NASA TECHNICAL NOTE

NASA TN D-5873

c. 1

NASA TN D-5873

SURVEY OF PROPERTIES OF T-111 (TANTALUM-8 TUNGSTEN-2 HAFNIUM)

by Paul E. Moorhead and Phillip L. Stone

Lewis Research Center
Cleveland, Ohio 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1970

1. Report No. NASA TN D-5873	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SURVEY OF PROPERTIES OF T-111 (TANTALUM-8 TUNGSTEN-2 HAFNIUM)		5. Report Date June 1970
		6. Performing Organization Code
7. Author(s) Paul E. Moorhead and Phillip L. Stone		8. Performing Organization Report No. E-5562
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		10. Work Unit No. 120-27
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Note
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A survey of available information concerning T-111 alloy is presented. This includes thermophysical properties, mechanical properties, melting and fabrication, welding, and resistance to alkali-metal corrosion. T-111 is shown to be a suitable engineering material for advanced space power systems.

17. Key Words (Suggested by Author(s)) Refractory metal alloys; Tantalum alloy T-111; Physical properties; Mechanical properties; Welding; Contamination; Alkali-metal systems	18. Distribution Statement Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	25	$3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

SURVEY OF PROPERTIES OF T-111 (TANTALUM-8 TUNGSTEN-2 HAFNIUM)

by Paul E. Moorhead and Phillip L. Stone

Lewis Research Center

SUMMARY

A survey of available information concerning T-111 alloy (tantalum-8 tungsten-2 hafnium) is presented. The thermophysical and mechanical properties of the alloy are delineated. T-111 is shown to be very strong up to 2400° F (1316° C) but is ductile even at -320° F (-196° C). From the standpoint of 1 percent creep in 10 000 hours at a stress of 2000 psi (1380 N/cm^2), the maximum application temperature of the alloy is 2350° F (1288° C). T-111 can be bent or otherwise formed at room temperature, although power requirements are high. The alloy, in general, has excellent welding characteristics. It is also highly resistant to alkali-metal corrosion up to at least 2300° F (1260° C). Based on the foregoing factors, T-111 is concluded to be a prime candidate for advanced space power applications.

INTRODUCTION

During the early phases of space power system development, the test systems were constructed of materials such as stainless steel and various nickel- and cobalt-base alloys. As service temperatures were increased and long life was demanded, extensive use was made of a columbium-base alloy, Cb-1 Zr (columbium-1 zirconium). This alloy, however, was limited by its creep resistance to a maximum usable temperature of approximately 2000° F (1093° C) for long-term applications.

In the development of advanced space power systems, there is a need for refractory alloys that must, as a minimum, be highly creep resistant in the temperature range of 1800° to 2400° F (982° to 1316° C), have a ductile-to-brittle bend transition temperature well below room temperature, be readily formable and weldable, and be capable of containing alkali metals such as lithium and potassium for long times at the aforementioned temperatures. The tantalum-base alloy T-111 meets these minimum requirements and is a prime candidate for space power applications.

Since 1962, when the alloy was initially developed, much has been done toward characterizing it. This report presents a survey of available information concerning T-111.

GENERAL INFORMATION

T-111 is basically a single-phase solid-solution tantalum-base alloy containing 8 percent tungsten and 2 percent hafnium. The 2-percent hafnium level was originally selected on the basis of ductility considerations (ref. 1). The amount of interstitials (oxygen, carbon, nitrogen, and hydrogen) significantly affects the strength and ductility of the alloy. Thus, limits are placed on these elements by specification: oxygen, 100 ppm; carbon, 50 ppm; nitrogen, 50 ppm; hydrogen, 10 ppm.

T-111 should not be heated above 600° F (316° C) in air. Above this temperature, the alloy absorbs interstitials from the air and therefore should be heated in a good vacuum, or in a protective atmosphere such as argon or helium.

Stress relieving of T-111 is normally accomplished at 2000° F (1093° C) for 1 hour. Although other heat treatments will effect recrystallization, 3000° F (1649° C) for 1 hour is the standard procedure presently utilized.

THERMOPHYSICAL PROPERTIES

T-111 has a density of 0.604 pound per cubic inch (16.72 g/cm^3) at 77° F (25° C) (ref. 2). Its melting point is 5400° F (2982° C) (ref. 3).

The specific heat, thermal conductivity, and thermal expansion of T-111 as a function of temperature are shown in figures 1 to 3. The average coefficient of thermal expansion from room temperature to several elevated temperatures is given in table I and is plotted in figure 4. The electrical resistivity of T-111 as a function of temperature is shown in figure 5. The total hemispherical emittance of T-111 as a function of temperature is given in table II. These data are presented graphically in figure 6.

MECHANICAL PROPERTIES

T-111 maintains its strength to relatively high temperatures. The mechanical properties of the alloy are affected by both heat treatment and chemical composition. The normal heat treatment given material before testing is a 1-hour anneal at 3000° F (1649° C). Oxygen, nitrogen, and hydrogen picked up in processing increase the yield

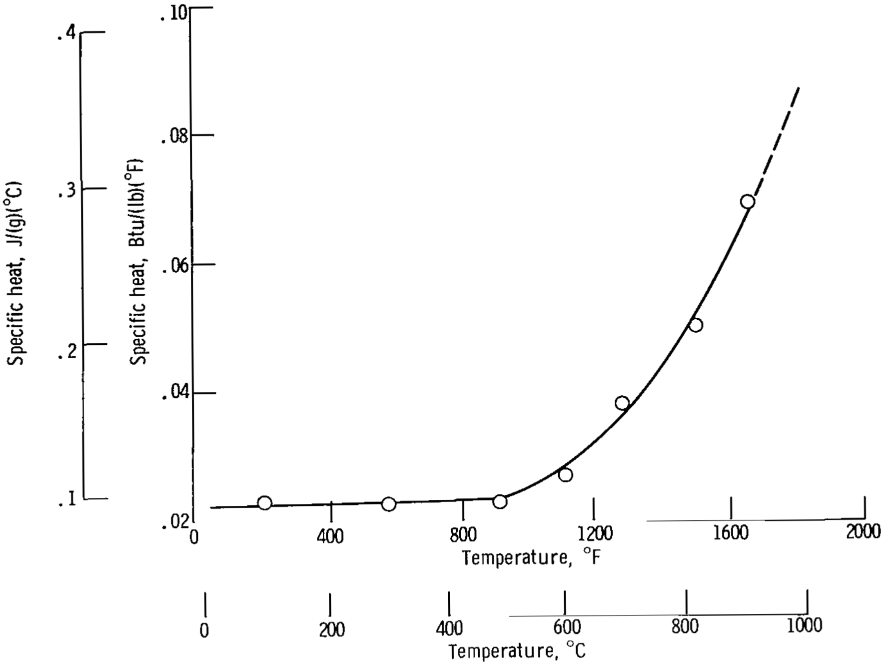


Figure 1. - Specific heat of T-111 tested in vacuum of 5×10^{-5} torr (ref. 17).

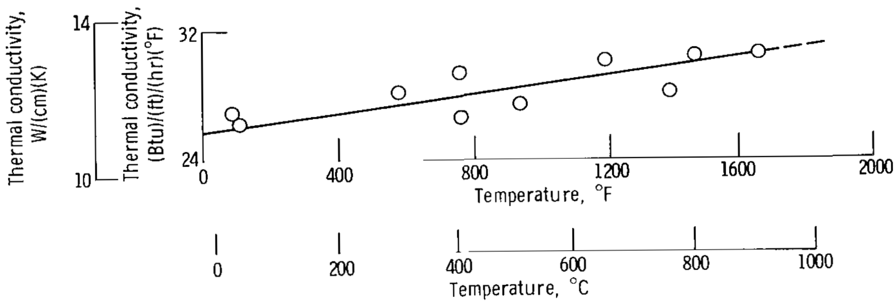


Figure 2. - Thermal conductivity of T-111 tested in vacuum at 5×10^{-6} torr (ref. 17).

and ultimate tensile strengths and generally decrease ductility. The yield strength, tensile strength, and elongation of typical T-111 sheet in both the stress-relieved and the recrystallized condition are plotted in figures 7 and 8 over the temperature range of -452° to 3500° F (-269° to 1927° C). The tensile strengths increase with decreasing test temperature, and the elongation remains high down to at least -320° F (-196° C) in the case of the stress-relieved material and to -420° F (-251° C) in the case of the annealed material. The strength properties converge and are about the same for both the stress-relieved and the annealed material at 2700° F (1482° C) and above.

