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TENSILE PROPERTIES OF UNALLOYED TANTALUM AT TEMPERATURES UP TO 1350° F (1000 K)

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ABSTRACT

Unalloyed tantalum tensile specimens of various shapes and different heats were tested at various elevated temperatures (450° to 1350° F (505 to 1005 K)) at a vacuum level of 4.1×10^{-6} torr (5.5×10^{-4} N/m^2) or less. Much scattering was observed in the ultimate stress, from 15 500 to 28 000 psi (10.5×10^7 to 19.3×10^7 N/m^2), among the different shapes tested at the same temperature, 1350° F (1005 K). Correlation, however, was good among specimens machined from the same heat, 20 200 to 23 400 psi (14.0×10^7 to 16.1×10^7 N/m^2) for the tube specimens.

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E-5206

SUMMARY

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Much scattering was observed in the ultimate stress, from 15 500 to 28 000 psi (10.5×10^7 to 19.3×10^7 N/m^2), among the different shapes tested at the same temperature, 1350° F (1005 K). Correlation, however, was good among specimens machined from the same heat, 20 200 psi to 23 400 psi (14.0×10^7 to 16.1×10^7 N/m^2) for the tube specimens.

INTRODUCTION

Auxiliary electrical power systems for spacecraft must supply power for several years. Since long life and reliability are a prime requirement in the design of these auxiliary power systems, much effort has gone into their development. Two of the problems associated with these systems are high operating temperatures, up to 2200° F (1477 K), and the containment material which must endure these high temperatures for long periods of time.

Refractory metals are especially applicable to high-temperature auxiliary power systems because of their good strength at elevated temperatures. Tantalum is one refractory metal under investigation (refs. 1 and 2). Information on the properties of tantalum can be found in references 3 to 7. Data found in references 3 to 7 are plotted in composite form in reference 2. These data, however, are difficult to use because of excessive scattering over the entire temperature range, 0° to 2200° F (255 to 1477 K). It is apparent from these data that in order to design with tantalum it would be most desirable to obtain properties of the actual material to be used. This report presents yield strength, tensile strength, percent elongation, and percent reduction of area for unalloyed tantalum specimens at various temperatures. The specimens were tested at vacuum levels from 4.1×10^{-6} to 0.3×10^{-6} torr (5.4×10^{-4} to 0.4×10^{-4} N/m^2) and temperatures from 75° to 1350° F (297 to 1005 K).

The materials tested are those used in the fabrication of a boiler for SNAP-8 (ref. 1).

TEST SPECIMENS AND MATERIAL ANALYSIS

Tensile specimens of unalloyed tantalum were machined from seamless drawn tubing having a 0.652-inch (16-mm) inside diameter and a 0.051-inch (1.3-mm) wall thickness. All tube tensile tests were performed according to the recommended test methods for refractory metal sheet given in reference 8. The specimen configuration and size is shown in figure 1. Special grips were designed to accommodate the tube curvature.

All tests, except the two at room temperature, were conducted in a vacuum chamber. The vacuum measurements were taken at the test temperatures. The high and low vacuum readings were 4.1×10^{-6} torr and 0.3×10^{-6} torr (5.4×10^{-4} and 0.4×10^{-4} N/m^2), respectively. A uniform strain rate of 0.05 ± 0.01 inch per inch per minute (0.13 ± 0.02 cm/cm/min) was used from zero strain to fracture. Most of the specimens were tested at 1350° F (1005 K). Included, however, are specimens tested at 75° F (297 K), 450° F (505 K), 500° F (533 K), 800° F (710 K), and 1100° F (866 K).

The tantalum material was taken from several different heats. The ingot analysis for each heat is shown in table I. A chemical analysis of the mill product was also made just prior to tensile testing for each heat and the results are presented in table II.

All specimens tested were recrystallization annealed and the ASTM grain size is between 4 and 7, with most in the 5 range.

