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Creep Behavior of Tungsten/Niobium and Tungsten/Niobium-1 Percent Zirconium Composites

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ABSTRACT

The creep behavior and microstructural stability of tungsten fiber reinforced niobium and niobium-1% zirconium was determined at 1400 and 1500 K in order to assess the potential of this material for use in advanced space power systems. The creep behavior of the composite materials could be described by a power law creep equation. A linear relationship was found to exist between the minimum creep rate of the composite and the inverse of the composite creep rupture life. The composite materials had an order of magnitude increase in stress to achieve 1 percent creep strain and in rupture strength at test temperatures of 1400 and 1500 K compared to unreinforced material. The composite materials were also stronger than the unreinforced materials by an order of magnitude when density was taken into consideration. Results obtained on the creep behavior and microstructural stability of the composites indicate significant potential improvement in high temperature properties and mass reduction for space power system components.

INTRODUCTION

Advanced materials will play a major role in meeting the stringent mass and performance requirements of future space power systems. The requirements for such a system, which may include a service life of greater than 7 years at a temperature in excess of 1350 K, dictate the use of refractory metals (Cooper 1984). The niobium-1% zirconium alloy has been suggested for use in space power conversion applications where resistance to liquid alkali metal corrosion at temperatures near 1000 K was the primary concern (Lane and Ault 1965 and Buckman 1984). The Nb-1% Zr alloy was not, however, developed for applications that required high creep strength for very long times at temperatures in excess of 1100 K. While current designs of space nuclear power systems specify niobium-base alloys for reactor, heat pipe, and power conversion components, future applications will need materials with greater high temperature strength and increased creep resistance to meet the mission requirements (Dokko et al. 1984).

A research program is being conducted at NASA Lewis Research Center to determine the feasibility of using tungsten fiber reinforced niobium or niobium-1% zirconium matrix composites to meet the anticipated increased temperature and creep resistance requirements imposed by advanced space power systems. The tensile properties of W/Nb composites were determined in a previous investigation (Westfall et al. 1986). The results obtained on the short time tensile properties indicated that W/Nb composites had significant improvements in high temperature strength and offer significant mass reductions for high temperature space power systems. However, the prime material requirement for space power systems applications is long time creep resistance. A study was thus conducted to determine the effect of long time high temperature exposure on the properties of these composites, with emphasis on their creep-rupture behavior at elevated temperatures.

MATERIALS, FABRICATION, AND TESTING

Tungsten fibers were chosen as reinforcement for niobium matrices because of their high elevated temperature strength and because of previous fabrication experience with tungsten fiber reinforced superalloy composites demonstrated at NASA Lewis Research Center. Various types of tungsten fibers have been used to reinforce superalloy matrices, and significant improvements have been demonstrated in the high temperature tensile strength and stress-rupture properties of composites compared to superalloys (Petrasek and Signorelli 1981). The experience gained from this type of composite materials technology was utilized to improve the properties of niobium alloys.

Materials

Two types of tungsten fibers were chosen as reinforcement material. Type 218CS tungsten fiber was selected as an example of a lower strength, unalloyed, commercially available lamp filament fiber. Type ST300, a tungsten-1.5% thorium oxide fiber, was selected as an example of a stronger, dispersion-strengthened tungsten fiber. A fiber diameter of 0.20 mm was used for both fiber materials. Unalloyed niobium and niobium-1% zirconium were obtained in the form of 1.59-mm-diameter wire from a commercial vendor. These niobium wires were to be used in the fabrication of composites via the arc spray process which will be described in the following section.

Fabrication

All of the W/Nb and W/Nb-1% Zr composite material tested in this program were fabricated using an arc-spray process developed at NASA Lewis Research Center (Westfall 1985). In this process the tungsten fibers were wound on a drum using a lathe to accurately align and space them. The drum was inserted into a chamber which was subsequently evacuated and back-filled with an inert atmosphere. The niobium or niobium-1% zirconium wire material was arc sprayed onto the drum surface by using a pressurized argon gas stream. After spraying, the coated fiber (monotape) was removed from the drum surface, cleaned, cut to the proper size, stacked up, sealed in a container, and hot isostatically pressed to produce unidirectionally fiber oriented composite panels.

Testing

Stress rupture tests were conducted on tungsten fibers at 1400 and 1500 K. The fiber was attached to a fixed mount, strung through a vertically mounted tantalum resistance furnace, and then appropriately deadweight loaded. The weight was supported by a retractable support during pumpdown and specimen heating.

Testing was conducted in a vacuum of 1×10^{-4} to 7×10^{-3} Pa. The fiber specimen was allowed to stabilize at the desired test temperature about 2 hours prior to loading. Specimen and furnace temperature was monitored with a platinum/platinum 13%-rhodium thermocouple. A microswitch connected in series with the furnace and an elapsed time meter was located directly under the weight and was used to determine the rupture time for each fiber specimen.

Creep rupture specimens were machined from composite panels and from arc sprayed matrix materials. The fiber content of the specimens ranged from 36 to 52 percent. The specimen configuration and dimensions are shown in Figure 1. Tungsten tabs were TIG welded on both sides of the ends of the composite specimens to prevent specimen shearing at the pin hole locations. The creep-rupture evaluation of the composites was performed with unidirectionally oriented fiber reinforced composite specimens, tested in the fiber direction. Creep rupture tests at both 1400 and 1500 K were conducted in a vacuum of 7×10^{-5} Pa. Creep strains were measured optically by using a cathetometer to sight on knoop hardness impressions initially placed 25 mm apart on the reduced section gauge length of the specimen. The precision of creep-strain measurements is estimated to be ±0.02 percent for the gauge length used. The strain on loading was measured and was incorporated in the reported total creep strain. Rupture times were determined in a manner similar to that for the fibers.

Microstructural analysis of the composites was conducted using optical and scanning electron microscopy. The fiber contents of each composite specimen was determined by cutting, polishing, and etching a cross section of the specimen near the fracture surface, then counting the total number of fibers within that area. The total fiber area was calculated and the fiber content was determined by dividing by the initial cross-sectional area of the composite specimen.

