

1. **GENERAL**
 T-222 is a moderate strength tantalum base alloy, developed under sponsorship of the Naval Air Systems Command (formerly Bureau of Naval Weapons)(1)(2)(3)(4). This alloy has a higher short-time elevated strength and improved creep resistance, as compared with T-111 (Ta-8W-2Hf). These improved properties are attributed to its higher solute content and the formation of the HfC dispersed second phase, and are achieved with only slight sacrifice in the excellent ductile-to-brittle weld behavior and fabricability of T-111. It is available in all mill forms.

1.01 **Commercial Designation**
 T-222 (Ta-10W-2.5Hf-0.01C)

1.02 **Alternate Designations**
 WC-222, Fansteel-222

1.03 **Specifications**
 Westinghouse PDS 30112-3

1.04 **Composition**
 Table 1.04

TABLE 1.04
 Westinghouse PDS 30112-3

Source	Percent	
	Minimum	Maximum
Carbon	0.008	0.0175
Nitrogen	---	0.0050
Oxygen	---	0.0100
Hydrogen	---	0.0010
Columbium	---	0.1000
Molybdenum	---	0.0200
Nickel	---	0.0050
Cobalt	---	0.0050
Iron	---	0.0050
Vanadium	---	0.0020
Tungsten	9.6	11.2
Hafnium	2.2	2.8
Tantalum	Balance	

1.05 **Heat Treatment**
 1.051 Stress relief, 2400F, 1 hour (vacuum, 1×10^{-5} torr or less).

1.052 Recrystallization, 2950-3050F, 1 hour with 80-90 percent cold work prior to final anneal. An equiaxed grain structure is discernable after 1 hour at 2500F on 90 percent cold-worked sheet, but 1 hour at 2600F is needed for full recrystallization (5).

1.053 Post weld heat treatment, 2400F, 1 hour (20).

1.054 Effect of annealing temperature on grain size, Figure 1.054 (5).

1.06 **Hardness**

1.061 Effect of annealing temperature on hardness, Figure 1.061 (5).

1.07 **Forms and Conditions Available**

Sheet	0.005 inch to 0.250 inch x random width and length
Rod	0.125 inch to 2.5 inches
Plate	0.125 inch to 1.0 inch x random width and length
Tubing	Special order
Wire	0.002 inch to 0.125 inch

1.08 **Melting and Casting Practice**

1.081 Starting electrodes are prepared from Ta-10W, Hf, and carbon. The Ta-10W master is prepared by electron beam melting. First melt ingots, 5.5 inches in diameter, are cast by consumable electrode technique, assembled into a second melt electrode, and remelted to produce an ingot 9 inches in diameter. Both first and second melting is done in vacuum.

1.09 **Special Considerations**

1.091 Heating of T-222 to incandescent temperatures for a short time results in a contaminated surface. Preventative measures must be taken, ie, heat in a vacuum, ultra-pure He or Ar, wrap in Ta foil, or can in Mo.

1.092 Creep tests lasting over 100 hours must be conducted in vacuums of 10-8 torr or less.

1.093 Use of hydrogen, nitrogen, carbon monoxide (CO), or high dew point (above -40F) inert gases for heat treat atmospheres must be avoided.

2. **PHYSICAL AND CHEMICAL PROPERTIES**

2.01 **Thermal Properties**

2.011 Melting point, 5400F estimated.

2.012 Phase changes.

2.0121 Time-temperature-transformation diagrams.

2.013 Thermal conductivity.

2.014 Thermal expansion.

2.015 Specific heat, approximately 0.036 BTU per lbF(32F).

2.016 Thermal diffusivity.

2.02 **Other Physical Properties**

2.021 Density, 0.604 lbs per cubic inch, 16.7 grams per cubic centimeter.

2.022 Electrical properties.

2.023 Magnetic properties.

2.024 Emissivity.

2.025 Damping capacity.

2.03 **Chemical Properties**

2.031 T-222, being a gettered alloy (Hf), is more stable in potassium than unalloyed Ta(6). Capsules made from this alloy when exposed to refluxing potassium for 4000 hours at three temperatures up to 2400F showed no corrosive attack (7). Films were found at the liquid-vapor interface on the capsules exposed to temperatures over 2200F. Film was identified as $K_2Ta_4O_{11}$ and WO_3 .