RESULTS AND DISCUSSION

The results of these tests are presented in table III, together with the tensile properties of sheet, plate, and rod specimens from reference 2. The shape of the raw material is given in the materials column. The vacuum level was measured at the test specimen temperature. Data shown include ultimate tensile strength, yield strength, elongation, and percent reduction in area. The specimens machined from tubing having an average ultimate strength higher than the specimens from either plate or sheet. The prior thermal and mechanical processing of the raw material, as reflected in the specimens shape, appears to have an influence on the tensile strength of the tantalum material. The grain size for each specimen is given. The influence of the grain size, however, is not known because of the limited number of tube specimens tested at any one heat. Similarly, the meaning of the different ingot analysis and mill product chemistry on the mechanical properties is not known.

The tensile properties of the tube specimens at various temperatures are shown in figure 2. The largest amount of scatter in the tube specimens occurs at the 1350° F (1005 K) temperature and may be the result of the slight chemistry difference among the various heats tested. Scattering at the other temperatures was small and may result from the limited number of specimens tested.

Within heat number G, for which four specimens were tested at 1350° F (1005 K), correlation is good. Correlation is also good for the 1-inch (25-mm) plate for which the specimens were machined from material of the same heat. The same holds true for each other shape, that is, the 1/4-inch (6.3-mm) plate, 5/32-inch (4-mm) sheet, and the 3/4-inch (19-mm) rod.

CONCLUDING REMARKS

Unalloyed tantalum tubes needed for a SNAP-8 boiler (ref. 1) were tested at 1350° F (1005 K) to determine the tensile properties of the material. Tensile data available on unalloyed tantalum proved to be inadequate because of the large amounts of scattering throughout the temperature range and the limited data at the required temperature range.

The results of the tensile tests in this report also showed a large amount of scattering, particularly between different heats. This may be the result of the slight chemistry and grain-size differences among the various heats. Within a heat for which more than one specimen was tested, correlation, however, was good. The shape of the raw material, that is, plate, sheet, tube, or rod, appeared to influence the ultimate strength of the tantalum tested. And the largest amount of data scatter seen occurred between the different shapes.

For the tantalum tubes tested, the lowest yield strength was 7000 psi (47×10^6 N/m^2). Because even weaker material might be received, a safety factor should be used in determining the allowable working stress. Before fabrication of an assembly utilizing unalloyed tantalum, tensile strength of the actual material at design operating temperature and in the shape in which it will be used should be measured in order to qualify the material for use.

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National Aeronautics and Space Administration,
Cleveland, Ohio August 6, 1969,
120-27.

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TABLE I. - TANTALUM INGOT ANALYSIS

Element	Heat													
	A		B		C		D		E		F		G	
	Composition, ppm													
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Al	<20	<20	<10	<10	<10	<10	<10	<10	23	25	16	15	<10	<10
B	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
C	<20	<20	<30	<30	<30	<30	30	30	30	40	30	<30	<30	<30
Ca	<10	<10	---	---	---	---	---	---	---	---	---	---	---	---
Cb	<50	230	960	620	58	96	63	150	<50	<50	<50	<50	56	<50
Cd	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Co	<5	<5	---	---	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cr	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cu	<2	2	<2	<2	<2	3	<2	<2	<2	<2	<2	<2	<2	<2
Fe	<15	15	22	23	<15	<15	<15	<15	<15	<15	<15	<15	<15	18
H	2.3	3.7	2.0	2.4	2.8	2.9	2.5	2.6	2.3	2.0	1.9	2.1	2.2	2.2
Mg	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Mn	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Mo	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
N	45	15	25	25	25	35	35	25	20	20	15	25	25	20
Ni	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
O	90	80	<50	<50	60	<50	50	<50	<50	<50	<50	<50	<50	<50
Pb	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	5
Si	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	10	12
Sn	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ti	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
V	<10	40	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
W	11	146	90	60	40	310	30	40	50	<10	<10	<10	240	280
Zn	<10	<10	<50	<50	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zr	<50	<50	60	50	<50	<50	<50	<50	<50	<30	<50	<50	<50	<50
	Brinell hardness number													
Range	67.7 to 75.2		64.6 to 71.5		59.7 to 66.8		62.5 to 71.5		66.8 to 79.6		64.8 to 76.8		62.5 to 69.1	
Average	70.1		69		63		68		74		70		66	

