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INFORMAL AEC RESEARCH
AND DEVELOPMENT REPORT

GAMD-8737

EVALUATION OF UCC GRADE TS-814

(AGQT-NP) ~~GRAPHITE~~ LOG

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1. INTRODUCTION

One task objective in the PSC materials program is the evaluation of various conventional needle-coke and a few nominally isotropic graphites for use in the PSC reactor core. The graphites that have been examined have been obtained from the three principal U. S. vendors and are being evaluated with respect to purity, thermal properties, mechanical properties, and cost. These graphites that have been evaluated for use as a moderator and structural lattice for fuel elements and as the surrounding neutron-reflecting material are as follows: Great Lakes Carbon Co. (GLCC) grades H-327 and H-328; Speer Carbon Co. (SCC) grades 9567 and RC4; and Union Carbide and Chemical Co. (UCC) EGCR grades TS-688 and TS-814.* The results of an evaluation of a full-size TS-814 (AGOT-NP) graphite log will be reported herein.

*Grade TS-814 is the same as TS-688, but with additional pitch impregnation.

2. EXPERIMENTAL MATERIAL AND TEST PROCEDURES

2.1. TEST MATERIAL

One 17-in.-diameter log of UCC grade TS-814 graphite produced in 1967 was sampled for mechanical and thermal/physical properties. A cursory evaluation of this log is presented in Table 1* (data provided by UCC).

2.2. SAMPLING PLAN AND TENSILE SPECIMEN CONFIGURATION

The mid-length slab from log 1 was sampled in accordance with the plan shown in Fig. 1. The samples were extracted as core-drilled rods with 0.500-in. diameters (for Type III[†] tensile bars). Samples for thermal/physical tests were taken at various locations on the cored rods, adjacent to the tensile bars.

2.3. TESTING PROCEDURES

The mechanical properties measured were ultimate tensile strength (UTS), strain-to-fracture (ϵ_F), tensile modulus of elasticity (E_T), and tensile secant modulus of elasticity (E_S). All of the above parameters were determined from tensile tests. The thermal/physical properties measured were coefficient of thermal expansion (CTE), thermal conductivity (k), and bulk density (ρ). Measurements of CTE and ρ were made on a single sample.

Test procedures are described in greater detail in the following subsections.

2.3.1. Measurement of Ultimate Tensile Strength (UTS), Strain-to-Fracture (ϵ_F), Tensile Modulus of Elasticity (E_T), and Tensile Secant Modulus of Elasticity (E_S)

Uniaxial tensile tests were performed at room temperature (22°C) with an Instron Universal Test Machine (model TTC-ML), geared for a cross-head rate of 0.005 in./min. Cylindrical tensile samples, 0.500-in.-diam. by

* All tables and figures are included at the end of this report.

† The Type III tensile-bar configuration, a circular-cross-section, glued-end rod is the type that GGA has used and prefers for testing, as discussed in Ref. 1.

4.00-in.-length, were attached to 1-in.-diam. stainless-steel shoulders by means of epoxy-cemented butt joints for gripping by the test machine with a universal device at each end of the pull-train. 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.⁽²⁾ E_s was computed as the slope between the origin and the fracture point on the stress-strain curve.

2.3.2. 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 0.500 in. in diameter by 0.50 in. long.

The measurements are made from 22^o to 1000^oC at a programmed heating rate of about 15^oC 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

$$\alpha_m = \frac{\Delta l}{l_0(t - t_0)}, \quad (1)$$

where

t = final temperature

t_0 = initial temperature

l_0 = initial length of specimen

Δl = change in length in the temperature range $t - t_0$

2.3.3. 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 xenon flash technique originally described by Parker et al.⁽³⁾ 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:

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

where ℓ is the thickness of the specimen and $t_{1/2}$ 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 Eq. (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. (4) 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° to 800°C. The specific heat C_p (cal/g/°K) was calculated from the following expression reported by Rossini et al. (5):

