MAR 29 1968

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Gulf General Atomic Incorporated

P. O. Box 608, San Diego, California 92112

MASTER

INFORMAL AEC RESEARCH
AND DEVELOPMENT REPORT

GAMD-8371

EVALUATION OF CANDIDATE GRAPHITES (AND CARBON) FOR PSC CORE-SUPPORT APPLICATIONS

Work done by:

N. Baker
V. Belliston
H. Evans
J. Furth
W. Price
J. Sommerfeld
H. Stier (Convair)

Report written by:

C. Meyers
K. Koyama

This document, which was prepared primarily for internal use at Gulf General Atomic, may contain preliminary or incomplete data. It is informal and is subject to revision or correction; it does not, therefore, represent a final report.

U. S. Atomic Energy Commission
Contract AT(04-3)-633
Project 901

6 February 1968

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

	<u>Page</u>
<u>Introduction</u>	1
<u>Test Procedures</u>	3
A. Measurement of Coefficient of Thermal Expansion (CTE)	3
B. Measurement of Thermal Conductivity (k)	4
C. Measurement of Density (ρ)	4
D. Measurement of Ultimate Compressive Strength (UCS)	5
E. Measurement of Ultimate Tensile Strength (UTS), Strain at Fracture(ϵ_F), and Tensile Modulus of Elasticity (E_T)	5
F. Measurement of Modulus of Rupture (MOR) and Flexural Modulus of Elasticity (E_F)	5
G. Measurement of Dynamic Modulus of Elasticity (E_D)	6
<u>Experimental Results</u>	7
A. Coefficient of Thermal Expansion (CTE)	7
B. Thermal Conductivity (k)	7
C. Bulk Density (ρ)	12
D. Ultimate Compressive Strength (UCS)	12
E. Ultimate Tensile Strength (UTS), Strain at Fracture (ϵ_F) and Tensile Modulus of Elasticity (E_T)	12
F. Modulus of Rupture (MOR) and Flexural Modulus of Elasticity (E_F)	12
G. Dynamic Modulus of Elasticity (E_D)	12
<u>Discussion of Results</u>	12
A. Coefficient of Thermal Expansion (CTE)	20
B. Thermal Conductivity (k)	20
C. Bulk Density (ρ)	21
D. Ultimate Compressive Strength (UCS)	21

	<u>Page</u>
E. Ultimate Tensile Strength (UTS), Strain at Fracture (ϵ_F) and Tensile Modulus of Elasticity (E_T)	22
F. Modulus of Rupture (MOR) and Flexural Modulus of Elasticity (E_F)	23
G. Dynamic Modulus of Elasticity (E_D)	24
H. Comparison of Moduli of Elasticity (E_D , E_T and E_F)	25
<u>Summary</u>	26
<u>Acknowledgements</u>	31
<u>References</u>	32
<u>Figures</u>	33

EVALUATION OF CANDIDATE GRAPHITES
(AND CARBON) FOR PSC CORE-SUPPORT APPLICATIONS

INTRODUCTION

The core-support graphite components provide the vertical support and the lateral restraint for the reactor core and reflector. The assembly consists of 37 core-support blocks of hexagonal cross-section, each approximately 37 in. between the parallel prism faces. Surrounding these blocks are 24 reflector support blocks keyed to the hexagonal blocks under the core and to the core barrel. Each of these graphite blocks is supported by three graphite posts with spherical ends to permit them to rock and accommodate the differential expansion between the various parts of the assembly.

Under normal operating conditions the core-support graphite blocks will be subjected to the weight load of the core and the differential coolant pressure, which together will be equivalent to a load of about 30,000 lbs on each block. The support posts (in compression) transfer the vertical load from the core support block to the floor below. Normal operating temperature for the core-support blocks will be ~1430F (777C); for the core barrel ~900F (482C); and for the core-support floor ~130F (54C).

This testing program was initiated upon request by C. O. Peinado and R. K. Luci (SR 213377) to provide adequate technical data upon which the selection of materials for purchase would be based.* The results of the evaluation of several candidate graphites (and one baked carbon) for core-support applications are reported herein. Table 1 presents a list of the candidate grades for which physical and mechanical properties were measured, as indicated therein.

Samples of grades MHLM (|| and ⊥) and PGX (|| and ⊥) were tested for core-support block application; H249 (|| and ⊥) and ATJ (50, 18 and 8) for post application; H205 (|| and ⊥) and ATJ (|| and ⊥) for seat and seat-insert applications; B205 (|| and ⊥), CBN (|| and ⊥), TS835 (X, Y and Z) and TS574 (X, Y and Z) for base application. Grades HLM, H271 and TS574 were included,

*Since this program has been somewhat restricted in time and funds available, sampling of the grades of interest has been restricted to one region of a single log for each grade. No attempt has been made herein to determine the range of parametric variations within nor amongst logs in each grade.

TABLE 1

TESTS PERFORMED^(a) ON CANDIDATES FOR CORE-SUPPORT COMPONENTS

Core-Support Component	Candidate Grade	Manufacturer ^(b)	Raw Stock Dimensions (in.)	Test Parameter Measured						
				UTS	UCS	MOR	E	CTE	K	ρ
BLOCKS:	HLM ^(c)	GLCC	42 D							
	MHLM	GLCC	by	X	X	X	X	X		X
	PGX	UCC	23 L	X	X	X	X	X		X
POSTS:	H249	GLCC	6 D	X	X	X	X	X		X
	H359	GLCC	by	X		X	X	X		X
	H271 ^(c)	GLCC	42 L							
	ATJ ^(d)	UCC		X	X	X	X	X		X
SEATS & INSERTS:	H205	GLCC	7½ D by 8 L	X	X	X	X	X	X	X
	ATJ ^(e)	UCC	8½ D by 4 L	X	X	X	X	X	X	X
BASE:	B205	GLCC	7½ D	X	X	X	X	X	X	X
	TS574	UCC	by							
	TS835	UCC	6 L	X	X		X	X	X	X
	CBN	UCC		X	X		X	X	X	X

NOTES: (a) Tests performed under this program indicated by "X" for each grade.

(b) GLCC - Great Lakes Carbon Co.; UCC - Union Carbide and Chemical

(c) Initially selected grade for evaluation, replaced subsequently by other alternates from same manufacturer. H271 replaced by H249 and H359; H359 eliminated in favor of H249 on basis of preliminary tensile screening tests.

(d) ATJ round-molded bar stock, ~9" x 12".

(e) ATJ rectangular - molded bar stock, 8" x 18" x 50".

although they were not tested beyond some preliminary results obtained before this program was initiated. (Grade H271 was actually replaced upon manufacturer's recommendation with grade H359, and again with grade H249.) All of the above grades were graphitic, except for B205 which was an ungraphitized baked carbon. Grade TS835 had been impregnated with MoS_2 and grade TS574 with both MoS_2 and Ag after graphitization to improve wear and friction characteristics.

TEST PROCEDURES

Five samples of each grade, orientation and type of test were experimentally evaluated with the exception of grade TS835 for which an inadequate initial amount of raw stock was available. As shown in Table 1, mechanical testing consisted of tensile, compressive and flexural tests at room temperature ($\sim 70^\circ\text{F}$) to measure ultimate tensile strength (UTS), ultimate compressive strength (UCS), modulus of rupture (MOR), modulus of elasticity (E) and density (ρ). Coefficient of thermal expansion (CTE) and thermal conductivity (k) were measured over the temperature ranges: 22—1000C and 22—800C (600C for TS835), respectively. Description of test procedures are given in more detail below.

A. Measurement of Thermal Expansion (CTE):

Linear thermal expansion measurements are made with a vitreous-silica differential dilatometer in which the expansion of the sample is sensed by a linear differential transformer. The output signal of the transformer is amplified and recorded by an X-Y recorder as a function of the sample temperature which is obtained with a Pt/Pt10Rh thermocouple. The samples were right circular cylinders 0.5 in. dia. by 0.5 in. long; and were the same ones used subsequently for the measurement of the ultimate compressive strength.

The measurements are made from 22 to 1000C at a programmed heating rate of about 15C per minute. A correction constant of $0.547 \times 10^{-6}/^\circ\text{C}$ is applied for the expansion of the vitreous silica.

The mean coefficient of linear thermal expansion, α_m , is calculated from the expression:

$$\alpha_m = \Delta l / l_o (t - t_o) \quad (1)$$

Where

- t = final temperature
- t_o = initial temperature
- l_o = initial length of specimen
- Δl = change in length in the temp. range $t - t_o$

B. Measurement of Thermal Conductivity (k):

The values of thermal conductivity were calculated from thermal diffusivity measurements made on disks 0.5 in. in diameter by 0.045 in. thick by the xeon flash technique originally described by PARKER, et al.¹ By irradiating the front surface of a sample with a very short pulse of radiant energy and monitoring the temperature history of the rear surface, the thermal diffusivity α can be obtained as follows:

$$\alpha = 0.139\ell^2/t_{\frac{1}{2}} \quad (2)$$

where ℓ is the thickness of the specimen and $t_{\frac{1}{2}}$ is the time at which the rear-face temperature excursion reaches half-maximum. The pulse raises the average temperature of the sample only a few degrees above the ambient temperature, which is controlled by a resistance-wound heater. The applicability of equation (2) depends on the duration of the heat pulse being negligibly small in comparison with the time required for heat to flow through the material; this condition is not always achieved in practice. Noninstantaneous pulses have the effect of retarding the rear-face transient, and it is necessary to correct for the finite pulse-time effect. This correction was made according to the method given by LARSON and KOYAMA.² The thermal conductivity k was obtained from the product of the thermal diffusivity α , density ρ , and specific heat C_p .^{*} Densities were measured at 25°C and are assumed to be constant over the temperature range 25-800°C. The specific heat C_p (cal/g/°K) was calculated from the following expression reported by ROSSINI, et al.³

$$C_p = 0.103 + 1.165 \times 10^{-3}T - 8.64 \times 10^{-7}T^2 + 2.32 \times 10^{-10}T^3 \quad (3)$$

C. Measurement of Density (ρ):

Bulk density for each grade of graphite was determined by weighting tensile bars to tenths of a milligram on an analytical balance and by calculating bar volume from dimensional measurements to tenths of a mil with micrometers. The ratio of the gross weight to the gross volume is the bulk density.⁴

*A highly reliable value of C_p for TS835 has not been found to date. Hence, both k and thermal diffusivity have been reported for grade TS835.