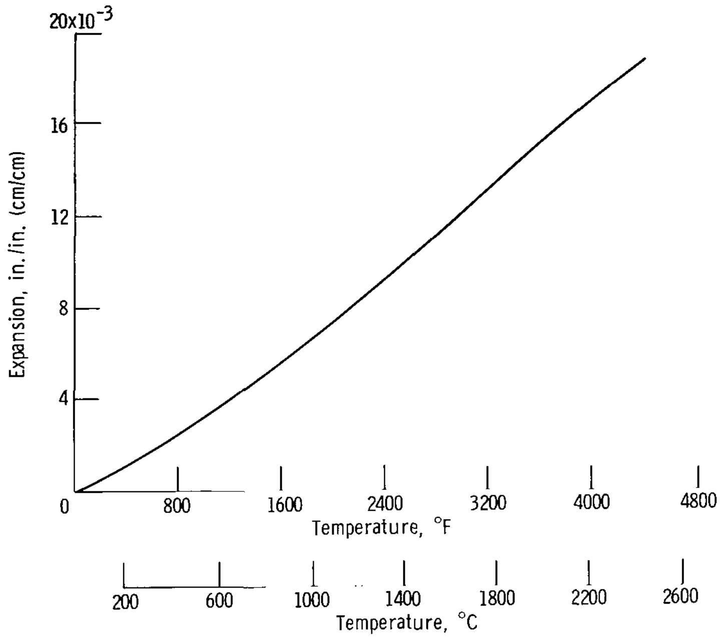


Figure 3. - Thermal expansion of T-111 (ref. 18).

TABLE I. - AVERAGE COEFFICIENT OF

THERMAL EXPANSION OF T-111 (REF. 1)

Temperature		Average coefficient of thermal expansion	
°F	°C	(in./in.)/°F	(cm/cm)/°C
80 to 500	25 to 260	3.1×10^{-6}	5.5×10^{-6}
80 to 1000	25 to 540	3.5	6.3
80 to 1500	25 to 815	3.9	7.0
80 to 2000	25 to 1095	3.9	7.0
80 to 2500	25 to 1365	4.0	7.2
80 to 3000	25 to 1650	4.2	7.5
80 to 3500	25 to 1925	4.2	7.5
80 to 4000	25 to 2205	4.2	7.6
80 to 4350	25 to 2400	4.3	7.8

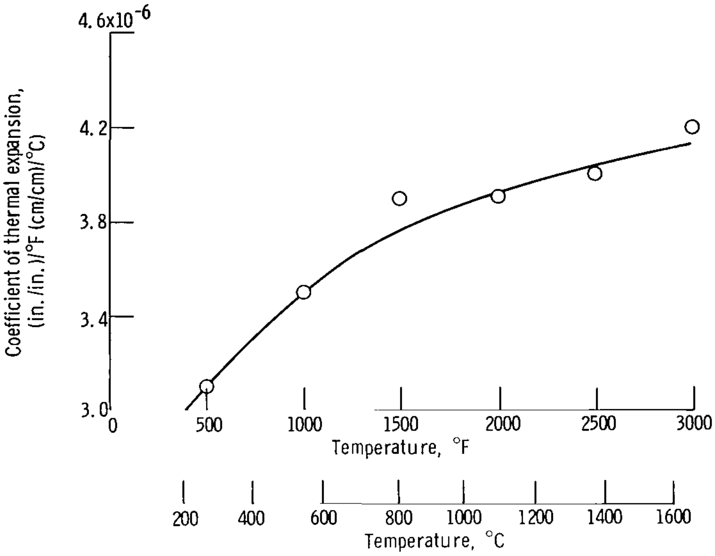


Figure 4. - Average coefficient of thermal expansion of T-111 (ref. 2).

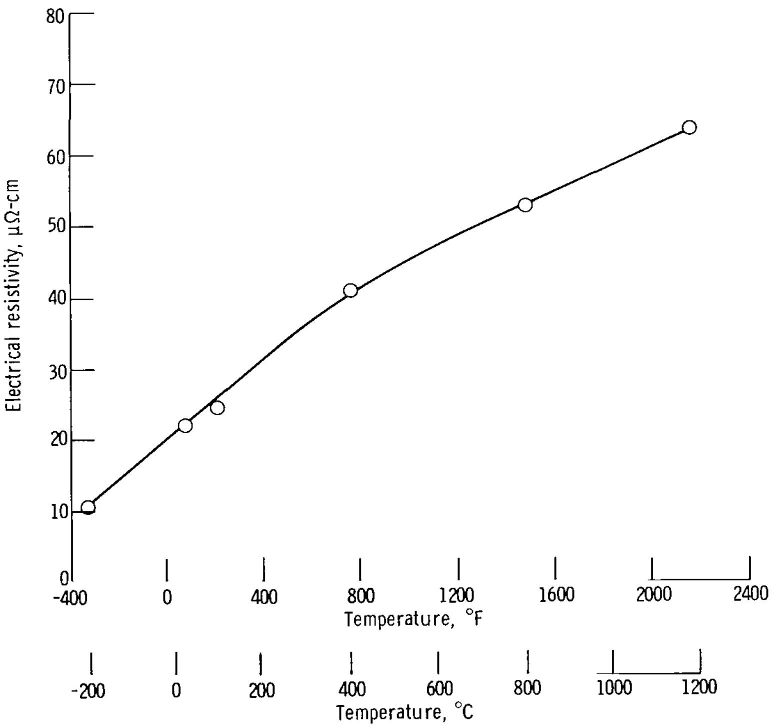


Figure 5. - Electrical resistivity of T-111 (ref. 18).

TABLE II. - TOTAL HEMISPHERICAL EMITTANCE OF T-111 (REF. 14)

Temperature		Emittance
°F	°C	
932	500	0.081
1112	600	.096
1292	700	.111
1472	800	.126
1652	900	.141
1832	1000	.156
2012	1100	.170
2192	1200	.184
2372	1300	.199
2552	1400	.213
2732	1500	.227

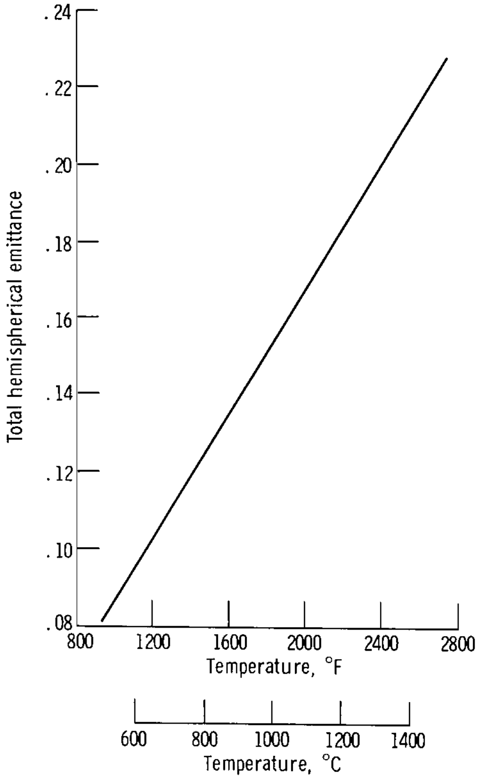


Figure 6. - Total hemispherical emittance of T-111 (ref. 14).