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

2.3.4. Measurement of Density (ρ)

Bulk density for each grade of graphite was determined by weighing 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. (6)

3. RESULTS AND DISCUSSION

In the interest of space-saving labels and sample descriptions, the following abbreviations have been adopted for use (in combinations) throughout this report:

NR = near
 AXL = axial
 RDL = radial
 EG = edge
 MR = mid-radius
 CL = centerline
 ENDA = end A
 MDLTH = mid-length
 ENDB = end B
 PL = parallel (parallel to log axis)
 PR = perpendicular (perpendicular to log axis)

3.1. TENSILE TESTS

Results of tensile tests have been compiled in Tables 2 through 4. All the UTS data are in tables with the suffix (a), the ϵ_F data in tables with the suffix (b), the E_T data in tables with the suffix (c), and the E_S data in tables with the suffix (d). Corresponding summary plots of stress versus strain are presented in Figs. 2 through 4. The six data points derived from the test record for each sample have been superposed in a summary for each group of replicate tests. A quadratic curve

$$y = A + Bx + Cx^2, \quad (4)$$

where y is engineering stress and x is engineering strain, has been drawn by the computer through these data using a least-squares fit. The coefficients for each curve have been printed out near the top of each figure.

It will be noted in Figs. 2 and 4 (PL/AXLNREG and PR/RDLNRMR, respectively) that the data scatter about the curves is significantly less than that shown in Fig. 3 (PL/AXLNRMR). In fact, the scatter in Fig. 4 is quite small. The PL UTS data are satisfactorily high with respect to the PSC specification for a 1500-psi minimum average between the NREG and the NRMR locations.⁽⁷⁾ The average of the mean UTS values for these two sample groups is ~1650 psi. A comparison of the individual sample listings in Tables 2(a) and 3(a) reveals that combinations of only the two lowest values of the fifteen or sixteen values in each table would yield average values below 1500 psi. Thus, grade TS-814 appears to be adequate for use in the PSC reactor core, although the PR UTS values are well below the 1000-psi level desired (but unspecified).

3.2. COEFFICIENT OF THERMAL EXPANSION (CTE)

Results of thermal expansion tests⁽⁸⁾ have been compiled in Table 5, and typical curves for each group of samples are presented in Figs. 5, 6, and 7. These CTE results are rather typical of the highly oriented, anisotropic needle-coke graphites. The anisotropy in CTE increases slightly in progressing radially from NRCL to NREG locations, as would be expected for a large-diameter conventional extrusion. These CTE results adequately meet the PSC specification.⁽⁷⁾

3.3. THERMAL CONDUCTIVITY (k)

Typical results of thermal conductivity measurements⁽⁸⁾ are presented in Figs. 8, 9, and 10 for the PR/RDLNREG, PR/RDLNRCL, and PL/AXLNRCL sample groups, respectively. The typical k values for the two groups of PR samples are essentially the same (Figs. 8 and 9). The curve for k in a single PL sample (Fig. 10), however, is considerably higher than those typical of the PR samples -- by factors of ~1.7 at room temperature and ~2.0 at 800°C. All k values are well above the minimum of 18 Btu-ft/hr-ft²-°F (or 0.074 cal-cm/sec-cm²-°C) specified for PSC fuel elements.⁽⁷⁾

3.4. BULK DENSITY

The results of bulk density measurements on the CTE samples reported above were 1.803 (+0.001) for the NREG group and 1.763 (+0.001) for the NRCL group, as shown in Tables 6(a) and (b). These results reflect the radial variation in bulk density resulting from extrusion-die pressure differentials and/or penetration of pitch impregnant later during processing. These bulk density data are well above the minimum level specified for PSC fuel elements.⁽⁷⁾