RESULTS AND DISCUSSION

Fiber Stress-Rupture Properties

The stress-rupture data obtained for 218CS and ST300 tungsten fibers used in this investigation are listed in Table 1. Figure 2 is a plot of the time to rupture as a function of the stress for ST300 and 218CS fibers tested at 1400 and 1500 K. The 100-hour rupture strength obtained for the ST300 fiber was 500 MPa at 1400 K and 352 MPa at 1500 K compared to 440 MPa at 1400 K and 338 MPa at 1500 K for the 218CS fiber. The long-time rupture strength of the 218CS fiber compares more favorably with that of the ST300 fiber. For example the 1000-hour rupture strength for 218CS was 360 MPa at 1400 K and 290 MPa at 1500 K compared to 380 MPa at 1400 K and 276 MPa at 1500 K for the ST300 fiber.

The potential 1000-hour rupture strength for a composite containing 50 vol % ST300 fiber in a matrix of niobium was calculated using the data obtained for the ST300 fibers. A calculation was also made for a composite containing 50 vol % W-Re-Hf-C fibers in a niobium matrix. The W-Re-Hf-C fiber is the strongest tungsten fiber produced to date but the fiber is not commercially available. Both calculations were made assuming that no fiber degradation occurred due to interfacial reactions between the fiber and matrix and that the fiber carries all of the load. It is assumed that the matrix does not carry any of the load, thus the load carried by the composite for rupture in 1000 hours is equal to the load necessary to rupture the fibers in 1000 hours. Since the cross-sectional area of the fibers in a 50 vol % composite is only one half of the total cross-sectional area of the composite then the stress on the composite for rupture in 1000 hours is equal to one half of the 1000-hour rupture stress for the fiber. The stress on the composite is thus the volume fraction of fiber contained in the composite times the rupture strength of the fiber. The projected 1000-hour rupture strengths for the composites are compared to the 1000-hour rupture strength values for niobium-1% zirconium in Figure 3. The projection indicates that the ST300/Nb composite has a potential 1000-hour rupture strength seven times that of Nb-1% Zr and that the W-Re-Hf-C/Nb composite has a potential 1000-hour rupture strength about 20 times greater than Nb-1% Zr.

Composite Creep-Rupture Properties

The creep-rupture data obtained for the composite and matrix materials are shown in Table 2 and include the types of tungsten fiber and fiber contents used, the applied stress on the composite, time for 1 percent strain and rupture and minimum creep rates. Also included in Table 2 is the calculated stress on the fiber assuming that the fiber carries all of the load applied to the composite. The calculated fiber stress was used to determine values for the stress on a composite normalized to 50 vol % fiber content as shown in Table 2. All of the composite data was normalized to 50 vol % fiber contents so that the effect of fiber content could be eliminated in property comparisons. The stress on the composite for a 50 vol % fiber content is thus the volume fraction fiber (0.5) times the stress on the fiber as described in the previous section of this paper. Such extrapolations were shown to be valid by previous work reported by McDanels and Signorelli, 1967. A typical creep curve for a composite material is shown in Figure 4. The composite material was ST300/Nb+1% Zr containing 40 vol % fiber and tested under an applied stress of 180 MPa at a temperature of 1400 K. The creep curves for the composite materials exhibited the three characteristic stages of creep associated with conventional materials. The strain to rupture ranged from 5 to 7 percent for the composite materials tested.

The fractured surfaces of composite specimens were examined using the scanning electron microscope. Figure 5 shows the fracture surface of a ST300/Nb composite. The fiber and matrix both failed in a ductile manner in stress-rupture. Further evidence of fiber and matrix ductile fracture behavior is shown in the optical microphotograph of Figure 6, where necking of the fiber is observed.

The effective use of fiber reinforcement to increase the creep resistance of niobium is shown in Figure 7. The time to cause 1 percent strain for arc sprayed niobium under an applied stress of 20 MPa was 17 hours while arc-sprayed niobium reinforced with 40 vol % fiber and stressed at an order of magnitude higher stress (200 MPa) had nearly an order of magnitude increase in the time to cause 1 percent creep strain. Increasing the fiber content results in further increases in creep resistance for the composites materials investigated.

The time to cause 1 percent strain, rupture, and the minimum creep rates were determined from the creep curves generated for the composite and matrix materials tested at 1400 and 1500 K. A comparison of the stress rupture strengths obtained for the composites and arc-sprayed niobium is shown in Figure 8. All of the composites were an order of magnitude stronger than the unreinforced arc-sprayed niobium. The use of higher strength fibers resulted in higher strength composites. The ST300 fiber reinforced composites were stronger at 1400 and 1500 K than composites reinforced with the weaker 218CS fibers. In contrast, the weaker matrix, niobium with ST300 fibers had a composite strength that was higher than that of the composite with the stronger niobium-1% zirconium matrix reinforced with the ST300 fibers.

A comparison was also made for the stress to cause 1 percent strain for the composites, PWC-11 (niobium-1% zirconium-0.1% carbon), and niobium-1% zirconium, Figure 9. The ST300/niobium material was the strongest while the 218CS/niobium composite material was the weakest of the composites investigated. The creep stress to cause 1 percent strain obtained for the composites were over an order of magnitude stronger over the time range shown compared to niobium-1% zirconium and about six times stronger than PWC-11.

The reinforcing fibers have a density over twice that of niobium. The 50 vol % fiber composite is thus over one and a half times heavier than niobium and density must be taken into consideration when making property comparisons. A comparison is made of the creep stress to density ratio for 1 percent strain for the composites, PWC-11 and niobium-1% zirconium in figure 10. Even on a density corrected basis the composites are over an order of magnitude stronger than niobium-1% zirconium and 3-1/2 to 4 times stronger than PWC-11.

Figure 11 shows the minimum creep rate against stress for the composites, and these data are compared with those obtained on arc-sprayed niobium tested at 1400 K. It is evident that the composites creep at a much slower rate than the niobium matrix material. Noting that the strain and strain rate compatibility must be maintained at the fiber-matrix interface during creep of a composite subjected to uniaxial loading, it is possible to estimate the relative magnitude of the stress on the matrix using Figure 11. For example, it is evident from Figure 11 that at 1400 K the ST300/Nb composites exhibit a minimum creep rate of about 1×10^{-8} sec^{-1} at 250 MPa. Using the strain rate compatibility arguments, Figure 11 suggests that a stress of about 15 MPa would enable the Nb matrix to creep at the same rate. It can be shown using the rule-of-mixtures, that the corresponding stress on the matrix is only about 3 percent of the total applied stress acting on a composite containing 50 vol % fibers.

