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Westinghouse Astronuclear Laboratory

IRRADIATION OF BATH SHIELD MATERIAL

AT AMBIENT TEMPERATURES

(Title Unclassified)

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Astronuclear
Laboratory

WANL-TME-1898

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AT AMBIENT TEMPERATURES

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AND DECLASSIFICATION~~

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I ABSTRACT

- (U) An irradiation of an extrusion of the NERVA 70-30 BATH shielding material was completed in WANL Irradiation Test #37/W407 at the Plum Brook Reactor Facility. Neutron fluences were $8.2 \times 10^{19} \text{ n/cm}^2$ ($E < 0.48 \text{ ev}$) and $9 \times 10^{18} \text{ n/cm}^2$ ($E > 1 \text{ Mev}$). The irradiation temperature was 590°R .
- (U) The irradiation caused an increase in the 0.2% offset tensile and compressive yield strengths and a decrease in the tensile elongation. The ultimate tensile strength, thermal conductivity, dimensions and hydrogen content were not affected.

II INTRODUCTION

(U) BATH is an aluminum-based composite material being developed at WANL for NERVA shielding. The material tested was of the 70-30 type. Details of composition and processing are classified and the reader is referred to the WANL NERVA Quarterly Progress Reports for the second and first quarters of 1968 for further information.

(U) As part of the evaluation of the material, irradiation test #37/W407 was conducted to obtain radiation effects data required for design of the shield. It was intended that this program be preliminary in nature since a more desirable cryogenic irradiation could not be scheduled. In addition, the material was still in the developmental stage. The mechanical properties and thermal conductivity tests are primarily measures of irradiation effects above room temperature. Such tests can indicate that significant effects will take place at lower temperatures, but it cannot be concluded that significant effects will not occur at lower temperatures. A cryogenic irradiation is needed for complete characterization of these properties. The hydrogen and dimensional measurement results, however, should not be changed by a cryogenic irradiation. Recent improvements in the material should not significantly affect any of the results.

(U) Generally, aluminum alloys are not affected by irradiations below 10^{19} n/cm^2 ($E > 1 \text{ Mev}$) at room temperature or above.⁽¹⁾ However, little is known about powder metallurgy products of the BATH category containing large quantities of brittle compounds. Since boron is present in appreciable amounts, transmutation product damage (He^4 and Li^7) must be considered. Loss of hydrogen from the material is another possibility which would reduce the effectiveness of the shield. This irradiation was intended to explore some of these possibilities before a final shield material and configuration were selected.

(1) "The Effects of Neutron Radiation on Structural Materials", REIC Report No. 45, Battelle, Columbus, Ohio (1967) p. 7.

(U) Test specifications were reported in WANL-TME-1708, Mod. No. 1, "Final Test Specification for Materials Test 37/W407, "dated January, 1968.

III CONCLUSIONS AND RECOMMENDATIONS

- (U) 1. Yield strength in tension and compression was increased by an ambient temperature irradiation to testing temperatures as high as 800°R. The ultimate tensile strength was not affected above room temperature.
- (U) 2. Tensile elongation was significantly reduced by neutron irradiation of $9 \times 10^{18} \text{ n/cm}^2$ ($E > 1 \text{ Mev.}$) and $8.2 \times 10^{19} \text{ n/cm}^2$ ($E < 0.48 \text{ ev}$). Brittle design criteria are required.
- (U) 3. No loss of hydrogen as a result of neutron irradiation should be expected during NERVA application of the material.
- (U) 4. No dimensional changes greater than 0.1% as a result of neutron irradiation should be expected during NERVA application. This amount could be tolerated in the present design because of component size and tolerances. Actual R-1 thermal fluences are 10^3 smaller than those of this test and this represents an additional safety factor.
- (U) 5. Thermal conductivity of the material was not affected by neutron irradiation above room temperature.
- (U) 6. A cryogenic irradiation test is recommended to completely characterize the mechanical and thermal properties, for it is expected that the irradiation effects will be greater at the low irradiation and testing temperatures.