3.5. IMPURITY ANALYSES

The results of impurity analyses have been included, since it is possible that high levels of the heavier metallic impurities may affect the measurements of bulk density in graphite. A general semi-quantitative spectrographic series of samples revealed no significant levels of impurities. Iron was quantitatively determined by means of the ion-absorption method. Iron was present in amounts less than 10 ppm in all nine samples analyzed, and less than 5 ppm in five of those nine samples.⁽⁹⁾ These samples of grade TS-814 were well within the limits of impurity specified for PSC fuel elements.⁽⁷⁾

4. SUMMARY AND CONCLUSIONS

A mid-length slab from one 17-inch-diameter log of UCC grade TS-814 graphite was sampled, and measurements were performed on mechanical and thermal/physical properties. Tensile tests yielded results for UTS, ϵ_F , E_T , and E_S at NREG, NRMN, and NRCL radial locations within this slab. The mean UTS values for two groups of PL samples were ~1782 psi and ~1524 psi at the NREG and the NRMN locations, respectively. The mean UTS value for a group of PR samples was ~756 psi at the NRMN location. Thermal expansion tests were conducted on two groups of PR samples and on one PL sample, with the following average results:

$$\begin{aligned} \text{PR/NREG} & \dots 4.49 \times 10^{-6} \text{ } ^\circ\text{C}^{-1} \\ \text{PR/NRCL} & \dots 3.85 \times 10^{-6} \text{ } ^\circ\text{C}^{-1} \\ \text{PL/NRCL} & \dots 2.03 \times 10^{-6} \text{ } ^\circ\text{C}^{-1} \end{aligned}$$

Thermal conductivities of these same sample groups were measured and found to range between ~0.30 (at room temperature) to ~0.10 (at 800°C) for the two PR groups, and between ~0.50 (at room temperature) and ~0.23 (at 800°C) for the single PL sample. Bulk density data ranged from an average of 1.763 (at NRCL location) to 1.808 g/cm³ (at NREG location).

In general, the mechanical and thermal/physical properties (as well as impurity levels) were within limits specified by GGA for PSC fuel element graphite.

REFERENCES

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3. Parker, W. J., et al., "Flash Method of Determining Thermal Diffusivity, Heat Capacity, and Thermal Conductivity," J. Appl. Phys. 32, 1679 (1961).
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9. Chaney, C. L., private communication, 1968.

Table 1
 PROPERTIES OF UCC GRADE TS-814
 (OR AGOT-NP) GRAPHITE, LOG 1^(a)

Overall Characteristics -

17" dia. x 34" long
 Billet Density: 1.78
 Resistivity: 5.01

	NRCL Samples (Middle of Log)		NREG Samples (End of Log)	
	PL	PR	PL	PR
Density, ρ (g/cm ³)	1.81 1.81 1.78	1.78 1.78 1.78 1.78	1.81 1.82 1.81 1.81	1.82 1.82 1.81 1.80
Young's Modulus, E_T ($\times 10^6$ psi)	1.95 1.99 1.79 2.01	.77 .77 .81 .81	2.16 2.19 2.21 2.18	.94 .96 .92 .92
Flexural Strength, MOR (psi)	2112 2089 2089 2451	1413 1597 1720 1843	2335 2335 3133 2949	1843 1966 1732 2027
Tensile Strength, UTS (psi) (dog bone)	1400 1220 900 1300	1400 1220 1180 1020	1620 1740 1620 1520	1100 1420 920 740
Tensile Strength, UTS (psi) (9/16" round)	1744 ^(b) 1984 ^(b) 912 1272 2336 2280 ^(b)	984 1280 840	1440 ^(b) 1860 ^(b) 1048 ^(b) 2392 1688 1568 ^(b)	1880 1912 1240 1120
Compressive Strength, UCS (psi)	5025 5200 5975 5025	4500 4700 4975 4875	5700 5425 5450 5200	5025 5075 5100 5025
CTE (cm/cm/ ^o C)	.19	2.59	.44	3.01
retest-----	(.27)	2.69	(.36)	3.01
	.23	2.55	.32	2.76
retest-----	(.27)	2.59	(.40)	2.67
	.23		.32	
	.27		.36	
Chemical Impurities				
Ash	0.020% (200 ppm)		120 ppm	
Fe	less than 100 ppm		less than 100 ppm	

(a) Samples taken at one end of log at NREG and NRCL locations.

