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Westinghouse Astronuclear Laboratory

IRRADIATION EFFECTS ON THE MECHANICAL AND ELECTRICAL PROPERTIES OF P-03,
H4LM AND 780-T GRAPHITES

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P-03, H4LM AND 780-T GRAPHITES

Prepared by:

R. P. Shogan

Approved by:

E. L. Layland, Manager
Materials Engineering
and Specifications

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D. E. Thomas,
Engineering Manager

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I. ABSTRACT

Three grades of graphite, H4LM (with and without silica impregnation), 780-T and P-03, were irradiated at 140°R in liquid nitrogen (LN₂) at the Ground Test Reactor (GTR). A neutron dose of 1.7×10^{17} to 4.5×10^{17} nvt ($E > 1$ Mev) and a gamma dose of 9×10^{10} to 1.5×10^{11} ergs/gm(C) were obtained. Room temperature tests were made on irradiated and unirradiated specimens for electrical resistivity, tensile strength and compressive strength after anneals at temperatures up to 1200°F. Some electrical resistivity data at higher temperatures are also reported.

The H4LM grade, with and without SiO₂ impregnation, was affected most by the irradiation. Impregnated H4LM in the "with grain" (W.G.) direction showed increases of 114% in electrical resistivity and 39% in compressive strength. Unimpregnated H4LM in the "across grain" (A.G.) direction showed a maximum tensile strength increase of 56%. The least affected was the P-03 grade with a 31% increase in electrical resistivity and a 15% increase in compressive strength. Impregnated H4LM, W.G., showed only a 17% increase in tensile strength. The other materials showed changes lying between these values.

The maximum changes in resistivity were found at room temperature before annealing, while the change in mechanical properties generally increased to a maximum with an anneal between 200°F and 400°F. The effects of the irradiation were nearly removed with annealing temperatures up to 500°F to 700°F where the properties reached a somewhat steady value slightly higher than those of the control (unirradiated) specimens.

II. INTRODUCTION

Because of extensive use of graphite as a moderator and to a lesser extent as a structural member in nuclear reactors, the effects of irradiation on its properties have been widely studied. Several summaries of the earlier work have been compiled by Kinchin⁽¹⁾ and Woods, et. al.⁽²⁾ More recent works are those by Simmons,⁽³⁾ Nightingale⁽⁴⁾ and Billington and Crawford.⁽⁵⁾

Neutron irradiation improves the mechanical properties and decreases the thermal and electrical conductivities. Dimensional changes are also found. These effects can be significant, such as a doubling of mechanical strength and a factor of fifty reduction in thermal conductivity with high dosage ($> 10^{21}$ nvt).⁽⁵⁾ Irradiation effects in graphite are the result of fast neutrons striking the lattice carbon atoms and displacing them into the interstitial spaces between the layer planes and into interstitial sites within planes. Recovery is complicated, since the size and distribution of interstitial and vacancy groups formed is a function of temperature. The irradiation-induced defects cause lattice strains, thus pinning dislocations. The layered planes are also restricted from slipping over each other. A more detailed description of these mechanisms can be found in Henning and Hove⁽⁶⁾ and Simmons et. al.,⁽⁷⁾ (3) the latter being more up to date.

Despite the vast amount of data available, measurements of irradiation effects on the materials tested in this report are useful since effects in graphite are highly dependent on the type of graphite and the irradiation parameters. In addition, mechanical property data, particularly as a function of annealing temperature, are not prevalent in the literature. This is probably the result of graphite being used more as a moderator material than as a structural component. Essentially no data on the mechanical properties of the materials examined here after a cryogenic irradiation have been published. The materials irradiated were selected because of their importance to the NERVA program. H4LM has been used in early NERVA reactors as the inner reflector, both in a nuclear and a structural function. The 780-T graphite was intended as a backup for H4LM. P-03 is being considered for various hardware in the NR series of reactors. These include the lateral support spring pin, and possibly lateral support seal and peripheral filler material. For these applications a neutron fluence of 10^{19} nvt ($E > 1$ Mev) can be expected.

III. EXPERIMENTAL PROCEDURE

Materials

The H4LM used in NERVA hardware was an extruded, coarse grain graphite supplied by Great Lakes Carbon Co. It was tested both with and without SiO_2 impregnation, which reduces permeability to hydrogen. Previous studies had shown that approximately 25% of the voids had been filled by the 4% pick up of SiO_2 in the impregnation process (PS 294545, Rev. 4). Specimens were taken from inner reflectors. 780-T is an extruded graphite, with double impregnation (an organic binder which densifies the material), supplied by the Speer Carbon Co. Specimens were taken from several 4" diameter logs, which were extruded from the same mix. Both the H4LM and the 780-T were tested in the "with grain" (W.G.) and "across grain" (A.G.) directions. The P-03 specimens were taken from conventionally molded blocks 4" x 4" x 1 1/4" supplied by the Pure Carbon Co. Only the W.G. direction was tested because of size limitations of the available material. However, the material is nearly isotropic.

Average densities in g/cc are H4LM unimpregnated, 1.78; impregnated, 1.85; 780-T 1.75; and P-03, 1.80.

Specimens

A total of 67 electrical resistivity, 175 tensile and 156 compression specimens was tested. The distribution of these specimens among the various materials, conditions and annealing temperatures is shown in Table 1. Several of the resistivity specimens were tested after several successively higher anneals.

Specimen drawings are shown in Fig. 1. The electrical resistivity specimen was a solid circular cylinder 2.257-inches long and .500-inch in diameter. Compression specimens were made by cutting this specimen into one-inch lengths after irradiation. The shoulder-loaded tensile specimens had a 0.40-inch diameter, one-inch long gage section with a 1.5-inch long parallel section.

Irradiation

The specimens were irradiated in the 3MW Ground Test Reactor (GTR) at General Dynamics/Fort Worth. The irradiation, designated GTR-16, was part of a continuing series of experiments sponsored by the Space Nuclear Propulsion Office, Cleveland, Ohio, to

determine the effects of nuclear irradiation on materials intended for use in the NERVA engine.

During the 1105 MW-hr. irradiation, the specimens were immersed in boiling liquid nitrogen (140°R). They received a neutron dose of 1.7×10^{17} to 4.5×10^{17} nvt ($E > 1 \text{ Mev}$) and a gamma dose of 9×10^{10} to 1.5×10^{11} ergs/gm(C). After warming to room temperature, the specimens were transported to the Westinghouse Astronuclear Laboratory (WANL) for testing. The major part of this irradiation involved metal (alloys) specimens which were irradiated and tested at 140°F . The results have been reported (WANL-TME-1281).