This means that for a first order prediction of creep behavior the creep of the composite can be described by creep equations for the reinforcing fiber. The minimum creep rate of the composite can thus be equated to the power law creep behavior as follows:

$$\dot{\varepsilon}_s + A \exp\left(\frac{-Q}{RT}\right) \sigma^n$$

$$\sigma = \sigma_f = \frac{\sigma_c}{V_f}$$

$$\dot{\varepsilon}_s = A \exp\left(\frac{-Q}{RT}\right) \left(\frac{\sigma_c}{V_f}\right)^n$$

where

σ_c is the stress on the composite

σ_f is the stress on the fiber assuming that the fiber carries the total load

V_f is the volume fraction fiber content

Q is the apparent creep activation energy

n is the creep-rate stress exponent

A is a constant for the fiber

The calculated composite creep activation energy, Q, of 465 to 490 kJ/mol agrees with results for other forms of tungsten tested in this temperature range. Robinson and Sherby (1969) propose that the creep of as-drawn fibers occurs by a dislocation mechanism controlled by grain-boundary or dislocation-pipe diffusion. The creep-rate stress exponent, n, for the ST300 reinforced composites ranged between 5 and 6 which is in agreement with values predicted by simple theories of dislocation-climb processes where n is about 5. It is unlikely that grain-boundary-diffusion creep or grain boundary sliding controls creep because of the oriented, elongated grain structure of the fibers.

The relationship between rupture life of the ST300 fiber reinforced composites and the minimum creep rate is shown in Figure 12. A linear inverse relationship was observed between rupture life and the minimum creep rate.

$$t_R = \frac{C}{\dot{\varepsilon}_S}$$

where $C = 0.036$. This relationship has been observed in other metals and is known as the Monkman-Grant relationship.

This relationship was also found to be valid for stainless steel composites reinforced with tungsten-thoria fibers (Warren and Larsson 1980) and for nickel coated and uncoated tungsten-thoria wires (Warren and Andersson 1982)/ The C value of 0.036 observed in this investigation compares favorably with the value of 0.0207 observed for nickel coated and uncoated fibers.

The minimum creep rate expression previously described for the composites can be substituted in the Monkman-Grant relationship to yield an expression which equates the composite rupture life with the stress on the composite and with the volume fraction fiber content as follows:

$$\frac{1}{t_r} = \left(\frac{1}{C}\right) A \exp\left(\frac{-Q}{RT}\right)\left(\frac{\sigma_c}{V_f}\right)^n$$

The above expression indicates that at a constant applied stress on the composite increasing the fiber volume fraction content will result in increased rupture life values for the composite.

Composite Microstructural Stability

One of the principal concerns in the use of fiber reinforced composites for long time exposure applications at elevated temperatures is the degree of reaction that occurs between the fiber and matrix materials. Excessive fiber/matrix reaction could degrade the fiber properties and thus the composite materials properties. There is general agreement that niobium and tungsten are completely miscible in the solid and liquid state and thus do not form any deleterious intermetallic compounds. Figure 13 compares the reaction at the fiber/matrix interface that occurred for ST300/Niobium-1% zirconium composites exposed for about 1000 hours at 1400 and 1500 K. As expected, the reaction at 1500 K is greater than at 1400 K however even at 1500 K the reaction was not excessive. The depth of penetration into the 0.2-mm diameter fiber was less than 0.01 mm. A possible explanation for why ST300/niobium composites were stronger than ST300/niobium-1% zirconium is that the niobium-1% zirconium matrix is more reactive with the fibers than niobium. The depth of penetration into the ST300 fiber that resulted upon exposure at 1500 K for the niobium and niobium-1% zirconium matrix composite materials is compared in Figure 14. The preliminary limited data indicates very little difference in the degree of fiber reaction that occurred for both materials. More data is thus needed to account for the strength difference observed for the two different matrix composites. The longest time of exposure was 2500 hours. The depth of penetration into the fiber for the 2500 hour exposured material was about 0.01 mm. The values for fiber reaction are in agreement with reference data (Arcella 1974) in the literature on rates of reactions observed between tungsten and niobium diffusion couples. The reaction results thus indicate good microstructural stability for this composite system.

Feasibility of W/Nb Composites for Advanced Space Power Applications

Advanced space power system components will require a nominal service life of 7 years or longer. In the interest of determining the potential of these materials for such applications, projections were made for both the 1000 hour and 100 000 hour (11.4 years) creep stress to yield 1 percent strain at 1400 and 1500 K and these were compared with similar projections made for PWC-11 and niobium-1% zirconium material (Figure 15). The composite materials offer a potential of more than an order of magnitude increase in strength compared to niobium-1% zirconium at both of the temperatures investigated while compared to PWC-11 at 1400 K the 100 000 hour composite strength potential is 8 to 10 times greater and at 1500 K it is 5 to 9 times greater.

Density corrected values for the stress to yield 1 percent strain at 1400 and 1500 K for the composites, PWC-11 and niobium-1% zirconium are shown in Figure 16. Even when density is taken into account the composites are still more than an order of magnitude stronger than niobium-1% zirconium. The composites are also 5 to 6 times stronger than projected values for PWC-11 at 1400 K and 3 to 5 times stronger at 1500 K. The strength to density values projected for the composites indicate a potential mass savings that could be realized by substitution of the composites to replace thicker sections of niobium-1% zirconium or the potential for increased service temperatures of components.

The results of this study indicated that tungsten fiber reinforced niobium and niobium-1% zirconium composites show promise for significant improvements in high temperature properties and offer significant mass reduction potential for high temperature space power systems.