(b) In gauge break.

Table 2(a)

ATTITUDE IN LOG PL/AXLNREG NRMDLTH

LOG NO. 1 GRAPHITE TYPE DESIGNATION TS-814

STRESS AT FRACTURE

THE NUMBER OF SAMPLES 15

THE MEAN OF THE SAMPLE 1781.5266000000

THE STANDARD DEVIATION IS 160.4428400000

SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
T-TS814-43-1	<u>1371.1322000000</u>	-2.56 ?
T-TS814-34-1	1587.6268000000	-1.21
T-TS814-4*-1	1640.6139000000	-.88
T-TS814-1-1	1723.4209000000	-.36
T-TS814-10-1	1733.7713000000	-.30
T-TS814-7-1	1744.1227000000	-.23
T-TS814-25-1	1752.5750000000	-.18
T-TS814-13-1	1601.0525000000	.12
T-TS814-37-1	1845.3585000000	.40
T-TS814-16*1	1878.6841000000	.61
T-TS814-28-1	1886.5955000000	.65
T-TS814-31-1	1907.2140000000	.78
T-TS814-22-1	1935.6139000000	.96
T-TS814-40-1	1948.4511000000	1.04
T-TS814-19*1	<u>1966.6665000000</u>	1.15

Table 2(b)

ATTITUDE IN LOG	<u>PL/AXLNREG NRMDLTH</u>
LOG NO. <u>1</u>	GRAPHITE TYPE DESIGNATION <u>TS-814</u>
<u>STRAIN AT FRACTURE</u>	
THE NUMBER OF SAMPLES <u>15</u>	
THE MEAN OF THE SAMPLE	<u>.0010013333</u>
THE STANDARD DEVIATION IS	<u>.0001777183</u>

SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
T-TS814-25-1	<u>.0007000000</u>	-1.70
T-TS814-43-1	.0007400000	-1.47
T-TS814-34-1	.0008100000	-1.08
T-TS814-4*-1	.0009100000	-.51
T-TS814-16*-1	.0009200000	-.46
T-TS814-10-1	.0009300000	-.40
T-TS814-31-1	.0009700000	-.18
T-TS814-37-1	.0010200000	.11
T-TS814-7-1	.0010400000	.22
T-TS814-13-1	.0010500000	.27
T-TS814-1-1	.0010700000	.39
T-TS814-28-1	.0010900000	.50
T-TS814-19*-1	.0012100000	1.17
T-TS814-22-1	.0012100000	1.17
T-TS814-40-1	<u>.0013500000</u>	1.96 ?

Table 2(c)

ATTITUDE IN LOG PL/AXLNREG NRMDLTH
 LOG NO. 1 GRAPHITE TYPE DESIGNATION TS-814
YOUNG'S MODULUS
 THE NUMBER OF SAMPLES 15
 THE MEAN OF THE SAMPLE 3457771.6000000000
 THE STANDARD DEVIATION IS 1342284.2000000000

SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
T-TS814-40-1	<u>1970686.9000000000</u>	-1.11
T-TS814-28-1	2393222.2000000000	-.79
T-TS814-4*-1	2523026.1000000000	-.70
T-TS814-13-1	2639473.5000000000	-.61
T-TS814-19*1	2691227.9000000000	-.57
T-TS814-1-1	2717105.0000000000	-.55
T-TS814-43-1	2749137.4000000000	-.53
T-TS814-7-1	2975877.0000000000	-.36
T-TS814-34-1	3135734.9000000000	-.24
T-TS814-10-1	3450292.2000000000	-.01
T-TS814-16*1	3669856.3000000000	.16
T-TS814-25-1	4050068.4000000000	.44
T-TS814-22-1	4787280.6000000000	.99
T-TS814-37-1	4896901.0000000000	1.07
T-TS814-31-1	<u>7216485.1000000000</u>	2.80 ?