Testing

Electrical resistivity measurements were made in the Thermophysical Properties Laboratory at WANL. Initially the resistivities were taken at elevated temperatures, using a system designed to heat five specimens simultaneously. Each irradiated specimen was tested at one elevated temperature. Resistance measurements were made at room temperature before and after annealing and at five minute intervals during heating and a 120-minute hold at temperature. A similar procedure was followed for the control specimens.

The majority of the resistivity measurements were taken only at room temperature before and after annealing the specimens in a muffle furnace. These specimens were annealed for 15 minutes at temperature in an argon atmosphere. The earlier "at temperature" experiments had indicated that this time period was sufficient. On many of the specimens, measurements were made after successively-higher temperature anneals. The time of the room-temperature anneals was about 1 1/2 years.

A 15-minute furnace anneal in argon was also used for the mechanical property specimens. These were tested at 0.02-inch per minute crosshead speed on a 20,000-lb. Instron machine at WANL's Mechanical Test Laboratory.

Four unimpregnated H4LM, W.G., compression specimens (one control, three irradiated) and four A.G. (two control, two irradiated) compression specimens were strain gaged to obtain modulus values. These specimens were tested without an anneal.

Data Analysis

Several of the "at temperature" control (unirradiated) specimens were thermally cycled to determine any effects on the resistivity. No significant changes were found. For this reason the room temperature control value used for comparison with the irradiated values was determined by averaging all of the control values regardless of heat treatment. The "sample deviation" of each test group was determined using the formula:

$$s = \left(\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1} \right)^{1/2}$$

where:

s = sample deviation

n = number of data points in the group

X_i = i th data value

$\bar{X}$ = control average

The difference between the control and irradiated values was considered to be significant, and attributed to the irradiation when:

$$(\bar{X}_c - \bar{X}_i) > s_i \text{ and } > s_c$$

where:

$\bar{X}_c$ = average control value

$\bar{X}_i$ = average irradiated value

s_i = irradiated sample deviation

s_c = control sample deviation

Although this is only one of many criteria which could be used, it is considered by the writer to be a conservative approach.

Because of the small number of specimens tested to obtain most of the data points, and the inherent scatter found in graphite testing, the deviations calculated are denoted as "sample deviations" rather than "standard deviations." The sample deviations should be used only as an indication of the scatter in the data.

IV. CONCLUSIONS

- (1) A 140°R irradiation to 3×10^{17} nvt ($E > 1$ Mev) has beneficial effects on the mechanical properties of the graphites tested. Tensile and compressive strengths, as well as the plastic strain the material can undergo (in compression), increased with irradiation. It is expected that the higher doses from the NR reactors will not have harmful effects on these properties.
- (2) Electrical resistivity is increased by irradiation. Even after the relatively low dose received in this irradiation ($> 3 \times 10^{17}$ nvt) increases of up to 114% were found. Similar effects on thermal conductivity might have significant effects on temperature profiles in future NERVA reactors.
- (3) The effects of the irradiation on all of the properties tested were largely removed by an anneal in the temperature range 500 to 700°F. However, slight residual effects remained after 1200°F anneals.
- (4) H4LM was most affected by the irradiation; P-03 was least affected. The magnitude of the effects of irradiation depend on the processing history of the graphite irradiated.

V. RESULTS AND DISCUSSION

The data from all of the measurements are recorded in Tables 2 through 7. Included are room temperature electrical resistivity, tensile strength, compressive strength, 0.2% offset compressive yield strength, plastic strain (in compression) and compressive modulus on control (unirradiated) specimens and on irradiated specimens after anneals to 1200°F. Resistivity measurements at temperatures up to 880°F are also given for P-03 and unimpregnated H4LM, W.G.

In addition to the individual specimen data, the tables contain specimen group averages, percent changes between irradiated and control groups, sample deviations and a notation as to whether an irradiation effect is thought to be significant, using the criterion outlined in the previous section. The "relative resistivity change," ρ/ρ_0 , is given for the resistivity specimens. A summary of the annealing study data is shown in Table 8.

The tabulated data are plotted in Figures 2 through 32. For the mechanical properties, the curves show the percent change in property vs. annealing temperature. The electrical resistivity data are plotted as ρ/ρ_0 vs. annealing temperature or as resistivity vs. temperature for the "at temperature" tests.

Electrical Resistivity

Irradiation increased the electrical resistivity of the graphites (Table 2, Figures 2 through 10). The maximum change was found at room temperature before any anneal. The maximum increase was 114% for the impregnated H4LM, W.G. Least affected was the P-03 (31.5%). The changes in the other materials fall between these limits. Annealing at temperatures up to 700°F decreased the resistivity difference rapidly. Above this temperature the irradiated values decreased only slightly up to the maximum annealing temperature of 1200°F. After the 1200°F anneal, residual increases between 5 and 13 percent still remained. A review of the literature indicates that this residual change will remain up to approximately 2700°F.

The magnitude of the resistivity change was greater for the "W.G." than the "A.G." direction. This effect is expected since, within the individual crystallites, the low resistivity layered planes, oriented in the "W.G." direction, are more sensitive to radiation-induced resistivity changes than those in the interlaminar direction. In an analogous effect, the larger

grained material showed a greater change than the smaller grained, (H4LM > 780-T > P-03) because the less predominate transcrystallite resistivity (in the bulk material) is more sensitive to change than the intercrystallite resistivity. While electron conduction is a minor mechanism of thermal conduction in graphite, decreases in thermal conductivity similar to those found here for electrical conductivity have been observed by other workers. Further investigation of this effect is planned for the NERVA development program.

Tensile Strength

The tensile strengths of all of the graphites increased with radiation. The maximum change, 56%, was found in unimpregnated H4LM, A.G. Table 4 gives the tensile data. This is plotted in Figures 11 through 17. The recovery curves differed somewhat from those for the electrical resistivity. For the P-03 and 780-T, the strength increases to a maximum with a low temperature anneal (200 to 400°F). After higher temperature anneals, the property recovers much like the resistivity. Again a residual strength increase was found.

The increase of strength with the low temperature anneals is unexplained. Most likely it is an effect related to the grouping of interstitials and/or vacancies. The absence of this effect in the resistivity data indicates that it occurs between the layered planes. A further, more scientific study would be needed to clarify this result.