2.0311 Corrosion of T-222 capsules exposed to high purity potassium, Table 2.0311.

TABLE 2.0311

Source		(7)		
Alloy		Ta-10.0W-2.5Hf-0.01C		
Form		Tubing		
Condition		Recrystallized, 3000F High Purity Potassium, < 20 ppm O_2 High Vacuum Chamber, 10^{-7} to 10^{-8} torr		
Temp, F	Time, hrs	Corrosive Attack	Oxygen in Capsule Walls, ppm	
			Pretest	Post test
1800	4000	No attack		
2200	4000	No attack, film		
2400	4000	No attack, film	48	57

2.032 T-222 sheet specimens welded under conditions which varied from a chamber evacuated to 2×10^{-5} torr to 2×10^{-2} torr (and back filled with 99.996 percent argon) were exposed to lithium at 2192F for 100 hours. The specimens showed no corrosion (8). On those specimens which were doped with 500 ppm O_2 before welding, areas of the base metal were heavily attacked. Annealing at 2400F eliminated the attack.

2.033 When T-222 is to be used as a structure at elevated temperatures in an oxidizing atmosphere, it requires a protective coating (see 4.054).

2.034 The alloy is inert to most acid reagents.

2.04 **Nuclear Properties**

2.041 Thermal neutron absorption cross section is 21.3 barns per atom (for pure Ta).

Ta
9.6 W
2.4 Hf
0.01 C

T-222

Ta
9.6 W
2.4 Hf
0.01 C
T-222

3. MECHANICAL PROPERTIES
3.01 Specified Room Temperature Mechanical Properties
Table 3.01

TABLE 3.01

Source	Westinghouse Purchasing Dept Spec 30112-3
Alloy	Ta-10W-2.5Hf-0.01C
Form	Bar or Rod
Condition	Cold Worked, Recrystallized 3000F
F _{tu} , ksi	135, maximum
F _{ty} , ksi	125, maximum
e, in 4D, percent	15, minimum

3.02 Mechanical Properties at Room Temperature
3.021 Tension.
3.0211 Stress-strain diagrams.
3.0212 Room temperature mechanical properties, Table 3.0212.

TABLE 3.0212

Source	(13)(14)(15)					
Alloy	Ta-10W-2.5Hf-0.01C					
Form	Sheet					
Condition	Cold-worked, recrystallized 1 hr at 3000F					
Direction	L(b)			T(a)		
Thickness, inch	.018	.040	.030	.018	.040	.030
F _{tu} , ksi	---	117.9	121.7	125.7	130.0	123.2
F _{ty} , ksi	---	105.5	110.5	110.6	113.7	113.8
e(1 inch), percent	---	26.3	24.6	25.0	23.5	24.7
F _{su} , ksi	---	---	---	---	89.2	---
F _{cy} , ksi	---	105.9	---	---	(c)	---
(a) Strain rate - 0.005 in/in/min up to 4 percent yield and 0.5 in/in/min to failure						
(b) Strain rate - 0.005 in/in/min to 0.6 percent offset and 0.05 in/in/min to failure						
(c) Loaded at crosshead speed of 0.010 in/min						
(d) Recrystallized rod (3000F, 1 hour) using strain rate of 0.005 in/in/min						

- 3.022 Compression (see Table 3.0212)
3.0221 Stress-strain diagrams.
3.023 Impact.
3.024 Bending (see 4.0323).
3.025 Torsion and shear (see Table 3.0212).
3.026 Bearing.
3.027 Stress concentration.
3.0271 Notch properties.
3.02711 Room temperature and cryogenic temperature notched and smooth tensile properties, Table 3.02711.

TABLE 3.02711

Source	(5)					
Alloy	Ta-10W-2.5Hf-0.01C					
Form	Sheet, 0.030 inch					
Condition	90 percent cold worked, recrystallized 1 hr, 3000F					
Notch	Per MAB-216-M, (c) 0.005 inch notch radius, 60°					
	Room Temp(a)		-200F(b)		-320F(b)	
	A	B	A	B	A	B
F _{tu} , ksi	145.4	121.7	179.2	145.5	209.7	176.0
ratio, A/B	1.19		1.23		1.19	
A- Notched B- Smooth						
(a) Average of 18 specimens, from 9 different sheets						
(b) Average of 2 specimens, from 2 different sheets						
(c) MAB-216-M specimen, pin loaded, gauge length 1 inch long by 0.5 inch wide						

- 3.0272 Fracture toughness.
3.028 Combined properties.
3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.0312 Effect of test temperature on the tensile properties of recrystallized and stress relieved sheet, Figure 3.0312.
3.032 Compression
3.0321 Stress-strain diagrams.
3.033 Impact.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.0372 Fracture toughness.
3.038 Combined properties.
3.04 Creep and Creep Rupture Properties
3.041 Creep rate and time to achieve 1 percent strain, Table 3.041.