Table 2(d)

ATTITUDE IN LOG		<u>PL/AXLNREG</u>	<u>NRMDLTH</u>
LOG NO.	<u>1</u>	GRAPHITE TYPE DESIGNATION <u>TS-814</u>	
<u>SECANT MODULUS</u>			
THE NUMBER OF SAMPLES	<u>15</u>		
THE MEAN OF THE SAMPLE	<u>1813553.6000000000</u>		
THE STANDARD DEVIATION IS	<u>249577.1100000000</u>		
SPECIMEN NO.	VALUE	SIGMAS FROM MEAN	
T-TS814-40-1	<u>1443297.1000000000</u>	-1.48	
T-TS814-22-1	1599680.9000000000	-.86	
T-TS814-1-1	1610673.7000000000	-.81	
T-TS814-19*1	1625344.2000000000	-.75	
T-TS814-7-1	1677041.1000000000	-.55	
T-TS814-13-1	1715288.1000000000	-.39	
T-TS814-28-1	1730821.6000000000	-.33	
T-TS814-4*-1	1802872.4000000000	-.04	
T-TS814-37-1	1809174.9000000000	-.02	
T-TS814-43-1	1852881.4000000000	.16	
T-TS814-10-1	1864270.8000000000	.20	
T-TS814-34-1	1960033.1000000000	.59	
T-TS814-31-1	1966200.0000000000	.61	
T-TS814-16*1	2042047.9000000000	.92	
T-TS814-25-1	<u>2503678.6000000000</u>	2.77 ?	

Table 3(a)

ATTITUDE IN LOG		PL/AXLNRMNR NRMDLTH
LOG NO.	<u>1</u>	GRAPHITE TYPE DESIGNATION <u>TS-814</u>
<u>STRESS AT FRACTURE</u>		
THE NUMBER OF SAMPLES	<u>16</u>	
THE MEAN OF THE SAMPLE	<u>1523.8382000000</u>	
THE STANDARD DEVIATION IS	<u>124.7644680000</u>	
SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
TTS814-108*1	<u>1288.6581000000</u>	-1.88 ?
TTS814-120-1	1376.2869000000	-1.18
TTS814-126-1	1381.4415000000	-1.14
TTS814-100*1	1427.8332000000	-.77
TTS814-130*1	1458.7609000000	-.52
TTS814-124*1	1474.2249000000	-.40
TTS814-122*1	1479.3795000000	-.36
TTS814-106-1	1479.3795000000	-.36
TTS814-110*1	1520.6166000000	-.03
TTS814-102-1	1530.9259000000	.06
TTS814-114-1	1613.4000000000	.72
TTS814-116*1	1654.6370000000	1.05
TTS814-104-1	1659.7916000000	1.09
TTS814-128*1	1659.7916000000	1.09
TTS814-118-1	1680.4102000000	1.25
TTS814-112-1	<u>1695.8741000000</u>	1.38

Table 3(b)