IV TEST PROCEDURES

Material

(CRD) Specimens were machined from 1 1/4" dia. bars of the 70-30 grade BATH material. Characterization data for this material can be found in the previously mentioned Quarterly Progress reports. The nominal composition by volume was 70% aluminum, 24% TiH₂ and 6% B₄C. The hydrogen content was 1.3%.

Specimens

(U) Test specimen designs are shown in Figures 1 thru 4. All test specimens were machined with the test axis in the extrusion direction. Both one and two inch long thermal conductivity specimens were used.

Radiation Environment

(U) Specimens were irradiated in the WANL W2-3 capsule in the horizontal-through-hole No. 1 (HT-1) of the Plum Brook reactor. A water environment was used as the experiment coolant. The test fixture was instrumented with six thermocouples including four attached to dummy specimens of the thermal conductivity design. Maximum specimen centerline temperature was 592°R while the specimen edge was at 589°R.

(U) Dosimetry included nickel wire and high purity aluminum wire with 0.1% cobalt. Previously obtained flux distributions for the facility were also available. From this information, average fluences of $8.2 \times 10^{19} \text{ n/cm}^2$ ($E < 0.48 \text{ ev}$) and $9 \times 10^{18} \text{ n/cm}^2$ ($E > 1 \text{ Mev.}$) were calculated. Attenuation of both fast and thermal fluences within the test specimens is not expected to be significant.⁽¹⁾ The fast fluence is expected to decrease by 5% in the first 0.25" of material thickness and 10% after 0.50". Thermal fluences should decrease by 10% after 0.25" and 26% after 0.50". These values include both incident thermal neutrons and thermalized fast neutrons. It is, therefore, concluded that the self shielding effect did

(1) Private communication - Radiation and Shielding Design

not significantly affect the properties measured in this investigation, for it is well established that such small variations in neutron exposure do not cause appreciable changes in the mechanical and physical properties of alloys. In addition, the fluences reported are well above those expected in the R-1 reactor ($6 \times 10^{17} \text{ n/cm}^2$ ($E > 1 \text{ Mev.}$) and $5 \times 10^{17} \text{ n/cm}^2$ ($E > 0.48 \text{ ev}$)).

Test Procedures

(U) Tensile and compressive specimens were tested with an Instron tensile test machine at PBRF. Data was obtained from the load-deflection curves. Test temperatures were obtained using liquid nitrogen (140°R) and a tube furnace (800°R). The axi-ality of the tensile test system was determined with strain gaged specimens. Misalignment was less than 5% during testing. Hydrogen content of specimens was determined at the Analytical Services Laboratory of WAPD, Waltz Mills, using a combustion procedure with the hydrogen collected as water. Accuracy was reported to be $\pm 2\%$ (relative). Specimens were obtained in sets of pairs from three locations. One specimen from each pair was irradiated while the other served as a control.

(U) Thermal conductivity measurements were made at WANL in the Thermophysical Properties Laboratory. The apparatus consisted of a comparative cut-bar arrangement contained in an evacuated bell-jar. A specimen was placed between two ARMCO-iron standard bars. The upper bar is equipped with a heater, while the lower one is terminated in a water-cooled heat sink. While the specimen itself is not equipped with thermocouples, the temperature gradient is determined along the system using a series of micro-thermocouples attached to the ARMCO-iron bars.

V RESULTS & DISCUSSION

Swelling

(U) Because of the high Boron 10 concentration in the material, thermal neutron irradiation could be expected to cause large amounts of gases (mostly He) to be generated. The pertinent reaction is:

(U) The maximum amount of gas that could be formed in this irradiation is of the order of $1 \times 10^{-3} \text{ cc He}^4 \text{ (STP)/cc of material}$. However, in the R-1 environment, the maximum amount formed would be about $6 \times 10^{-6} \text{ cc He}^4 \text{ (STP)/cc of material}$.