TABLE 3.041

Source	(15)			
Alloy	Ta-10W-2.5Hf-0.01C			
Form	Sheet, 0.030 inch			
Condition	85 percent cold worked, stress relief 2400F, 2 hrs, recrystallized 2800F, 1 hr			
Test	Vacuum, 10 ⁻⁵ torr			
Temp F	Stress, σ ksi	Creep Rate, e, sec ⁻¹	Time to Achieve 1 percent strain, hr	
2000	16.0	4.8x10 ⁻¹¹	(a)	
2000	20.0	1.0x10 ⁻¹⁰	(b)	
2200	8.0	3.6x10 ⁻¹⁰	7500	
2200	12.0	1.2x10 ⁻⁹	2600	
2200	16.0	2.8x10 ⁻⁹	860	
2400	2.5	4.0x10 ⁻¹⁰	5100	
2400	4.0	1.6x10 ⁻⁹	1500	
2400	6.0	3.8x10 ⁻⁹	880	
2400	8.0	8.1x10 ⁻⁹	320	
2600	2.5	7.7x10 ⁻⁹	330	
2600	4.0	1.8x10 ⁻⁸	135	
(a) Test terminated after 10,000 hrs with 0.22 percent strain				
(b) Test in progress; 0.45 percent strain at 5100 hours				

- 3.042 Effect of temperature on allowable stress to achieve 1 percent total strain in 10,000 hours, Figure 3.042.
3.043 Effect of temperature and stress on creep properties for material recrystallized at 2500 and 3000F, Figure 3.043.
3.044 Stress rupture data of sheet at 2400F, Table 3.044.

TABLE 3.044

Source	(5)			
Alloy	Ta-10W-2.5Hf-0.01C			
Form	Sheet, 0.030 inch			
Condition	90 percent cold worked, recrystallized 3000F, 1 hr			
Test	Vacuum, <10 ⁻⁵ torr, 2400F			
Stress ksi	Transition(a) Time, hrs	Min Creep Rate Percent/Hr	Rupture Time, hrs	
33.0	3.0	0.320	12.8	
25.0	8.0	0.016	57.6	
33.0	2.2	0.488	8.4	
25.0	7.5	0.090	59.7	
(a) Second to third stage creep				

- 3.05 Fatigue Properties
3.051 Comparison of fatigue properties of bare T-222 and coated T-222 at room temperature, Figure 3.051.
- 3.06 Elastic Properties
3.061 Poisson's ratio.
3.062 Modulus of elasticity, Figure 3.062.
3.063 Modulus of rigidity.
4. FABRICATION
- 4.01 Formability
4.011 General. The alloy has good forming characteristics. It can be blanked, punched, sheared, drilled, and reamed without edge cracking at room temperature. All normal sheet metal forming operations—bending, brake forming, drawing, and spinning—can be practiced at room temperature (18).
4.012 Extrusion.
4.0121 The cast ingot is lath conditioned. A typical sequence calls for turning a 9 inch ingot to an approximate 8.44 diameter, jacketing with 1/4 inch mild steel, heating the canned ingot to 2200F, and extruding using a 2 to 1 ratio.
4.013 Forging.
4.0131 Extruded billets can be side forged readily at 2200F, after a 3000F, 1 hour heat treatment (5).
4.014 Rolling.
4.0141 Rolling of forged sheet bar is customarily accomplished at 800F until a thickness of 0.150 inch is achieved. Subsequent rolling is accomplished at room temperature.
4.015 Fabrication of hot sections can be made at room temperature using conventional drop hammer practice.
- 4.02 Machining and Grinding
4.021 Shearing. This has proven to be a practical method of separating blank parts from sheet stock. Standard production shears equipped with a sharp blade and set for a clearance of 0.001 to 0.002 inch is recommended for producing clean, sound edges (18).
4.022 Band sawing. A Starrett blade No. T-SBCS-12, or equivalent, with 32 teeth per inch and wavy set when operated at 75 sfpm, with a Macco (or equivalent) water soluble oil coolant, provides the best life and most material cut (18).
4.023 Milling. It is difficult to achieve a good finish on a milled surface. Following is considered to be the best recommendation (18).
4.0231 Conventional milling for rough and finish cuts:
Cutter High speed steel
Speed 30-35 feet per minute
Feed 0.001 to 0.003 inch per flute
Depth 0.10 inch for rough reverse climb mill, zero set for finish
Coolant Macco-water solution (1 to 30)
4.024 Drilling. Obtaining good finishes is difficult.
Drill Cobalt high speed steel
Shape Straight or stepped
Speed 660 RPM
Feed 0.0015 inch per revolution
Coolant Macco-water solution (1 to 30)
4.025 Reaming and countersinking.
Tool High speed steel
Feed Hand-fed
Shape 6 flute
Speed 325 RPM (ream)
250 RPM (countersink)
4.026 Single point cutting. Cemented carbide tools with cutting speeds of the order of 100 sfm will produce good results. Too slow speed causes tearing. The tool design should include:
10° back rake
5° side rake
5° side clearance
45° trail angle
0.020 inch nose radius