D. Measurement of Ultimate Compressive Strength (UCS):

Ultimate compressive strength was determined uniaxially at room temperature by pressing 0.500 in. dia. x 0.50 in. long cylinders of each grade and orientation of graphite to be evaluated. (These test samples were the same as those used previously for CTE measurements, described in Part A.) An Instron Universal Test Machine (model TTC-M1), geared for a cross-head rate of .005 in./min., was used to press the sample cylinders between two platens. UCS was computed from the ratio of the load at fracture (from a record of a Baldwin load-cell output) over the original cross-sectional area of the specimen.⁵

E. Measurement of Ultimate Tensile Strength (UTS), Strain at Fracture (ϵ_F), and Tensile Modulus of Elasticity (E_T):

Uniaxial tensile tests were performed at room temperature (22C with an Instron Universal Test Machine (model TTC-M1), geared for a cross-head rate of .005 in./min. Cylindrical tensile samples 0.500 in. dia. x 4.00 in. long were attached to 1 in. dia. Al shoulders by means of epoxy-cemented butt joints for gripping by the test machine in a conventional manner. UTS was computed from the ratio of the load at fracture (from a record of a Baldwin load-cell output) over the original cross-sectional area of the specimen. ϵ_F was computed from the ratio of the extension of the specimen to fracture (from a record of a Baldwin B3M extensometer attached to the specimen) over the initial gauge-length (1.000 in., as determined by the extensometer). E_T was computed at the point of departure from the initial linearity of the recorded load-extension curve, taking the ratio of the load times the initial gauge-length over the extension times the initial cross-sectional area of the specimen.⁶

F. Measurement of Modulus of Rupture (MOR) and Flexural Modulus of Elasticity (E_F):

Flexural tests were performed at room temperature (~22C) with an Instron Universal Test Machine (model TM-L), geared for a cross-head rate of .005 in./min. Cylindrical beam samples 0.200 in. dia. x 1.75 in. long were loaded in four-point bending to fracture within a precision testing jig centered between two loading

plattens. Load-point spacings were 0.500 in. uniformly between adjacent loading points, with 1.500 in over-all.

Beam center-point deflection was recorded as a function of applied load, using a GA-designed deflectometer together with an Electro Instrument X-Y recorder, and two Sanborn pre-amplifiers. Applied load was measured by means of a sensitive Baldwin load-cell; and resulting deflection was measured by means of a deflectometer calibrated strain-gauged cantilevered beam, the unsupported end of which was in contact with the mid-point of the span of test specimen. MOR was computed from the following relation for a beam of circular cross-section:⁷

$$\begin{aligned} \text{MOR} &= 2\alpha P_f / \pi R^3, \text{ wherein} \\ \alpha &= \text{uniform spacing between adjacent loading points.} \\ P_f &= \text{load at fracture.} \\ R &= \text{Specimen radius.} \end{aligned}$$

E_F was computed from the following relation:⁷

$$\begin{aligned} E_F &= \frac{\alpha P (3l^2 - 4\alpha^2)}{12\pi R^4 \delta}, \text{ wherein} \\ \delta &= \text{center-point deflection of beam at fracture.} \\ l &= \text{over-all spacing between outer pair of loading points.} \end{aligned}$$

G. Measurement of Dynamic Modulus of Elasticity (E_D):

Dynamic modulus of elasticity was measured at room temperature using a Magnatest Elastomat (Type FM-500), which utilizes a sonic resonance method to determine the elastic moduli of solids. The specimens tested were the same as those used subsequently in tensile tests, described in Part E. In these tests the longitudinal mode of excitation was employed, and E_D was computed from the following relation:⁸

$$E_D = 4 \rho_m (L f_\ell)^2, \text{ wherein} \quad (5)$$

ρ_m = mass density of specimen material.

L = over-all length of specimen.

f_ℓ = fundamental resonant frequency, longitudinal mode.

Correction factors for geometrical and thermal effects for the experimentally determined E_D were considered insignificant and were neglected.

EXPERIMENTAL RESULTS*

A. Coefficient of Thermal Expansion (CTE):

Typical curves for thermal strain as functions of temperature, grade and specimen orientation are presented in Figures 1-10. Mean values and standard deviations of thermal strains at 400 and 1000C and "average" CTE values over the range 22-1000C are compiled in Table 2.

B. Thermal Conductivity (k):

Typical plots of the experimental data for thermal conductivity between 22 and 800C are presented in Figures 11-21 as functions of grade and specimen orientation. Mean values and standard deviations of k over this temperature range are compiled in Table 3. The TS835 values for k were computed from the most reliable estimate of C_p presently available (based upon a chemical mixture of 19% MoS_2 and 81% graphite). In the event that a better value for C_p is found subsequently, k can be recomputed using the experimentally measured thermal diffusivities which also have been compiled in Table 3.

*For space and time conservation on this program all the raw test data have not been included in this report. In lieu of complete data compilations, mean values with standard deviations, range of parametric variation, "typical" specimen data and "all-data-summary" plots have been utilized.

TABLE 2

COMPILATION OF THERMAL STRAIN AND OF CTE VALUES

Grade Design'n. and Orientation	No. of Samples	Mean Thermal Strain and St'd Dev'n at 400C $\text{in./in.}^\circ\text{C} (\times 10^3)$	Mean Thermal Strain and St'd Dev'n at 1000C $\text{in./in.}^\circ\text{C} (\times 10^3)$	Mean CTE 22-1000C and Standard Deviation $\text{in./in.}^\circ\text{C} (\times 10^6)$	CTE Range 22-1000C (d) $\text{in./in.}^\circ\text{C} (\times 10^6)$	Typical Specimen Figure 10
ATJ (50°-Dir'n)	4, 1/4 (a)	1.02 $\pm$.08 .99 $\pm$.05	3.53 $\pm$.19 3.47 $\pm$.17	3.57 $\pm$.19 3.50 $\pm$.11	3.39 - 3.85	ATJ-2-C/1
ATJ (18°-Dir'n)	4, 1/4 (a)	1.02 $\pm$.12 .99 $\pm$.10	3.54 $\pm$.14 3.59 $\pm$.13	3.63 $\pm$.15 3.63 $\pm$.13	3.46 - 3.80	ATJ-2-B/1
ATJ (8°-Dir'n)	4, 1/4 (a)	1.50 $\pm$.06 1.48 $\pm$.03	4.79 $\pm$.04 4.80 $\pm$.02	4.88 $\pm$.05 4.90 $\pm$.04	4.82 - 4.92	ATJ-2-B/1
ATJ (-Dir'n)	4, 1/4 (a)	1.57 $\pm$.11 1.58 $\pm$.07	4.75 $\pm$.19 4.84 $\pm$.05	4.86 $\pm$.19 4.95 $\pm$.05	4.53 - 5.01	ATJ-1-D/2
ATJ (⊥-Dir'n)	4, 1/4 (a)	1.14 $\pm$.09 1.11 $\pm$.07	3.69 $\pm$.15 3.73 $\pm$.14	3.76 $\pm$.14 3.80 $\pm$.13	3.60 - 3.91	ATJ-1-B/2
E205 (-Dir'n)	3, 1/3 (a)	2.23 $\pm$.17 2.24 $\pm$.03	6.76 $\pm$.29 6.80 $\pm$.13	6.92 $\pm$.30 6.96 $\pm$.13	6.48 - 7.26	E205-1-E/3
E205 (⊥-Dir'n)	4, 1/4 (a)	2.04 $\pm$.07 2.03 $\pm$.05	6.11 $\pm$.13 6.16 $\pm$.09	6.25 $\pm$.13 6.30 $\pm$.09	6.06 - 6.40	E205-1-D/3
CBH (-Dir'n)	4, 1/4 (a)	1.78 $\pm$.11 1.78 $\pm$.08	5.87 $\pm$.13 5.83 $\pm$.11	5.99 $\pm$.11 5.96 $\pm$.10	5.89 - 6.13	CBH-1-E/4
CBH (⊥-Dir'n)	4, 1/4 (a)	1.21 $\pm$.09 1.18 $\pm$.06	4.11 $\pm$.14 4.06 $\pm$.06	4.21 $\pm$.14 4.15 $\pm$.06	4.08 - 4.45	CBH-1-A/4
E205 (-Dir'n)	4, 1/4 (a)	2.15 $\pm$.09 2.14 $\pm$.02	6.62 $\pm$.25 6.71 $\pm$.19	6.86 $\pm$.17 6.93 $\pm$.08	6.60 - 7.02	E205-1-C/5
E205 (⊥-Dir'n)	3, 1/3 (a)	2.01 $\pm$.04 2.01 $\pm$.04	6.36 $\pm$.05 6.36 $\pm$.03	6.51 $\pm$.05 6.50 $\pm$.03	6.45 - 6.57	E205-1-C/5
E249 (-Dir'n)	4, 1/4 (a)	.92 $\pm$.04 .92 $\pm$.02	3.32 $\pm$.10 3.28 $\pm$.05	3.41 $\pm$.10 3.37 $\pm$.04	3.32 - 3.57	E249-1-B/6
E249 (⊥-Dir'n)	5, 1/3 (a)	1.31 $\pm$.07 1.33 $\pm$.06	4.47 $\pm$.12 4.47 $\pm$.08	4.57 $\pm$.13 4.58 $\pm$.09	4.40 - 4.71	E249-1-D/6