The H4LM graphites were tested in tension with no anneal and after a 600°F heat treatment. Consequently, a recovery curve comparable to that given for the other materials cannot be shown. If the H4LM follows the trends of the other graphites, the strength would increase with a low-temperature anneal. Like the other graphites, a large percentage of the increase had been annealed out by 600°F.

The irradiated, impregnated H4LM, W.G., values after the 600°F anneal are lower (7%) than the unirradiated values. This effect is not noted on the other properties of this material and is probably due to the scatter in the data. Generally, the experimental scatter was quite high for the tensile measurements.

Figure 33 shows a typical, broken graphite tensile specimen. All of the specimens broke in the gage length. The fractures were intergranular and macroscopically identical for irradiated and unirradiated specimens.

Compressive Properties

The compressive strength of the graphites tested increased with irradiation. The maximum difference in strength between the irradiated and control specimens, like that for the tensile specimens, was found after an anneal at approximately 250°F. This was followed by a decrease in strength with annealing up to 600 to 800°F and a residual strength difference above that temperature (Table 5, Figures 18 through 24). Only the impregnated H4LM did not show the initial increase in strength.

The compressive yield strength, shown in Table 6 and Figures 25 through 31, were taken at 0.2% offset on the load deflection curves. Their annealing characteristics are similar to that of the compressive strengths.

The effects of the irradiation on the compressive modulus of the unimpregnated H4LM in both directions is shown in Figure 32. These were taken as the initial slope of the load-strain curve as obtained using strain-gaged specimens. The irradiation increased the moduli approximately 100% for W.G. specimens.

The increase in compressive modulus is the result of the lattice carbon atoms being displaced into the spaces between the layered planes by the fast moving neutrons. These defects prohibit sliding of the plane which is the primary mode of elastic deformation in graphites. On the other hand, increases in the tensile and compressive strengths result from pinning of dislocations by irradiation-produced defects.

Changes in plastic deformation in compression as the result of the irradiation are shown in Table 7. Although there is a large amount of scatter in the data, a general increase is found in this property which anneals out with temperature. A 60% increase for 780-T, A.G., at room temperature was the maximum change found.

Photographs of typical failed compression specimens are shown in Figures 34 through 38. The mode of failure for the P-03 specimens (Fig. 34) was very irregular, but similar for both irradiated and unirradiated materials.

Failure was not similar for the irradiated and unirradiated 780-T or H4LM materials. In general, the unirradiated specimens of these materials failed longitudinally and on planes of the order of 45° to the axis of the specimens. The irradiated, unannealed specimens, on the other hand, fractured almost entirely on planes between 30° and 60° to the specimen axis.

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TABLE 1
Distribution of Specimens
Electrical Resistivity⁽¹⁾ (2) (3)
Temperature of Anneal

Material	R.T.	250°F	500°F	750°F	1000°F	1200°F
P-03	10, (5)	5	2	3	3, (2)	2
780-T, A.G.	5, (3)	2	3	4	3, (3)	--
780-T, W.G.	4, (3)	3	3	4	3, (3)	3
H4LM, Imp., A.G.	2, (3)	2	2	2	2, (3)	--
H4LM, Imp., W.G.	2, (3)	2	2	2	2, (3)	--
H4LM, Unimp., A.G.	8, (3)	3	2	3	3, (3)	3
H4LM, Unimp., W.G.	10, (6)	3	4	7	6, (2)	3

Compression⁽²⁾ (3)

Material	R.T.	250°F	500°F	750°F	1000°F	1200°F
P-03	3, (5)	3	3	3	3	3
780-T, A.G.	4, (5)	3	3	3	3	3
780-T, W.G.	3, (6)	3	3	3	3	3
H4LM, Imp., A.G.	3, (4)	3	3	3	3	--
H4LM, Imp., W.G.	3, (5)	3	3	3	3	--
H4LM, Unimp., A.G.	3, (4)	3	3	3	3	3
H4LM, Unimp., W.G.	4, (4)	3	4	3	3	3

Tensile⁽²⁾ (3)

Material	R.T.	200°F	400°F	600°F	800°F	1000°F	1200°F
P-03	5, (6)	--	3	3, (3)	3	3, (3)	3
780-T, A.G.	5, (5)	3	3	3, (3)	--	3, (3)	3
780-T, W.G.	6, (6)	5	5	5, (3)	5	5	5
H4LM, Imp., A.G.	5, (5)	--	--	5, (3)	--	--	--
H4LM, Imp., W.G.	5, (5)	--	--	5, (3)	--	--	--
H4LM, Unimp., A.G.	4, (5)	--	--	4,	--	--	--
H4LM, Unimp., W.G.	5, (5)	--	--	5, (3)	--	--	--

(1) These refer to number of measurements since individual specimens were tested at several anneal temperatures.

(2) Numbers in parentheses ( ) are controls (unirradiated).

(3) A.G. - against grain, W.G. - with grain.

TABLE 2
ELECTRICAL RESISTIVITY DATA
IN $m\Omega \cdot cm$
Temperature of Anneal, °F