ATTITUDE IN LOG	<u>PL/AXLNRM NRMDLTH</u>	
LOG NO. <u>1</u>	GRAPHITE TYPE DESIGNATION <u>TS-814</u>	
<u>STRAIN AT FRACTURE</u>		
THE NUMBER OF SAMPLES	<u>16</u>	
THE MEAN OF THE SAMPLE		<u>.0010037499</u>
THE STANDARD DEVIATION IS		<u>.0001550860</u>
SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
TTS814-130*1	<u>.0007700000</u>	-1.51
TTS814-116*1	.0008400000	-1.06
TTS814-100*1	.0008600000	-.93
TTS814-108*1	.0008800000	-.80
TTS814-120-1	.0008800000	-.80
TTS814-118-1	.0009500000	-.35
TTS814-124*1	.0009600000	-.28
TTS814-122*1	.0009800000	-.15
TTS814-112-1	.0010000000	-.02
TTS814-110*1	.0010100000	.04
TTS814-102-1	.0010200000	.10
TTS814-114-1	.0010300000	.17
TTS814-126-1	.0010800000	.49
TTS814-104-1	.0012000000	1.27
TTS814-128*1	.0012700000	1.72
TTS814-106-1	<u>.0013300000</u>	2.10 ?

Table 3(c)

ATTITUDE IN LOG	PL/AXLNRM R NRMDLTH	
LOG NO. <u>1</u>	GRAPHITE TYPE DESIGNATION <u>TS-814</u>	
<u>YOUNG'S MODULUS</u>		
THE NUMBER OF SAMPLES <u>16</u>		
THE MEAN OF THE SAMPLE <u>2375646.5000000000</u>		
THE STANDARD DEVIATION IS <u>1448416.2000000000</u>		
SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
TTS814-108*1	<u>1767302.5000000000</u>	-.77
TTS814-106-1	1836337.8000000000	-.72
TTS814-126-1	1847076.6000000000	-.71
TTS814-104-1	2094069.4000000000	-.54
TTS814-114-1	2104808.2000000000	-.53
TTS814-100*1	2108713.3000000000	-.53
TTS814-124*1	2126285.9000000000	-.52
TTS814-112-1	2216491.9000000000	-.46
TTS814-110*1	2216492.0000000000	-.46
TTS814-102-1	2226801.2000000000	-.45
TTS814-128*1	2577316.2000000000	-.21
TTS814-120-1	2671036.8000000000	-.14
TTS814-130*1	3550969.1000000000	.47
TTS814-118-1	4329891.2000000000	1.00
TTS814-116*1	5979373.8000000000	2.14 ?
TTS814-122*1	<u>6357380.1000000000</u>	2.40 ?

Table 3(d)

ATTITUDE IN LOG PL/AXLNRM NRMDLTH
 LOG NO. 1 GRAPHITE TYPE DESIGNATION TS-814
SECANT MODULUS
 THE NUMBER OF SAMPLES 16
 THE MEAN OF THE SAMPLE 1544828.3000000000
 THE STANDARD DEVIATION IS 222367.7100000000

SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
TTS814-106-1	<u>1112315.4000000000</u>	-1.95 ?
TTS814-126-1	1279112.5000000000	-1.19
TTS814-128*1	1306922.6000000000	-1.07
TTS814-104-1	1383159.7000000000	-.73
TTS814-108*1	1464384.2000000000	-.36
TTS814-102-1	1500907.7000000000	-.20
TTS814-110*1	1505560.9000000000	-.18
TTS814-122*1	1509570.9000000000	-.16
TTS814-124*1	1535650.9000000000	-.04
TTS814-120-1	1563962.3000000000	.09
TTS814-114-1	1566407.7000000000	.10
TTS814-100*1	1660271.1000000000	.52
TTS814-112-1	1695874.1000000000	.68
TTS814-118-1	1768852.8000000000	1.01
TTS814-130*1	1894494.8000000000	1.57
TTS814-116*1	<u>1969806.0000000000</u>	1.91 ?