TABLE 2

(Continued)

Grade Design'n. and Orientation	No. of Samples	Mean Thermal Strain and St'd Dev'n at 400C in./in.-°C (x 10 ³)	Mean Thermal Strain and St'd Dev'n at 1000C in./in.-°C (x 10 ³)	Mean CTE 22-1000C and Standard Deviation in./in.-°C (x 10 ⁶)	CTE Range 22-1000C ^(d) in./in.-°C (x 10 ⁶)	Typical Specimen Figure 10
MEHM (-Dir'n)	5 ^(a)	.86 ± .04 .86 ± .03	3.05 ± .05 3.03 ± .03	3.12 ± .05 3.11 ± .03	3.08 - 3.19	MEHM-1-A/7
MEHM (⊥-Dir'n)	4 ^(a)	1.34 ± .20 1.25 ± .03	4.51 ± .54 4.27 ± .08	4.37 ± .09 4.37 ± .09	4.25 - 4.46	MEHM-1-A/7
FOX (-Dir'n)	5 ^(a)	1.09 ± .08 1.13 ± .05	3.87 ± .08 3.89 ± .07	3.96 ± .08 3.98 ± .07	3.87 - 4.04	FOX-1-E/8
FOX (⊥-Dir'n)	5 ^(a)	.89 ± .05 .88 ± .02	3.36 ± .08 3.39 ± .05	3.44 ± .08 3.47 ± .05	3.31 - 3.51	FOX-1-C/8
TS574 (X-Dir'n)	1	1.27 ± —	2.72 ± — ^(b)	3.56 ± — ^(b)	—	TS574-1-A/9
TS574 (Y-Dir'n)	2	2.87 ± .05	5.88 ± .13 ^(b)	7.65 ± — ^(b)	—	TS574-1-B/9
TS574 (Z-Dir'n)	1	1.27 ± —	2.72 ± — ^(b)	3.50 ± — ^(b)	—	TS574-1-D/9
TS835 (X-Dir'n)	2	1.34 ± .13	2.28 ± .15 ^(a)	3.94 ± .35 ^(a)	3.69 - 4.19	TS835-1-A/10
TS835 (Y-Dir'n)	3	1.12 ± .02	1.92 ± .02 ^(a)	3.32 ± .05 ^(a)	3.28 - 3.37	TS835-1-C/10
TS835 (Z-Dir'n)	2	4.23 ± 1.89	4.71 ± .09 ^(a)	8.14 ± .21 ^(a)	7.99 - 8.29	TS835-1-A/10

NOTES: (a) Values for thermal strain and CTE > 1.10s from the gross mean value were neglected here.

(b) Measurements were made over the range 22-800C only due to volatility of additives.

(c) Measurements were made over the range 22-600C only due to volatility of additive.

(d) Range consists of minimum and maximum values for five samples.

(e) The k values for the Y direction are somewhat in question due to difficulties experienced with the experimental method employed.

TABLE 3

COMPILATION OF THERMAL CONDUCTIVITY VALUES (a)

Grade Design'n. and Orientation	No. of Samples (b)	Mean Thermal Conductivity (k) and St'd Dev'n at 25°C cal/cm-sec-°C (x 10 ²)	k - Range at 25°C (d) cal/cm-sec-°C (x 10 ²)	Mean Thermal Conductivity (k) and St'd Dev'n at 800C cal/cm-sec-°C (x 10 ²)	k - Range at 800C (d) cal/cm-sec-°C (x 10 ²)	Typical Specimen Figure No.(c)
ATJ-1 (-Dir'n)	5 4;3	24.8 ± 1.4 25.2 ± 1.2	23.0 - 26.1	12.3 ± .4 12.3 ± .3	11.7 - 12.8	ATJ-1-E/11;12
ATJ-1 (┘-Dir'n)	5 4;3	29.3 ± .9 29.0 ± .8	28.3 - 30.3	16.2 ± .9 16.2 ± .4	15.0 - 17.3	ATJ-1-A/11;12
B205 (-Dir'n)	4 4;4	.57 ± .03 .57 ± .03	.53 - .60	.87 ± .04 .86 ± .01	.85 - .93	B205-1-C/13;14
B205 (┘-Dir'n)	5 3;4	.57 ± .02 .57 ± .01	.54 - .59	.95 ± .03 .94 ± .02	.93 - .99	B205-1-E/13;14
CEN (-Dir'n)	4 4;4	4.2 ± .03 4.2 ± .03	3.9 - 4.7	4.0 ± .2 4.0 ± .2	3.7 - 4.2	CEN-1-C/ 15;16
CEN (┘-Dir'n)	5 3;4	5.5 ± .2 5.5 ± .1	5.2 - 5.7	5.0 ± .4 4.9 ± .4	4.6 - 5.6	CEN-1-C/15;16
H205 (-Dir'n)	5 4;3	27.8 ± 1.5 28.4 ± .6	25.2 - 28.9	15.7 ± 1.1 15.8 ± .1	14.0 - 17.0	H205-1-A/17;18
H205 (┘-Dir'n)	5 3;3	27.2 ± .9 27.2 ± .1	26.0 - 28.4	16.3 ± .5 16.3 ± .4	15.7 - 16.9	H205-1-B/17;18
T8574 (X-Dir'n Z-Dir'n)	1	~ 47.0 ± —	—————	20.0 ± —	—————	T8574-1-A/19
T8574 (Y-Dir'n)	1	~ 6.0 ± — (e)	—————	4.8 ± — (e)	—————	T8574-1-A/19
T8835 (X-Dir'n)	2	~ 8.7 ± —	—————	5.7 ± —	—————	T8835-1-A/20
T8835 (Y-Dir'n)	2	~ 8.5 ± —	—————	4.5 ± —	—————	T8835-1-A/20
T8835 (Z-Dir'n)	2	~ 4.3 ± —	—————	3.0 ± —	—————	T8835-1-A/20
(THERMAL DIFFUSIVITY DATA, cm ² /sec x 10 ²)						
T8835 (X-Dir'n)	2	27.0 ± 1.0	26.3 - 27.7	7.7 ± 0.0	7.7 - 7.7	T8835-1-A/21
T8835 (Y-Dir'n)	2	25.0 ± 1.4	24.0 - 26.0	6.4 ± .4	6.2 - 6.7	T8835-1-A/21
T8835 (Z-Dir'n)	2	12.5 ± .8	12.0 - 13.1	3.9 ± .1	3.8 - 4.0	T8835-1-A/21

TABLE 3

- NOTES: (a) Mean values and standard deviations are presented in two rows; the upper row for all the results and the lower row for only those results falling within 1.1 σ from the mean of all values.
- (b) The number of samples averaged are indicated for upper and lower rows. Upper row was 5 for both 25 and 800C data groups. First figure on lower row for 25C data; second for 800C data.
- (c) First figure number indicated is curve for typical specimen; second is scatter band for data from all 5 specimens in group.
- (d) Range consists of minimum and maximum values for 5 samples.

C. Bulk Density (ρ):

Experimental data on room-temperature density measurements have been compiled in Table 4, which presents the statistical mean, the standard deviation and the range of values of ρ for the indicated grade and number of specimens.

D. Ultimate Compressive Strength (UCS):

Experimental results on room-temperature UCS have been compiled in Table 5, which presents the statistical mean value, the standard deviation and the range of values for the indicated orientation grade, and number of specimens.

E. Ultimate Tensile Strength (UTS), Strain at Fracture (ϵ_F) and Tensile Modulus of Elasticity (E_T):

Experimental results on room-temperature stress at fracture or ultimate tensile strength, on strain at fracture and on tensile modulus of elasticity have been compiled in Table 6. In this table are shown the statistical mean value, the standard deviation and the range of values of UTS, ϵ_F , and E_T . Figures 22-65 are pairs of curves illustrating a "typical" specimen and an "all-data-summary" of replicate data for each parameter by grade and orientation.

F. Modulus of Rupture (MOR) and Flexural Modulus of Elasticity (E_F):

Experimental results on room-temperature modulus of rupture and on flexural modulus of elasticity have been compiled in Table 7, which presents the mean value, the standard deviation and the range of values for MOR and E_F .

G. Dynamic Modulus of Elasticity E_D :

Experimental results on room-temperature dynamic modulus have been compiled in Table 8, which presents the mean value, the standard deviation and the range of E_D .

DISCUSSION OF RESULTS

In this section the tabulated results have been illustrated in bar-graph form. The competing grades of graphite (and carbon) have been grouped by function as a core-support component to facilitate direct comparison of property levels.