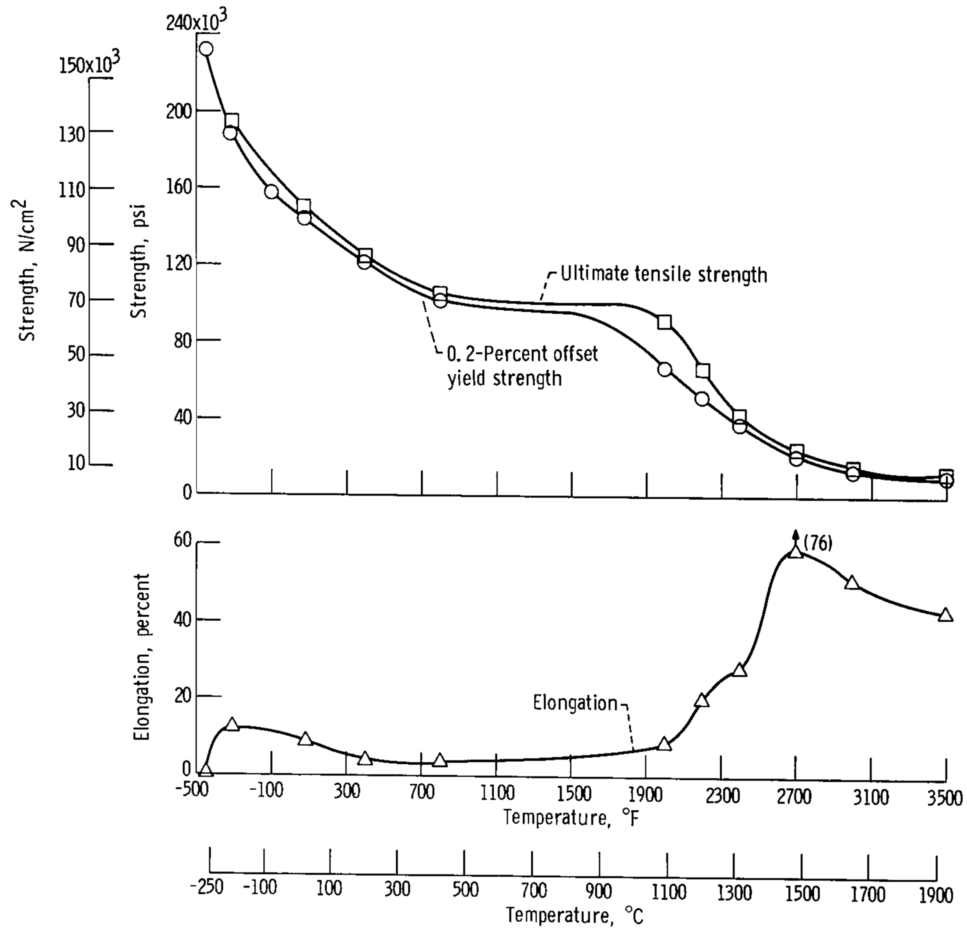


Figure 7. - Tensile data for T-111 0.28-inch (0.71-cm) sheet stress relieved at 2000° F (1093° C) for 1 hour (ref. 18).

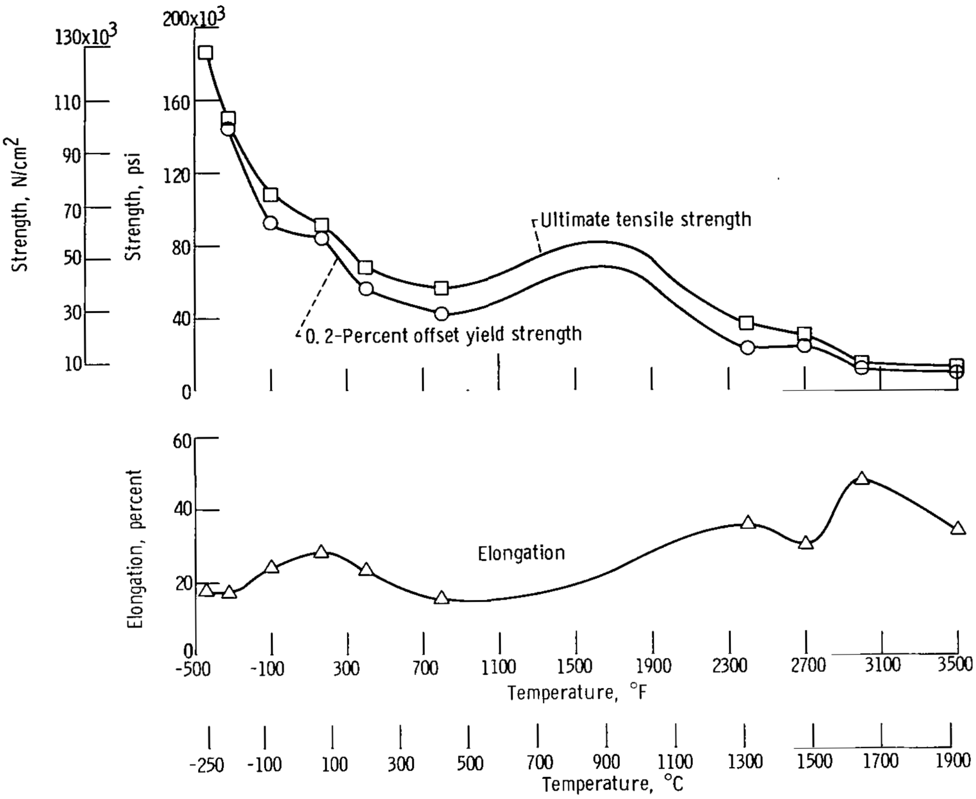


Figure 8. - Tensile data for T-111 recrystallized at 3000° F (1649° C) for 1 hour (refs. 18 and 24).

The modulus of elasticity of T-111 as a function of temperature is shown in figure 9. The values are close to those for pure tantalum.

Creep data for T-111 are shown in table III. These data were obtained from specimens of commercial heats recrystallized at 3000° F (1649° C) and tested in vacuum at less than 10^{-8} torr.

The stress as a function of the Larson-Miller parameter (using a constant of 15) for time to 1 percent creep is plotted in figure 10. Typical time-temperature creep points show a maximum use temperature of 2350° F (1288° C) for 10 000-hour life for 1 percent creep at 2000 psi (1380 N/cm^2).

The utilization of the 3000° F (1649° C) recrystallization temperature results in superior creep properties compared with lower temperatures such as 2600° F (1427° C). This is evident in figure 11, which compares specimens that were taken from the same sheet and tested under the same conditions. The 3000° F (1649° C) annealing temperature was therefore selected as the one that produced the highest creep strength consistent with the capability of commercially available vacuum annealing facilities. Higher annealing temperatures up to 3600° F (1982° C) have been shown to produce higher creep

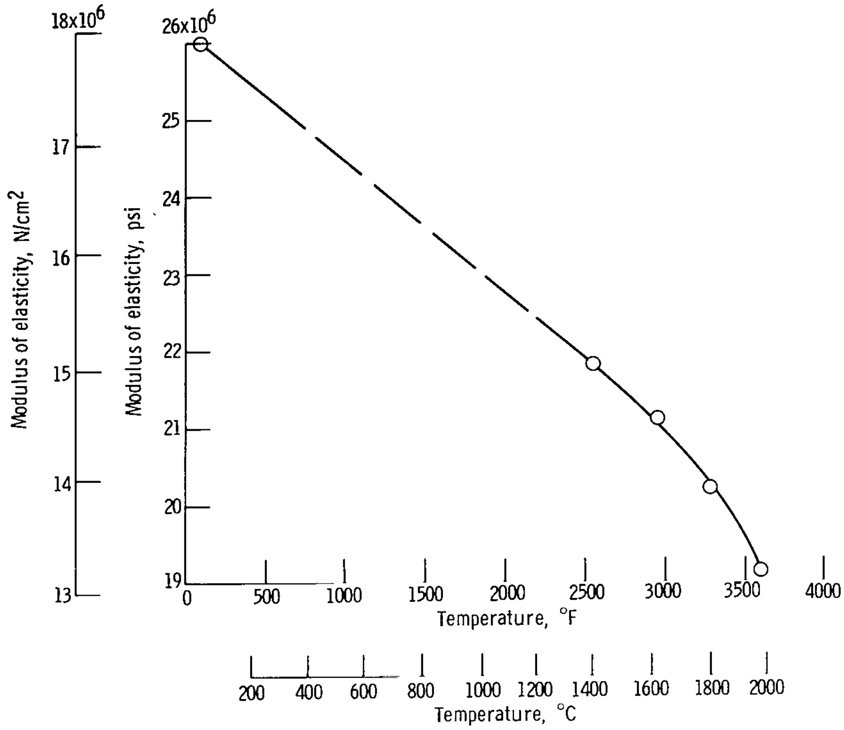


Figure 9. - Modulus of elasticity of T-111 test in vacuum of 5×10^{-6} torr (ref. 19).

strength (unpublished data of R. Titran of Lewis). Higher annealing temperatures, however, also produce larger grain sizes, and the maximum grain size allowable then becomes the limiting factor.