SUMMARY

A study was conducted to determine the feasibility of using tungsten fiber reinforced niobium and niobium-1% zirconium matrix composites to meet the anticipated increased temperature and creep resistance requirements imposed by advanced space power systems. The creep behavior and microstructural stability of tungsten fiber/niobium and niobium-1% zirconium composites were determined at 1400 and 1500 K in order to assess the potential of these materials for advanced space power systems. Based upon this study the following observations were drawn:

1. Tungsten fiber reinforced niobium and niobium-1% zirconium composite materials were successfully fabricated using an arc-spray process followed by a hot isostatic pressing procedure. Fully densified composites were produced having negligible fiber/matrix interfacial reaction.

2. The creep behavior of the composite materials investigated can be expressed approximately in terms of an empirical equation of the form:

$$\dot{\varepsilon}_s = A \exp\left(\frac{-Q}{RT}\right) \sigma^n$$

Values for n ranged from 5 to 6 for the ST300 fiber reinforced composites and the values of Q ranged from 465 to 490 kJ/mol.

3. A linear relationship exists between the minimum creep rate of the composite and the inverse of the composite creep rupture life such that $T_R = 0.036/\dot{\varepsilon}_S$.

4. The tungsten fiber reinforced niobium and niobium-1% zirconium composite materials had an order of magnitude increase in the stress to yield 1 percent creep strain at test temperatures of 1400 and 1500 K compared to niobium-1% zirconium while compared to PWC-11 the composite was 8 to 10 times stronger at 1400 K and 5 to 9 times stronger at 1500 K.

5. The composite materials were also stronger than the unreinforced niobium-1% zirconium by an order of magnitude when density was taken into consideration. The composites also had stress to yield 1 percent creep strain to density values 5 to 6 times greater than PWC-11 at 1400 K and 3 to 5 times PWC-11 at 1500 K.

6. Thermal exposure for 2500 hours at 1500 K caused a depth of penetration into the fiber of only 0.01 mm, demonstrating good fiber/matrix compatibility.

7. The results obtained on the creep behavior and microstructural stability indicated that tungsten fiber reinforced niobium and niobium-1% zirconium composites show promise for significant improvements in high temperature properties and mass reductions for space power system components.

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REFERENCES

1. Acella, F.G.: Interdiffusion Behavior of Tungsten or Rhenium and Group V and VI Elements and Alloys of the Periodic Table, Part I. NASA CR-134490, 1974.
2. Buckman, R.W., Jr.: A Review of Tantalum and Niobium Alloy Production. Refractory Alloy Technology for Space Nuclear Power Applications, R.H. Cooper Jr. and E.E. Hoffman, eds., CONF-8308130, DOE, 1984, pp. 86-97.
3. Cooper, R.H., Jr.: Potential Refractory Alloy Requirements for Space Nuclear Power Applications. Refractory Alloy Technology for Space Nuclear Power Applications, R.H. Cooper Jr. and E.E. Hoffman, eds., CONF-8308130, DOE, 1984, pp. 14-17.

4. Dokko, W., et al.: Applications for Composites and Beryllium in the SP-100 Power System, JPL-D-1948, Jet Propulsion Laboratory, 1984.

5. Lane, J.R.; and Ault, G.M.: The Refractory Metals Sheet Rolling Program. Met. Eng. Q., vol. 5, no. 3, Aug. 1965, pp. 23-29.

6. McDanels, D.L.; Signorelli, R.A.; and Weeton, J.W.: Analysis of Stress Rupture and Creep Properties of Tungsten Fiber Reinforced Copper Composites. Fiber-Strengthened Metallic Composites, ASTM-STP-427, ASTM, 1967, pp. 124-148.

7. Petrasek, D.W.; and Signorelli, R.A.: Tungsten Fiber Reinforced Superalloys - A Status Review. Ceram. Eng. Sci. Proc., vol. 2, no. 7-8, July-Aug. 1981, pp. 739-786.

8. Robinson, S.L.; and Sherby, O.D.: Mechanical Behaviour of Polycrystalline Tungsten at Elevated Temperature. Acta Met., vol. 17, no. 2, Feb. 1969, pp. 109-125.

9. Warren, R.; and Larsson, L.O.K.: Matrix Composition and Fiber/Matrix Compatibility in W-Wire Reinforced Composites. Proceedings of the Scandinavian Symposium in Materials Science, University of Lulea, 1980.

10. Warren, R.; and Andersson, C.H.: Short-Term Tensile Strength and Creep Behaviour of Tungsten Wires Up to 1100 °C. High Temp.-High Press., vol. 14, no. 1, 1982, pp. 41-51.

11. Westfall, L.J.: Tungsten Fiber Reinforced Superalloy Composite Monolayer Fabrication by an Arc-Spray Process. NASA TM-86917, 1985.

12. Westfall, L.J., et al.: Preliminary Feasability Studies of Tungsten/ Niobium Composites for Advanced Space Power Systems Applications. NASA TM-87248, 1986.

TABLE 1. Stress-Rupture Data for 0.20 mm Diameter 218CS and ST300 Fiber Material

	Fiber Material			
	218CS		ST300	
Test Temperature °K	Stress MPa	Rupture Life Hours	Stress MPa	Rupture Life Hours
1400	586	4.3	758	3.4
	552	7.9	690	4.8
	517	17.3	690	10.9
	483	33.1	620	15.0
	483	42.4	620	15.2
	448	63.1	620	19.6
	414	165.5	586	23.1
	379	811.3	586	33.4
	345	1479.4	552	33.9
			517	64.2
			483	99.3
			483	123.8
			483	131.7
			448	192.5
			448	333.3
			414	402.3
1500	448	2.9	517	3.9
	448	1.7	483	5.8
	414	3.5	448	12.8
	414	7.1	414	19.9
	379	17.9	414	33.9
	379	37.1	379	32.2
	379	16.1	379	39.8
	362	53.0	345	104.9
	345	117.5	345	188.5
	345	91.2	310	342.6
	328	310.0	280	533.8