TABLE 4

COMPILATION OF BULK DENSITY VALUES

<u>Grade Designation</u>	<u>No. of Samples</u>	<u>Mean Value (gms/cc.)</u>	<u>Standard Deviation</u>	<u>Range</u>
ATJ-1 (& ⊥)	12	1.784	±0.024	{ 1.731- 1.818
ATJ-2 (X, Y & Z)	18	1.765	±0.114	{ 1.650- 2.162
B205 (& ⊥)	10	1.518	±0.004	{ 1.514- 1.526
CBN (& ⊥)	12	1.710	±0.009	{ 1.696- 1.722
H205 (& ⊥)	12	1.747	±0.060	{ 1.563- 1.803
H249 (& ⊥)	9	1.876	±0.004	{ 1.871- 1.882
H359 (& ⊥)	8	1.740	±0.013	{ 1.725- 1.754
MHLM (& ⊥)	12	1.816	±0.042	{ 1.685- 1.836
PGX (& ⊥)	12	1.773	±0.020	{ 1.732- 1.793
TS-835 (X, Y & Z)	7	1.885	±0.060	{ 1.824- 2.014

TABLE 5

COMPILATION OF ULTIMATE COMPRESSIVE STRENGTH VALUES^(a)

Grade Designation	Orientation	No. of Samples	Mean Value psi ($\times 10^{-3}$)	Std. Deviation psi ($\times 10^{-3}$)	Range psi ($\times 10^{-3}$) ^(b)
ATJ-1	()	5	10.42	$\pm .22$	(10.10 -
		3	10.43	$\pm .06$	(10.70
ATJ-1	(⊥)	5	10.56	$\pm .60$	(10.10 -
		4	10.38	$\pm .39$	(11.50
ATJ-2	(8)	5	10.06	$\pm .23$	(9.83 -
		4	9.97	$\pm .15$	(10.40
ATJ-2	(18)	5	9.42	± 1.17	(8.23 -
		4	8.95	$\pm .58$	(11.30
ATJ-2	(50)	5	10.82	$\pm .55$	(10.10 -
		3	10.83	$\pm .32$	(11.50
B205	()	5	20.32	$\pm .94$	(18.90 -
		4	20.68	$\pm .57$	(21.20
B205	(⊥)	5	21.36	± 1.00	(20.00 -
		3	21.37	$\pm .42$	(22.70
CBN	()	5	13.34	$\pm .24$	(13.10 -
		5	13.34	$\pm .24$	(13.60
CBN	(⊥)	5	12.76	$\pm .27$	(12.40 -
		3	12.77	$\pm .15$	(13.10
H205	()	5	13.24	$\pm .62$	(12.70 -
		4	12.98	$\pm .22$	(14.30
H205	(⊥)	5	12.58	$\pm .22$	(12.30 -
		4	12.65	$\pm .17$	(12.80
H249	()	5	8.39	$\pm .19$	(8.10 -
		4	8.46	$\pm .11$	(8.59
H249	(⊥)	5	8.00	$\pm .36$	(7.74 -
		4	7.85	$\pm .15$	(8.60
MHLM	()	5	5.69	$\pm .24$	(5.48 -
		4	5.69	$\pm .15$	(6.04

TABLE 5 (Continued)

<u>Grade Designation</u>	<u>Orientation</u>	<u>No. of Samples</u>	<u>Mean Value psi (x 10⁻³)</u>	<u>Std. Deviation psi (x 10⁻³)</u>	<u>Range psi (x 10⁻³)^(b)</u>
MHIM	(⊥)	5	6.58	+ .98	(5.83 -
		4	6.08	- .46	8.08)
PGX	()	5	6.94	+ .05	(6.87 -
		3	6.94	- .04	7.00)
PGX	(⊥)	5	6.86	+ .22	(6.70 -
		4	6.76	- .08	7.23)
TS835	(X)	2	5.77	+ .74	(5.24 -
		2	5.77	- .74	6.29)
TS835	(Y)	3	6.06	+ .34	(5.78 -
		2	5.87	- .13	6.44)
TS835	(Z)	2	7.24	+ .74	(6.72 -
		2	7.24	- .74	7.76)

Notes: (a) Mean values and standard deviations are presented in two rows; the upper row for all the results and the lower row for only those results falling within 1.1σ from the mean of all values.

(b) Range consists of minimum and maximum values for five samples.

TABLE 6

Grade Designation	Orientation	No. Samples	COMPILATION OF STRAIN AT FRACTURE VALUES (ϵ_F)			COMPILATION OF STRESS AT FRACTURE VALUES (UTS)			COMPILATION OF YOUNG'S MODULUS VALUES (E_T)			Typical Specimen	Figure No.
			Mean Value, in./in. ($\times 10^{-3}$)	Std. Deviation in./in. ($\times 10^{-3}$)	Range in./in. ($\times 10^{-3}$)	Mean Value in./in. ($\times 10^{-3}$)	Std. Deviation in./in. ($\times 10^{-3}$)	Range in./in. ($\times 10^{-3}$)	Mean Value psi ($\times 10^{-5}$)	Std. Deviation psi ($\times 10^{-6}$)	Range psi ($\times 10^{-6}$)		
ATJ-1		5	2.579	± 1.0004	.85 - 3.40	1.818	$\pm .573$	.809 - 2.244	.972	$\pm .142$	.750 - 1.103	T-ATJ-1-E	22
ATJ-1	⊥	5	2.407	$\pm .180$	2.13 - 2.60	2.963	$\pm .217$	2.723 - 3.141	1.500	$\pm .165$	1.263 - 1.711	T-ATJ-1-D	24
ATJ-2	8°	5	3.658	$\pm .327$	3.35 - 4.17	2.382	$\pm .247$	2.169 - 2.779	.951	$\pm .362$	.720 - 1.585	T-ATJ-2-D	26
ATJ-2	18°	4	2.552	$\pm .569$	1.87 - 3.16	2.305	$\pm .443$	1.913 - 2.969	1.205	$\pm .154$	.974 - 1.286	T-ATJ-2-B	28
ATJ-2	50°	5	2.919	$\pm .195$	2.70 - 3.17	3.318	$\pm .358$	2.962 - 3.773	1.616	$\pm .726$	1.095 - 2.896	T-ATJ-2-E	30
B205		5	1.754	$\pm .165$	1.57 - 1.90	2.391	$\pm .147$	2.195 - 2.520	1.425	$\pm .154$	1.310 - 1.684	T-B205-1-A	32
B205	⊥	4	1.768	$\pm .114$	1.65 - 1.88	2.644	$\pm .238$	2.323 - 2.859	1.579	$\pm .170$	1.332 - 1.708	T-B205-1-D	34
CBN		5	2.638	$\pm .345$	2.15 - 3.12	2.241	$\pm .290$	1.918 - 2.665	1.301	$\pm .376$	.992 - 1.805	T-CBN-1-A	36
CBN	⊥	5	2.336	$\pm .180$	2.10 - 2.60	3.077	$\pm .181$	2.816 - 3.291	1.695	$\pm .228$	1.439 - 1.924	T-CBN-1-B	38
H205		5	3.015	$\pm .240$	2.70 - 3.35	3.255	$\pm .218$	3.022 - 3.511	1.429	$\pm .250$	1.083 - 1.77	T-H205-1-B	40
H205	⊥	5	3.700	$\pm .094$	3.60 - 3.80	3.626	$\pm .099$	3.456 - 3.712	1.242	$\pm .092$	1.115 - 1.347	T-H205-1-C	42
H249		4	2.445	$\pm .313$	2.10 - 2.82	2.792	$\pm .276$	2.451 - 3.096	1.591	$\pm .149$	1.439 - 1.791	T-H249-1-A	44
H249	⊥	4	3.400	$\pm .924$	2.02 - 3.95	1.904	$\pm .378$	1.379 - 2.278	.679	$\pm .127$	.532 - .817	T-H249-1-E	46
H359		5	2.410	$\pm .200$	2.12 - 2.63	2.248	$\pm .201$	2.031 - 2.443	1.059	$\pm .224$	.688 - 1.285	T-H359-1-B	48
H359	⊥	4	1.498	$\pm .577$	.970 - 2.22	1.055	$\pm .239$	.827 - 1.314	.835	$\pm .067$	.743 - .884	T-H359-1-C	50
MHLM		5	1.354	$\pm .142$	1.10 - 1.43	1.279	$\pm .123$	1.131 - 1.432	1.151	$\pm .107$	1.004 - 1.301	T-MHLM-1-A	52
MHLM	⊥	5	2.436	$\pm .297$	2.10 - 2.85	1.489	$\pm .242$	1.307 - 1.900	.807	$\pm .084$	.742 - .946	T-MHLM-1-C	54
PGX		5	2.806	$\pm .222$	2.57 - 3.15	1.688	$\pm .151$	1.522 - 1.863	.784	$\pm .118$	.602 - .921	T-PGX-1-E	56
PGX	⊥	5	2.060	$\pm .629$	1.10 - 2.64	1.624	$\pm .356$	1.039 - 1.928	1.194	$\pm .184$	1.065 - 1.499	T-PGX-1-D	58
TS835	X	1	1.450	$\pm .000$	None	1.436	$\pm .000$	None	1.273	$\pm .000$	None	T-TS835-1-B	60
TS835	Y	2	1.700	$\pm .000$	None	1.672	$\pm .055$	1.633 - 1.711	1.285	$\pm .022$	1.269 - 1.301	T-TS835-1-A	62
TS835	Z	2	1.460	$\pm .113$	1.38 - 1.54	.821	$\pm .038$	.795 - .848	.626	$\pm .078$	.571 - .682	T-TS835-1-A	64