TABLE II. - MILL PRODUCT

CHEMISTRY, PARTS PER MILLION

Heat	Oxygen	Nitrogen	Carbon	Hydrogen
A	90	5	20	3.3
B	19	25	15	<5
C	15	22	19	<5
D	14	23	20	<5
E	14	19	15	<5
F	15	19	14	<5
G	19	20	14	<5

TABLE III. - TENSILE PROPERTIES OF UNALLOYED TANTALUM

Material	Temperature		Vacuum[a]		Ultimate tensile strength		Yield strength (0.2 percent offset)		Elongation, percent	Reduction of area, percent,	Condition of tantalum as received	ASTM grain size
	°F	K	torr	N/m²	psi	N/m²	psi	N/m²				
5/32-in. (3.9-mm) sheet	1350	1005	1.0×10^{-6}	1.3×10^{-4}	17.3×10^{3}	11.7×10^{7}	7.0×10^{3}	4.8×10^{7}	56	93	See ref. 2	6
			1.8	2.4	17.3	11.7	6.6	4.5	52	95		
			1.1	1.4	17.5	12.0	5.9	4.1	61	92		
			1.3	1.7	17.5	12.0	6.6	4.5	56	88		
			1.0	1.3	17.6	12.1	7.6	5.2	51	95		
			1.0	1.3	18.1	12.5	8.7	6.0	55	91		
0.161-in. (4.1-mm) plate	1350	1005	1.0×10^{-6}	1.3×10^{-4}	17.7×10^{3}	12.2×10^{7}	6.5×10^{3}	4.5×10^{7}	68	93	Unknown	6
			1.8	2.4	17.1	11.8	6.4	4.2	61	89	Unknown	6
			1.0	1.3	17.3	11.7	6.7	4.6	74	86	Unknown	6
1/4-in. (6.3-mm) plate	1350	1005	0.98×10^{-6}	1.3×10^{-4}	15.5×10^{3}	10.7×10^{7}	6.2×10^{3}	4.3×10^{7}	64	90	See ref. 2	-----
			2.0	2.6	15.9	11.0	5.3	3.7	62	79		-----
			2.6	3.5	16.0	11.0	5.0	3.5	44	79		-----
			.94	1.3	16.3	11.2	5.0	3.5	61	85		-----
			2.1	2.8	16.8	11.6	7.7	5.3	52	73		-----
			2.4	3.2	17.5	12.0	5.0	3.5	59	84		-----
1-in. (25.4-mm) plate	1350	1005	5.0×10^{-6}	6.6×10^{-4}	18.0×10^{3}	12.4×10^{7}	10.7×10^{3}	7.4×10^{7}	32	81	See ref. 2	5
			1.0	1.3	21.0	14.5	9.0	6.2	41	84	See ref. 2	
			2.6	3.5	21.2	14.6	8.5	5.8	37	83	See ref. 2	
			3.4	4.5	21.7	14.9	9.6	6.6	44	84	Heat A	
			2.0	2.6	22.8	15.7	9.7	6.7	32	82	Heat A	
			1.0	1.3	23.4	16.1	9.3	6.4	40	79	Heat A	
0.652-in. (16-mm) by 0.051-in. (1.3-mm) wall tube	1350	1005	0.3×10^{-6}	0.4×10^{-4}	23.4×10^{3}	16.1×10^{7}	8.8×10^{3}	6.0×10^{7}	34	63	Heat B	4
			2.8	3.7	19.7	13.6	9.3	6.4	45	71	Heat C	4
			1.0	1.3	22.8	15.7	10.6	7.3	38	67	Heat D	4
			.50	.6	25.5	17.6	10.1	6.9	44	59	Heat D	6 to 7
			1.8	2.4	28.8	19.8	12.8	8.8	33	65	Heat E	
			1.2	1.6	25.9	17.7	7.0	4.8	38	70	Heat F	
			1.2	1.6	20.2	13.9	8.4	5.8	47	74	Heat G	
			1.6	2.1	23.4	16.1	8.6	5.9	40	67		5
			.6	.8	23.2	16.0	7.6	5.2	35	67		5
			1.0	1.3	22.4	15.4	9.6	6.6	39	68		5
	1100	866	3.8×10^{-6}	5.0×10^{-4}	26.2×10^{3}	18.1×10^{7}	9.9×10^{3}	6.8×10^{7}	27	73	Heat G	5
			4.1	5.4	26.0	17.9	8.2	5.6	25	74	Heat G	5
	800	700	1.0×10^{-6}	1.3×10^{-4}	29.0×10^{3}	20.0×10^{7}	12.7×10^{3}	8.7×10^{7}	37	77	Heat G	5
			2.0	2.6	30.6	21.1	11.8	8.1	33	76		5
	500	533	1.0×10^{-6}	1.3×10^{-4}	31.6×10^{3}	21.8×10^{7}	10.1×10^{3}	6.9×10^{7}	45	79	Heat G	5
			2.8	3.7	30.8	21.2	9.9	6.8	45	77	Heat G	5
3/4-in. (19-mm) diameter rod	450	505	(b)		29.0×10^{3}	20.0×10^{7}	10.6×10^{3}	7.3×10^{7}	69	100	See ref. 2	7
	450	505	(b)		28.8	19.8	11.1	7.6	69	100	See ref. 2	7
	450	505	(b)		28.0	19.3	10.2	7.0	66	100	See ref. 2	7
0.652-in. (16-mm) by 0.051-in. (1.3-mm) wall tube	75	297	--------		40.3×10^{3}	27.8×10^{7}	24.6×10^{3}	16.9×10^{7}	58	74	Heat G	7
			--------		38.8	26.8	18.1	12.5	54	80	Heat G	7