- 4.03 Welding
4.031 General. GTA, electron beam, and resistance welding can be used to join this alloy to itself and to other tantalum alloys. Extreme care must be taken to avoid contamination, as contaminants will cause weld ductility to decrease rapidly. A vacuum purged weld box, back filled with high purity helium and/or argon (less than 5 ppm H₂O and 5 ppm O₂) is the best means of avoiding contamination. Helium is the preferred welding atmosphere. The weld box should be capable of 5 x 10⁻⁶ torr and < 3 x 10⁻⁵ torr per minute leak rate. Foil, sheet, and plate welding has been performed satisfactorily (19)(20).
4.032 Recommended GTA and electron beam weld conditions, Table 4.032.

Ta
9.6 W
2.4 Hf
0.01 C

T-222

TABLE 4.032

Source	(19)(20)	
Alloy	Ta-10W-2.5HF-0.01C	
Form	Sheet, 0.035 inch	
Condition	80 percent cold worked, recrystallized 3000F, 1 hour	
Weld Procedure	GTA	EB(a)
Inches per Minute	30	15
Clamp Spacing, Inch	0.250	0.500
Amperes	190	0.0038
Post Weld Anneal, F	2400, 1 hr	2400, 1 hr
Weld Width, top/bottom, inch	.180/1.59	0.035/0.026
BDBTT, F (b)	<-320(c)	<-320(c)
(a) All EB welds with 60°, 0.050 inch longitudinal deflection and 150 KV beam voltage		
(b) BDBTT = bend ductile brittle transition temperature at 1 t bend radius		
(c) Longitudinal and transverse bends		

- 4.0321 Elevated temperature tensile properties of annealed base metal and GTA welds using conditions in Table 4.0321.

TABLE 4.0321

Source	(19)(20)					
Alloy	Ta-10W-2.5HF-0.01C					
Form	Sheet, 0.035 inch					
Condition	85 percent cold worked, recrystallized 3000F, 1 hr + weld + 2400F, 1 hr post weld treatment					
Weld Parameters	See Table 4.032					
	Base Metal			Transverse Weld		
Test Temp, F	1800	2100	2400	1800	2100	2400
F _{tu} , ksi	63	58	40	60	53	41
F _{ty} , ksi	34	32	27.5	36	33	28
e _l (1 inch), percent	10	14	20	6	7	11

- 4.0322 Room temperature tensile properties for welded plate, Table 4.0322.

TABLE 4.0322

Source	(19)(20)	
Alloy	Ta-10W-2.5HF-0.01C	
Form	Plate, 0.375 inch	
Condition	Recrystallized 3000F, 1 hr + weld + 2400F, 1 hr post weld treatment	
Direction	longitudinal	transverse
F _{tu} , ksi	100.7	101.1
F _{ty} , ksi	88.0	88.2
e _l , percent	21.9(a)	18.7(b)
RA, percent	68.3	74.4
(a) 1 1/2 inch gauge length		
(b) 2 inch gauge length		

CODE 5404

PAGE 3

Ta
9.6 W
2.4 Hf
0.01 C
T-222

4.0323 Bend transition temperature for base metal GTA, and electron beam welded sheet, Table 4.0323.

TABLE 4.0323

Source	(19)(20)
Alloy	Ta-10W-2.5Hf-0.01C
Form	Sheet, 0.035 inch
Condition	Recrystallized 3000F, 1 hr + weld + 2400F, 1 hr
Weld Parameters	See Table 4.032
	Bend Transition Temp F(a)
Base Metal	-300 to <-320
Electron Beam Welded	-300 to <-320
Gas Tungsten Arc Welded	-100 to <-320
(a) All bends 1 t radius Higher temperature failures include ductile tears occurring at or near the 90° target bend angle.	