TABLE 7

COMPILATION OF MODULUS OF RUPTURE AND FLEXURAL MODULUS OF ELASTICITY DATA

<u>Grade Designation</u>	<u>Orientation</u>	<u>No. of Samples</u>	<u>Modulus of Rupture</u>			<u>Modulus of Elasticity</u>		
			<u>Mean</u> <u>psi(x10³)</u>	<u>Std. Dev.</u> <u>psi(x10³)</u>	<u>Range</u> <u>psi(x10³)</u>	<u>Mean</u> <u>psi(x10⁻⁶)</u>	<u>Std. Dev.</u> <u>psi(x10⁻⁶)</u>	<u>Range</u> <u>psi(x10⁻⁶)</u>
ATJ-1	()	6	4.72	.49	4.11 - 5.36	2.045	.200	1.763 - 2.257
ATJ-1	(⊥)	5	6.16	.54	5.49 - 6.94	2.689	.309	2.204 - 3.020
ATJ-2	(8)	6	4.63	.13	4.48 - 4.78	1.756	.114	1.638 - 1.970
ATJ-2	(18)	6	6.08	.47	5.52 - 6.89	1.247	.037	1.205 - 1.303
ATJ-2	(50)	6	6.10	.42	5.70 - 6.50	2.754	.157	2.560 - 2.972
B205	()	6	4.46	.26	4.18 - 4.82	2.865	.248	2.386 - 3.045
B205	(⊥)	4	4.82	.19	4.67 - 5.09	2.895	.223	2.690 - 3.210
B205	()	6	6.13	.19	5.87 - 6.36	1.338	.064	1.238 - 1.403
B205	(⊥)	6	6.25	.40	5.52 - 6.63	1.283	.037	1.219 - 1.322
B249	()	6	5.79	.17	5.54 - 6.01	3.089	.354	2.666 - 3.571
B249	(⊥)	5	3.390	.51	2.71 - 3.95	2.168	.293	1.852 - 2.500
B359	()	5	4.16	.64	3.38 - 4.97	2.282	.252	2.079 - 2.673
B359	(⊥)	5	4.50	.68	3.48 - 5.16	2.332	.179	2.047 - 2.512

TABLE 8

COMPILATION OF DYNAMIC MODULUS OF ELASTICITY DATA

<u>Grade Designation</u>	<u>Orientation</u>	<u>No. of Samples</u>	<u>Mean Value psi x 10⁻⁶</u>	<u>Std. Deviation psi x 10⁻⁶</u>	<u>Range psi x 10⁻⁶</u>
ATJ-1	()	4	1.125	$\pm .020$	1.096 - 1.140
		3	1.135	$\pm .007$	1.127 - 1.140
ATJ-1	(⊥)	4	1.867	$\pm .073$	1.774 - 1.928
		3	1.897	$\pm .047$	1.843 - 1.928
ATJ-2	(8)	4	1.233	$\pm .291$	1.066 - 1.668
		3	1.008	$\pm .032$	1.066 - 1.125
ATJ-2	(18)	3	1.412	$\pm .065$	1.349 - 1.479
ATJ-2	(50)	4	1.725	$\pm .058$	1.685 - 1.813
		3	1.699	$\pm .012$	1.685 - 1.709
B205	()	4	1.552	$\pm .013$	1.541 - 1.568
		3	1.546	$\pm .009$	1.541 - 1.557
B205	(⊥)	4	1.626	$\pm .014$	1.606 - 1.636
		3	1.633	$\pm .005$	1.627 - 1.636
CBN	()	4	1.260	$\pm .010$	1.246 - 1.268
		3	1.264	$\pm .005$	1.259 - 1.268
CBN	(⊥)	4	1.858	$\pm .031$	1.818 - 1.895
		2	1.859	$\pm .007$	1.854 - 1.864
H205	()	4	1.642	$\pm .027$	1.612 - 1.666
		3	1.653	$\pm .022$	1.627 - 1.666
H205	(⊥)	4	1.557	$\pm .003$	1.553 - 1.560
		3	1.558	$\pm .002$	1.557 - 1.560
H249	()	4	1.282	$\pm .003$	1.241 - 1.307
		2	2.039	$\pm .002$	2.037 - 2.040
H249	(⊥)	3	.078	$\pm .010$	.775 - .794

Table 8 (Continued)

<u>Grade Designation</u>	<u>Orientation</u>	<u>No. of Samples</u>	<u>Mean Value psi x 10⁻⁶</u>	<u>Std. Deviation psi x 10⁻⁶</u>	<u>Range psi x 10⁻⁶</u>
H359	()	4	1.425	$\pm .014$	1.409 - 1.437
		3	1.430	$\pm .011$	1.417 - 1.437
H359	(⊥)	3	1.125	$\pm .026$	1.097 - 1.147
		-	-	-	-
MHLM	()	4	1.576	$\pm .028$	1.549 - 1.605
		-	-	-	-
MHLM	(⊥)	4	1.083	$\pm .067$	1.031 - 1.182
		3	1.050	$\pm .017$	1.031 - 1.067
PGX	()	4	1.062	$\pm .039$	1.028 - 1.114
		3	1.044	$\pm .022$	1.028 - 1.069
PGX	(⊥)	4	1.228	$\pm .007$	1.217 - 1.233

A. Coefficient of Thermal Expansion (CTE):

Figures 66-69 compare CTE values of competing grades by core-support function: blocks, posts, post-seats and bases.

For the blocks grade PGX appears to be very nearly isotropic in CTE, as shown in Figure 66; whereas grade MHLM appears anisotropic. The CTE for MHLM ($\parallel$) is $\sim 79\%$ of that for PGX ($\parallel$); and the CTE for MHLM ($\perp$) is $\sim 127\%$ of that for PGX ($\perp$).

For the posts grades ATJ (log 2) and H249, both appear to be anisotropic in CTE, as illustrated in Fig. 67. With respect to the axial direction - H249 ($\parallel$) and ATJ-2(50) - and a lateral direction H249 ($\perp$) and ATJ-2(8) - in these logs the CTE values are nearly the same in each case. The ATJ-2 second lateral direction - (18) - shows essentially the same CTE as does the axial - (50) - direction.

For the post seats, as shown in Fig. 68, grade H205 appears to be nearly isotropic, but grade ATJ (log 1) is anisotropic. With respect to the axial direction - H205 ($\parallel$) and ATJ-1 ($\parallel$) - the CTE value for H205 is $\sim 141\%$ of that for ATJ-1. In the radial direction - H205 ($\perp$) and ATJ-1 ($\perp$) - the CTE value for H205 is $\sim 173\%$ of that for ATJ-1.

For the base application as shown in Fig. 69, grade B205 appears to be roughly isotropic in CTE, but grades CBN, TS574 and TS835 are anisotropic. With respect to the axial direction - H205 ($\parallel$), CBN ($\parallel$), TS574(X)* - the CTE value for B205 is $\sim 116\%$ of that for CBN, $\sim 194\%$ of that for TS574 and $\sim 176\%$ for that of TS835. In the lateral directions - B205 ($\perp$), CBN ($\perp$), TS574(Y), TS574(Z), TS835(Y), and TS835(Z) - the CTE value for B205 is $\sim 148\%$ of that for CBN, $\sim 82\%$ for that of TS574(Y), $\sim 179\%$ for that of TS574(Z), $\sim 188\%$ for that of TS835(Y), and $\sim 77\%$ of that for TS835(Z).

B. Thermal Conductivity (k):

Figures 70 and 71 compare k values of core-support competing grades at 25 and 800C for post seats and for bases.

For the post seats, as shown in Fig. 70, grade H205 appears to be nearly

*The X direction has been assumed to be the axial direction of our small-block samples taken from TS574 and TS835 logs by the vendor.

isotropic in k at both test temperatures; but ATJ (log l) is anisotropic. In all three graphites k decreases from 25 to 800C. In the axial direction - H205 (||) and ATJ-1 (||) - the k values for H205 are ~112% and ~128% of those for ATJ-1 at 25 and 800C, respectively. In the radial direction - H205 (⊥) and ATJ-1 (⊥) - the k values for H205 are ~93% of and nearly the same as those for ATJ-1 at 25 and 800C, respectively.

For the bases, as shown in Fig. 71, grade B205 appears to be nearly isotropic in k at both test temperatures; but CBN, TS574 and TS835 are anisotropic. In CBN and the two impregnated graphites - TS574 and TS835 - k decreases as test temperature increases from 25 to 800C; however, in B205 - a baked, ungraphitized carbon - k increases appreciably between 25 and 800C. In the axial direction - B205 (||), CBN (||), TS574(X)*, and TS835(X)* - the k values for B205 are ~14% and ~21% of those for CBN at 25 and 800C, respectively, ~1.3% and ~4.4% of those for TS574 at 25 and 800C, respectively; and ~7.4% and ~15% of those for TS835 at 25 and 800C, respectively. In the lateral directions - B205 (⊥), CBN (⊥), TS574(Y), TS574(Z), TS835(Y) and TS835(Z) - the k values for B205 are ~10% and ~19% of those for CBN at 25 and 800C, respectively; ~1.0% and ~2.2% of those for TS574(Y) at 25 and 800C, respectively; ~7.5% and ~21% of those for TS835(Y) at 25 and 800C, respectively; and ~15% and ~33% of those for TS835(Z) at 25 and 800, respectively.

C. Bulk Density (ρ):

Figures 72-75 compare room temperature ρ values of competing grades for core-support components; blocks in Fig. 72; posts in Fig. 73; post-seats in Fig. 74; and bases in Fig. 75. All grades have ρ values in the range 1.7 - 1.9 gms./cc., except for B205 which is ~1.5.

D. Ultimate Compressive Strength (UCS):

The UCS values of the grades competing for each core-support functional component have been grouped for comparison in Figures 76-79.

*See footnote on page 20.

Fig. 76 compares grades MHLM and PGX for block application. Grade PGX appears to be nearly isotropic in UCS, whereas grade MHLM does not. In the axial direction the UCS values for PGX are ~122% and ~106% of those for MHLM in the (||) and (⊥) orientations, respectively.

