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WANL-TME-1695

November, 1967

Westinghouse Astronuclear Laboratory

EFFECTS OF STABILIZATION TREATMENT

ON ATJ GRAPHITE

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I. ABSTRACT

The material investigated consisted of six cylindrical blanks of ATJ graphite. Each was divided into two samples, one of which was dimensionally stabilized by heating to 2450 C (4442F) in argon and holding for one hour at temperature. Specimens of the stabilized and of the untreated material were prepared from these samples and various properties evaluated. Test results indicated that the stabilization treatment produced significant reductions in volatile impurities, and in thermal expansivity, and slight reductions in density, in flexure strength, and a slight increase in electrical resistance. Calculated standard deviations indicated that stabilization also tended to reduce the variability of these properties with the exception of electrical resistance.

II. INTRODUCTION

The performance of components manufactured from ATJ graphite will be improved if the variability in properties is minimized. One such characteristic which influences performance considerably during thermal cycling is dimensional stability.

The stabilization treatment, accomplished by heating to approximately 2500 C (4532F) in an inert atmosphere at reduced pressure, was used to obtain the desired uniformity of properties and to improve dimensional stability. An additional purpose of the treatment is the relief of any thermal stresses which might cause distortion or cracks during machining or the coating process. In general, the aim of this investigation was to determine the effects of the heat treatment on the properties of ATJ graphite, on their uniformity, and whether any induced changes in properties might be detrimental to performance of parts.

Some of the mechanical and physical properties of molded ATJ graphite, determined on samples taken from 9 x 20 x 24-inch blocks supplied by the Carbon Products Division of Union Carbide and Carbon, were reported in WANL-TME-956⁽¹⁾ and in WANL-TME-1377.⁽²⁾ Some of the test results reported in these TME's, which may be considered somewhat representative of ATJ graphite, are included in Tables I and II for comparison with the findings of this investigation.

Preliminary data on the effect of stabilization treatment on the dimensions of pressed and graphitized ATJ graphite have been reported in WANL-TME-1377.⁽²⁾ Heating to 2500 C and holding for 30 minutes caused an expansion in the across-grain direction (parallel to the molding force) of .00105 in/in which was retained after cooling to room temperature. The effect in the with-grain direction was not reported.

III. EXPERIMENTAL PROCEDURE

Sample Material

Six right cylindrical blanks taken from 9 x 20 x 24-inch blocks of ATJ graphite, conforming to Purchasing Department Specification 30008 produced by the Carbon Products Division of Union Carbide Corporation, were chosen at random for investigation. PDS 30008 requires trimming of as-molded blocks, control of coke particle size to 0.006 inch maximum, density of 1.70 g/cc minimum, average minimum flexure strength of 2770 psi with-grain and 2000 psi across-grain, and maximum ash content of 0.25% by weight.

Identifications and dimensions of the sample cylinders were as follows:

<u>Serial No.</u>	<u>Diameter, Inches</u>	<u>Height, Inches</u>	<u>Density Reported by Supplier g/cc</u>
41223	3	2 1/2	1.74
41247	3	2 1/2	1.74
41503	3	2 1/2	1.74
41639	3	2 1/2	1.75
NC1961	4	2 1/2	1.74
NC2961	4	2 1/2	1.76

Two samples were obtained from each cylinder by cutting it through a plane which included its longitudinal central axis.

Stabilization Treatment

Six of the half-cylinder samples were heat-treated in an induction-heated furnace, each furnace charge consisting of two samples and about 200 production blanks. The material was heated to 2450°C (4442F) in about 6 1/2 hours, held at temperature for one hour, and cooled to room temperature in about 30 hours, the furnace atmosphere being argon throughout the cycle. Temperatures and furnace atmospheres were as follows:

<u>Sample No.</u>	<u>Furnace Charge No.</u>	<u>Temperature Range</u>	<u>Argon Pressure, mm. of Hg</u>	<u>Argon Flow Rate, liters per min.</u>
A-41223 A-41639	R-101	2400-2500 C (4352-4532 F)	45 - 49	10
A-41247 A-41503	R-102	2400-2460 C (4352-4460 F)	36 - 42	10
NC 1961-A NC 2961-A	R-105	2370-2515 C (4298-4559 F)	45 - 47	10

Chemical Composition

Samples from two stabilized and two companion untreated sections were analyzed for impurities by spectrographic analysis, and for ash content by weight of residue after combustion in a muffle furnace. These analyses and data taken from WANL-TME-956⁽¹⁾ for comparison are shown in Table I.