(U) Micrometer measurements were made on 14 compression specimens before and after irradiation on both length and diameters to the nearest 0.0001". The average lengths of the specimens both before and after irradiation were 1.060 inches, while the average diameter increased from 0.359 inches to 0.362 inches. The increase in diameter is thought to be the result of a swelling of hydride particles on the surface. These particles were oriented in the specimen axis direction and are not thought to affect the length measurements. Additional measurements are scheduled in WANL Irradiation Test No. 37/W411. Because of the lower thermal fluence expected in the R-1, however, it is not expected that swelling greater than 0.1% would be encountered.

Hydrogen Content

(U) Results of the chemical analysis showed that the average hydrogen content increased 1.36% after irradiation. This increase is within the $\pm 2\%$ accuracy of the tests. Since the neutron fluences involved were much greater than those expected in the R-1, no hydrogen loss is expected.

Mechanical Properties

- (U) Mechanical property data are tabulated in Table 1. These data have been analyzed using the analysis of variance technique. The 0.05 level of significance was used to assess each effect. Figures 5 thru 8 present the data as curves of average values with .95/.99 statistical tolerance limits which imply that with 95% confidence at least 99 percent of the material population would have values greater than the limits.
- (U) Yield strengths (Figures 5 and 6) were significantly increased by the irradiation while the ultimate tensile strength (Figure 7) was unaffected. Tensile elongation (Figure 8) was decreased. Except for the compressive yield strength, the changes persisted to 800°R. Compression tests were made until the specimen had undergone a 50% reduction in length. Only the irradiated specimens tested at 140°R failed before this criterion was reached. Under these conditions, average compressive ultimate strength was 78.9 ksi with a total plastic strain of 27.6%.
- (U) Several tensile and compression specimens were held at 835°R for one hour prior to testing at room temperature. The irradiation effects annealed out for the compression specimens but not for the tensile specimens. Holding the specimens at temperature for one hour vs. five minutes before testing did not affect the properties at 800°R.
- (U) Visual inspection of the test specimens before irradiation showed large voids (up to 1/16" in width) on the surface caused by segregation of the non-metallics and subsequent removal during machining. In addition, a surface finish better than 32 micro inches r. m. s could not be obtained. The high variability in the data are attributed to these conditions. A more homogeneous material will be used for future irradiation testing.

Thermal Conductivity

- (U) The thermal conductivity results, shown in Figure 9, also show quite a large scatter. Four unirradiated and five irradiated specimens were tested with generally three test temperatures per specimen. Analysis of the data indicated no significant effect of irradiation

or test temperature (570–800°R) on the results. An overall standard deviation and 0.95/0.99 statistical tolerance limit were determined from a "pool" of the data.

Influence of Irradiation Temperature

- (U) Lattice damage caused by irradiation "anneals out" as temperature is increased. Thus, as a general rule, the irradiation temperature should not be greater than the test temperature. The increases in strength and loss in ductility found in this experiment can be expected to be magnified below room temperature after a cryogenic irradiation. Possibly thermal conductivity changes (decreases would be expected) could also be found at cryogenic temperatures after irradiation. These data are valid for direct application above room temperature.
- (U) Dimensional and hydrogen content changes are not due to lattice damage, and these measurements would not be affected by a cryogenic irradiation.

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TABLE 1

<u>Test Temperature</u>	<u>Fluence</u> n/cm^2 (E > 1 Mev)	<u>BATH Shield</u>			
		<u>Tensile Yield Strength</u>	<u>Ultimate Tensile Strength</u>	<u>Elongation</u>	<u>Compressive Yield Strength</u>
140	0	16.9	23.0	2.6	18.5
		11.1	13.8	0.6	18.5
		15.0	22.1	4.0	
	9×10^{18}	22.2	24.8	0.7	22.0
		18.0	21.1	0.7	24.1
		13.8	19.0	0.8	24.1
	0	11.2	19.2	2.5	12.0
		11.9	19.3	2.5	12.2
		11.3	18.2	4.1	11.5
540	9×10^{18}	14.5	18.4	1.0	14.8
		14.9	20.1	1.6	16.2
		14.4	20.4	1.5	14.8
	0	11.0	14.2	3.2	10.0
		9.4	12.4	7.1	9.5
		8.5	12.4	4.5	
800	9×10^{18}	11.3	15.5	2.5	9.7
		9.7	13.7	4.0	9.2
		9.7	13.6	3.2	
	0				