Material	Irradiated							Unirradiated	
	Specimen No	80°F	250°F	500°F	750°F	1000°F	1200°F	Specimen No	80°F 1000°F
P-03	P-18	2,559	-----	-----	1,802	-----	-----	P-20	1,94 1,97
	P-33	2,557	-----	-----	1,764	-----	2,03	P-23	1,92 1,96
	P-5	2,402	2,302	-----	-----	2,00	1,99	P-38	1,91 -----
	P-8	2,595	-----	2,116	-----	-----	-----	P-48	1,89 -----
	P-14	2,416	-----	2,046	-----	-----	-----	P-31	1,88 -----
	P-3	2,641	2,482	-----	-----	2,06	-----	-----	-----
	P-2	2,473	2,391	-----	-----	2,03	-----	-----	-----
	P-16	2,479	-----	-----	1,996	-----	-----	-----	-----
	P-37	2,565	2,483	-----	-----	-----	-----	-----	-----
	P-40	2,565	2,540	-----	-----	-----	-----	-----	-----
	Average	2,525	2,400	2,081	1,854	2,030	2,01	-----	1,92 -----
	Sample Deviation	0,058	0,100	0,064	0,124	0,005	0,089	-----	0,057 -----
780-Y W.G.	10-A	2,000	1,94	1,50	1,34	1,33	-----	5-A	1,165 1,217
	21-A	1,875	1,86	1,41	1,32	1,30	-----	8-A	1,197 1,183
	28-A	1,931	1,87	1,48	1,33	1,33	-----	9-A	1,207 1,207
	18-A	1,768	-----	-----	1,32	-----	-----	-----	-----
	Average	1,89	1,89	1,46	1,33	1,32	-----	-----	1,20 -----
	Sample Deviation	0,118	0,085	0,160	0,036	0,017	-----	-----	0,057 -----
	% Change	57,5	57,5	21,7	10,8	10,0	-----	-----	-----
	Significant	Yes	Yes	Yes	Yes	Yes	-----	-----	-----
	ρ/ρ_0	1,58	1,58	1,22	1,11	1,10	-----	-----	-----
	4-T	2,475	2,46	1,90	1,80	1,74	-----	2-T	1,62 1,607
	10-T	2,197	2,24	1,74	1,71	-----	-----	23-T	1,62 1,60
	5-T	2,50	-----	1,91	1,77	-----	-----	24-T	1,60 1,60
780-Y A.G.	7-T	2,50	-----	-----	1,76	1,74	-----	-----	-----
	8-T	2,41	-----	-----	-----	1,73	-----	-----	-----
	Average	2,42	2,35	1,85	1,76	1,74	-----	-----	1,61 -----
	Sample Deviation	0,15	0,16	0,09	0,015	0,02	-----	-----	0,10 -----
	% Change	50,3	46,0	14,9	9,3	8,1	-----	-----	-----
	Significant	Yes	Yes	Yes	Yes	Yes	-----	-----	-----
	ρ/ρ_0	1,50	1,46	1,15	1,09	1,08	-----	-----	-----
H4LM Unimpregnated A.G.	T-27	1,585	1,411	-----	-----	-----	-----	T-3	904 900
	T-15	1,569	1,437	-----	-----	-----	-----	T-8	916 927
	T-17	1,654	-----	-----	1,006	-----	1,00	T-9	904 900
	T-29	1,717	-----	-----	886	-----	-----	-----	-----
	T-9	1,587	-----	1,056	-----	1,003	-----	-----	-----
	T-28	1,815	-----	1,168	-----	-----	1,072	-----	-----
	T-7	1,548	1,449	-----	-----	1,000	-----	-----	-----
	T-10	1,595	-----	-----	980	1,003	977	-----	-----
	Average	1,634	1,432	1,112	957	1,002	1,016	-----	908 -----
	Sample Deviation	0,088	0,019	0,025	0,063	0,005	0,050	-----	0,007 -----
	% Change	80,0	57,7	22,5	5,4	10,4	11,9	-----	-----
	Significant	Yes	Yes	Yes	No	Yes	Yes	-----	-----
H4LM Unimpregnated W.G.	A-83	1,709	-----	-----	8135	-----	-----	A-1	854 -----
	A-67	1,464	1,299	-----	-----	-----	-----	A-34	850 870
	A-35	1,945	-----	1,166	1,136	1,04	1,035	A-45	883 873
	A-39	1,637	-----	1,014	1,034	927	902	A-26	785 -----
	A-10	1,583	1,451	1,113	1,00	1,00	-----	A-42	862 -----
	A-14	1,412	1,290	1,00	91	91	875	A-96	809 -----
	A-40	1,683	-----	-----	989	-----	-----	-----	-----
	A-43	1,842	-----	-----	994	-----	-----	-----	-----
	A-48	1,630	-----	-----	-----	950	-----	-----	-----
	A-62	1,765	-----	-----	-----	990	-----	-----	-----
	Average	1,667	1,347	1,076	982	970	937	840	-----
	Sample Deviation	0,161	0,095	0,082	0,100	0,049	0,086	0,031	-----
H4LM Impregnated A.G.	T-37	1,700	1,67	1,21	1,03	1,03	-----	T-36	900 903
	T-56	1,885	1,81	1,26	90	1,07	-----	T-41	934 930
	-----	-----	-----	-----	-----	-----	-----	T-49	860 903
	Average	1,79	1,74	1,24	96	1,05	-----	-----	905 -----
	Sample Deviation	0,111	0,102	0,042	0,099	0,039	-----	-----	0,027 -----
	% Change	97,8	92,3	37,0	4,1	11,0	-----	-----	-----
	Significant	Yes	Yes	Yes	No	Yes	-----	-----	-----
	ρ/ρ_0	1,98	1,92	1,77	1,06	1,14	-----	-----	-----
	A-79	1,94	1,83	1,21	1,05	1,01	-----	A-76	799 83
	A-90	1,60	1,60	1,10	94	93	-----	A-55	840 84
	-----	-----	-----	-----	-----	-----	-----	A-77	800 83
	Average	1,77	1,71	1,15	99	97	-----	-----	824 -----
H4LM Impregnated W.G.	Sample Deviation	0,240	0,164	0,085	0,080	0,041	-----	-----	0,021 -----
	Significant	Yes	Yes	Yes	Yes	Yes	-----	-----	-----
	% Change	114,8	107,9	39,6	20,4	18,0	-----	-----	-----
	ρ/ρ_0	2,15	2,08	1,40	1,20	1,18	-----	-----	-----
	-----	-----	-----	-----	-----	-----	-----	-----	-----

TABLE 3
"At Temperature"
Electrical Resistivity Data
Values in $m\Omega$ -cm

Unirradiated Specimens

"P-03"

Specimen No.	Test Temperature				
	80°F	355°F	430°F	590°F	750°F
P-23	1.924	1.544	1.479	1.384	1.320

"Unimpregnated
H4LM
W.G."

Specimen No.	Test Temperature				
	80°F	175°F	480°F	690°F	880°F
A-34	0.854	0.742	0.714	0.700	0.702

Irradiated Specimens

"P-03"

"Unimpregnated H4LM
W.G."