Test Specimen Preparation

Figure 1 shows the locations of test specimens in the half cylinders. The longitudinal axes of all specimens were in the across-grain direction, Figure 2 shows the configuration of the flexure strength specimen and Figure 3, of the thermal expansivity specimen.

The flexure strength specimens were used for determinations of density, electrical resistivity and flexure strength in that order. For each property, results of individual tests for the eight specimens representing each sample are shown in Table I of the Appendix. The samples are arranged in the order of increasing average density as stabilized. This format is continued in all tables showing test results. Each specimen is identified by the sample number combined with a number from 1 to 8. The average value for each sample derived from individual test results and the standard deviation for each set of values are given in Table II.

Test Procedures

1. Density Determinations: Density was determined from the ratio of weight to volume, the latter calculated from dimensions, using the flexure strength specimens (Figure 2). Weight was measured to the nearest 0.0001 gram, and dimensions, to the nearest 0.0001 inch.
2. Electrical Resistance: The flexure strength specimens were used to determine electrical resistance at room temperature. A 40-cycle alternating current was passed longitudinally through each specimen and the voltage drop across a 1 1/2 inch span was measured. The resistance for each specimen was then calculated from the current-voltage relation.
3. Flexure Strength: Flexure strength determinations were made by stressing the 0.250-inch square test bar to fracture using the four-point loading method with a cross-head speed of 0.02 inch per minute. The loads were applied by round steel pins 0.75 inch apart for the inner span and 2.25 inches apart for the outer span.
4. Thermal Expansivity: Specimens of the form shown in Figure 3 were used to determine thermal expansion characteristics. The three-inch long specimen required for testing, not obtainable from the sample material, was formed by cementing two lengths together.

The expansion produced by heating from room temperature to various temperatures between 1234 C (2256F) and 2124 C (3855F) were measured. Data were obtained during one heating cycle and, after cooling to room temperature, the specimens were reheated through another cycle. The original data are

tabulated in Table 2 of the Appendix. The values of per cent expansion as ordinates were plotted graphically in Figure 4 with test temperatures as abscissas.

The average coefficient of thermal expansion from room temperature to each test temperature was calculated from the corresponding per cent expansion. Average coefficients for the range 20 to 2100 C (68 to 3812F) are presented in Table II. Individual values are shown graphically in Figure 5, and in tabular form in Table 3 of the Appendix.

Specimen lengths were measured at room temperature before and after the first heating cycle. Permanent length changes expressed in per cent are shown in Table II.

5. Hydrogen Corrosion Testing: A specimen from each sample was prepared for corrosion testing. However, of four specimens tested, two test runs were incomplete because furnace fixtures failed prematurely. The remaining specimens could not be tested, since the testing facilities were used continuously for quality control tests during this period.

IV. DISCUSSION

The analyses presented in Table I indicate that the stabilization treatment reduces total impurities, as measured by the ash content, by about one-half. For the four-inch diameter blank, NC 1961, the reduction was from 0.151% to 0.072% and for the three-inch blank, 41223, from 0.091% to 0.049%. For the untreated condition, the ash content (0.151%) of the four-inch diameter blank, NC 1961, as manufactured, was considerably higher than that (0.091%) of the three-inch diameter blank, 41223. Time of manufacture may account for the difference; NC 1961 having been produced in the period just before July 1963, and 41223 before September 1965, according to the manufacturer's certifications of material. The analyses for specific impurities also show the same trend in reductions for Al, B, Ba, Ca, Fe, Si, Ti, V and Zr, although the order of magnitude varies considerably. For many impurities, changes in the content could not be detected by spectrographic analysis, since calibration does not extend to the content present in the four samples, and only the upper limit is reported.