4.0543 Mechanical properties at elevated temperature for two coated T-222 systems, Table 4.0543.

TABLE 4.0543

Source	(17)					
Alloy	Ta-10W-2.5Hf-0.01C					
Form	Sheet, 0.040 inch					
Condition	Recrystallized 3000F, 1 hr + coating					
Coating	Solar TNV-13(11)		Sylvania R516(9)			
Test Temp, F	2600	3100	3400	2600	3100	3500
F _{tu} , ksi(L)	41.8	20.6	12.7	35.2	22.4	14.4
F _{ty} , ksi	33.6	19.8	11.2	31.2	20.2	14.1
e, percent (1 inch)	46.5	66.0	76	15.5	54.0	74
F _{su} , ksi	37.3	17.3	10.8	31.2	17.2	6.4
F _{cy} , ksi	28.8	16.4	13.4	34.4	17.1	13.1

4.0544 Fatigue properties of coated T-222 (see Figure 3.051).

4.04 Heat Treatment

4.05 Surface Treatment

4.051 Pickling can be done in a solution made up of 20-35 percent HF, 0-10 percent H₂SO₄, 20-35 percent HNO₃, and 30-50 percent H₂O at temperatures up to 140F.

4.052 Metallography. In the final polishing stages an acid polish composed of 100 ml acetic acid, 60 ml nitric acid, and 3 ml of hydrofluoric acid can be used, followed by etching for examination by swabbing in a 50 ml HNO₃, 30 grams NH₄F₂, 20 ml H₂O solution (5).

4.053 Chemical milling. A solution of two parts HF at 70 percent strength, two parts HNO₃ at 40 percent Baumé and 1.5 parts H₂O can remove 1 mil per minute per side when fresh.

4.0531 The as-chem milled material is embrittled as evidenced by bend and welding tests. A heat treatment in argon at 2150F for 90 minutes of the chem milled part wrapped in tantalum foil restores fabricability (14).

4.054 Coating.

4.0541 General. Most coatings developed for use on T-222 are based on the diffusional growth of oxidation-resistant intermetallic layers. The tungsten barrier-tungsten disilicided systems of Sylvania (9) and TRW (10) and tungsten disilicide coating of Solar (11) and Vitro (12), are the most promising candidates for achieving oxidation protection systems.

4.0542 Oxidation test data. The Solar TNV-13 and Sylvania R516 coating have been examined critically for application to T-222 structures as well as the coatings of TRW and Vitro (18). Comparative data are given in Table 4.0542.

TABLE 4.0542

Source	(15)					
Alloy	Ta-10W-2.5Hf-0.01C					
Form	Sheet, 0.040 inch					
Condition	Recrystallized 3000F, 1 hour + coating					
Coating System	Life-Cycle(c) in Which Failure Occurred					
Temp F	Cycle Min	Sylvania	TRW	Solar	Vitro	
1600 (a)	60	8,63	1,1,1	20*,20*,20*	3,3,1	
3100 (b)	60	1,1,1,8,21	20*,1,1	20*,7,10*	10*,10*,3	
3500	30	9,3,1	17,5,1	11,11,5	6,1,1	
3600	15	12,9,1	14,2,1	7,2,1	6,2,1	
*Test terminated without failure						
(a) Test in slowly moving air at 1 atm pressure						
(b) Test in 10 cubic feet/hr flowing air						
(c) Cycle from indicated temperature and time to room temperature						

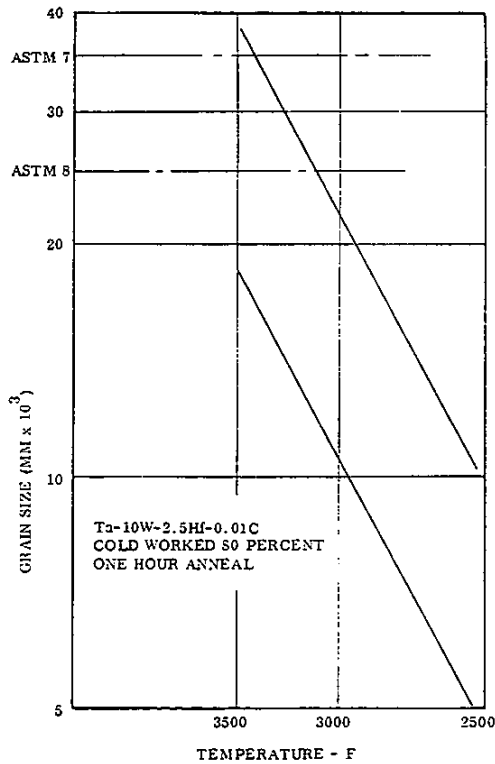


FIG. 1.054 GRAIN SIZE vs ANNEALING TEMPERATURE (5)