Specimen No.	Temperature		Specimen No.	Temperature	
P-2	220°F	2.16	A-10	223°F	1.28
P-5	282°F	2.066	A-14	226°F	1.131
P-3	300°F	2.220	A-67	300°F	1.234
P-14	495°F	1.618	A-39	480°F	.809
P-8	545°F	1.659	A-35	580°F	.918
P-16	740°F	1.464	A-43	732°F	.780
P-18	780°F	1.455	A-40	774°F	.777
P-33	800°F	1.424	A-83	806°F	.702

TABLE 4
TENSILE STRENGTH DATA
IN KSI

Material	Temperature of Anneal									
	Irradiated					Unirradiated				
	800°F	2000°F	4000°F	6000°F	8000°F	10000°F	12000°F	800°F	6000°F	10000°F
P-03	5.85	----	6.88	4.49	5.54	5.53	5.48	5.69	5.19	5.41
	5.99	----	6.79	4.41	5.88	5.77	5.62	5.48	5.93	4.17
	5.54	----	6.12	6.05	5.48	5.01	5.41	4.45	4.56	6.05
	5.64	----	----	----	----	----	----	5.34	----	----
	6.93	----	----	----	----	----	----	4.56	----	----
	----	----	----	----	----	----	----	5.46	----	----
	Average	5.99	----	6.60	4.98	5.63	5.44	5.50	5.19	----
	Sample	0.60	----	0.52	0.76	0.22	0.48	0.11	0.65	----
	Deviation	15.4	----	27.2	-4.0	8.5	4.8	6.0	----	----
	% Change	Yes	----	Yes	No	No	No	----	----	----
	Significant	Yes	----	Yes	No	No	No	Yes	----	----
780-T W.G.	5.44	5.87	4.41	4.49	3.35	3.93	4.41	2.93	3.22	----
	4.26	4.20	4.16	4.07	3.78	2.89	3.74	3.10	3.73	----
	3.21	5.30	4.21	3.45	3.19	3.43	3.73	2.94	4.14	----
	5.16	4.41	4.27	3.28	3.47	2.98	3.81	3.33	----	----
	5.72	4.06	5.15	3.20	3.82	3.20	3.07	3.32	----	----
	4.48	----	----	----	----	----	----	2.58	----	----
	Average	4.74	4.77	4.44	3.70	3.52	3.29	3.75	3.28	----
	Sample	0.92	0.56	0.41	0.56	0.27	0.41	0.42	0.31	----
	Deviation	44.7	45.5	34.2	12.8	7.3	.3	14.3	----	----
	% Change	Yes	Yes	Yes	No	No	No	Yes	----	----
	Significant	Yes	Yes	Yes	No	No	No	Yes	----	----
780-T A.G.	5.16	5.66	5.15	4.00	----	3.32	2.89	3.38	3.07	2.98
	3.53	5.30	4.72	3.98	----	3.63	2.87	2.02	3.19	3.03
	4.13	2.89	3.81	3.33	----	3.52	3.76	3.02	2.53	2.57
	3.71	----	----	----	----	----	----	3.17	----	----
	3.69	----	----	----	----	----	----	3.88	----	----
	Average	4.04	4.62	4.56	3.76	----	3.49	3.17	3.23	----
	Sample	0.66	1.52	0.68	0.40	----	0.16	0.46	0.38	----
	Deviation	25.0	43.1	41.2	16.4	----	8.0	-2.0	----	----
	% Change	Yes	No	Yes	Yes	----	No	No	----	----
	Significant	Yes	No	Yes	Yes	----	No	No	----	----
H4LM Impregnated W.G.	2.85	----	----	1.72	----	----	----	1.68	1.51	----
	3.44	----	----	2.90	----	----	----	2.65	2.25	----
	2.05	----	----	1.42	----	----	----	2.46	2.50	----
	2.87	----	----	1.93	----	----	----	2.52	----	----
	1.86	----	----	2.43	----	----	----	2.32	----	----
	Average	2.61	----	----	2.08	----	----	2.24	----	----
	Sample	0.65	----	----	0.59	----	----	0.33	----	----
	Deviation	16.7	----	----	-7.7	----	----	----	----	----
	% Change	No	----	----	No	----	----	----	----	----
	Significant	No	----	----	No	----	----	----	----	----
H4LM Impregnated A.G.	3.51	----	----	2.90	----	----	----	2.32	2.60	----
	3.81	----	----	2.88	----	----	----	2.28	2.39	----
	3.51	----	----	2.87	----	----	----	2.40	2.23	----
	3.78	----	----	2.56	----	----	----	2.59	----	----
	3.16	----	----	2.63	----	----	----	2.54	----	----
	Average	2.55	----	----	2.77	----	----	2.43	2.41	----
	Sample	0.26	----	----	0.16	----	----	0.135	0.18	----
	Deviation	4.9	----	----	13.5	----	----	----	----	----
	% Change	Yes	----	----	Yes	----	----	----	----	----
	Significant	Yes	----	----	Yes	----	----	----	----	----
H4LM Unimpregnated W.G.	3.71	----	----	2.15	----	----	----	1.36	1.05	----
	3.74	----	----	1.83	----	----	----	1.75	2.15	----
	1.56	----	----	1.72	----	----	----	2.32	2.50	----
	1.76	----	----	2.78	----	----	----	2.25	----	----
	3.25	----	----	2.52	----	----	----	2.00	----	----
	Average	2.80	----	----	2.20	----	----	1.92	----	----
	Sample	0.16	----	----	0.45	----	----	0.54	----	----
	Deviation	45.8	----	----	14.5	----	----	----	----	----
	% Change	Yes	----	----	No	----	----	----	----	----
	Significant	Yes	----	----	No	----	----	----	----	----
H4LM Unimpregnated A.G.	3.51	----	----	2.72	----	----	----	2.01	----	----
	3.59	----	----	2.28	----	----	----	2.38	----	----
	3.35	----	----	2.72	----	----	----	2.24	----	----
	3.10	----	----	2.83	----	----	----	2.21	----	----
	----	----	----	----	----	----	----	2.04	----	----
	Average	3.39	----	----	2.64	----	----	2.17	----	----
	Sample	0.22	----	----	0.24	----	----	0.152	----	----
	Deviation	56.0	----	----	21.6	----	----	----	----	----
	% Change	Yes	----	----	Yes	----	----	----	----	----
	Significant	Yes	----	----	Yes	----	----	----	----	----