A comparison of the density decreases, up to 1.72% of the untreated specimen weights (from Table II), with decreases in ash content, 0.052% and 0.079% (from Table I), suggests that some carbonaceous material is volatilized during the stabilization treatment. Loss of adsorbed moisture might account for part of the difference, but smoke reported as observed through the furnace port holes during the stabilization treatment is evidence of volatilization.

The average values, as determined from test results and tabulated in Table II, indicate that density and flexure strength were reduced somewhat in most samples. The indicated properties do not differ greatly from those found

(1)
in the investigation reported in WANL-TME-956. Compared to the values given
in the previous report, densities of untreated samples are in the upper part of
the range, flexure strengths are slightly higher and coefficients of thermal
expansion are significantly lower. A previous investigation, (3) not formally
reported, showed that flexure strength was affected as follows, based on across-
grain specimens in each condition:

	<u>Stabilized</u>	<u>Untreated</u>
Average flexure strength	3819 psi	4083 psi
Highest value	4080 psi	4420 psi
Lowest value	3640 psi	3410 psi

These average values are within the range found in the investigation
reported herein.

It should be noted that if the value for flexure strength of specimen
NC-1961B-3 (Table I of the Appendix), 3170 psi (which could be considered too low
to be representative of the sample), were deleted, the average for this untreated
sample would be 4331 psi instead of 4186. The flexure strength value for each
of the untreated samples would then be greater than for the companion stabilized
sample.

Thermal expansivity data, presented in Tables 2 and 3 of the Appendix
and in Figures 4 and 5, indicate that stabilized ATJ graphite consistently expands
less on heating from room temperature to 2100 C (3857F) than the untreated
material, especially for temperatures over 1600 C (2912F). The spread in values
is also somewhat less at these temperatures for the stabilized material, as shown
by Figures 4 and 5.

Based on the data given in Table II, the stabilization treatment seems to have no consistent effect on permanent dimensional changes caused by the first heating cycle. It can be concluded that a coating procedure, which involves a similar heating cycle, would not cause out-of-tolerance dimensional changes.

The average density and the average flexure strength of each sample are represented graphically in Figure 6. It is evident that, in general, as density increases, flexure strength also increases. The ranges of density and flexure strength values for the individual specimens representing each sample are also shown. The wide spread of flexure strength values is evident, but no marked difference in the variability of stabilized and untreated material is apparent. However, the standard deviations shown in Table II indicate that the stabilization treatment significantly reduces the variability of flexure strength. The standard deviations for density values given in Table II indicate that stabilization has little effect on its uniformity. An increase in the spread of electrical resistance and, hence of thermal conductivity, is indicated.

The average density of each sample is compared with its reported coefficient of thermal expansion in Figure 7. It indicates that there is very little correlation between density and average thermal expansivity to 2100 C (3857F) for the stabilized material. The results for untreated material indicate a trend toward higher rates of expansion as density increases.

V. CONCLUSIONS

In general, the results of analyses and tests indicate that the stabilization treatment produces a significant reduction of some volatile impurities, a slight reduction of density and flexure strength and has little effect on electrical and thermal conductivity. Judging from the standard deviations for the flexure strength and density values, the stabilization treatment tends to promote uniformity of these properties. A contrary effect is indicated for electrical resistance. Test results indicate that the treatment reduces the coefficient of thermal expansion and its variability, especially on heating to temperatures over 1600 C, a characteristic which would influence performance of components made from ATJ graphite. Corrosion tests on test lobes of stabilized ATJ graphite coated along with production parts indicate that stabilization treatment has no detrimental effect on corrosion performance.

The principal conclusion from these findings seems to be that ATJ graphite parts cut from parent block can be dimensionally stabilized without degrading the mechanical or thermophysical properties.