Contamination during creep testing can yield misleading data. In order to demonstrate this, an experiment was conducted (ref. 4) wherein two specimens cut from the same piece of material were creep tested for the same period of time at a stress of 9190 psi (6340 N/cm^2) and a temperature of 2500° F (1371° C). One specimen was tested in a liquid-nitrogen-trapped diffusion-pumped system at 4×10^{-5} to 2.8×10^{-6} torr and the other in an ion-pumped system at 1×10^{-7} to 4.5×10^{-9} torr. These data, summarized in table IV, show that the specimen tested in the ion-pumped system exhibited 10 times the creep rate of the one tested in the diffusion-pumped system. Interstitial analysis revealed that the disparity in test data resulted from the gross pickup of oxygen and carbon by the specimen tested in the diffusion-pumped system. The microstructure of the specimen tested in the ion-pumped system did not show any change, whereas a precipitate (probably a carbide) formed in the specimen tested in the diffusion-pumped system (fig. 12). Thus, it is imperative that specimens be tested under ultrahigh vacuum conditions to guarantee representative data for space applications. Normally, this is in ion-pumped vacuum test units at a pressure of 10^{-8} torr or lower.

TABLE III. - SUMMARY OF T-111 ULTRAHIGH VACUUM CREEP TEST RESULTS (REF. 15)

[Material annealed at 3000° F (1649° C) for 1 hr.]

Test	Heat	Stress		Test temperature		Creep life, hr		Termination of test		Larson-Miller parameter for 1 percent creep, $P = T_{^oR}(15 + \log t_{hr})$
		psi	N/cm^2	°F	°C	1 Percent	2 Percent	Time, hr	Percent creep	
S-19	70616	8.0×10^3	5 510	2200	1204	2 000	3 325	4 870	3.368	48.7×10^3
S-21	70616	12.0	8 260	2200	1204	1 140	1 800	3 840	6.548	48.0
S-23	70616	12.0	8 260	2120	1160	3 150	[a]5 925	3 698	1.225	47.7
S-22	70616	20.0	13 800	2000	1093	670	1 100	1 099	2.010	43.8
S-24	70616	20.0	13 800	1860	1016	4 730	[a]8 100	4 946	1.090	43.3
S-25	D-1670	15.0	10 300	2000	1093	1 340	[a]2 660	1 584	1.210	44.6
S-26	D-1670	17.0	11 700	1800	982	9 540	[a]16 550	9 624	1.030	42.9
S-28	D-1670	.5	340	2600	1427	[a]55 000	[a]136 300	(b)	(b)	60.0
S-27	D-1102	13.0	8 950	2000	1093	1 880	3 350	3 459	2.082	45.0
S-32	D-1102	5.0	3 440	2200	1204	4 050	[a]8 875	4 322	1.042	49.5
S-40	D-1102	17.0	11 700	1800	982	8 558	[a]17 265	8 717	1.028	42.8
S-33	65076	8.0	5 510	2200	1204	2 850	[a]5 350	2 976	1.048	49.1
S-34	65076	11.0	7 580	2000	1093	10 800	[a]21 500	10 875	1.010	46.9
S-30	65079	3.5	2 410	2400	1316	860	1 720	2 137	2.372	51.3
S-31	65079	5.0	3 440	2200	1204	6 160	[a]12 500	6 594	1.092	50.0
S-35	65079	5.0	3 440	2200	1204	5 400	[a]11 000	5 522	1.048	49.9
S-42	65079	3.5	2 410	2300	1263	3 810	[a]7 500	4 247	1.122	51.3
S-47	65079	24.0	16 500	1750	954	[a]38 000	[a]76 500	(b)	(b)	43.3
S-48	65079	2.4	1 650	2330	1275	[a] 5 500	[a]14 390	6 284	1.200	52.3
S-50	65079	8.5	7 220	2000	1093	[a]24 000	--------	5 735	.272	47.7
S-43	65079	18.0	12 400	2000	1093	[a]1 500	[a]2 760	361	.108	44.7
S-44A	65079	9.5	6 550	2172	1189	[a]3 250	--------	467	.152	48.7
S-59	D-1183	13.0	8 950	2000	1093	[a]15 000	--------	(b)	(b)	47.2
S-60	D-1183	35.0	24 100	1600	870	[a]8 500	--------	(b)	(b)	39.0
S-68	650028	1.0	690	2560	1403	2 300	--------	(b)	(b)	55.5
S-69	650028	30.0	20 700	1625	885	(c)	--------	(b)	(b)	(c)
B-43	650028	20.0	13 800	2000	1093	1 823	--------	1 840.8	1.012	44.8
B-44	650028	35.0	24 100	2000	1093	16	--------	55.1	7.582	39.8
P-1	8048	19.0	13 100	2000	1093	[a]2 200	--------	(b)	(b)	----

[a]Extrapolated.
[b]Test in progress.
[c]Insufficient to extrapolate.

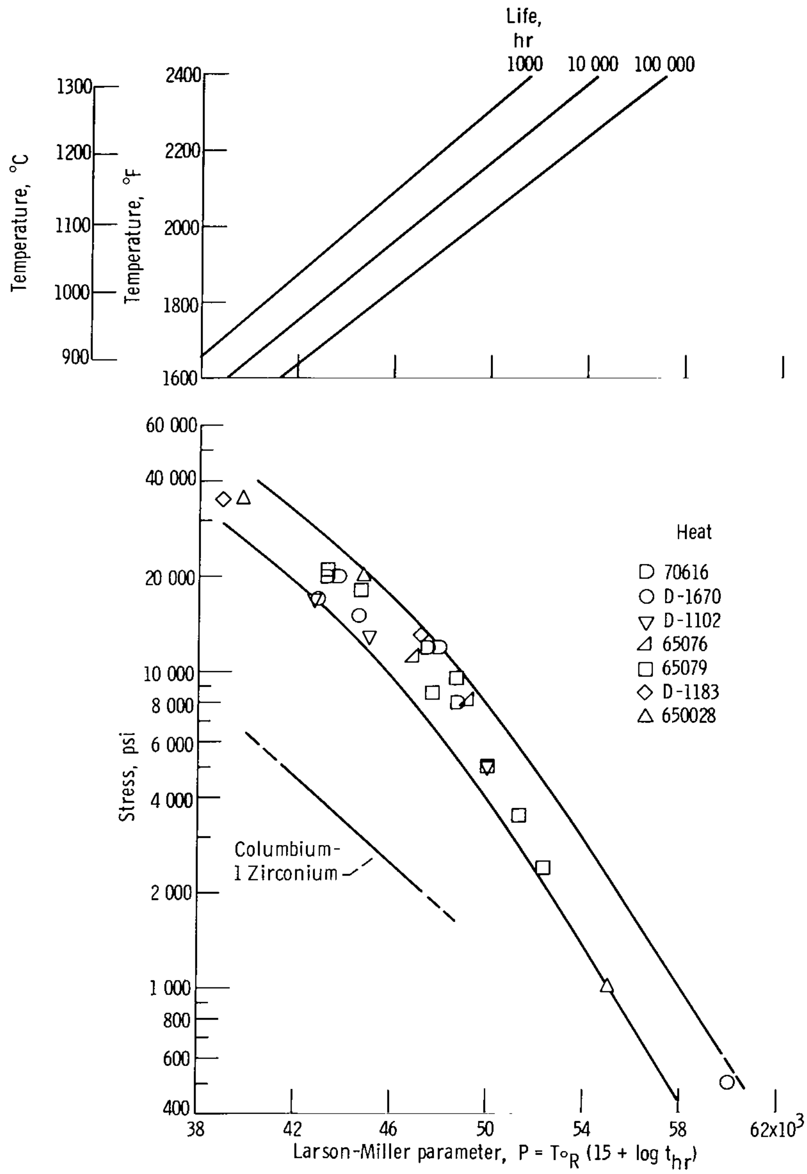


Figure 10. - Stress as function of Larson-Miller parameter for 1-percent creep annealed at 3000° F (1649° C) for 1 hour.

