AUTHOR: S. S. MANSON

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

1 GENERAL

Although Mar-M-246 was originally developed by Martin Metals[a] in 1965, it is presently under intense development because of its unique high-temperature strength which makes it of special interest to the United States of America (U.S.A.) Space Shuttle. The alloy is ideally suited for applications requiring high strength, creep resistance, and oxidation resistance at elevated temperatures, particularly within the 1200–1900 F range. It is a nickel-base alloy with additions of tungsten and molybdenum for solid solution strengthening, chromium for oxidation resistance, tantalum for carbide strengthening, and aluminum and titanium which strengthen by precipitation of finely dispersed gamma prime, $Ni_3(Al, Ti)$. The combination of hardening mechanisms and solid solution strengthening results in expectional creep-resistance and creep-rupture strength.

The selection of this alloy for the turbine in the U.S.A. Space Shuttle has focused additional developmental attention, resulting in improvements through directional and monocrystalloy solidification through the addition of hafnium. Although the hafnium addition has not been combined with other changes in chemistry to produce optimum metallurgical stability, it has resulted in improved high-temperature strength and ductility which have enhanced both creep-rupture and fatigue properties. Later modifications involving additions of both hafnium and other elements have produced an alloy which is structurally more stable for long time high-temperature exposure. To differentiate this alloy from the Mar-M-246 alloy made for space shuttle applications (which do not involve long time service), the other alloy has been renamed Mar-M-247, and will be the subject of another chapter in this handbook. In the present chapter only the standard Mar-M-246 and its hafnium-modified variant are characterized.

1.01 Commercial Designation
Mar-M Alloy 246.

1.02 Alternate Designations
Mar-M-246, Vertex Mar-M-246 (28).

1.03 Specifications

1.031 Specifications for standard alloy suggested by alloy developer, Table 1.031.

1.04 Composition

1.041 Composition limits specified by alloy developer, Table 1.041.

1.042 Composition of two hafnium-modified heats used in alloy characterization, Table 1.042.

1.05 Heat Treatment
Alloy may be used in as-cast condition.

1.051 Alloy developer recommends heat treatment from 1500 to 1700 F if intended application is 1200 to 1400 F. Alloy developer recommends heat treatment at 1500 F in order to obtain the best balance of improved ductility and strength at 1200 to 1400 F without significantly affecting creep resistance (22, p. 1.0). Typically, an aging treatment of 50 hours at 1550 F followed by air cooling has been used (see Figures 3.04211 and 3.0621).

1.052 Heat treatment for the hafnium-modified alloy used in characterizing alloys for the U.S.A. Space Shuttle; 2230 F ± 20 F, 2 hr (± 10 min) in vacuum or protective atmosphere; cool to room temperature; reheat in vacuum or protective atmosphere to 1600 F ± 25 F, 24 hr; cool to room temperature (23).

1.06 Hardness
36–42 R_C (22, p. 2.0).

1.07 Forms and Conditions Available

1.071 Alloy is cast to shape. Principal use is turbine blades and completely cast turbine wheels.

1.072 Directionally solidified and single-crystal turbine blades have also been made.

1.08 Melting and Casting Practice

1.081 Castings are made from either remelted metal from a master heat, or directly from a master heat. Vacuum is maintained during melting, in transition from melting and pouring, and during pouring. Gates, sprues, risers, and rejected castings may be used only in preparation of master heat; they may not be remelted directly without refining for pouring of castings. For directional solidified casting a unidirectional thermal gradient is maintained in the mold cavity, so that the solidification front proceeds parallel to the thermal gradient.

1.09 Special Considerations

1.091 Mar-M-246 alloy is one of the strongest alloys at high temperatures.

1.092 Although oxidation and sulfidation resistance are lower than for some nickel-base alloys, suitable coatings have been developed to overcome these limitations, and the alloy has been extensively used under hot-corrosion and oxidation conditions.

1.093 Addition of hafnium has led to improvements in strength fatigue and ductility, also higher creep-rupture resistance. Although the addition of hafnium was initially not accompanied with optimum balance of other chemical elements to produce an alloy of good metallurgical stability in the long time usage range, the improvements have been adequate for short time applications such as the turbine of the U.S.A. Space Shuttle. Later modifications of chemistry have led to a new alloy, redesignated as Mar-M-247, which possesses long-term stability as well as the desirable strength characteristics of Mar-M-246.

1.094 Alloy has been developed in directionally solidified and single-crystal form.

1.095 A considerable amount of data for alloy characterization has been obtained because of the selection of the hafnium-modified alloy for the turbine of the U.S.A. Space Shuttle.

(a) A division of Martin Marietta in Wheeling, Illinois.

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

2 PHYSICAL PROPERTIES AND ENVIRONMENTAL EFFECTS

2.01 Thermal Properties

2.011 Melting range, 2230 to 2475 F (22, p. 2.0).

2.012 Phase changes.

2.0121 Minor phase concentrations for alloy at long exposure of 5000 hr at various high temperatures, Figure 2.0121.

2.0122 Addition of hafnium results in MC carbides in which hafnium replaces titanium which goes to the matrix and strengthens it. Hafnium forms uniformly discrete MC carbides and retards formation of secondary carbides. Therefore, hafnium additions increase strength and ductility. (27, p. 1089, 1091-1092).