TABLE 2. Composite Creep Rupture Data

Composite System	Temperature °K	Composite Stress, MPa	Composite Stress Normal. to 50 vol %, MPa	Vol % Fiber	Fiber Stress, MPa	Time to 1% Strain, Hours	Rupture Time, Hours	Minimum Creep Rate, sec^{-1}	Creep Stress to Density Ratio For 1% Strain, m
ST300/ Nb + 1% Zr	1400	180	209	43.0	418	238	1490	7.04E-09	1539
		200	210	48.0	420	277	1614	8.43E-09	1547
		200	241	41.0	483	240	1104	9.26E-09	1775
		220	210	52.0	420	340	2325	6.56E-09	1547
		250	257	49.0	514	70	379	2.64E-08	1893
	1500	120	140	43.0	280	107	742	1.70E-08	1031
		130	130	50.0	259	190	921	9.65E-09	958
		160	163	49.0	327	72	425	2.77E-08	1201
		206	212	49.0	425	17	53	1.17E-07	1562
ST300/ Nb	1400	180	228	39.0	456	243	----	7.80E-09	1679
		190	255	37.0	511	233	850	9.70E-09	1878
		200	261	38.0	522	102	----	1.90E-08	1923
		210	279	38.0	557	56	388	2.95E-08	2055
		220	289	38.0	578	40	249	3.12E-08	2129
	1500	95	124	38.0	248	825	----	2.93E-09	913
		100	126	44.0	252	710	2485	3.20E-09	928
		110	147	37.0	295	178	937	1.04E-08	1083
		130	173	38.0	346	88	344	2.30E-08	1274
		150	183	41.0	367	56	284	3.15E-08	1348
218/Nb	1400	135	167	40.0	335	476	590	5.13E-09	
		150	186	40.0	372	330	455	7.79E-09	
	1500	80	112	36.0	223	255	683	9.15E-09	
		90	125	36.0	249	120	293	2.07E-08	
		100	137	36.0	275	66	126	3.50E-08	
Nb	1400	15	---	----	---	233	----	1.06E-08	
		20	---	----	---	17	60	1.00E-07	
		25	---	----	---	5	29	5.00E-07	
	1500	5	---	----	---	56	523	3.90E-08	
		10	---	----	---	7	79	3.20E-07	
		15	---	----	---	3	69	7.80E-08	
Nb + 1% Zr	1400	20	---	----	---	6	1607	1.20E-07	

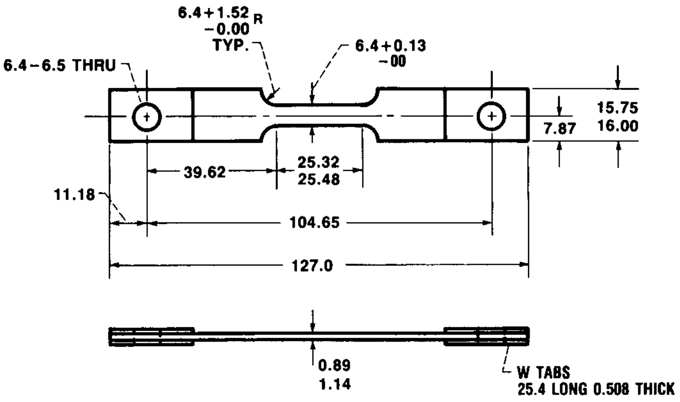


FIGURE 1. - TENSILE CREEP-RUPTURE TEST SPECIMEN (DIMENSIONS IN MM).

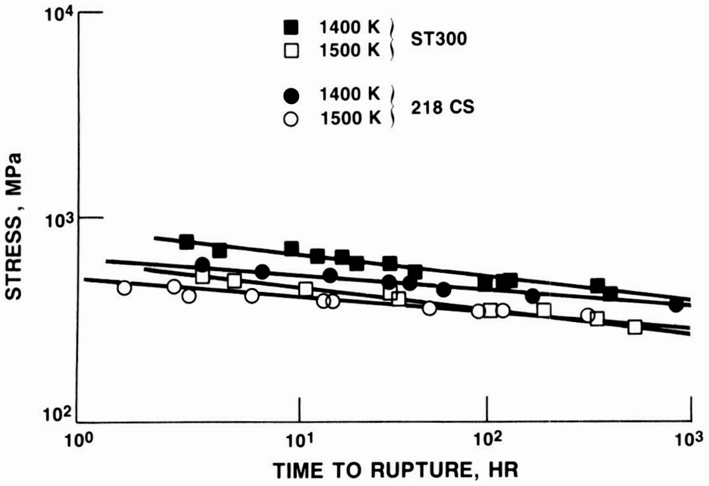


FIGURE 2. - COMPARISON OF THE STRESS RUPTURE LIVES FOR ST300 (W + 1.5% THO$_2$) AND 218 CS FIBERS.

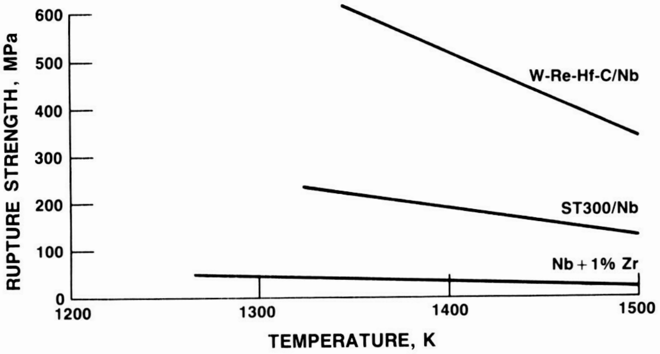


FIGURE 3. - PROJECTED 1000 HR RUPTURE STRENGTH FOR 50 V/O W/NB COMPOSITES COMPARED TO NB + 1% ZR.

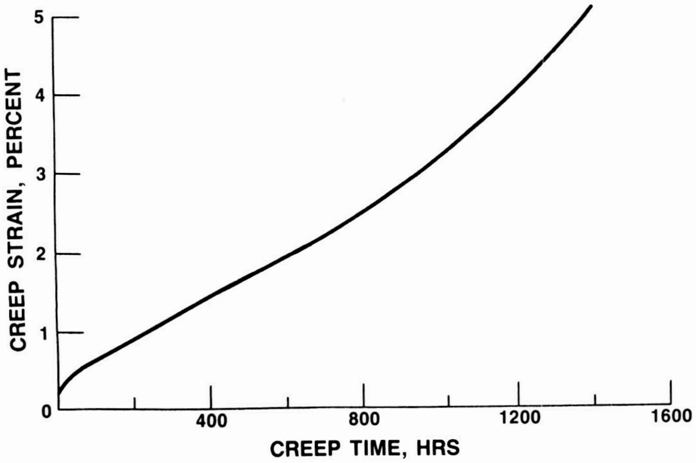


FIGURE 4. - TYPICAL CREEP CURVE FOR 40 V/O ST300/NB + 1% ZR COMPOSITE MATERIAL TESTED AT 1400 K AND 180 MPA.