Fig. 77 compares grades H249 and ATJ (log 2) for post application. Both grades appear to be very roughly isotropic. In the axial direction the UCS for ATJ-2(50) is ~120% greater than that for H249 (||). In the lateral directions the UCS values for ATJ-2(18) and ATJ-2(8) are ~118% and ~112%, respectively, greater than that for H249 (⊥).

Fig. 78 compares grades H205, and ATJ (log 1) for post-seat application. Grade ATJ-1 appears to be nearly isotropic in UCS, and grade H205 rather roughly so. In the axial direction the UCS for H205 (||) is ~127% of that for ATJ-1 (||). In the radial direction the UCS for H205 (⊥) is ~119% of that for ATJ-1 (⊥).

Fig. 79 compares grades B205 and TS835 for base application. Both grades B205 and CBN appear to be roughly isotropic in UCS, while grade TS835 is anisotropic. In the axial direction the UCS for TS835(X)* is ~28% and ~43% of those for B205 (||) and CBN (||), respectively. In the lateral directions the UCS values for TS835(Y) and TS835(Z) are ~28% and ~34%, respectively, that for B205 (⊥); and ~48% and ~57%, respectively, that for CBN (⊥).

E. Ultimate Tensile Strength (UTS), Strain at Fracture (ϵ_F) and Tensile Modulus of Elasticity (E_T):

The UTS, ϵ_F and E_T values of the grades competing for each core-support functional component have been grouped for comparison in Figures 80-91.

Figures 80-82 compare grades MHLM and PGX for block application. Grade PGX is nearly isotropic in UTS and ϵ_F , but not in E_T . Grade MHLM is nearly isotropic in E_T , roughly so in UTS, but not in ϵ_F . In the axial direction MHLM (||) is ~76% and ~50% that of PGX (||) in UTS and ϵ_F values, respectively; while the E_T value for MHLM (||) is ~112% of that for PGX (||). In the lateral or radial direction MHLM (⊥) is ~92% and ~67% that of PGX (⊥) in UTS and E_T values, respectively; while the ϵ_F value for MHLM (⊥) is ~114% of that for PGX (⊥).

*See footnote on page 20.

Figures 83-85 compare grades H249 and ATJ (log 2) for post application. Both grades are anisotropic in UTS, ϵ_F and E_T . In the axial direction the UTS, ϵ_F and E_T values for H249 ($\parallel$) are $\sim 85\%$, $\sim 83\%$, and $\sim 95\%$, respectively, of those for ATJ-2(50). In the lateral directions the UTS, ϵ_F , and E_T values for H249 ($\perp$) are $\sim 79\%$, $\sim 13\%$, and $\sim 57\%$, respectively, of those for ATJ-2(18); and $\sim 80\%$, $\sim 92\%$ and $\sim 72\%$, respectively, of those for ATJ-2(8). Grade H359 is included on Figures 83-85 only for comparison with grade H249^{**}.

Figures 86-88 compare grades H205 and ATJ (log 1) for post-seat application. Although grade H205 appears to be rather roughly isotropic in UTS, ϵ_F and E_T , grade ATJ-1 is anisotropic. In the axial direction the UTS, ϵ_F and E_T values for H205 ($\parallel$) are $\sim 179\%$, $\sim 116\%$ and $\sim 68\%$, respectively, of those for ATJ-1 ($\parallel$). In the radial direction the UTS, ϵ_F , E_T values for H205 ($\perp$) are $\sim 122\%$, $\sim 154\%$ and $\sim 83\%$, respectively, of those for ATJ-1 ($\perp$).

Figures 89-91 compare grades B205, CBN, and TS835 for base application. Grade B205 appears to be nearly isotropic in ϵ_F and E_T , but only roughly so in UTS. Grades CBN and TS835 are roughly isotropic in ϵ_F ; otherwise these grades are anisotropic. In the axial direction the UTS, ϵ_F , and E_T values for B205 ($\parallel$) are $\sim 167\%$, $\sim 120\%$ and $\sim 112\%$, respectively, of those for TS835(X)^{*}; whereas the UTS, ϵ_F and E_T values for CBN ($\parallel$) are $\sim 156\%$, $\sim 174\%$ and $\sim 102\%$, respectively, of those for TS835(X)^{*}. In the lateral directions the UTS, ϵ_F and E_T values for B205 ($\perp$) are $\sim 158\%$, $\sim 106\%$ and $\sim 123\%$, respectively, of those for TS835(Y); and $\sim 322\%$, $\sim 120\%$ and $\sim 252\%$, respectively, of those for TS835(Z). Also, the UTS, ϵ_F and E_T values for CBN ($\perp$) are $\sim 184\%$, $\sim 135\%$ and $\sim 132\%$, respectively, of those for TS835(Y); and $\sim 375\%$, $\sim 153\%$ and $\sim 272\%$, respectively, of those for TS835(Z).

F. Modulus of Rupture (MOR) and Flexural Modulus of Elasticity (E_F):

Figures 92-99 present MOR and E_F values for candidate grades, grouped for comparison by core-support functional application.

^{*}See footnote on page 20.

^{**}Grades H249 and H359 both were recommended by GLCC initially. Since H249 exhibited higher mechanical properties than H359, H249 was chosen as the GLCC contender for post components.

The MOR and E_F values for grade MHLM are compared in Figures 92-93 for block application.[†] Grade MHLM appears to be rather roughly isotropic in both MOR, but not in E_F .

The MOR and E_F values for grades H249 and ATJ (log 2) are compared in Figures 94 and 95 for post application. Neither grade H249 nor ATJ-2 is isotropic in either MOR or E_F . In the axial direction the values of MOR and E_F for H249 ($\parallel$) are ~95% and ~112%, respectively, of those for ATJ-2(50). In the lateral direction the MOR and E_F values for H249 ($\perp$) are ~56% and ~174%, respectively, of those for ATJ-2(18); and ~73% and ~123%, respectively of those for ATJ-2(8). Grade H359 is included on Figures 94 and 95 only for comparison with grade H249.^{**}

The MOR and E_F values for grades H205 and ATJ (log 1) are compared in Figures 96 and 97 for post-seat application. Grade H205 appears to be nearly isotropic in MOR and E_F , whereas grade ATJ-1 is anisotropic. In the axial direction the values of MOR and E_F for ATJ-1 ($\parallel$) are ~77% and ~153%, respectively, of those for H205 ($\parallel$). In the radial direction the values of MOR and E_F for ATJ-1 ($\perp$) are ~98% and ~209%, respectively, of those for H205 ($\perp$).

The MOR and E_F values for grade B205 are presented in Figures 98 and 99 for base applications.[†] Grade B205 appears to be nearly isotropic in MOR and E_F .

G. Dynamic Modulus of Elasticity (E_D):

Figures 100-103 present E_D values for candidate grades, grouped for comparison by core-support functional application. Related values of E_T and E_F also have been superimposed along with E_D upon these figures to allow a comparison of values by different test methods.

^{**}See footnote page 23.

[†]For grade TS835 there was not sufficient material available to allow for flexure specimens.

[‡] E_F values for PGX had to be deleted due to a suspected switch in identification of orientations.

The E_D values for grade MHLM are presented in Figure 100 for block application. MHLM does not appear to be isotropic in E_D .

The E_D values for grades H249 and ATJ (log 2) are compared in Figure 101 for post application. Neither grade H249 nor ATJ-2 appear to be isotropic in E_D . In the axial direction the E_D value H249 ($\parallel$) is $\sim 118\%$ of that for ATJ-2(50). In the lateral directions the E_D value for H249 ($\perp$) is $\sim 56\%$ and $\sim 65\%$ of those for ATJ-2(18) and ATJ-2(8), respectively.

The E_D values for grades H205 and ATJ (log 1) are compared in Figure 102 for post-seat application. Grade H205 is roughly isotropic in E_D , however, grade ATJ-1 is anisotropic in E_D . In the axial direction the E_D value for H205 ($\parallel$) is $\sim 146\%$ of that for ATJ-1 ($\parallel$). In the radial direction the E_D value for H205 ($\perp$) is $\sim 83\%$ of that for ATJ-1 ($\perp$).

The E_D values for grades B205, TS835 and CBN are compared in Figure 103 for base application. Grade B205 is roughly isotropic in E_D , however, both TS-835 and CBN are anisotropic in E_D . In the axial direction the E_D value for B205 ($\parallel$) is about the same as and $\sim 123\%$ of those for TS835(X)* and CBN ($\parallel$), respectively. In the lateral directions the E_D value for B205 ($\perp$) is about the same as, $\sim 228\%$ and $\sim 88\%$ of those for TS835(Y), TS835(Z) and CBN ($\perp$), respectively.

H. Comparison of Moduli of Elasticity (E_D , E_T and E_F) from Three Test Methods:

A comparison of values for the modulus of elasticity (E) computed from experimental data by three different methods - sonic resonance, uniaxial tension and flexure - has been illustrated for each grade and orientation in Figures 100 - 103. Although there is poor correlation in results among the three methods in terms of magnitudes for E, a comparison between E values for the two or three sample orientations within each grade exhibits a consistent trend in E regardless of the method.