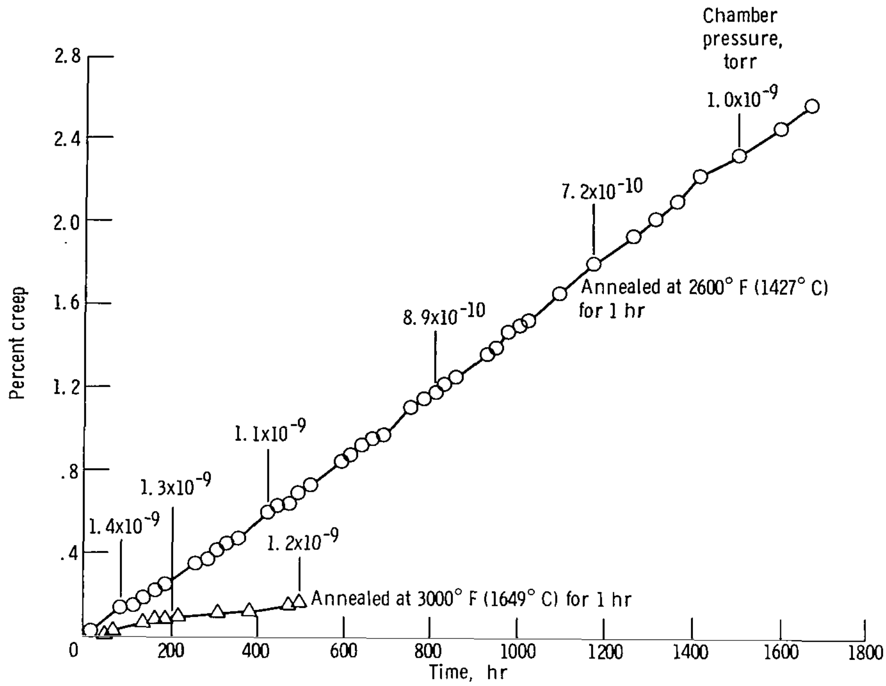
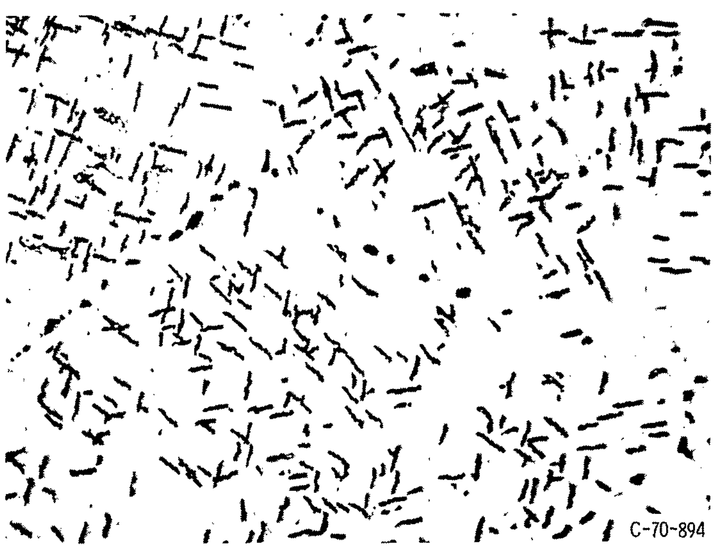


Figure 11. - Creep of T-111 alloy tested at 2200° F (1204° C) and 8000 psi (5.52×10^3 N/cm^2) in vacuum environment of 10^{-8} torr (ref. 20).

TABLE IV. - CONTAMINATION OF T-111 ALLOY CREEP TESTED IN DIFFUSION-PUMPED VACUUM SYSTEM AND IN ION-PUMPED SYSTEM (REF. 4)

	Diffusion pumped	Ion pumped
Pressure, torr		
Start	4×10^{-5}	1×10^{-7}
Finish	2.8×10^{-6}	4.5×10^{-9}
Temperature, ^{o}F; ^{o}C	2500; 1371	2500; 1371
Stress, psi; N/cm^2	9190; 6340	9190; 6340
Time, hr	172	172
Strain, percent	0.3	3.0
Chemical analysis, ppm		
Nitrogen		
Before test	10	10
After test	10	10
Oxygen		
Before test	15	15
After test	290	38
Carbon		
Before test	26	26
After test	260	20

(a) Area near surface of specimen tested in ion-pumped system. X1500.



(b) Area near surface of specimen tested in diffusion-pumped system. X1500.

Figure 12. - Microstructure of T-111 alloy tested in ion-pumped vacuum system and in diffusion-pumped system (ref. 4). Specimen electropolished.

Stress-rupture testing of T-111 has not been extensive. Prior to 1968, the longest duration test point published had been less than 50 hours (ref. 5). Stephenson and McCoy at Oak Ridge National Laboratory (ORNL) have recently performed a stress-rupture investigation of T-111 that includes data of 1800 hours duration (ref. 6). The material was stress relieved at 2192° F (1200° C) and then cold worked 20 percent prior to test, which is an uncommon condition. Although the tests were conducted at a vacuum level on the order of 2×10^{-7} torr, the oxygen content of the test specimens rose from 50 ppm to a level of 100 to 300 ppm during the test. The data of Stephenson and McCoy are presented as a function of the Larson-Miller parameter in figure 13. Also shown are several short-time (< 100 hr) data points obtained by several investigators for T-111 in both the stress-relieved and recrystallized condition. There appears to be a tendency of the Stephenson-McCoy data toward higher strength values as the test temperature was

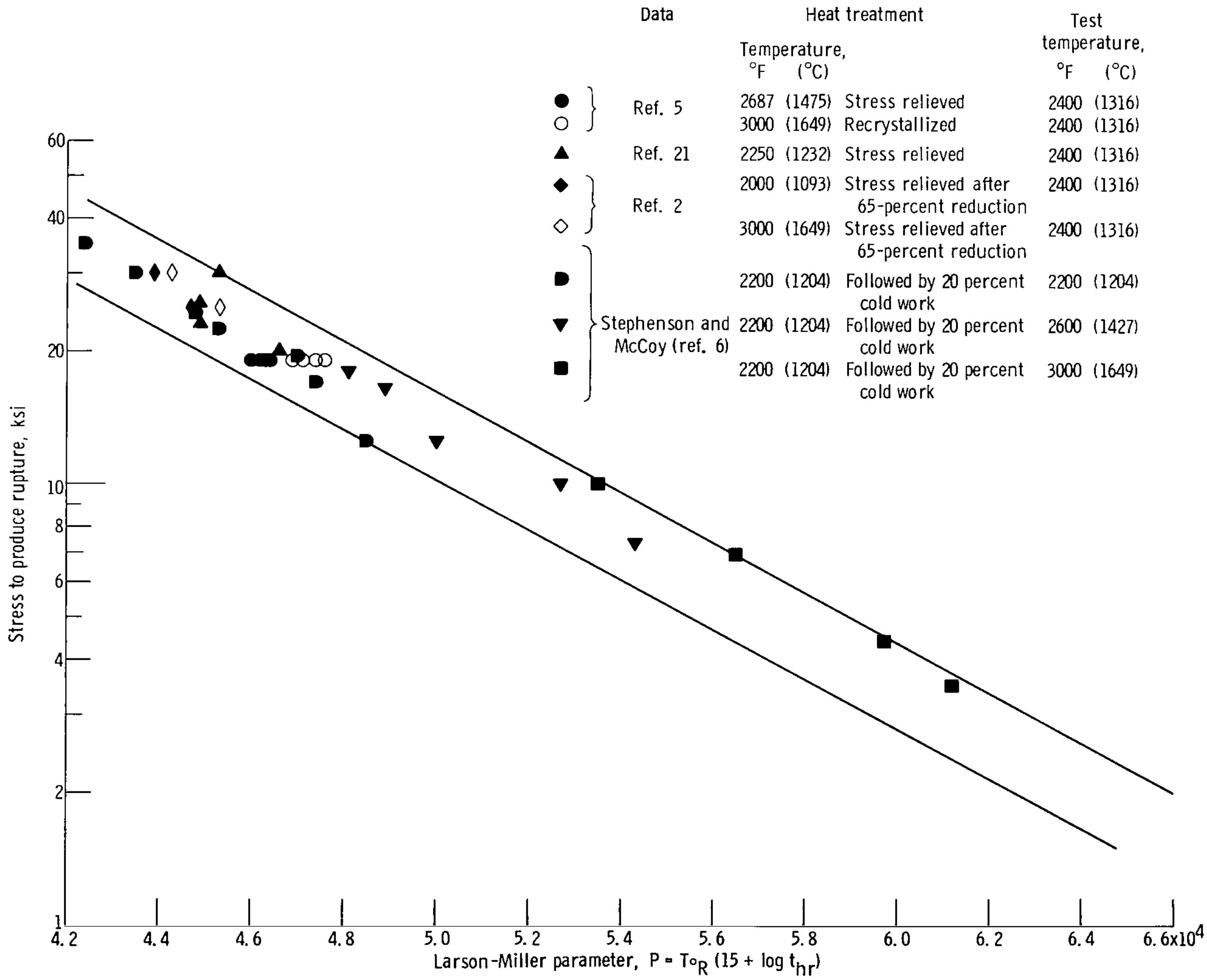


Figure 13. - Stress to produce rupture as function of Larson-Miller parameter for T-111.

increased from 2199° to 3002° F (1204° to 1650° C), which would be expected if oxygen pickup was occurring and creating a significant effect. Whether or not the uncommon pretest metallurgical condition and the increased oxygen content of the ORNL specimens had a significant effect on the stress-rupture strengths observed is not clear, but the authors believe the results should be treated with caution. The short-time data of other investigators, on the other hand, is insufficient to characterize the stress-rupture behavior of T-111. It is therefore evident that more testing would be required to fully characterize the stress-rupture behavior of the material.