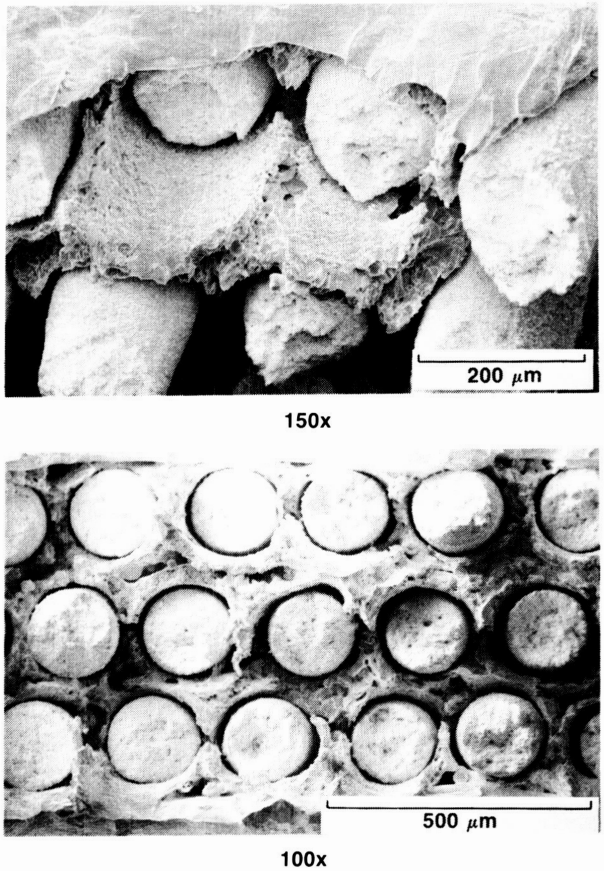


FIGURE 5. - FRACTURE SURFACE OF ST300/NB COMPOSITE SPECIMEN TESTED AT 1500 K AND 150 MPA FOR 284.5 HR.

100x

FIGURE 6. - FRACTURE SECTION OF ST300/Nb + 1% Zr CREEP RUPTURE SPECIMEN TESTED AT 1400 K AND 220 MPa FOR 2325 hr.

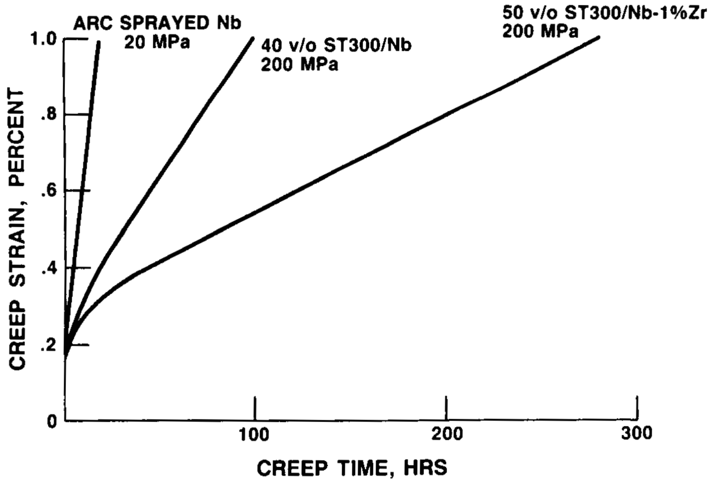


FIGURE 7. - 1400 K CREEP CURVES FOR ST300/Nb AND Nb-1% Zr COMPOSITES AND Nb MATRIX MATERIAL.

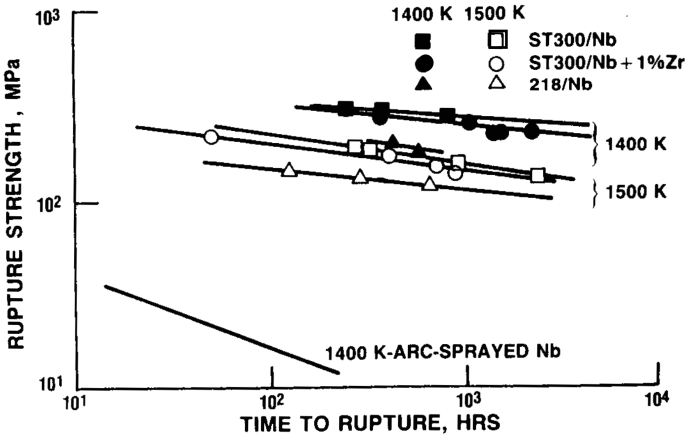


FIGURE 8. - COMPARISON OF STRESS RUPTURE LIVES OF COMPOSITES AND ARC-SPRAYED NIOBIUM. COMPOSITES NORMALIZED TO 50 VOL PERCENT FIBER CONTENT.

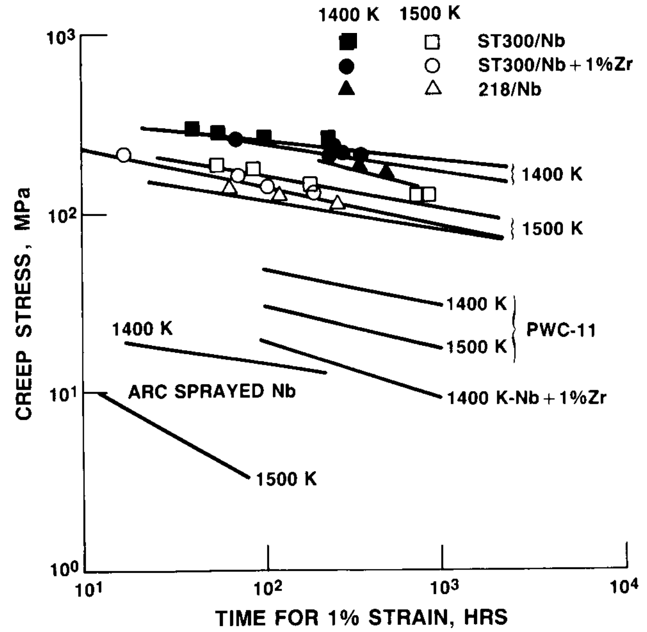


FIGURE 9. - COMPARISON OF CREEP STRESS FOR 1% CREEP STRAIN FOR COMPOSITES, PWC-11, NB + 1% ZR, AND ARC-SPRAYED NB. COMPOSITES NORMALIZED TO 50 VOL PERCENT FIBER CONTENT.