[a] Vacuum measured at test temperature.
[b] Vacuum level at test temperature 10^{-5} torr.

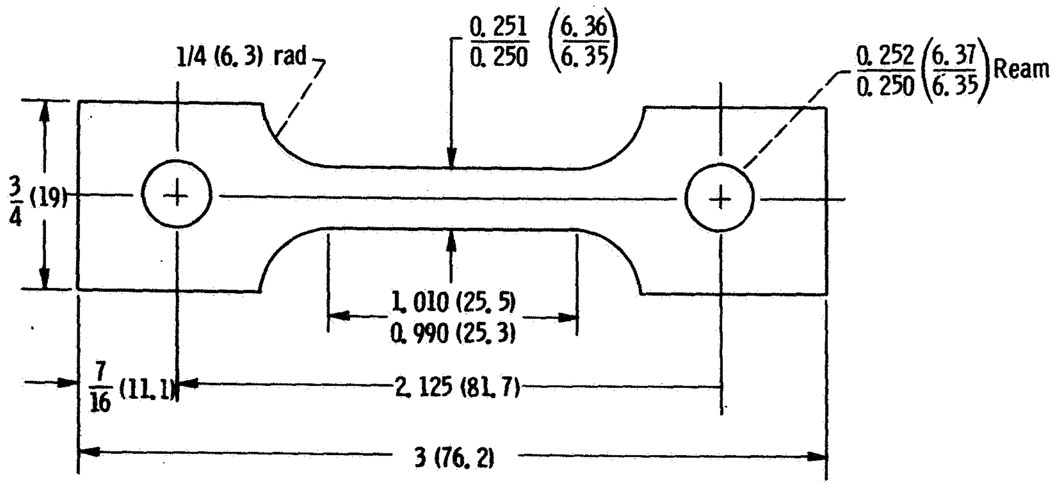

Figure 1. - Specifications for tensile test specimens. (All dimensions in inches (mm).)