T-111 also exhibits an extremely low ductile-to-brittle transition temperature, as determined by the 1-t bend-radius test. Even in the tungsten-inert-gas (TIG) as-welded condition, the transition temperature is -320° F (-196° C).

CONTAMINATION

T-111 is affected by contamination in the same manner as are other tantalum-base alloys. Contamination by oxygen not only increases strength and reduces ductility but also can promote corrosion of the alloy in an alkali-metal environment. As indicated in the previous section, contamination of the alloy can occur during any stage of processing or in service when the temperature exceeds 600° F (316° C) if proper precautions are not taken. The level to which T-111 and other refractory metals will be contaminated is a function not only of the purity of the environment, but also of the temperature and the time at temperature to which the material is exposed. During the processing of an ingot to sheet, annealing in a vacuum of 10^{-5} torr, achieved by means of liquid-nitrogen-trapped diffusion pumps, is normally acceptable when exposure time at temperature is about 1 hour. For long-time exposure at elevated temperatures, a vacuum of less than 10^{-8} torr, achieved by such means as ion pumps or turbomolecular pumps, is required.

The pressure required to avoid exceeding a specified oxygen contamination level at a given time and temperature may be estimated by the kinetic theory of gases. A convenient form of this equation is that used by Inouye (ref. 7). The sticking factor that should be used in this equation is approximately 0.3 (ref. 8).

ALKALI-METAL CORROSION RESISTANCE

The resistance of columbium and tantalum and their alloys to alkali-metal corrosion is dependent in part on the level and disposition of internal oxygen. T-111 is very resistant to alkali-metal attack, as illustrated in figure 14. This corrosion resistance is

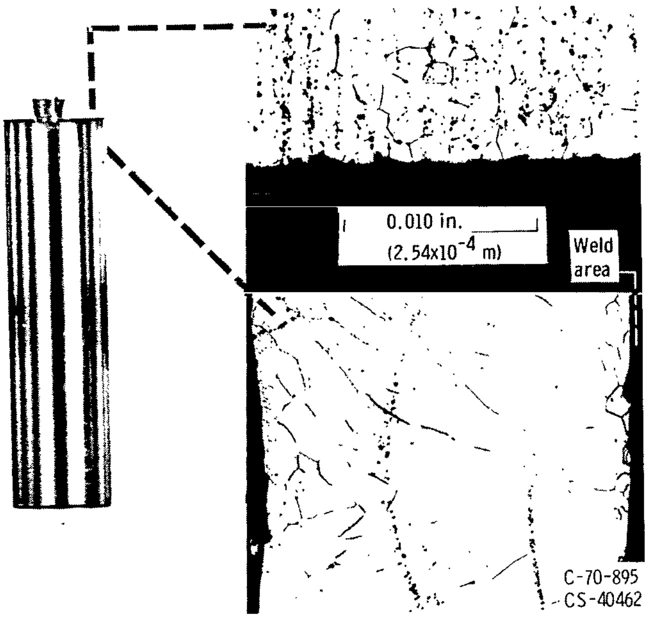


Figure 14. - Corrosion of T-111 gettered alloy by potassium after 2000 hours at 2400° F (1316° C) (ref. 22).

due to the hafnium combining with the oxygen to form oxides that are more stable thermodynamically than alkali-metal oxides. In the absence of strong oxide-forming elements, such as hafnium or zirconium, oxygen can precipitate in the form of tantalum oxides primarily concentrated at the grain boundaries. This can lead to catastrophic attack, since the alkali metal reacts with the less thermodynamically stable tantalum oxides to form a potassium-tantalum complex oxide that is soluble in potassium. This condition is illustrated by Ta-10W (tantalum-10 tungsten), an alloy similar to T-111 but lacking the hafnium (fig. 15). In a much shorter time and at a lower temperature than the T-111 (fig. 14), the Ta-10W was severely corroded. However, the gettering element can become locally saturated with oxygen and, in that case, T-111 and Ta-10W would be attacked in a similar manner. It is thus apparent that, from the standpoint of alkali-metal corrosion resistance, the limitation of oxygen pickup and the maintenance of its proper disposition during fabrication, welding, and heat treatment are extremely critical. Tungsten-inert-gas welding atmospheres must be low in oxygen, nitrogen, and water vapor. Postweld annealing must be utilized to permit the unsaturated hafnium to combine with any base metal oxides formed during welding; postweld annealing and/or heat treatment must be conducted in vacuum at less than 10^{-5} torr.

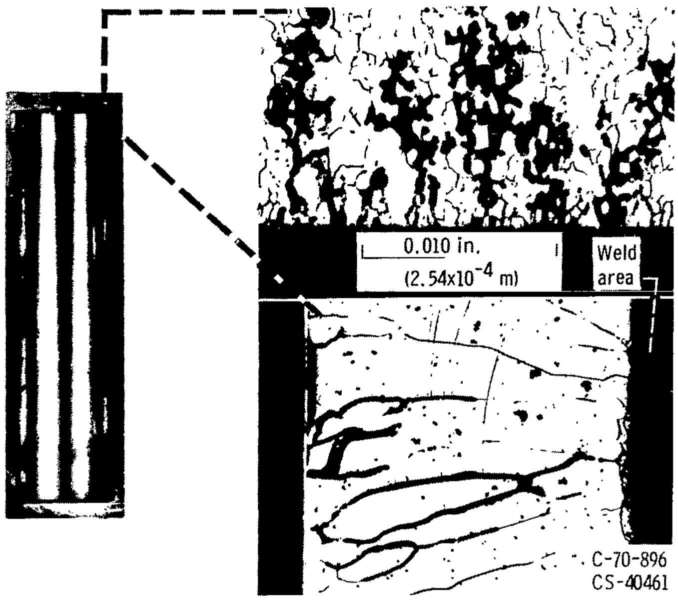


Figure 15. - Corrosion of tantalum-10 tungsten ungettered alloy by potassium after 128 hours at 1800° F (982° C) (ref. 22).

MELTING AND FABRICATION

Several steps are necessary to produce a homogeneous ingot of T-111. First, a master alloy of tantalum and tungsten is produced, normally by electron-beam melting. The hafnium is then alloyed with the master alloy by means of at least two vacuum arc melts. The resultant ingot after machining is usually clad with steel and is hot reduced by extrusion or forging at 2200° to 2300° F (1204° to 1260° C) to a round billet or sheet bar depending on the end product to be produced (ref. 9). When large reductions are to be made, the practice is to clad with molybdenum, which oxidizes sacrificially and also lubricates the surface. Hot reduction is then normally conducted at approximately 3000° F (1649° C). The resultant round billet or sheet bar is surface conditioned, pickled, and recrystallized prior to further breakdown.

Subsequent working to produce a final product such as sheet or tubing is performed at room temperature if possible, but oftentimes a temperature of 600° to 800° F (316° to 427° C) is utilized, particularly when large amounts of reduction are being made.

Surface conditioning of the final product consists of hand grinding to remove minor flaws and pickling to assure cleanliness.

T-111 mill products are readily available, subsequently fabricable and, although power requirements are high, they can be sheared, blanked, spun, drawn, punched, and bent at room temperature without cracking. Lubrication should be used to prevent galling against the tubing. For tubing, a bend diameter of 10 times the tube diameter is presently the minimum utilized. After forming, T-111 parts should be stress relieved since some postforming cracking has been observed.