A critical evaluation of the procedures by which E has been measured using these three methods yields the following decreasing order of preference or confidence level: E_D ; E_T ; E_F . Although the sonic resonance method requires supporting approximate E values from one of the other methods to facilitate the

*See footnote on page 20.

prediction of resonant frequencies for reasonably rapid measurements, the measurements are much less subjective than are those by the other two methods. The magnitude of mean E_D may be somewhat higher than that of mean E_T due to the difference in strain values at which E was measured. For example, for ATJ-1 ($\parallel$) the mean E_T of 5 samples is 970,715 psi $\pm$ 142,289; and if the sample deviating from the mean by $\sim 1.6\sigma$ is deleted, the σ value for the 4 remaining samples is still rather high at $\sim 90,000$ psi. For the same grade and orientation the mean E_F of 6 samples is 2,044,701 psi $\pm$ 200,447; and if the sample deviating from the mean by $\sim 1.4\sigma$ is deleted, the σ value for the 5 remaining samples is still high at $\sim 21,500$ psi. However, for the same grade and orientation the mean E_D of 4 samples is 1,125,324 psi $\pm$ 20,486; and if the sample deviating from the mean by $\sim 1.4\sigma$ is deleted, the σ value for the 3 remaining samples drops to only 6,843 psi. Thus, it may be noted that the scatter or uncertainty in experimental measurements for E is lower by a factor of 5-10 times for the sonic resonance method.

The uncertainty in the measurement appears to be the greatest in the flexure method (for E_F). Although as much care in the experimental procedures may have been exercised in employing this method as for the other two, the assumptions of purely elastic deformation (upon which the relation for the computation was based) may have introduced some increase in scatter as well as magnitude variations in mean E_F .

V. Summary

Several PSC core-support candidate graphites and one baked carbon have been evaluated for selected physical and mechanical properties and have been compared within each component group. These comparisons of parametric values by component group or core-support function have been illustrated in Figures 66-103. Table 9 provides a summary of and index to these figures by component group.

An examination of the figures listed in Table 9 will permit an over-all ranking of candidates within each component group. The candidates for the various core-support components have been ranked in the following order of decreasing parametric values (at $\sim 70F$) for all orientations by the component group and parameter indicated:

Base Component

(Coefficient of Thermal Expansion - CTE)

CTE: TS835(Z) > TS574(Y) > B205($\parallel$) > B205($\perp$) > CBN($\parallel$) > CBN($\perp$) >
 TS835(X) > TS574(X) > TS574(Z) > TS835(Y)

TABLE 9

SUMMARY OF AND INDEX TO FIGURES COMPARING
PARAMETRIC VALUES OF CORE-SUPPORT CANDIDATES BY COMPONENT GROUP

<u>Test Parameter</u>	C O M P O N E N T		G R O U P	
	<u>Base (Fig. No.)</u>	<u>Block (Fig. No.)</u>	<u>Post (Fig. No.)</u>	<u>Post-Seat (Fig. No.)</u>
CTE	69	66	67	68
ϵ_F	90	81	84	87
E_D	103	100	101	102
E_F	99	93	95	97
E_T	91	82	85	88
k	71	--	--	70
MOR	98	92	94	96
ρ	75	72	73	74
UCS	79	76	77	78
UTS	89	80	83	86

(Tensile Strain to Fracture - ϵ_F)

ϵ_F : CBN(||) > CBN(⊥) > B205(|| and ⊥) > TS835(Y) > TS835(X and Z)

(Dynamic Modulus of Elasticity - E_D)

E_D : CBN(⊥) > B205(⊥) > TS835(Y) > B205(||) > TS835(X) > CBN(||) > TS835(Z)

(Flexural Modulus of Elasticity - E_F)

E_F : B205(⊥) > B205(||)

(Tensile Modulus of Elasticity - E_T)

E_T : CBN(⊥) > B205(⊥) > B205(||) > CBN(||) > TS835(Y) > TS835(X) > TS835(Z)

(Thermal Conductivity - k)

k: TS574(X and Z) > TS835(X) > TS835(Y) > TS835(Z) > TS574(Y) > CBN(⊥) > CBN(||) > B205(|| and ⊥)

(Modulus of Rupture - MOR)

MOR: B205(⊥) > B205(||)

(Bulk Density - ρ)

ρ : TS835 > CBN > B205

(Ultimate Compressive Strength - UCS)

UCS: B205(⊥) > B205(||) > CBN(||) > CBN(⊥) > TS835(Z) > TS835(Y) > TS835(X)

(Ultimate Tensile Strength - UTS)

UTS: CBN(⊥) > B205(⊥) > B205(||) > CBN(||) > TS835(Y) > TS835(X) > TS835(Z)

Block Component

(Coefficient of Thermal Expansion-CTE)

CTE: MHLM(⊥) > PGX(||) > PGX(⊥) > MHLM(||)

(Tensile Strain to Fracture - ϵ_F)

ϵ_F : PGX(||) > MHLM(⊥) > PGX(⊥) > MHLM(||)

(Dynamic Modulus of Elasticity - E_D)

E_D : MHLM(||) > PGX(⊥) > MHLM(⊥) > PGX(||)

(Flexural Modulus of Elasticity - E_F)

$$\underline{E_F}: \text{MHLM}(\parallel) > \text{MHLM}(\perp)$$

(Tensile Modulus of Elasticity - E_T)

$$\underline{E_T}: \text{PGX}(\perp) > \text{MHLM}(\parallel) > \text{MHLM}(\perp) > \text{PGX}(\parallel)$$

(Modulus of Rupture - MOR)

$$\underline{\text{MOR}}: \text{PGX}(\parallel) > \text{MHLM}(\parallel) > \text{MHLM}(\perp) > \text{PGX}(\perp)$$

(Bulk Density - ρ)

$$\underline{\rho}: \text{MHLM} > \text{PGX}$$

(Ultimate Compressive Strength-UCS)

$$\underline{\text{UCS}}: \text{PGX}(\parallel) > \text{PGX}(\perp) > \text{MHLM}(\perp) > \text{MHLM}(\parallel)$$

(Ultimate Tensile Strength - UTS)

$$\underline{\text{UTS}}: \text{PGX}(\parallel) > \text{PGX}(\perp) > \text{MHLM}(\perp) > \text{MHLM}(\parallel)$$

Post Component

(Coefficient of Thermal Expansion-CTE)

$$\underline{\text{CTE}}: \text{ATJ-2(8)} > \text{H249}(\perp) > \text{ATJ-2(18)} > \text{ATJ-2(50)} > \text{H249}(\parallel)$$

(Tensile Strain to Fracture - ϵ_F)

$$\underline{\epsilon_F}: \text{ATJ-2(8)} > \text{H249}(\perp) > \text{ATJ-2(50)} > \text{ATJ-2(18)} > \text{H249}(\parallel)$$

(Dynamic Modulus of Elasticity - E_D)

$$\underline{E_D}: \text{H249}(\parallel) > \text{ATJ-2(50)} > \text{ATJ-2(18)} > \text{ATJ-2(8)} > \text{H249}(\perp)$$

(Flexural Modulus of Elasticity - E_F)

$$\underline{E_F}: \text{H249}(\parallel) > \text{ATJ-2(50)} > \text{H249}(\perp) > \text{ATJ-2(8)} > \text{ATJ-2(18)}$$

(Tensile Modulus of Elasticity - E_T)

$$\underline{E_T}: \text{ATJ-2(50)} > \text{H249}(\parallel) > \text{ATJ-2(18)} > \text{ATJ-2(8)} > \text{H249}(\perp)$$

(Modulus of Rupture - MOR)

$$\underline{\text{MOR}}: \text{ATJ-2(50)} > \text{ATJ-2(18)} > \text{H249}(\parallel) > \text{ATJ-2(8)} > \text{H249}(\perp)$$

$$\underline{\rho}: \text{H249} > \text{ATJ-2}$$

(Ultimate Compressive Strength-UCS)

UCS: ATJ-2(50) > ATJ-2(8) > ATJ-2(18) > H249(||) > H249(⊥)

(Ultimate Tensile Strength-UTS)

UTS: ATJ-2(50) > H249(||) > ATJ-2(18) > ATJ-2(8) > H249(⊥)

Post-Seat Component

(Coefficient of Thermal Expansion - CTE)

CTE: H205(||) > H205(⊥) > ATJ-2(||) > ATJ-1(⊥)

(Tensile Strain to Fracture - ϵ_F)

ϵ_F : H205(⊥) > H205(||) > ATJ-1(||) > ATJ-1(⊥)

(Dynamic Modulus of Elasticity - E_D)

E_D : ATJ-1(⊥) > H205(||) > H205(⊥) > ATJ-1(||)

(Flexural Modulus of Elasticity - E_F)

E_F : ATJ-1(⊥) > ATJ-1(||) > H205(||) > H205(⊥)

(Tensile Modulus of Elasticity - E_T)

E_T : ATJ-1(⊥) > H205(||) > H205(⊥) > ATJ-1(||)

(Thermal Conductivity - k)

k: ATJ-1(⊥) > H205(||) > H205(⊥) > ATJ-1(||)

(Modulus of Rupture - MOR)

MOR: H205(⊥) > ATJ-1(⊥) > H205(||) > ATJ-1(||)

(Bulk Density - ρ)

ρ : ATJ-1 > H205

(Ultimate Compressive Strength - UCS)

UCS: H205(||) > H205(⊥) > ATJ-1(⊥) > ATJ-1(||)

(Ultimate Tensile Strength - UTS)

UTS: H205(⊥) > H205(||) > ATJ-1(⊥) > ATJ-1(||)

ACKNOWLEDGEMENTS

The authors acknowledge with appreciation for their participation in various parts of this experimental program the following persons: N. Baker, V. Belliston, H. Evans, J. Furth, W. Prices, J. Sommerfield, M. Skinner, H. Stier and Dr. T. Trozera.