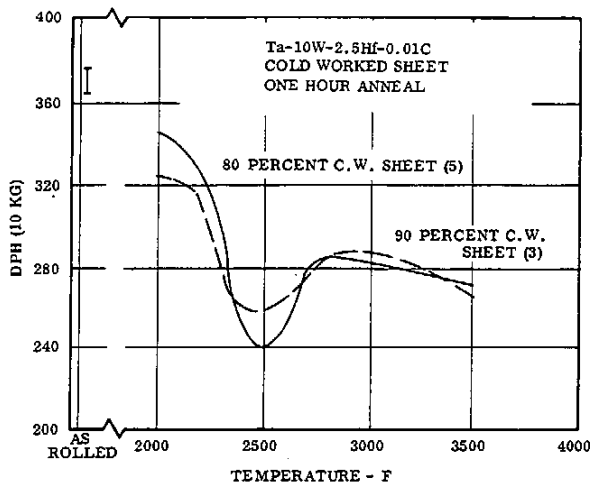


FIG. 1.061 EFFECT OF ANNEALING TEMPERATURE ON HARDNESS (3,5)

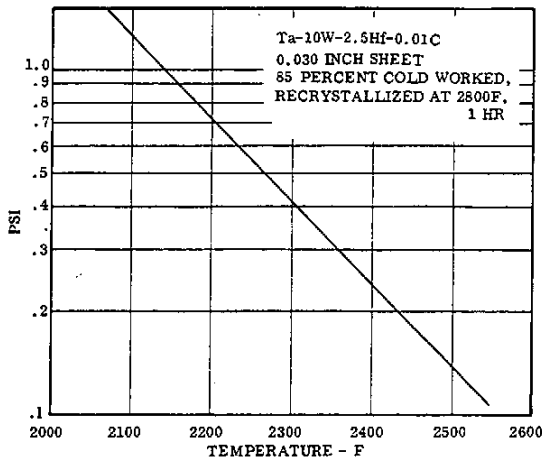


FIG. 3.042 EFFECT OF TEMPERATURE ON ALLOWABLE STRESS TO ACHIEVE ONE PERCENT TOTAL STRAIN IN 10,000 HRS. (15)

Ta
9.6 W
2.4 Hf
0.01 C
T-222

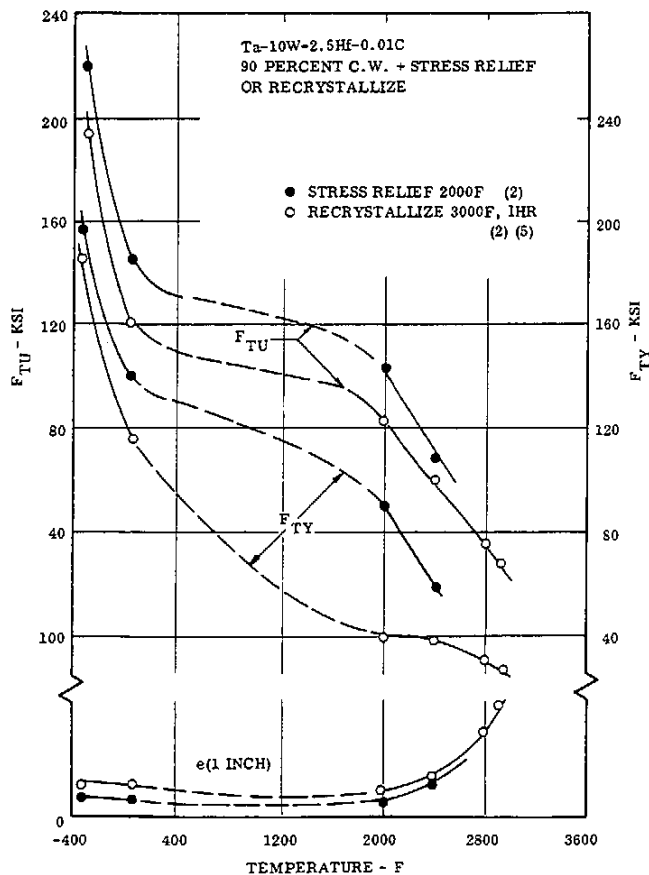


FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF STRESS RELIEVED AND RECRYSTALLIZED SHEET. (15)