A great amount of effort has been extended in fabricating T-111 tubing into difficult shapes. Recently, both seamless and welded T-111 tubing have been successfully produced with a 3-inch (7.62-cm) outside diameter and a 0.080-inch (0.203-cm) wall and a 4.25-inch (10.8-cm) outside diameter and a 0.125-inch (0.32-cm) wall. Bellows, 2.125 inches (5.40 cm) long, 0.85-inch (2.16-cm) outside diameter by 0.59-inch (1.50-cm) inside diameter by 0.008-inch (0.020-cm) wall, were successfully produced and utilized in high-temperature alkali-metal valves. These valves operated successfully for 5000 hours during which time hundreds of cycles were accumulated.

MACHINEABILITY

The machineability of T-111 is similar to that of tantalum and other tantalum-base alloys. The material is soft and tends to gall and weld to the cutting tool. High-speed steel tools can be used in all operations. Carbide tools are often used, especially for single point cutting and face milling operations; grade C-2 carbide is recommended. Sharp cutting tools are essential, and high positive rake angles are recommended. Nominal speeds and feeds for various machining operations can be determined from reference 10. The cutting fluids most normally used are soluble oil emulsions. For drilling, reaming, and tapping, however, cutting oils that contain sulfur or chlorine are preferred. T-111 loads grinding wheels rapidly, and frequent dressing of the wheels and plentiful quantities of grinding fluid are required. Normally, wheels with an aluminum oxide abrasive and a vitrified bond are used. T-111 parts should be stress relieved after machining to preclude postmachining cracking, which has occasionally been observed.

WELDING

T-111, in general, has excellent welding characteristics but must be handled properly to avoid contamination during welding. The alloy has been welded by both the tungsten-inert-gas and the electron-beam processes. As previously mentioned, the welding atmosphere must be controlled to avoid oxygen and nitrogen contamination. Copper electrodes must not be used for resistance spot welding of thermocouples to T-111 parts because the copper diffuses into the T-111 and can cause cracks by the formation of a low-melting eutectic with hafnium. Unpublished data from Westinghouse Astronuclear show that nickel can diffuse into T-111 and cause cracking by eutectic formation with hafnium. Contact with any metals that form low-melting-point eutectics with hafnium should be avoided.

Tungsten-Inert-Gas Welding

Parts should be properly prepared for welding to avoid porosity or contamination. Particular care should be exercised when sheared edges are to be butt welded, since improper preparation can result in unacceptable porosity due to residue from the cleaning operation. Several methods of decreasing a tendency toward porosity are machining the edges prior to welding or pickling with 20 percent nitric acid, 15 percent hydrofluoric acid, 10 percent sulfuric acid, balance water, and removing the pickling residue (or hydrogen) by vacuum annealing at 2000° F (1093° C) for 1 hour (ref. 11). Acceptable contamination levels in the welding chamber are less than 5 ppm for oxygen, less than 10 ppm for water, and less than 15 ppm for nitrogen. In order to achieve and maintain these levels, the welding chamber must be capable of being pumped down to 10^{-5} torr or less with a maximum leak rate of 3×10^{-5} torr per minute. The welding chamber should also be capable of being heated to 120° to 200° F (49° to 93° C) by means of circulating water or heat lamps to reduce subsequent wall outgassing of water vapor during welding. The chamber should then be backfilled with helium or argon having an oxygen-plus-water-vapor content of less than 1 ppm and a nitrogen content of less than 5 ppm. Neoprene gloves that have been checked for sulfur emission appear to be the most satisfactory for use in welding chambers (ref. 12). The atmosphere in the chamber should be monitored for oxygen and water vapor and the welding discontinued when the oxygen content exceeds 5 ppm or the water vapor exceeds 20 ppm.

Welding parameters of 15 inches per minute (38.1 cm/min), 3/8-inch (0.95-cm) clamp spacing, and 115 amperes have produced excellent welds in 0.035-inch (0.089-cm) sheet. Even the poorest set of parameters utilized, however, gave a ductile-to-brittle transition temperature of -225° F (-143° C) with a 1-t bend radius, which suggests that welding parameters are not extremely critical to maintaining good ductility in T-111.

Electron-Beam Welding

Electron-beam welding was studied with a 150-kilovolt electron-beam welder (ref. 13). Variation of the voltage over the range of 70 to 150 kilovolts using the minimum beam diameter did not influence weld configuration. Cyclic beam deflection in the longitudinal and transverse directions was also investigated. Parameters were set to give 110 percent of theoretical full penetration. All the welds made within this range of parameters had a ductile-to-brittle transition temperature of -320° F (-196° C).

Plate Welding

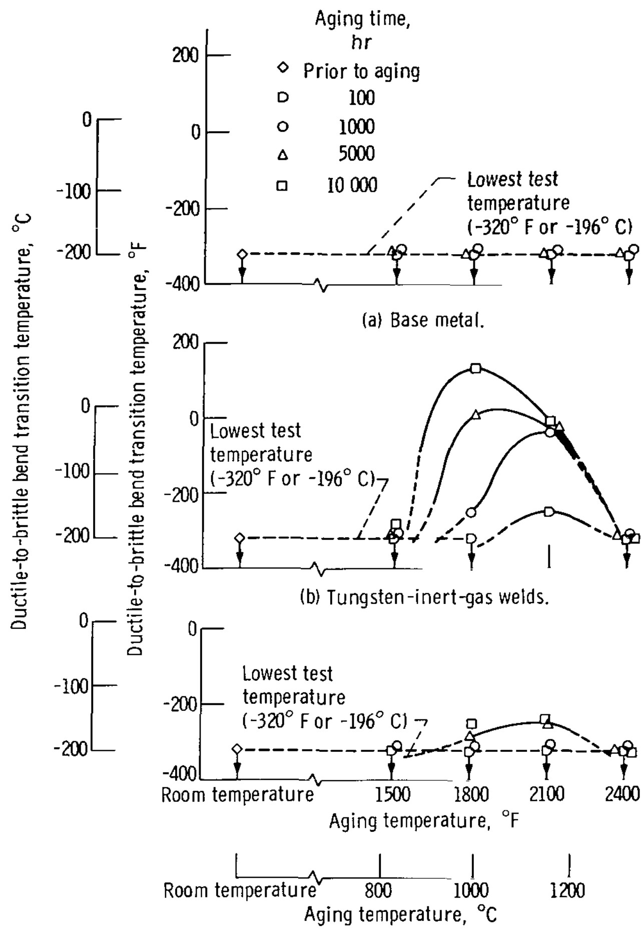
Plate welding tests were accomplished by manual tungsten-arc welding using helium shield gas in a weld box monitored for both oxygen and water vapor (ref. 13). The maximum moisture level was set at 10 ppm as a practical concession because of a higher heat input and the attendent outgassing in the chamber. A pickup of oxygen of 7 to 12 ppm was not statistically significant. The ductile-to-brittle transition temperatures were 120° to 140° F (49° to 60° C) over a 3-t bend radius. A cracking problem was encountered, however, in the multiple-pass tungsten-inert-gas welds in plates. Cracks did not occur in single-pass welds or in the final pass of a multipass weld. The cracks are caused by grain boundary separation, which indicates a weaker grain boundary than the matrix.

Plate sections up to 0.4 inch (1.01 cm) thick have, however, been successfully welded by the electron-beam method. These were single-pass welds and were given a postweld anneal.

POSTHEATING AND AGING EFFECTS

As mentioned previously in the Alkali-Metal Corrosion Resistance section, when T-111 is to be utilized for alkali-metal containment, a postweld anneal of 1 hour at 2400° F (1316° C) is required. After postweld annealing, the weld zones exhibit an aging reaction (as measured by an increase in the bend ductile-to-brittle transition temperature employing a 1-t bend radius) when the welds are held at a range of elevated temperatures for long times (see fig. 16). The aging effects are more pronounced on tungsten-inert-gas welds than on electron-beam welds. At 1500° and 2400° F (816° and 1316° C), no effect is noted, but the effect can clearly be seen at 1800° and 2100° F (982° and 1149° C). The reaction is most severe at 1800° F (982° C).

It is recognized that, although the 1-t bend radius test is a severe test of ductility, it is not actually quantitative. In order to determine quantitative values, as-welded and postweld annealed specimens were aged at various temperatures and times and were then tensile tested at 32° F (0° C). Representative results are shown in table V. It can readily be seen that all specimens, including those with transition temperatures above 32° F (0° C) (notably specimens 5A, 5B, 57A, 8A, and 42A, table V) have more than adequate ductility (22 to 28 percent elongation and 44 to 57 percent reduction of area with



(c) Electron-beam welds.

