma_{o,u} &= 59,000 \text{ psi, Fig. 2 [60,000];} \\ B_{u,1.5} &= 94,000 \text{ psi, Fig. 3 [95,200 psi];} \\ \sigma_{o,y} &= 24,700 \text{ psi, average curve of Fig. 2 [25,000 psi];} \\ B_{y,1.5} &= 62,500 \text{ psi, Fig. 3 [61,200 psi].}\end{aligned}$$

For $k = 1.37$:

$$\begin{aligned}\text{From Equation 6, } B_{u,1.37} &= 94,000 + (1.37 - 1.5) 59,000 = 86,300 \text{ psi [87,100 psi];} \\ \text{From Equation 9, } B_{y,1.37} &= 62,500 + (1.37 - 1.5) 24,700 = 59,300 \text{ psi [58,100 psi].}\end{aligned}$$

The value for $B_{y,1.37}$ would differ by less than 2% if the upper or lower-bound curve had been used in obtaining $\sigma_{o,y}$ from Fig. 2.

- For the same material, what is the allowable bending modulus for allowable stress $\sigma_a = 57,000$ psi, and section factor $k = 1.37$?

First, $\sigma_{t,y} < \sigma_a < \sigma_{t,u}$; $50,000 < 57,000 < 65,000$.

$$\text{Therefore, from Equation 12, } Z_2 = (B_{u,1.37} - B_{y,1.37}) / (\sigma_{t,u} - \sigma_{t,y}) = 86,300 - 59,300 / 65,000 - 50,000 = 1.80.$$

$$\text{From Equation 13, } B_{a,1.37} = B_{u,1.37} - Z_2 \sigma_{t,u} + Z_2 \sigma_a = 86,300 - 1.80 (65,000) + 1.80 \sigma_a = 1.80 \sigma_a - 30,700.$$

$$\text{For } \sigma_a = 57,000 \text{ psi, } B_{a,1.37} = 71,900 \text{ psi; or from Fig. 6, } B_{a,1.37} = 72,000 \text{ psi.}$$

$$\text{Interpolation of the exact theoretical curve gives } B_{a,1.37} = 71,500 \text{ psi. (Ref. 2)}$$

DATE 1 MAY 1966
SUPERSEDES

**PLASTIC BENDING
MODULUS**

- Determine bending-modulus curves for the full range of section factors and stress levels

First $\sigma_{p,1} = 40,000$ psi, Fig. 4 (40,000 psi).

From Equation 6,

$$B_{u,1.9} = 94,000 + 0.4 (59,000) = 117,600 \text{ psi } [119,500 \text{ psi}];$$

$$B_{u,1.7} = 94,000 + 0.2 (59,000) = 105,800 \text{ psi } [107,500 \text{ psi}];$$

$$B_{u,1.3} = 94,000 + (-0.2) (59,000) = 82,000 \text{ psi } [83,000 \text{ psi}];$$

$$B_{u,1.1} = 94,000 + (-0.4) (59,000) = 70,400 \text{ psi } [71,000 \text{ psi}].$$

From Equation 9,

$$B_{y,1.9} = 62,500 + (1.9 - 1.5) (24,700) = 72,400 \text{ psi } [70,000 \text{ psi}];$$

$$B_{y,1.7} = 62,500 + (1.7 - 1.5) (24,700) = 67,400 \text{ psi } [65,500 \text{ psi}];$$

$$B_{y,1.3} = 62,500 + (1.3 - 1.5) (24,700) = 57,600 \text{ psi } [56,500 \text{ psi}];$$

$$B_{y,1.1} = 62,500 + (1.1 - 1.5) (24,700) = 52,600 \text{ psi } [52,000 \text{ psi}];$$

The plastic-bending curves drawn from the above data are shown in Fig. 6.

- The curves in Figures 2 to 4 were obtained from theoretical plastic-bending data for about fifty materials--including aluminum alloys, magnesiums, steels, Inconels, titaniums, and berylliums--at room and elevated temperatures. For all these materials, the ultimate elongation was greater than 2%. For values below this, ultimate bending modulus calculated from these curves will be non-conservative. However, the curves and equations will predict bending modulus for any metal within 10% of the exact theoretical value.

6. References

1. F. B. Cozzone, "Bending Strength in the Plastic Range," Journal of the Aeronautical Sciences, May, 1943.
2. "Bending Strength in the Plastic Range", Lockheed Report S.M. #53C, March, 1952.

FIGURE 6 - PLASTIC BENDING MODULUS FOR 1014-T6 FORGING

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APPENDIX B

EFFECTS OF IRRADIATION ON STRUCTURAL MATERIALS

TO BE PUBLISHED