Table 4(a)

ATTITUDE IN LOG	PR/RDLNRM NRMDLTH	
LOG NO. <u>1</u>	GRAPHITE TYPE DESIGNATION <u>TS-814</u>	
<u>STRESS AT FRACTURE</u>		
THE NUMBER OF SAMPLES <u>12</u>		
THE MEAN OF THE SAMPLE	<u>756.4525500000</u>	
THE STANDARD DEVIATION IS	<u>171.2049600000</u>	
SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
T-TS814-C1-1	<u>341.5789200000</u>	-2.42 ?
T-TS814-C3-1	605.3771500000	-.88
T-TS814-C3-1	690.9210100000	-.38
T-TS814-C5-1	690.9210100000	-.38
T-TS814-A5-1	722.2954800000	-.20
T-TS814-C5-1	755.6139900000	-.00
T-TS814-A5-1	769.0628000000	.07
T-TS814-A1-1	813.2319500000	.33
T-TS814-C1*1	872.9902200000	.68
T-TS814-C5-1	910.8771500000	.90
T-TS814-C1-1	941.9297700000	1.08
T-TS814-C3*1	<u>962.6315200000</u>	1.20

Table 4(b)

ATTITUDE IN LOG PR/RDLNRMR NRMDLTH
 LOG NO. 1 GRAPHITE TYPE DESIGNATION TS-814
STRAIN AT FRACTURE
 THE NUMBER OF SAMPLES 12
 THE MEAN OF THE SAMPLE .0013149999
 THE STANDARD DEVIATION IS .0004294076

SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
T-TS814-C1-1	<u>.0003600000</u>	-2.22 ?
T-TS814-D3-1	.0009000000	-.97
T-TS814-A3-1	.0011200000	-.45
T-TS814-C5-1	.0011300000	-.43
T-TS814-A1-1	.0012300000	-.20
T-TS814-C3-1	.0013000000	-.03
T-TS814-A5-1	.0013000000	-.03
T-TS814-D5-1	.0015500000	.55
T-TS814-D3*1	.0015800000	.62
T-TS814-D1*1	.0016300000	.73
T-TS814-D1-1	.0016300000	.73
T-TS814-D5-1	<u>.0020499999</u>	1.71

Table 4(c)

ATTITUDE IN LOG	<u>PR/RDLNRM</u>	<u>NRMDLTH</u>
LOG NO. <u>1</u>	GRAPHITE TYPE DESIGNATION <u>TS-814</u>	
<u>YOUNG'S MODULUS</u>		
THE NUMBER OF SAMPLES	<u>12</u>	
THE MEAN OF THE SAMPLE	<u>1163541.0000000000</u>	
THE STANDARD DEVIATION IS	<u>442649.1800000000</u>	
SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
T-TS814-05-1	<u>661306.0100000000</u>	-1.13
T-TS814-01*1	<u>692849.3800000000</u>	-1.06
T-TS814-A5-1	<u>831419.2500000000</u>	-.75
T-TS814-C3-1	<u>840889.9100000000</u>	-.72
T-TS814-05-1	<u>862573.0600000000</u>	-.68
T-TS814-C1-1	<u>1035087.6700000000</u>	-.29
T-TS814-03*1	<u>1062326.7000000000</u>	-.23
T-TS814-C5-1	<u>1250892.2000000000</u>	.21
T-TS814-03-1	<u>1385698.8000000000</u>	.50
T-TS814-01-1	<u>1495126.6000000000</u>	.75
T-TS814-A1-1	<u>1753775.0000000000</u>	1.33
T-TS814-A3-1	<u>2074548.1000000000</u>	2.07 ?

Table 4(d)

ATTITUDE IN LOG PR/RDLNRMR NRMDLTH
 LOG NO. 1 GRAPHITE TYPE DESIGNATION TS-814
SECANT MODULUS
 THE NUMBER OF SAMPLES 12
 THE MEAN OF THE SAMPLE 610196.2000000000
 THE STANDARD DEVIATION IS 129816.8020000000

SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
T-TS014-05-1	<u>444330.3200000000</u>	-1.28
T-TS014-05-1	487492.9000000000	-.95
T-TS014-03-1	531477.7000000000	-.61
T-TS014-01*1	535576.8200000000	-.57
T-TS014-A5-1	555611.9100000000	-.42
T-TS014-01-1	577871.0200000000	-.25
T-TS014-03*1	609260.4500000000	-.01
T-TS014-05-1	611434.5300000000	.01
T-TS014-A1-1	661164.1900000000	.39
T-TS014-03-1	672641.2700000000	.48
T-TS014-A3-1	680663.2300000000	.59
T-TS014-01-1	<u>944830.3600000000</u>	2.61 ?