Ta
9.6 W
2.4 Hf
0.01 C

T-222

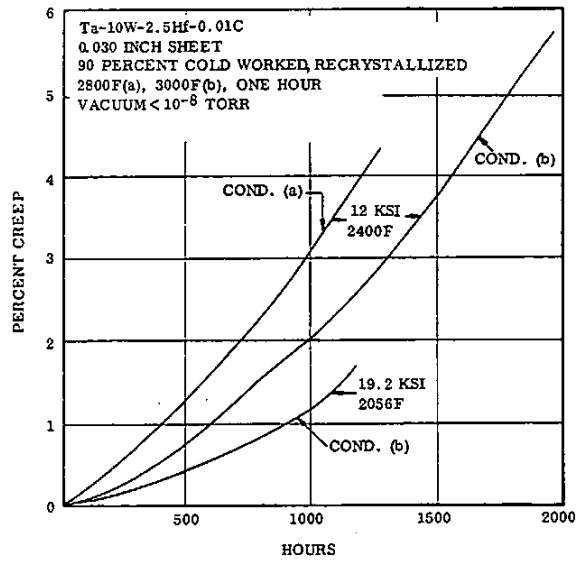


FIG. 3.043 EFFECT OF TEMPERATURE AND STRESS ON CREEP PROPERTIES FOR MATERIAL RECRYSTALLIZED AT 2800 AND 3000F. (16)

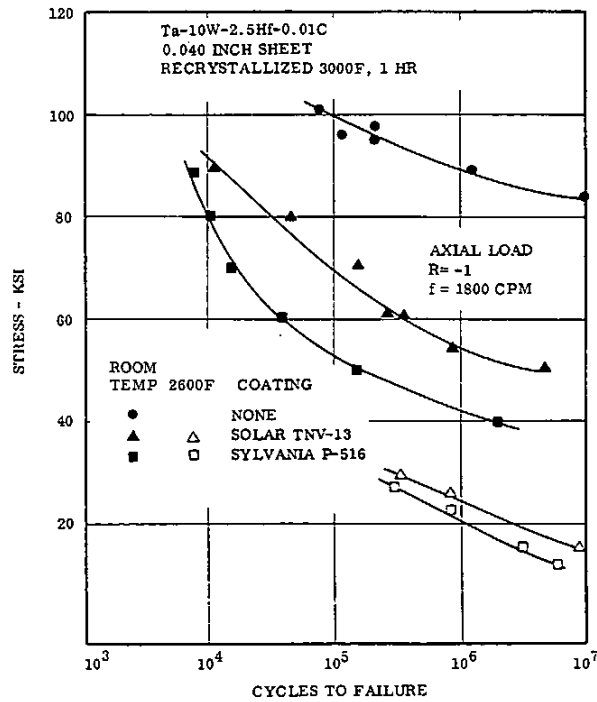


FIG. 3.051 COMPARISON OF FATIGUE PROPERTIES OF BARE AND COATED T-222 AT ROOM TEMPERATURE AND 2600F. (17)

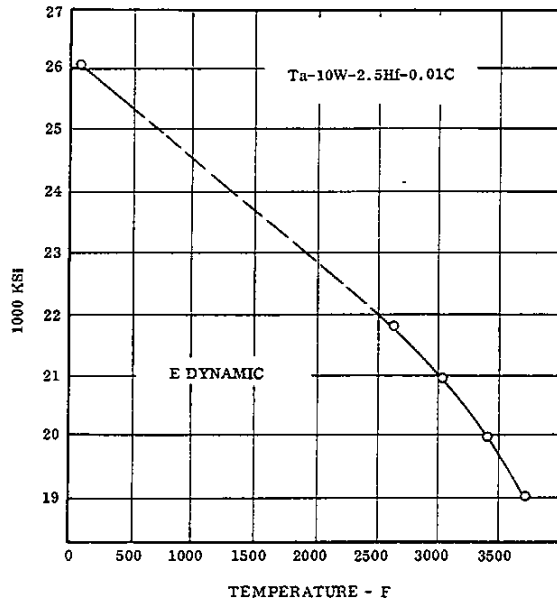


FIG. 3.062 ELASTIC MODULUS

(21)