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1. V. Kachur, Properties of ATJ Graphite, WANL-TME-956, November 4, 1964.
2. V. Kachur, Evaluation of New Graphites for Nerva Support Blocks, WANL-TME-1377, February 23, 1966.
3. H. O. Hanzlik, "ATJ Thermal Stability", letter to L. L. France, June 16, 1965.

TABLE I
CHEMICAL COMPOSITION

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Sample No.	Ash Content, Weight Per Cent	Spectrographic Analysis, ppm														
		<u>Ag</u>	<u>Al</u>	<u>Au</u>	<u>B</u>	<u>Ba</u>	<u>Be</u>	<u>Bi</u>	<u>Ca</u>	<u>Cd</u>	<u>Co</u>	<u>Cr</u>				
1. A41223 *	.049 (490 ppm)	< 3	< 30	< 300	2.6	7.9	< 1	< 30	98	< 100	< 30	< 30				
2. B41223	.091 (910 ppm)	"	"	"	2.0	8.3	"	"	165	"	"	"				
3. NC-1961A *	.072 (720 ppm)	"	"	"	2.4	12	"	"	150	"	"	"				
4. NC-1961B	.151 (1510 ppm)	"	52	"	9.1	17	"	"	250	"	"	"				
5. TME 956(1)	-	< 0.3	45	-	5.0	15	< 0.3	< 3	675	< 10	< 1	< 10				
6. TME 956(2) .137/.163		.02/.03	78/79	-	2.1/1.5	6.5/4.1	< .02/< .01	< .05/< .04	375/260	< 2/< 1	.7/.4	10/6.7				
Spectrographic Analysis, ppm																
	<u>Cs</u>	<u>Cu</u>	<u>Fe</u>	<u>In</u>	<u>K</u>	<u>Li</u>	<u>Mg</u>	<u>Mn</u>	<u>Mo</u>	<u>Na</u>	<u>Nb</u>	<u>Ni</u>	<u>P</u>	<u>Pb</u>	<u>Rb</u>	<u>Sb</u>
1.	< 100	< 10	< 10	< 100	< 10	< 3	< 1	< 10	< 30	< 10	< 10	< 100	< 100	< 100	< 30	< 100
2.	"	"	10	"	"	"	"	"	"	"	"	"	"	"	"	"
3.	"	"	14	"	"	"	"	"	"	"	"	"	"	"	"	"
4.	"	"	320	"	"	"	1.0	"	"	"	"	"	"	"	"	"
5.	"	< 0.5	10	< 10	"	"	"	< 1	< 3	< 3	< 3	< 3	"	< 10	"	< 10
6.	-	.7/.4	173/115	< 2/< 1	-	-	.4/1.4	.8/.5	.7/.5	-	< .05/< .04	3.0/3.3	-	.3/.4	-	< 5/< 4
Spectrographic Analysis, ppm																
	<u>Si</u>	<u>Sn</u>	<u>Sr</u>	<u>Ta</u>	<u>Th</u>	<u>Ti</u>	<u>Tl</u>	<u>V</u>	<u>W</u>	<u>Zn</u>	<u>Zr</u>					
1.	19	30	< 10	< 100	< 100	21	< 100	26	< 100	< 100	< 3					
2.	38	"	10	"	"	23	"	27	"	"	"					
3.	< 3	"	10	"	"	24	"	32	"	"	5.0					
4.	250	"	10	"	"	52	"	52	"	"	5.4					
5.	85	< 10	< 10	< 10	< 10	75	-	50	< 10	< 10	10					
6.	26/18	< .2/< .1	15/11	< .5/< .4	-	220/137	-	49/35	11/6	23/16	1.7/1.3					

* Stabilized
< = Less than

TABLE II

PHYSICAL AND MECHANICAL PROPERTIES -
AVERAGE VALUES AND STANDARD DEVIATIONS
(across-grain)