REFERENCES

1. Parker, W. J., et al., "Flash Method of Determining Thermal Diffusivity, Heat Capacity, and Thermal Conductivity," J. Appl. Phys. 32, p. 1679, (1961)
2. Larson, K. B. and Koyama, K., "Correction for Finite Pulse-Time Effects in Very Thin Samples Using the Flash Method of Measuring Thermal Diffusivity," J. Appl. Phys. 38, p. 465, (1967).
3. Rossini, F. D., et al., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Comprising the Tables of the American Petroleum Institute Research Project 44, Carnegie Press, Pittsburgh (1953).
4. ASTM Specification E 12-61T.
5. ASTM Specification E 9-61.
6. ASTM Specification E 8-61T.
7. Larson, P. G. and Cox, W. J., Mechanics of Materials (J. Wiley & Sons, 2nd Ed., 1947); p. 125-132 and 414.
8. Magnaflux Corporation, Operating Manual for Magnatest Elastomat (Type FM-500), p. 12-13.

Fig. 1 Linear thermal expansion of ATJ graphite, 1-B ($\perp$) and 1-D ($\parallel$). (Run Number - F0476/F0469, Date - 10 October 1967)

Fig. 2 Linear thermal expansion of ATJ graphite, 2-B (8-in. direction), 2-B (18-in. direction), and 2-C (50-in. direction). (Run number - F0479/F0485-9, Date - 10 October 1967)

Fig. 3 Linear thermal expansion of B205 carbon, 1-D (⊥) and 1-E (||). (Run number - F0542/F0548, Date - 10 October 1967)

Fig. 4 Linear thermal expansion of CBN graphite, 1-A ($\perp$) and 1-E ($\parallel$). (Run number - F0533/F0534, Date - 9 October 1967)

Fig. 5 Linear thermal expansion of H2O5 graphite, 1-C (||) and 1-C ($\perp$). (Run number - FO511/FO516, Date - 10 October 1967)

Fig. 6 Linear thermal expansion of H249 graphite, 1-B ($\parallel$) and 1-D ($\perp$). (Run number - F0500/F0557, Date - 10 October 1967)

Fig. 7 Linear thermal expansion of MHLM graphite, 1-A ($\parallel$) and 1-A ($\perp$). (Run number - F0519/F0524, Date - 18 October 1967)

Fig. 8 Linear thermal expansion of PGX graphite, 1-C ($\perp$) and 1-E ($\parallel$). (Run number - F0497/F0500, Date - 10 October 1967)

Fig. 9 Linear thermal expansion of TS-574 graphite containing Ag and MoS₂ in the X, Y, and Z directions. (Run number - E0531-3, Date - 10 October 1967)

Fig. 10 Linear thermal expansion of TS-835 graphite, 1-A (X direction), 1-C (Y direction), and 1-A (Z direction). (Run number - F0599/F0604, Date - 10 October 1967)

Fig. 11 Thermal conductivity of ATJ graphite by flash method, 1-A (I) and 1-E (II), $\rho = 1.766$ g/cc.
(Run number - F0582/F0588, Date - 11 October 1967)

Fig. 12 Thermal conductivity of ATJ graphite ($\parallel$ and $\perp$) by flash method; each band represents results of five samples, 1-A to 1-E, $\rho = 1.766$ g/cc. (Run number - F0584-8/F0579-83, Date - 11 October 1967)

Fig. 13 Thermal conductivity of B205 carbon by flash method, l-E ($\perp$) and l-C ($\parallel$), $\rho = 1.516$ g/cc.
(Run number - F0593/F0598, Date - 18 October 1967)

Fig. 14 Thermal conductivity of B205 carbon ($\parallel$ and $\perp$) by flash method; each band represents results of five samples, 1-A to 1-E, $\rho = 1.516$ g/cc. (Run number - F0589-5/F0591-8, Date - 11 October 1967)

Fig. 15 Thermal conductivity of CBN graphite by flash method, 1-C ($\parallel$ and $\perp$), $\rho = 1.706$ g/cc.
(Run number - F0561/F0566, Date - 11 October 1967)

Fig. 16 Thermal conductivity of CBN graphite ($\parallel$ and $\perp$) by flash method; each band represents results of five samples, 1-A to 1-E, $\rho = 1.706 \text{ g/cc}$. (Run number - F0559-63/F0564-68, Date - 11 October 1967)

Fig. 17 Thermal conductivity of H2O5 graphite by flash method, 1-A ($\parallel$) and 1-B ($\perp$), $\rho = 1.755$ g/cc.
(Run number - F0569/F0575, Date - 11 October 1967)

Fig. 18 Thermal conductivity of H2O5 graphite ($\parallel$ and $\perp$) by flash method; each band represents results of five samples, 1-A to 1-E, $\rho = 1.755$ g/cc. (Run number F0569-73/F0574-8, Date - 11 October 1967)

Fig. 19 Thermal conductivity of TS-574 graphite containing Ag and MoS₂ by comparative method; specimen number A in the X, Z, and Y directions. (Run number - E0606/F0024, Date - 10 October 1967)

Fig. 20 Thermal conductivity of TS-835 graphite by flash method; specimen number A in the X, Y, and Z directions. (C_p based on 19 wt-% MoS_2 , $\rho = 1.885 \text{ g/cc.}$) (Run number - F0606, 8-10, Date - 10 October 1967)

Fig. 21 Thermal diffusivity of TS-835 graphite by flash method; specimen number A in X, Y, and Z directions. (Run number - FO606, 8-10, Date - 10 October 1967)

Fig. 22

SPECIMEN NO. T-ATJ-1-E
LOG NO. 1
LOCATION PARALLEL
GRAPHITE TYPE ATJ
MANUFACTURER UCC

ENGINEERING STRESS
(PSI)

STRAIN ($\times 10^3$)

54

2

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

Fig. 28

SPECIMEN NO. T-ATJ-2-B
LOG NO. 2
LOCATION 18IN.DIR.
GRAPHITE TYPE ATJ
MANUFACTURER UCC

ENGINEERING STRESS
(PSI)

Fig. 36

SPECIMEN NO. T-CBN-1-A
LOG NO. 1
LOCATION PARALLEL
GRAPHITE TYPE CBN
MANUFACTURER UCC

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

Fig. 42

SPECIMEN NO. T-H205-1-C
LOG NO. 1
LOCATION PERPENDICULAR
GRAPHITE TYPE H-205
MANUFACTURER GLCC

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

Fig. 44

SPECIMEN NO. T-H249-1-A
LOG NO. 1
LOCATION PARALLEL
GRAPHITE TYPE H-249
MANUFACTURER GLCC

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

—
—

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

ENGINEERING STRESS
(PSI)

Fig. 66 Comparison of CTE values in graphites for core-support blocks.

Fig. 67 Comparison of CTE values in graphites for core-support posts.

Fig. 68 Comparison of CTE values in graphites for core-support-post seats.

Fig. 69 Comparison of CTE values in carbon and graphites for core-support bases.

Fig. 71 Comparison of k values in carbon and graphites for core-support bases.

Fig. 71 Comparison of k values in graphites for core-support-post seats.

Fig. 72 Comparison of ρ values in graphites for core-support blocks.

Fig. 73 Comparison of ρ values in graphites for core-support posts.

Fig. 74 Comparison of ρ values in graphites for core-support-post seats.

Fig. 75 Comparison of ρ values in graphites for core-support bases.

Fig. 76 Comparison of UCS values in graphites for core-support blocks.

Fig. 77 Comparison of UCS values in graphites for core-support posts.

Fig. 78 Comparison of UCS values in graphites for core-support-post seats.

Fig. 79 Comparison of UCS values in carbon and graphite for core-support bases.

Fig. 80 Comparison of UTS values in graphites for core-support blocks.

Fig. 81 Comparison of ϵ_F values in graphites for core-support blocks.

Fig. 82 Comparison of E_T values in graphites for core-support blocks.

Fig. 83 Comparison of UTS values in graphites for core-support posts.

Fig. 84 Comparison of ϵ_F values in graphites for core-support posts.

Fig. 85 Comparison of E_T values in graphites for core-support posts.

Fig. 86 Comparison of UTS values in graphites for core-support-post seats.

Fig. 87 Comparison of ϵ_F values in graphites for core-support-post seats.

Fig. 88 Comparison of E_T values in graphites for core-support-post seats.

Fig. 89 Comparison of UTS values in carbon and graphite for core-support bases.

Fig. 90 Comparison of ϵ_F values in carbon and graphite for core-support bases.

Fig. 91 Comparison of E_T values in carbon and graphites for core-support bases.

Fig. 92 Comparison of MOR values in MHLM graphite for core-support blocks.

Fig. 93 Comparison of E_F values in MHLM graphite for core-support blocks.

Fig. 94 Comparison of MOR values in graphites for core-support posts.

Fig. 95 Comparison of E_F values in graphites for core-support posts.

Fig. 96 Comparison of MOR values in graphites for core-support-post seats.

Fig. 97 Comparison of E_F values in graphites for core-support-post seats.

Fig. 98 Comparison of MOR values in B205 carbon for core-support bases.

Fig. 99 Comparison of E_F values in B205 carbon for core-support bases.

Fig. 100 Comparison of tensile and flexural moduli of elasticity with dynamic modulus of elasticity in graphites for core-support blocks.

Fig. 101 Comparison of tensile and flexural moduli of elasticity with dynamic modulus of elasticity in graphites for core-support posts.

Fig. 102 Comparison of tensile and flexural moduli of elasticity with dynamic modulus of elasticity in graphites for core-support-post seats.

Fig. 103 Comparison of tensile and flexural moduli of elasticity with dynamic modulus of elasticity in carbon and graphites for core-support bases.