TABLE 5
COMPRESSIVE STRENGTH DATA
IN KSI

Temperature of Anneal

Material	Irradiated							Unirradiated
P-03	80°F	250°F	500°F	750°F	1000°F	1200°F	80°F	
	15.91	17.78	14.97	15.53	15.68	13.74	16.29	
	17.98	17.58	15.56	15.48	15.66	15.48	15.76	
	18.61	17.23	16.16	16.16	15.40	18.61	15.48	
	-----	-----	-----	-----	-----	-----	12.70	
	-----	-----	-----	-----	-----	-----	15.71	
	Average	17.50	17.53	15.56	15.72	15.58	15.94	15.19
780-T W.G.	Sample	1.42	0.19	0.60	0.38	0.13	0.92	0.14
	Deviation	15.2	15.4	2.4	3.5	2.6	4.3	-----
	% Change	Yes	Yes	No	No	No	No	-----
	Significant	9.96	11.26	9.90	9.29	8.84	8.55	8.53
		8.83	11.03	9.80	9.52	8.64	8.41	8.46
		8.60	10.15	9.24	8.13	9.22	10.10	8.03
		-----	-----	-----	-----	-----	-----	8.86
780-T A.G.		-----	-----	-----	-----	-----	-----	8.14
		-----	-----	-----	-----	-----	-----	9.90
	Average	9.13	10.81	9.65	8.98	8.90	9.02	8.65
	Sample	0.73	0.57	0.36	0.74	0.30	0.94	0.68
	Deviation	5.5	25.0	11.6	3.8	2.9	4.3	-----
	% Change	No	Yes	Yes	No	No	No	-----
	Significant	10.73	12.07	11.44	10.28	10.51	9.04	7.83
H4LM Impregnated W.G.		11.11	13.26	9.27	9.80	10.35	9.60	9.49
		9.92	12.10	8.61	8.43	8.03	10.10	10.30
		12.55	-----	-----	-----	-----	-----	10.00
		-----	-----	-----	-----	-----	-----	10.83
	Average	11.08	12.48	9.77	9.50	9.63	9.58	9.69
	Sample	0.94	0.68	1.48	0.96	1.38	0.53	1.14
	Deviation	14.3	28.8	0.8	-2.0	-0.6	-1.1	-----
H4LM Impregnated A.G.	% Change	Yes	Yes	No	No	No	No	-----
	Significant	10.40	10.93	10.10	8.74	8.75	-----	8.05
		11.51	9.44	9.52	6.89	7.31	-----	7.76
		10.48	10.78	9.75	8.84	8.53	-----	7.28
		-----	-----	-----	-----	-----	-----	8.65
		-----	-----	-----	-----	-----	-----	6.55
	Average	10.80	10.38	9.79	8.16	8.20	-----	7.66
H4LM Unimpregnated W.G.	Sample	0.62	0.82	0.28	1.10	0.78	-----	0.56
	Deviation	39.2	33.8	26.2	5.2	5.7	-----	-----
	% Change	Yes	Yes	Yes	No	No	-----	-----
	Significant	11.54	11.26	10.10	8.94	8.84	-----	8.64
		11.79	10.61	9.90	8.48	9.03	-----	9.12
		12.42	10.98	8.45	8.71	8.26	-----	11.42
		-----	-----	-----	-----	-----	-----	9.08
H4LM Unimpregnated A.G.	Average	11.92	11.0	9.48	8.71	8.71	-----	9.56
	Sample	0.31	0.31	0.96	0.23	0.40	-----	1.25
	Deviation	24.7	14.5	-0.8	-8.9	-8.9	-----	-----
	% Change	Yes	Yes	No	No	No	-----	-----
	Significant	6.77	7.94	5.83	5.45	6.74	4.29	5.43
		6.60	6.78	6.12	4.94	5.66	6.54	5.91
		6.77	7.74	7.88	5.72	5.76	6.74	5.25
H4LM Unimpregnated A.G.		8.48	-----	5.10	-----	-----	-----	6.67
	Average	7.16	7.42	6.23	5.37	6.05	5.86	5.82
	Sample	0.89	0.63	0.70	0.40	0.60	1.36	0.63
	Deviation	23.0	27.5	7.0	-7.7	4.0	.7	-----
	% Change	Yes	Yes	No	No	No	No	-----
	Significant	8.93	8.69	8.63	7.30	6.88	7.07Δ	7.04
		8.70	8.48	7.37	7.25	7.31	7.39	7.13
H4LM Unimpregnated A.G.		8.39	9.06	7.27	7.28	7.23	7.07	7.09
		-----	-----	-----	-----	-----	-----	7.15
	Average	8.67	8.74	7.81	7.31	7.14	7.18	7.21
	Sample	0.36	0.29	0.63	0.05	0.23	0.18	0.13
	Deviation	20.2	21.2	8.3	1.4	-1.0	-0.4	-----
	% Change	Yes	Yes	No	No	No	No	-----
	Significant							

TABLE 6
0.2% COMPRESSIVE YIELD STRENGTH DATA
IN KSI

Temperature of Anneal

Material	Irradiated						Control	
	80°F	250°F	500°F	750°F	1000°F	1200°F	80°F	
P-03	13.18	13.74	13.81	12.63	12.88	12.93	13.38	
	13.36	14.44	12.75	13.13	12.98	13.11	13.51	
	14.02	13.89	13.03	16.04	12.12	15.28	12.68	
	-----	-----	-----	-----	-----	-----	12.58	
	-----	-----	-----	-----	-----	-----	12.63	
	Average	13.52	14.02	13.20	13.93	12.66	13.77	12.96
% Change	4.3	8.2	1.8	7.5	-2.3	6.2	-----	
780-T W.G.	8.70	9.57	7.45	7.83	7.52	7.27	8.08	
	8.74	8.87	8.21	8.12	7.64	7.31	7.45	
	7.47	8.41	7.60	6.87	7.27	8.41	6.64	
	-----	-----	-----	-----	-----	-----	7.40	
	-----	-----	-----	-----	-----	-----	7.20	
	-----	-----	-----	-----	-----	-----	7.07	
Average	8.30	8.95	7.75	7.61	7.48	7.66	7.31	
% Change	13.5	22.4	6.0	4.1	2.3	4.8	-----	
780-T A.G.	9.14	7.58	7.37	6.59	7.65	6.97	5.70	
	7.17	8.28	7.75	7.42	7.55	7.12	6.54	
	6.92	7.88	5.63	5.91	5.56	7.35	6.95	
	7.83	-----	-----	-----	-----	-----	7.98	
	-----	-----	-----	-----	-----	-----	8.28	
	Average	7.79	7.91	6.92	6.64	6.92	7.15	7.09
% Change	9.9	11.6	-2.4	-6.3	-2.4	0.8	-----	
H4LM Impregnated W.G.	7.58	8.38	7.65	6.44	6.16	-----	6.23	
	8.33	7.35	6.92	5.80	5.60	-----	5.58	
	7.80	8.10	7.17	6.46	6.24	-----	5.93	
	-----	-----	-----	-----	-----	-----	6.18	
	-----	-----	-----	-----	-----	-----	5.80	
	Average	7.90	7.94	7.25	6.23	6.00	-----	5.94
% Change	33.0	33.7	22.0	4.9	1.0	-----	-----	
H4LM Impregnated A.G.	8.36	8.08	6.44	6.06	6.46	-----	5.86	
	8.41	7.36	6.82	5.88	6.61	-----	6.06	
	7.98	7.37	5.86	6.24	5.96	-----	7.94	
	-----	8.27	-----	-----	-----	-----	6.37	
	Average	8.25	8.27	6.37	6.06	6.34	-----	6.56
	% Change	25.4	26.1	-2.9	-7.6	-3.4	-----	-----
H4LM Unimpregnated W.G.	5.80	5.81	4.63	4.85	5.13	3.84	3.46	
	4.28	5.30	4.93	4.04	4.41	5.31	4.58	
	5.66	6.09	5.89	4.87	4.32	5.17	4.16	
	5.86	-----	4.83	-----	-----	-----	5.20	
	Average	5.40	5.73	5.07	4.59	4.62	4.77	4.35
	% Change	24.1	31.7	16.6	5.6	6.2	9.6	-----
H4LM Unimpregnated A.G.	5.37	5.92	5.40	6.08	4.75	5.05	5.25	
	5.23	6.06	5.28	5.10	5.38	5.17	4.17	
	5.78	6.80	5.61	5.38	4.85	5.77	5.01	
	-----	-----	-----	-----	-----	-----	4.06	
	Average	5.46	6.26	5.59	5.52	4.99	5.33	4.62
	% Change	18.2	35.5	21.0	19.5	8.0	15.4	-----