Sample No.	Density		Electrical Resistance		Flexure Strength		Average Thermal Expansion, 20 to 2100C in./in./°C (X10 ⁻⁶)	Thermally Induced Dimensional Change, Per Cent
	g/cc	σ	Milliohms	σ	psi	σ		
A41503*	1.7128	.0018	12.33	.024	3640	173	4.76	+.004
B41503	1.7217	.0018	12.28	.012	3674	310	5.09	+.018
A41247*	1.7178	.0014	12.29	.020	3894	120	4.85	-.001
B41247	1.7169	.0034	12.27	.016	3971	126	4.87	+.022
NC2961A*	1.7323	.0087	12.24**	.017	3889	90	4.76	+.007
NC2961B	1.7471	.0077	12.25**	.007	3950	136	4.98	+.009
A41639*	1.7324	.0037	12.27	.022	3876	104	4.85	+.031
B41639	1.7638	.0056	12.24	.009	4175	127	5.05	-.009
A41223*	1.7491	.0069	12.28	.012	4009	126	--	--
B41223	1.7572	.0075	12.24	.011	4155	184	--	--
NC1961A*	1.7649	.0096	11.28**	.156	4221	156	4.73	+.028
NC1961B	1.7587	.0075	11.46**	.100	4186	412	5.28	+.021
Average Stabilized	1.7349	--	12.12	--	3922	--	4.79	+.020
Average Untreated	1.7442	--	12.13	--	4019	--	5.05	+.020
Per TME-956 ⁽¹⁾ (across grain)	1.69/1.76	--	--	--	3450/3890	115/163	5.29	+.105#

* Stabilized

** Specimens .275 x .275 x 2.500 inches

Heated to 2500 C for 30 minutes

<u>CODE</u>	<u>TEST SPECIMEN</u>
1	HYDROGEN CORROSION TEST LOBE PER WANL DRAWING 367D865
2	THERMAL EXPANSIVITY SPECIMEN
3	SPECIMEN FOR DETERMINATIONS OF FLEXURE STRENGTH ELECTRICAL RESISTIVITY AND DENSITY

FIGURE 1 Location of Specimens

FIGURE 2 Flexure Strength Specimen

FIGURE 3 Thermal Expansivity Specimen

612128-1B

FIGURE 4

Average Thermal Expansion in Per Cent from
20 C (68F) to Indicated Temperature (across-grain)

FIGURE 5

Average Coefficient of Thermal Expansion
from Room to Indicated Temperature (across-grain)

FIGURE 6

Density vs Flexure Strength (across-grain)

FIGURE 7

Density vs Thermal Expansivity
(across-grain) from 20 to 2100 C (68 to 3812F)

APPENDIX

TEST VALUES FOR INDIVIDUAL SPECIMENS

TABLE 1

MEASUREMENTS FOR INDIVIDUAL SPECIMENS (across-grain)

<u>Specimen No.</u>	<u>Density, g/cc</u>	<u>Flexural Strength, psi</u>	<u>Electrical Resistance, Milliohms</u>
A41503-1	1.7168	3670	12.34
-2	1.7129	3540	12.28
-3	1.7114	3480	12.31
-4	1.7140	3320	12.35
-5	1.7113	3870	12.35
-6	1.7130	3830	12.35
-7	1.7120	3750	12.34
-8	1.7111	3660	12.35
* Average	1.7128	3640	12.33
B41503-1	1.7212	3780	12.30
-2	1.7229	3150	12.27
-3	1.7235	4010	12.27
-4	1.7198	3910	12.28
-5	1.7192	3870	12.29
-6	1.7246	3850	12.26
-7	1.7224	3640	12.27
-8	1.7198	3180	12.27
Average	1.7217	3674	12.28
A41247-1	1.7172	3820	12.30
-2	1.7174	3820	12.30
-3	1.7147	4060	12.30
-4	1.7186	3990	12.30
-5	1.7189	3850	12.24
-6	1.7182	4010	12.30
-7	1.7184	3670	12.30
-8	1.7193	3930	12.30
* Average	1.7178	3894	12.29