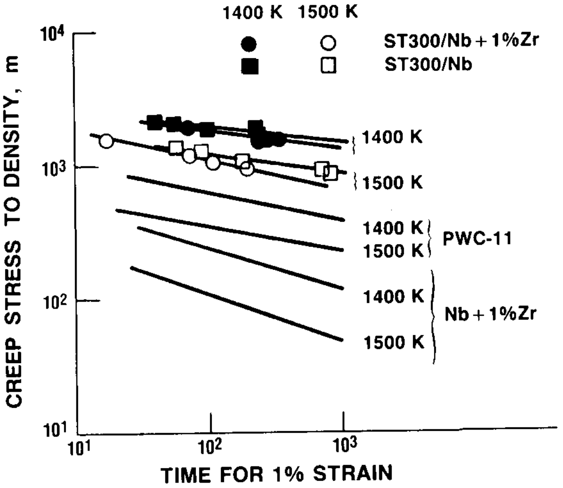


FIGURE 10. - COMPARISON OF CREEP STRESS TO DENSITY RATIO FOR 1% CREEP STRAIN FOR COMPOSITES, PWC-11 AND NB + 1% ZR. COMPOSITES NORMALIZED TO 50 VOL PERCENT FIBER CONTENT.

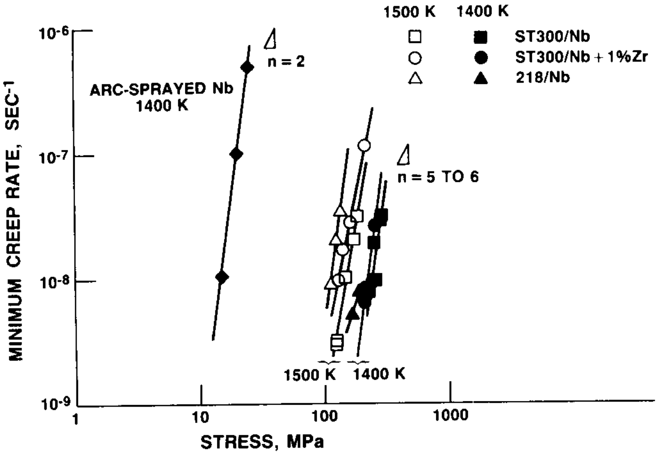


FIGURE 11. - COMPARISON OF MINIMUM CREEP RATE FOR COMPOSITES AND ARC-SPRAYED NB. COMPOSITES NORMALIZED TO 50 VOL PERCENT FIBER CONTENT.

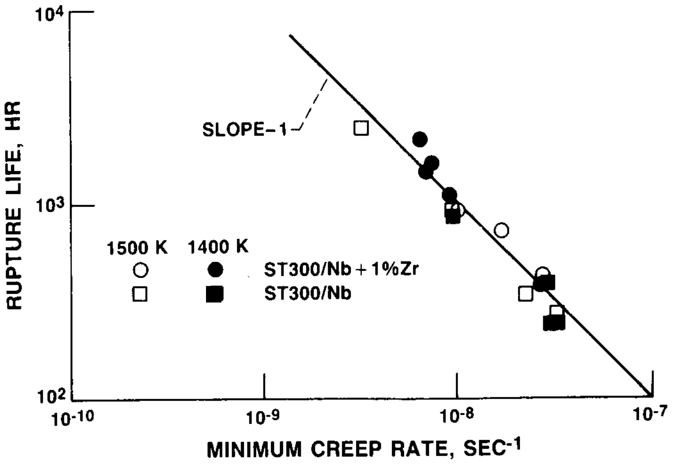
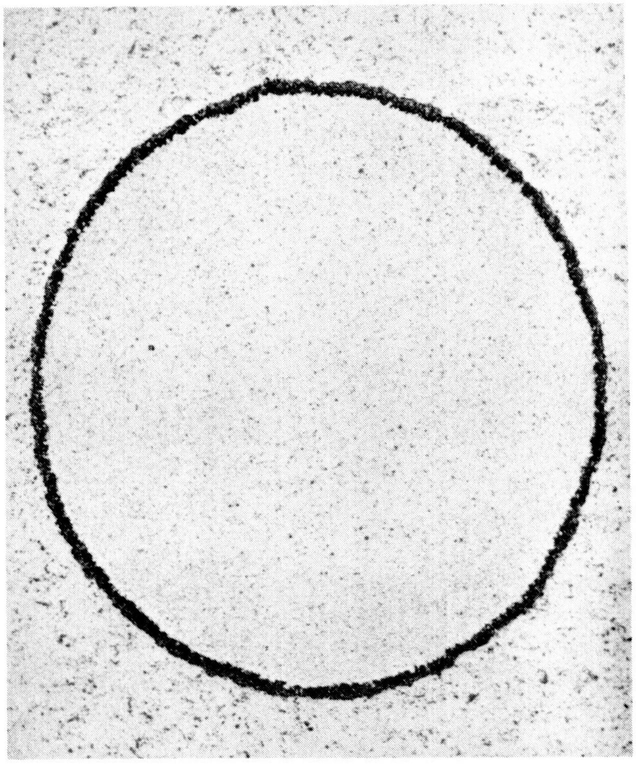
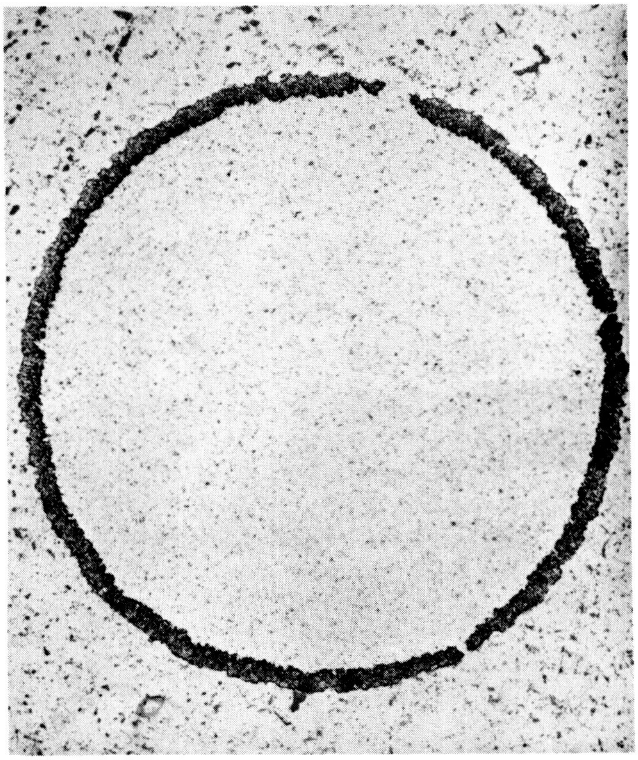