TABLE 7
Plastic Deformation
In Inches/Inch
Temperature of Anneal

Material		Irradiated					Control
P-03	80°F	250°F	500°F	750°F	1000°F	1200°F	80°F
	.0056	.0078	.0034	.0054	.0056	.0034	.0050
	.0100	.0054	.0054	.0046	.0050	.0050	.0044
	.0084	.0084	.0062	.0022	.0052	.0056	.0056
	----	----	----	----	----	----	.0044
	----	----	----	----	----	----	.0058
Average	.0077	.0072	.0050	.0041	.0053	.0047	.0050
% Change	54.0	44.0	0.0	-18.0	6.0	-6.0	-----
780-T W.G.	.0058	.0056	.0098	.0050	.0076	.0064	.0068
	.0024	.0088	.0064	.0078	.0052	.0058	.0048
	.0060	.0070	.0078	.0060	.0066	.0080	.0060
	----	----	----	----	----	----	.0072
	----	----	----	----	----	----	.0050
	----	----	----	----	----	----	.0066
Average	.0047	.0071	.0080	.0063	.0065	.0067	.0066
% Change	-28.8	7.6	21.2	-4.5	-1.5	-1.5	-----
780-T A.G.	.0142	.0156	.0136	.0118	.0088	.0076	.0076
	.0154	.0160	.0062	.0068	.0100	.0070	.0106
	.0162	.0126	.0144	.0130	.0110	.0092	.0124
	----	----	----	----	----	----	.0076
	----	----	----	----	----	----	.0080
	----	----	----	----	----	----	.0092
Average	.0153	.0147	.0114	.0105	.0099	.0079	.0092
% Change	66.3	59.8	23.9	14.1	7.6	-14.1	-----
H4LM Unimpregnated W.G.	80°F	250°F	500°F	750°F	1000°F	1200°F	80°F
	.0060	.0142	.0098	.0056	.0012	.0054	.0094
	----	.0094	.0094	.0074	.0104	.0100	.0072
	----	.0102	.0142	.0064	.0116	.0120	.0096
	----	----	.0088	----	----	----	-----
	----	----	----	----	----	----	.0087
Average	.0060	.0113	.0105	.0065	.0111	.0091	.0087
% Change	-31.0	29.9	19.5	-25.3	27.6	4.6	-----
H4LM Unimpregnated A.G.	.0156	.0184	.0194	.0118	.0122	.0120	.0122
	----	.0168	.0130	.0140	.0144	.0162	.0124
	----	.0140	.0100	.0112	.0148	.0108	-----
	----	----	.0130	----	----	----	-----
	----	----	----	----	----	----	.0123
	----	----	----	----	----	----	-----
Average	.0156	.0164	.0138	.0123	.0138	.0130	.0123
% Change	26.8	33.3	12.2	0.0	12.2	5.7	-----
H4LM Impregnated W.G.	.0156	.0100	.0140	.0122	.0152	----	.0100
	.0146	.0086	.0126	.0058	.0094	----	.0106
	.0140	.0154	.0122	.0106	.0128	----	.0086
	----	----	----	----	----	----	.0120
	----	----	----	----	----	----	.0050
	----	----	----	----	----	----	.0092
Average	.0147	.0113	.0129	.0092	.0125	----	.0092
% Change	59.8	22.8	40.2	0.0	35.9	----	-----
H4LM Impregnated A.G.	.0192	.0190	.0208	.0156	.0112	----	.0136
	.0176	.0160	.0158	.0122	.0140	----	.0158
	.0242	.0188	.0128	.0118	.0106	----	.0162
	----	----	----	----	----	----	.0146
	----	----	----	----	----	----	.0150
	----	----	----	----	----	----	-----
Average	.0203	.0179	.0165	.0132	.0119	----	.0150
% Change	35.3	19.3	10.0	-12.0	-20.7	----	-----