TABLE 1 (continued)

B41247-1	1.7206	3830	12.26
-2	1.7189	3730	12.25
-3	1.7200	4100	12.26
-4	1.7177	4100	12.28
-5	1.7179	3940	12.28
-6	1.7138	4000	12.26
-7	1.7171	4100	12.27
-8	1.7088	3970	12.30
<u>Average</u>	<u>1.7169</u>	<u>3971</u>	<u>12.27</u>
NC-2961A-1	1.7410	3910	12.24*
-2	1.7420	4050	12.24*
-3	1.7415	3990	12.20*
-4	1.7310	3860	12.25*
-5	1.7315	3900	12.25*
-6	1.7331	3830	12.24*
-7	1.7195	3820	12.25*
-8	1.7186	3750	12.26*
* <u>Average</u>	<u>1.7323</u>	<u>3889</u>	<u>12.24</u>
NC-2961B-1	1.7400	4070	12.25*
-2	1.7376	3950	12.26*
-3	1.7408	4010	12.25*
-4	1.7445	4000	12.24*
-5	1.7479	3740	12.25*
-6	1.7478	Lost	12.25*
-7	1.7582	4120	12.24*
-8	1.7600	3760	12.24*
<u>Average</u>	<u>1.7471</u>	<u>3950</u>	<u>12.25</u>
A41639-1	1.7380	4020	12.25
-2	1.7338	3970	12.25
-3	1.7336	3940	12.26
-4	1.7369	3900	12.26
-5	1.7315	3680	12.26
-6	1.7289	3870	12.26
-7	1.7302	3760	12.30
-8	1.7264	3870	12.32
* <u>Average</u>	<u>1.7324</u>	<u>3876</u>	<u>12.27</u>
B41639-1	1.7536	3930	12.25
-2	1.7622	4200	12.24
-3	1.7696	4290	12.24
-4	1.7579	4100	12.25
-5	1.7662	4070	12.24
-6	1.7719	4330	12.24
-7	1.7630	4300	12.24
-8	1.7658	4180	12.22
<u>Average</u>	<u>1.7638</u>	<u>4175</u>	<u>12.24</u>

* Specimen .275 x .275 x 2.500 inches

TABLE 1 (concluded)

A41223-1	1.7513	4220	12.27
-2	1.7427	3820	12.25
-3	1.7380	4040	12.28
-4	1.7532	3870	12.27
-5	1.7491	4160	12.28
-6	1.7437	3960	12.29
-7	1.7607	4010	12.26
-8	1.7544	3990	12.27
* Average	1.7491	4009	12.28
B41223-1	1.7564	4170	12.24
-2	1.7628	4290	12.24
-3	1.7709	4470	12.22
-4	1.7500	4220	12.25
-5	1.7543	4220	12.24
-6	1.7640	4070	12.22
-7	1.7477	3840	12.25
-8	1.7516	3960	12.24
Average	1.7572	4155	12.24
NC-1961A-1	1.7527	4350	11.40*
-2	1.7560	4090	11.30*
-3	1.7538	3960	11.50*
-4	1.7637	4290	11.40*
-5	1.7696	4390	11.30*
-6	1.7662	4320	11.20*
-7	1.7793	4300	11.10*
-8	1.7777	4130	11.00*
* Average	1.7649	4221	11.28
NC-1961B-1	1.7706	4360	11.30*
-2	1.7660	4450	11.40*
-3	1.7632	3170	11.40*
-4	1.7595	4510	11.50*
-5	1.7573	4340	11.40*
-6	1.7572	4350	11.50*
-7	1.7497	3970	11.60*
-8	1.7464	4340	11.60*
Average	1.7587	4186	11.46

* Specimen .275 x .275 x 2.500 inches

TABLE 2

THERMAL EXPANSION MEASUREMENTS (across-grain)