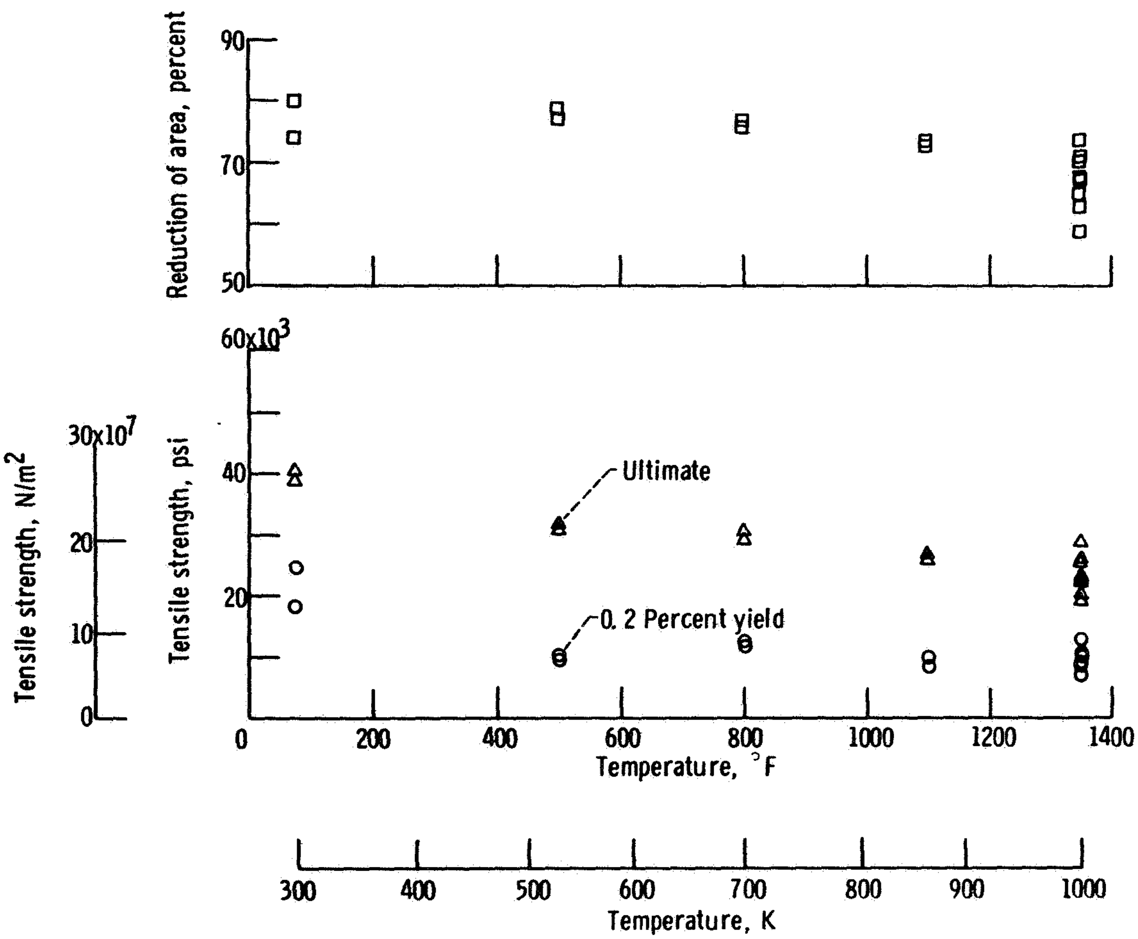

Figure 2. - Tensile properties of unalloyed tantalum tubing 0.652-inch (16-mm) inside diameter by 0-051-inch (1.3-mm) wall.