REFERENCES

1. A.L. Field, Jr., et al, "Research and Development of Tantalum and Tungsten Base Alloys," Final Report (May 26, 1961), Naval BuWeps Contract No. as 58-852-C, Westinghouse Research Laboratory
2. R.L. Ammon and R.T. Begley, "Pilot Production of Tantalum Alloy Sheet," Summary Phase Report (June 15, 1963), Naval BuWeps Contract No. w 62-0656-d, Westinghouse Astronuclear Laboratory Report PR-M-009
3. R.L. Ammon and R.T. Begley, "Pilot Production and Evaluation of Tantalum Alloy Sheet," Summary Phase Report II (July 1, 1964), Naval BuWeps Contract N600(19)-59762, Westinghouse Astronuclear Laboratory Report PR-M-009
4. R.L. Ammon, et al, "Pilot Production and Evaluation of Tantalum Alloy Sheet," Summary Phase Report III (October 30, 1965), Naval BuWeps Contract No. w 64-0394-d, Westinghouse Astronuclear Laboratory Report PR-M-014
5. A.M. Filippi, "Production and Quality Evaluation of T-222 Tantalum Alloy Sheet," Final Report (January 31, 1968), Navy Contract No. w 66-0538-d, Westinghouse Astronuclear Laboratory Report PR-(KK)-003
6. J.H. Stang, et al, "Compatibility of Liquid and Vapor Alkali Metals with Construction Materials," DMC 227 (April 15, 1966)
7. C.M. Scheuerman and C.A. Barrett, "Compatibility of Cb and Ta Alloys with Refluxing Potassium," Report No. NASA TN-D-3429, Lewis Research Center, Cleveland, Ohio (May, 1966)
8. "Fuels and Materials Development Program," Quarterly Progress Report, ORNL-4330, Oak Ridge National Laboratory (June 30, 1968)
9. S. Priceman and L. Sama, "Development of Slurry Coatings for Ta, Cb, and Mo Alloys," AFML-TR-65-204, Sylvania Electric Products, AF33(615)-1721 (September, 1965)
10. H.A. Kmuciak and J.O. Gadd, "Manufacturing Techniques for Application of Duplex W/Si Coating on Ta Components," Fourth Interim Progress Report No. ER-6970-4, TRW Inc., Contract AF33(615)-5404 (July 30, 1967)
11. R.T. Wimber and A.R. Stetson, "Development of Coatings for Ta Alloy Nozzle Vanes," Solar Report No. NASA-CR-54529, RDR-1396-3, Contract NAS3-7276 (July, 1967)
12. M.H. Ortner and S.J. Klach, "Development of Protective Coatings for T-222 Alloy," Vitro Labs Report No. NASA CR-54578, Contract NAS3-7613 (December, 1966)
13. R.E. Jackson, "Tantalum System Evaluation," McDonnell-Douglas, Interim Technical Report No. 9, Contract AF33(615)-3935 (May 1, 1968 to August 1, 1968)
14. Ibid, Interim Technical Report No. 4 (February 1, 1967 to May 1, 1967)
15. R.H. Titran, "Creep of Tantalum T-222 Alloy in Ultra-High Vacuum for Times up to 10,000 Hours," NASA TN-D-4605, Lewis Research Center (May, 1968)
16. J.C. Sawyer and E.A. Steigerwald, "Generation of Long Time Creep Data of Refractory Alloys at Elevated Temperatures," NASA CR-1115, TRW Equipment Laboratories, Contract NAS3-2545 (August, 1968)
17. R.E. Jackson, "Tantalum System Evaluation," McDonnell-Douglas, Interim Technical Report No. 7, Contract AF33(615)-3935 (November 1, 1967 to February 1, 1968)
18. Ibid, Interim Technical Report No. 3, Contract AF33(615)-3935 (November 1, 1966 to February 1, 1967)
19. G.G. Lessmann and D.R. Stoner, "Welding Refractory Metal Alloys for Space Power System Applications," Westinghouse Astronuclear Laboratory, 9th National SAMPE Symposium, Dayton, Ohio (November 15-17, 1965)
20. G.G. Lessmann, "The Comparative Weldability of Refractory Metal Alloys," Welding Journal Research Supplement (December, 1966)
21. P. Armstrong, Table SVS 3-63-1 (Communication to R.L. Ammon, Westinghouse Astronuclear Lab) Los Alamos Scientific Laboratory (March 28, 1963)

Ta
9.6 W
2.4 Hf
0.01 C

T-222