Sample		Per Cent Expansion Measured at Indicated Temperature (°C)								
A-41503*	°C	1356	1581	1735	1831	1269	1623	1869	1931	2121
	Per Cent	.537	.669	.757	.814	.523	.710	.831	.887	1.007
B-41503	°C	1345	1579	1725	1832	1259	1615	1863	1922	2107
	Per Cent	.575	.702	.785	.871	.536	.734	.878	.926	1.065
A-41247*	°C	1344	1566	1723	1819	1254	1609	1844	1913	2113
	Per Cent	.544	.677	.765	.810	.532	.717	.845	.898	1.017
B-41247	°C	1345	1566	1723	1819	1254	1609	1844	1913	2113
	Per Cent	.555	.686	.777	.834	.517	.703	.836	.880	1.020
NC-2961A*	°C	1331	1554	1706	1805	1234	1590	1829	1889	2093
	Per Cent	.537	.664	.744	.799	.507	.692	.816	.867	.989
NC-2961B	°C	1359	1595	1739	1839	1273	1629	1872	1933	2124
	Per Cent	.565	.688	.789	.826	.537	.731	.871	.932	1.068
A-41639*	°C	1344	1566	1723	1819	1254	1609	1844	1913	2113
	Per Cent	.544	.677	.765	.810	.532	.717	.845	.898	1.017
B-41639	°C	1359	1595	1739	1839	1273	1629	1872	1933	2120
	Per Cent	.556	.682	.771	.844	.546	.727	.873	.925	1.066
NC-1961A*	°C	1344	1579	1725	1832	1259	1615	1863	1922	2104
	Per Cent	.563	.719	.776	.842	.502	.697	.845	.880	.986
NC-1961B	°C	1341	1559	1714	1829	1244	1608	1859	1913	2089
	Per Cent	.554	.693	.795	.892	.513	.709	.883	.945	1.084
		→ First heating cycle				→ Second heating cycle				

* Stabilized

TABLE 3
COEFFICIENTS OF THERMAL EXPANSION (across-grain)

Sample		Average Coefficients of Thermal Expansion, 10^{-6} in/in./°C - 20°C to Indicated Temperature								
A-41503*	°C	1356	1581	1735	1831	1269	1623	1869	1931	2121
	α	4.02	4.28	4.42	4.49	4.18	4.43	4.50	4.64	4.78
B-41503	°C	1345	1579	1725	1832	1259	1615	1863	1922	2107
	α	4.34	4.50	4.60	4.80	4.32	4.59	4.76	4.87	5.10
A-41247*	°C	1344	1566	1723	1819	1254	1609	1844	1913	2113
	α	4.11	4.38	4.49	4.50	4.30	4.52	4.64	4.74	4.86
B-41247	°C	1345	1566	1723	1819	1254	1609	1844	1913	2113
	α	4.15	4.44	4.56	4.64	4.18	4.43	4.58	4.65	4.88
NC-2961A*	°C	1331	1554	1706	1805	1234	1590	1829	1889	2093
	α	4.09	4.33	4.42	4.47	4.18	4.40	4.52	4.64	4.76
NC-2961B	°C	1359	1595	1739	1839	1273	1629	1872	1933	2124
	α	4.22	4.36	4.59	4.55	4.28	4.56	4.70	4.87	5.00
A-41639*	°C	1344	1566	1723	1819	1254	1609	1844	1913	2113
	α	4.11	4.38	4.49	4.50	4.30	4.52	4.64	4.74	4.86
B-41639	°C	1359	1595	1739	1839	1273	1629	1872	1933	2120
	α	4.14	4.33	4.49	4.64	4.37	4.53	4.70	4.83	5.07
NC-1961A*	°C	1344	1579	1725	1832	1259	1615	1863	1922	2104
	α	4.25	4.62	4.56	4.64	4.05	4.37	4.58	4.63	4.73
NC-1961B	°C	1341	1559	1714	1829	1244	1608	1859	1913	2089
	α	4.20	4.50	4.69	4.94	4.19	4.47	4.80	4.99	5.26
		→ First heating cycle				→ Second heating cycle				

* Stabilized