(1) (2)

1 A 05

1 A 005

ITEM NO.	L ± .001
1	1.000
2	2.000

TABLE 1

.5000 ± .0005 DIA

SEE TABLE 1

1 B 005

8

2 MATERIAL TO BE USED WILL BE SPECIFIED BY COGNIZANT ENGINEER

1 MARK PART NO. ON CONTAINER PER P294517-1

2	1	2	SPECIMEN	800C082H02-				
2	1	1	SPECIMEN	800C082H01-				
	SYM	ITEM NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	ZONE
	QTY. REQD							
LIST OF MATERIALS								
UNLESS OTHERWISE SPECIFIED				CONTRACT NO.	NP-1			
INTERPRET DWG PER MIL-D-1000				DATE	10-31-67			
DIM IN INCHES BASED ON 88°F				DATE	10-31-67			
TOLERANCES - DO NOT SCALE				DATE	10-31-67			
2PL. DEC	3PL. DEC	ANGLES	16	DATE	10-31-67			
±	±	±	AA	DATE	10-31-67			
-	1	⊙		DATE	10-31-67			
NEXT ASSY.	USED ON	P294517-1	IDENT	Westinghouse Astronuclear Laboratory				
G	APPLICATION	SPECIFICATION	TYPE	Pittsburgh, Pennsylvania				
DWG. CODE NO.	3	751512-DZ		SPECIMEN				
INFORMATION CATEGORY				THERMAL CONDUCTIVITY				
17 17. 14/1/67				IRRADIATION				
AUTHORIZED CLASSIFIER				DATE				
DWG. SIZE	C	CODE IDENT NO.	14683	DWG. NO.	800C082			
SCALE	4/1	WT ACT	WT CALC	SHEET	OF 1			

FIGURE 2

Compression Specimen Design

- 2 MATERIAL TO BE USED WILL BE SPECIFIED BY COGNIZANT ENGINEER
1. MARK PART NO. ON CONTAINER PER P294517-1

SPECIMEN		800C083H01-							
QTY. REQD	SYM	ITEM NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	ZONE	
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED				CONTRACT NO. NP-1		Westinghouse Astronuclear Laboratory Pittsburgh, Pennsylvania SPECIMEN HYDROGEN ANALYSIS			
INTERPRET DWG PER MIL-D-1000 DIM IN INCHES UNLESS NOTED OTHERWISE				DATE OF DWG 10-31-67					
TOLERANCES - DO NOT SCALE				CHECKED 11-7-67					
ZPL DEC SPL DEC ANGLES 63				DATE 11/9/67					
± ±.005 ±				ANALYST		STRESS			
- 1				MATERIAL 800C083H01-7-67					
NEXT ASSY.	USED ON	P294517-1	IDENT	INFORMATION CATEGORY		DWG NO. 800C083			
G	APPLICATION	SPECIFICATION	TYPE	UNCLASSIFIED		CODE IDENT NO. 14683			
DWG. CODE NO.	3	751512-DZ		AUTHORIZED CLERK DATE 11/1/67		SCALE 4/1		WT ACT WT CALC SHEET OF 1	

FIGURE 3

Thermal Conductivity Specimen Design

Hydrogen Analysis Specimen Design

FIGURE 5

0.2% Offset Tensile Yield Strength of
Irradiated BATH Material

FIGURE 6

0.2% Offset Compressive Yield Strength of
Irradiated BATH Material

FIGURE 7

Ultimate Tensile Strength of
Irradiated BATH Material

FIGURE 8

Tensile Elongation of
Irradiated BATH Material

FIGURE 9

Thermal Conductivity of
Irradiated BATH Material

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