FIGURE 12. - RELATIONSHIP BETWEEN RUPTURE LIFE AND MINIMUM CREEP RATE FOR COMPOSITES. COMPOSITES NORMALIZED TO 50 VOL PERCENT FIBER CONTENT.



(a) 400x



(b) 400x

FIGURE 13. - COMPARISON OF AMOUNT OF ST300/NB + 1% ZR FIBER/MATRIX INTERFACIAL REACTION FOLLOWING 1000 HR EXPOSURE AT (A) 1400 AND (B) 1500 K.

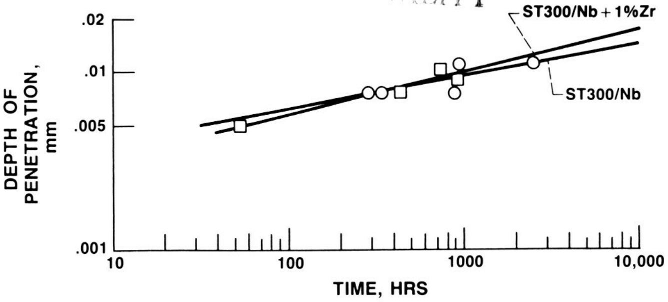


FIGURE 14. - COMPARISON OF DEPTH OF REACTION PENETRATION VERSUS TIME AT 1500 K FOR ST300/NB AND NB-1% ZR COMPOSITES.

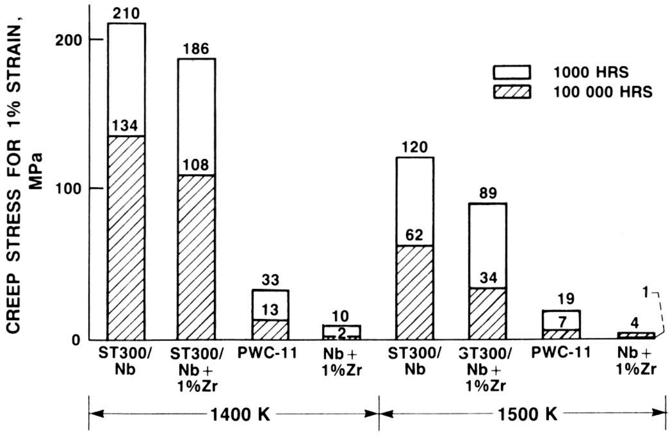


FIGURE 15. - COMPARISON OF THE PROJECTED 1000 AND 100 000 HR CREEP STRESS TO ACHIEVE 1% CREEP STRAIN AT 1400 AND 1500 K. 50 VOL PERCENT FIBER CONTENT COMPOSITES.

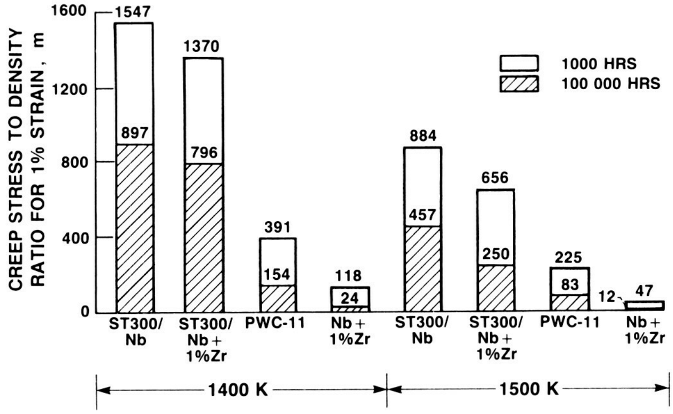


FIGURE 16. - COMPARISON OF PROJECTED 1000 AND 100 000 HR CREEP STRESS TO DENSITY RATIO TO ACHIEVE 1% CREEP STRAIN. 50 VOL PERCENT CONTENT COMPOSITES.

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16. Abstract
The creep behavior and microstructural stability of tungsten fiber reinforced niobium and niobium-1 percent zirconium was determined at 1400 and 1500 K in order to assess the potential of this material for use in advanced space power systems. The creep behavior of the composite materials could be described by a power law creep equation. A linear relationship was found to exist between the minimum creep rate of the composite and the inverse of the composite creep rupture life. The composite materials had an order of magnitude increase in stress to achieve 1 percent creep strain and in rupture strength at test temperatures of 1400 and 1500 K compared to unreinforced material. The composite materials were also stronger than the unreinforced materials by an order of magnitude when density was taken into consideration. Results obtained on the creep behavior and microstructural stability of the composites indicate significant potential improvement in high-temperature properties and mass reduction for space power system components.

17. Key Words (Suggested by Author(s))
Creep behavior; Composites; Niobium;
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