TABLE 8
SUMMARY OF IRRADIATION EFFECTS ON GRAPHITE

Property	Grade	Direction	Control r.t.	Irradiated - Temperature of Anneal						
				r.t.	250°F	500°F	750°F	1000°F	1200°F	
Electrical Resistivity (m Ω -cm)	P-03		1.92	2.525	2.400	2.081	1.854	2.031	2.01	
	780-T	A.G.	1.61	2.42	2.35	1.85	1.76	1.74		
		W.G.	1.21	1.89	1.89	1.46	1.33	1.32		
	H4LM Unimpreg.	A.G.	.908	1.634	1.432	1.112	.957	1.002	1.016	
		W.G.	.840	1.667	1.347	1.073	.982	.970	.937	
	H4LM Impreg.	A.G.	.905	1.98	1.92	1.37	1.06	1.11		
		W.G.	.824	1.77	1.713	1.15	.992	.972		
Compressive Strength (KSI)	P-03		15.19	17.50	17.53	15.56	15.72	15.58	15.94	
	780-T	A.G.	9.69	11.08	12.48	9.77	9.50	9.63	9.58	
		W.G.	8.65	9.13	10.81	9.65	8.98	8.90	9.02	
	H4LM Impreg.	A.G.	9.56	11.92	10.95	9.48	8.71	8.71		
		W.G.	7.66	10.80	10.38	9.79	8.16	8.20		
	H4LM Unimpreg.	A.G.	7.21	8.67	8.74	7.81	7.31	7.14	7.18	
		W.G.	5.82	7.16	7.42	6.23	5.37	6.05	5.86	
Percent Plastic Deformation in Compression	P-03		.50	.77	.72	.50	.41	.53	.47	
	780-T	A.G.	1.53	1.47	1.14	1.05	.99	.79		
		W.G.	.66	.47	.71	.80	.63	.65	.67	
	H4LM Impreg.	A.G.	1.50	2.03	1.79	1.65	1.32	1.19		
		W.G.	.92	1.47	1.13	1.29	.92	1.25		
	H4LM Unimpreg.	A.G.	1.23	1.56	1.64	1.38	1.23	1.38	1.30	
		W.G.	.87	.60	1.13	1.05	.65	1.11	.91	
Tensile Strength (KSI)	780-T	A.G.	3.23	r.t.	200°F	400°F	600°F	800°F	1000°F	1200°F
		W.G.	3.28	4.04	4.62	4.56	3.76		3.49	3.17
	H4LM Impreg.	A.G.	2.42	4.74	4.77	4.44	3.70	3.52	3.29	3.75
		W.G.	2.24	3.55			2.77			
	H4LM Unimp.	A.G.	2.18	2.61			2.08			
		W.G.	1.92	3.39			2.64			
	P-03		5.19	2.80			2.20			
				5.99		6.60	4.98	5.63	5.44	5.50

ELECTRICAL RESISTIVITY SPECIMEN

COMPRESSION SPECIMEN

TENSILE SPECIMEN

611903-2B

FIGURE 1
Specimen Design

FIGURE 2
 ρ/ρ_0 vs. Temperature for P-03
 $\rho_0 = 1.92 \text{ m}\Omega\text{-cm}$

FIGURE 3
 ρ/ρ_0 vs. Temperature for 780-T W.G.
 $\rho_0 = 1.20 \text{ m}\Omega\text{-cm}$

FIGURE 4
 ρ/ρ_0 vs. Temperature for 780-T A.G.
 $\rho_0 = 1.61 \text{ m}\Omega\text{-cm}$

FIGURE 5

ρ/ρ_0 vs. Temperature for Unimpregnated H4LM, W.G.

$$\rho_0 = 0.840 \text{ m}\Omega\text{-cm}$$

FIGURE 6
 ρ/ρ_0 vs. Temperature for Unimpregnated H4LM, A.G.
 $\rho_0 = 0.908 \text{ m}\Omega\text{-cm}$

FIGURE 7
 ρ/ρ_0 vs. Temperature for Impregnated H4LM, W.G.
 $\rho_0 = 0.824 \text{ m}\Omega\text{-cm}$

FIGURE 8
 ρ/ρ_0 vs. Temperature for Impregnated H4LM, A.G.
 $\rho_0 = 0.905 \text{ m}\Omega\text{-cm}$

FIGURE 9
Electrical Resistivity of Irradiated P-03 vs. Temperature

FIGURE 10

Electrical Resistivity of Irradiated, Unimpregnated H4LM, W.G., vs. Temperature

FIGURE 11
Change in Tensile Strength of Irradiated P-03 vs. Annealing Temperature

FIGURE 12
Change in Tensile Strength of Irradiated 780-T, W.G., vs. Annealing Temperature

FIGURE 13
Change in Tensile Strength of Irradiated 780-T, A.G., vs. Annealing Temperature

FIGURE 14

Change in Tensile Strength of Irradiated, Unimpregnated H4LM, W.G., vs. Annealing Temperature

FIGURE 15

Change in Tensile Strength of Irradiated, Unimpregnated H4LM, A.G., vs. Annealing Temperature

FIGURE 16
Change in Tensile Strength of Irradiated, Impregnated H4LM, W.G., vs. Annealing Temperature

FIGURE 17

Change in Tensile Strength of Irradiated, Impregnated H4LM, A.G., vs. Annealing Temperature

FIGURE 18
Change in Compressive Strength of Irradiated P-03 vs. Annealing
Temperature

FIGURE 19

Change in Compressive Strength of Irradiated 780-T, W.G., vs. Annealing Temperature

FIGURE 20

Change in Compressive Strength of Irradiated 780-T, A.G., vs. Annealing Temperature

FIGURE 21

Change in Compressive Strength of Irradiated, Unimpregnated H4LM, W.G., vs.
Annealing Temperature

FIGURE 22
Change in Compressive Strength of Irradiated, Unimpregnated H4LM, A.G., vs.
Annealing Temperature

FIGURE 23
Change in Compressive Strength of Irradiated, Impregnated H4LM, W.G., vs.
Annealing Temperature

FIGURE 24
Change in Compressive Strength of Irradiated, Impregnated H4LM, A.G., vs.
Annealing Temperature

FIGURE 25

Change in 0.2% Compressive Yield Strength of Irradiated P-03 vs. Annealing Temperature

FIGURE 26

Change in 0.2% Compressive Yield Strength of Irradiated 780-T, W.G., vs. Annealing Temperature

FIGURE 27

Change in 0.2% Compressive Yield Strength of Irradiated 780-T, A.G., vs. Annealing Temperature

FIGURE 28

Change in 0.2% Compressive Yield Strength of Irradiated, Unimpregnated H4LM, W.G., vs.
Annealing Temperature

FIGURE 29
Change in 0.2% Compressive Yield Strength of Irradiated, Unimpregnated H4LM, A.G. vs.
Annealing Temperature

FIGURE 30
Change in 0.2% Compressive Yield Strength of Irradiated, Impregnated, H4LM, W.G., vs.
Annealing Temperature

FIGURE 31
Change in 0.2% Compressive Yield Strength of Irradiated, Impregnated, H4LM, A.G., vs.
Annealing Temperature

611903-1B

FIGURE 32
Room Temperature Compressive Modulus of Irradiated and Control Unimpregnated H4LM,
W.G. and A.G.

FIGURE 33
Typical Mode of Failure in All Tensile Specimens

Irradiated

Unirradiated

FIGURE 34
Failed P-03 Compression Specimen

Irradiated

Unirradiated

FIGURE 35
Failed 780-T, W.G., Compression Specimen

Irradiated

Unirradiated

FIGURE 36
Failed 780-T, A.G., Compression Specimen

FIGURE 37
Failed Impregnated H4LM, W.G., Compression Specimen

Irradiated

Unirradiated

FIGURE 38
Failed Impregnated H4LM, A.G., Compression Specimen

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