Table 5

RESULTS OF THERMAL EXPANSION TESTS
ON UCC GRADE TS-814 GRAPHITE, LOG 1⁽⁷⁾

Sample No.	Run No.	Mean CTE ($^{\circ}\text{C}^{-1} \times 10^6$) (22 $^{\circ}$ to 1000 $^{\circ}\text{C}$ Range)		
		PR/NREG	PR/NRCL	PL/NRCL
2-1 (Inner)	G-0338		3.73	
4-6 (Inner)	G-0343		3.97	
4-6 (Outer)	G-0339	4.64		
1-1 (outer)	G-0341	4.38		
2-6 (Outer)	G-0342	4.45		
3-1 (Outer)	G-0344	4.50		
(Center)	G-0340			2.03
Average		4.49 $\left\{ \begin{array}{l} +0.15 \\ -0.11 \end{array} \right.$	3.85 (± 0.12)	2.03

Table 6(a)

ATTITUDE IN LOG NREGLOG NO. 1GRAPHITE TYPE DESIGNATION TS-814BULK DENSITY (GMS/CC)THE NUMBER OF SAMPLES 4THE MEAN OF THE SAMPLE 1.8083849800THE STANDARD DEVIATION IS .0012386702

SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
C-OT-1-1-1	<u>1.8072300000</u>	-.93
C-OT-4-0-1	<u>1.8074799900</u>	-.73
C-OT-3-1-1	<u>1.8090100000</u>	.50
C-OT-2-6-1	<u>1.8098200000</u>	1.16

Table 6(b)

ATTITUDE IN LOG MRCLLOG NO. 1GRAPHITE TYPE DESIGNATION TS-814BULK DENSITY (GMS/CC)THE NUMBER OF SAMPLES 3THE MEAN OF THE SAMPLE 1.7632199800THE STANDARD DEVIATION IS .0125431632

SPECIMEN NO.	VALUE	SIGMAS FROM MEAN
C-IN-4-6-1	<u>1.7536499900</u>	-.76
C-IN-2-1-1	<u>1.7585900000</u>	-.37
C-LC-1	<u>1.7774200000</u>	1.13

Fig. 1. Sampling plan for mid-length slab from Log 1, UCC grade TS-814 graphite

ENGINEERING STRESS

TENSILE TEST CURVE FITS

LOG 1 TS-814 PL/AXLNREG,
NRMDLTH

A = -7.310+08 B = 2.337+06 C = 1.651+02

Figure 2

ENGINEERING STRESS

TENSILE TEST CURVE FITS)

LOG 1
A = -7.289+08TS-814
B = 2.146+06PL/AXLNRMR, NRMDLTH
C = 8.204+01

Figure 3

ENGINEERING STRESS T E N S I L E T E S T C U R V E F I T S)

 $A = -1.384+08$ $B = 6.921+05$ $C = 1.004+02$

Figure 4

Fig. 5. Linear thermal expansion of TS-814 graphite, (PR) Log 1, sample 3-1, outer

Fig. 6. Linear thermal expansion of TS-814 graphite, (PR) Log 1, sample 4-6, inner

Fig. 7. Linear thermal expansion of TS-814 graphite, (PL) Log 2, center

Fig. 8. Thermal conductivity of TS-814 graphite, (PR) Log 1, sample 2-6, outer

Fig. 9. Thermal conductivity of TS-814 graphite, (PR) Log 1, sample 2-1, inner

Fig. 10. Thermal conductivity of TS-814 graphite, (PL) Log 1, center