Figure 16. - Ductile-to-brittle bend transition temperature of T-111 as function of aging parameters (1-t bend radius) (ref. 23).

uniform elongations of 13.6 to 16.5 percent). As-welded specimens that were aged for 5000 hours at 2100° F (1149° C) and had transition temperatures of 80° F (27° C) exhibited a total elongation of 25 percent and a reduction of area of 28 percent at failure.

It is apparent from this test series that, although the 1-t bend radius transition temperature of T-111 is increased to as high as 150° F (66° C) because of in-service aging (with or without postweld annealing), the tensile ductility of the material at temperatures as low as 32° F (0° C) is not affected.

Some aging response was noted in electron-beam welds postweld annealed over the temperature range of 2400° to 2700° F (1316° to 1482° C). The increase in the ductile-to-brittle transition temperature was less than that with tungsten-inert-gas welds and, hence, is of doubtful engineering significance.

TABLE V. - LONGITUDINAL TENSILE PROPERTIES OF T-111 TUNGSTEN-INERT-GAS WELDS AT 32° F (0° C) (REF. 16)

Specimen	Weld type	1-Hour postweld annealing temperature		Stability aging time, hr at 2100° F (1149° C)	1-t Bend transition temperature		Tensile properties						
							0.2-Percent yield strength[a]		Ultimate stress		Uniform strain, percent	Elongation, percent	Reduction in area, percent,
		°F	°C		°F	°C	psi	N/cm²	psi	N/cm²			
2A	Low heat input, 15 in./min (38.1 cm/min)	None	None	None	-320	-196	79 700	54 950	97 600	67 300	13.6	22	44
5A	9730 J/in. (3830 J/cm)	None	None	1000	125	52	74 900	51 640	91 000	62 700	15.8	26	57
20A	↓	2500	1371	None	-320	-196	79 000	54 470	92 000	63 400	16.4	28	44
5B	↓	2500	1371	1000	125	52	76 200	52 540	92 300	63 600	16.5	25	56
25B	↓	2700	1482	None	-320	-196	79 900	55 100	92 800	64 000	15.2	27	50
8A	↓	2700	1482	1000	125	52	75 400	52 000	91 100	62 800	15.8	25	50
39A	High heat input, 6 in./min (15.25 cm/min)	2400	1316	1000	-50	-46	74 000	51 000	89 200	61 500	16.1	28	52
42A	18 900 J/in. (7440 J/cm)	2600	1427	1000	150	66	73 200	50 500	87 900	60 600	16.5	25	49

[a]Strain rate, 0.005 (in./in.)/min (0.005 (cm/cm)/min) to 0.5 percent yield strength, then 0.05 (in./in.)/min (0.05 (cm/cm)/min) to failure.

CONCLUSIONS

From this survey of the properties of the tantalum alloy T-111 (tantalum-8 tungsten-2 hafnium), the following conclusions were drawn:

1. T-111 is very strong up to 2400° F (1316° C) and is ductile even at -320° F (-196° C).

2. On the basis of 1 percent creep strain in 10 000 hours at a stress of 2 000 psi (1380 N/cm^2), the maximum temperature of application of the alloy is 2350° F (1288° C).

3. Although power requirements are high, T-111 can be bent or otherwise formed at room temperature.

4. T-111, in general, has excellent welding characteristics.

5. T-111 is high resistant to alkali-metal corrosion up to at least 2300° F (1260° C).

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 24, 1970,
120-27.

REFERENCES

1. Amon, R. L.; and Begley, R. T.: Pilot Production and Evaluation of Tantalum Alloy Sheet. Rep. WANL-PR-(M)-003, Westinghouse Elec. Corp., Feb. 16, 1963.

2. Begley, R.: T-111 Tantalum-Base Alloy Refractory Metal. Special Tech. Data 52-365, Westinghouse Elec. Corp., Mar. 1963.

3. Buckman, R. W., Jr.; and Begley, R. T.: Development of Dispersion Strengthened Tantalum-Base Alloy. Rep. WANL-PR-(Q)-009, Westinghouse Elec. Corp. (NASA CR-54935), 1966.

4. Buckman, R. W.: Operation of an Ultra High Vacuum Creep Testing Laboratory. Presented at the Ninth Annual Conference on Vacuum Metallurgy, American Vacuum Society, New York, N.Y., June 27-29, 1966.

5. Harrison, R. W., ed.: Advanced Refractory Alloy Corrosion Loop Program. General Electric Co. (NASA CR-72335), Apr. 15, 1967.

6. Stephenson, R. L.; and McCoy, H. E., Jr.: The Creep-Rupture Properties of Some Refractory Metal Alloys. III. Comparative Mechanical Behavior of Some Tantalum-Base Alloys. J. Less-Common Metals, vol. 15, no. 4, Aug. 1968, pp. 415-424.

7. Inouye, H.: Contamination of Refractory Metals by Residual Gases in Vacuums below 10^{-6} Torr. Rep. ORNL-3674, Oak Ridge National Lab., Sept. 1964.

8. Harrison, R. W.; and Hoffman, E. E.: Contamination of Tantalum and Tantalum Alloys in Low Pressure Oxygen Environments. Presented at the American Vacuum Society Vacuum Metallurgy Conference, Beverly Hills, Calif., June 10-13, 1968.

9. Filippi, A. M.: Production and Quality Evaluation of T-222 Tantalum Alloy Sheet. Rep. WANL-PR-KK-003, Westinghouse Elec. Corp., Jan. 31, 1968. (Available from DDC as AD-837296.)

10. Lyman, Taylor, ed.: Machining. Vol. 3 of Metals Handbook. Eighth ed., ASM, 1967.

11. Lessmann, G. G.: The Comparative Weldability of Refractory Metal Alloys. Welding J. Res. Suppl., vol. 45, no. 12, Dec. 1966, pp. 540-s to 560-s.

12. Lessmann, G. G.; and Stoner, D. R.: Determination of Weldability and Elevated Temperature Stability of Refractory Metal Alloys. Rep. WANL-PR-(P)-005, Westinghouse Elec. Corp. (NASA CR-54232), 1964.

13. Lessmann, G. G.; and Stoner, D. R.: Determination of the Weldability and Elevated Temperature Stability of Refractory Metal Alloys. Rep. WANL-PR-(P)-006, Westinghouse Elec. Corp. (NASA CR-54301), 1965.

14. Peterson, Sigferd, ed.: Metals and Ceramics Division Annual Progress Report for Period Ending June 30, 1964. Rep. ORNL-3670, Oak Ridge National Lab., Oct. 1964.

15. Sheffler, K. D.: Generation of Long Time Creep Data on Refractory Alloys at Elevated Temperatures. TRW Equipment Labs. (NASA CR-72632), July 7, 1969.

16. Lessmann, G. G.: Determination of Weldability and Elevated Temperature Stability of Refractory Metal Alloys. Rep. WANL-PR-(P)-016, Westinghouse Elec. Corp., Oct. 1969.

17. Kueser, P. E.; Toth, J. W.; and McRae, R. C.: Bore Seal Technology Topical Report. Rep. WAED-64-54E, Westinghouse Elec. Corp. (NASA CR-54093), Dec. 1964.

18. Ammon, R. L.; and Begley, R. T.: Pilot Production and Evaluation of Tantalum Alloy Sheet. Rep. WANL-PR-M-006, Westinghouse Elec. Corp., Oct. 15, 1963.

19. Astronuclear Lab. Staff: Elastic Modulus and Thermal Expansion of Tantalum T-111 Alloy. Westinghouse Electric Corp., Feb. 1964.

20. Sawyer, J. C.; and Steigerwald, E. A.: Generation of Long-Time Creep Data of Refractory Alloys at Elevated Temperatures. TRW Equipment Labs. (NASA CR-54895), Jan. 8, 1966.

21. Anon.: Data Sheet on Ta-10W and Ta-8W-2Hf Alloy Sheet. National Research Corp., May 2, 1963.

22. Anon.: Space Power Systems Advanced Technology Conference. NASA SP-131, 1966.

23. Lessmann, G. G.; and Gold, R. E.: Determination of the Weldability and Elevated Temperature Stability of Refractory Metal Alloys. Rep. WANL-PR-(P)-014, Westinghouse Elec. Corp., Oct. 1969.

24. Sheffler, K. D.; Sawyer, J. C.; and Steigerwald, E. A.: Mechanical Behavior of Tantalum-Base T-111 Alloy at Elevated Temperature. NASA CR-1436, 1969.

NASA-Langley, 1970 —— 17 E-5562

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546