2.013 Thermal conductivity.

2.0131 Thermal conductivity of conventionally cast alloy, Figure 2.0131.

2.0132 Thermal conductivity of directionally solidified alloy, Figure 2.0132.

2.014 Thermal expansion, Figure 2.014.

2.015 Specific heat of directionally solidified alloy, Figure 2.015.

2.016 Thermal diffusivity of directionally solidified alloy, Figure 2.016.

2.02 Other Physical Properties

2.021 Density, 0.305 lb/in.^{3}, 8.5 g/cc (22, p. 2.0).

2.022 Electrical properties.

2.023 Magnetic properties.

2.024 Emittance.

2.025 Damping.

2.03 Chemical Environments

2.031 Oxidation. Similar to other nickel-base alloys, Mar-M-246 lacks inherent oxidation resistance for long time exposure at the high temperatures and stresses permitted by its inherent strength and creep resistance. The problem is exaggerated when cyclic stresses are present, so that the cyclic strains cause spalling, exposing new surface each cycle. However, the alloy lends itself to protection by surface coatings, predominantly aluminides, as with other nickel-base alloys.

2.0311 Oxidation characteristics of conventionally cast alloy in static air, Figure 2.0311.

2.0312 Weight change for directionally solidified and single-crystal hafnium-modified Mar-M-246 turbine blades thermally cycled by alternate immersion in two fluidized beds, Figure 2.0312.

2.0313 Weight change, during thermal cycling in fluidized beds, of directionally solidified turbine blades of hafnium-modified Mar-M-246 protected by various plasma spray coatings, Figure 2.0313.

2.0314 Weight change, during thermal cycling in fluidized beds, of directionally solidified turbine blades of hafnium-modified Mar-M-246 protected by several additional plasma spray coatings, Figure 2.0314.

2.0315 Variation of aluminide layer thickness and sigma phase depth with exposure time in argon for conventionally cast turbine blades, with comparison to another nickel-base alloy, B-1900, Table 2.0315.

2.032 Hot corrosion. Although some investigations in hot corrosion of Mar-M-246 have suggested that it is inferior in resistance to some nickel-base alloys (e.g., Figure 2.0323), others show its resistance to be comparable, and explainable on the basis of the elemental content of the alloy (Figures 2.0321 and 2.0322, also Figures 2.0324-2.0327).

2.0321 Comparison of hot corrosion behavior of Mar-M-246 in a marine turbine simulator with other nickel- and cobalt-base alloys, Figure 2.0321.

2.0322 Corrosion rates for a series of nickel-base alloys as determined in a test rig simulating stationary gas turbine operating conditions. Alloys are ordered according to increasing creep strength, showing Mar-M-246 to be the strongest of those tested, Figure 2.0322.

2.0323 Comparison of hot corrosion resistance of conventionally cast small turbine blades of Mar-M-246 with resistance of other nickel-base alloys tested in a hot gas turbine rig, Figure 2.0323.

2.0324 Hot corrosion resistance for alloy protected by 2 or 3.5 mil standard aluminide coating, and comparison with three other alloys tested under similar conditions, Figure 2.0324.

2.0325 Correlation of corrosion resistance in a test rig simulating gas turbine conditions for a series of nickel-base alloys including Mar-M-246. Figure shows corrosion performance at 1562 F (850 C) in relation to content of elements chromium, aluminum, and titanium, Figure 2.0325.

2.0326 Correlation of corrosion resistance in a test rig simulating gas turbine conditions for a series of nickel-base alloys including Mar-M-246. Figure shows corrosion performance at 1562 F (850 C) in relation to several ratios of the elements chromium, aluminum, and titanium, Figure 2.0326.

2.0327 Corrosion rates for three nickel-base alloys including Mar-M-246 showing linearity of Arrhenius plot of rate versus the reciprocal of the absolute temperature in temperature range of 1382 to 1742 F. Other nickel-base alloys do not necessarily show such linearity, Figure 2.0327.

2.04 Nuclear Environments

3 MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 No official specifications currently exist either by AMS or ASTM.

3.012 See Table 1.031 for suggested specifications by alloy developer.

3.02 Mechanical Properties at Room Temperature

See 3.03.

3.021 Tension.

3.0211 Stress-strain diagrams.

3.0212 Room temperature mechanical properties of hafnium-modified alloy cast to test specimen shape or machined from turbine blades, Table 3.0212.

3.022 Compression.

3.0221 Stress-strain.

3.023 Impact.

3.0231 Ballistic impact effects on subsequent corrosion exposure for conventionally cast Mar-M-246, with comparison to another nickel-base alloy, B-1900, Table 3.0231.

3.024 Bending.

3.025 Torsion and shear.

3.026 Bearing.

3.027 Stress concentration.

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

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3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.0312 Average tensile properties of conventionally cast alloy from room temperature to 2000 F, Figure 3.0312.
3.0313 Tensile properties at 1500 to 1800 F for hafnium-modified Mar-M-246 in directionally solidified and single-crystal form, Table 3.0313.
3.0314 Tensile properties at room and elevated temperatures of directionally solidified hafnium-modified Mar-M-246 in 5000 psig helium, Figure 3.0314.
3.0315 Tensile properties at room and elevated temperatures for directionally solidified hafnium-modified Mar-M-246 in 5000 psig hydrogen, Figure 3.0315.
3.0316 Effect of aluminum manganese coating on tensile properties at room and elevated temperatures, Figure 3.0316.
3.032 Compression.
3.0321 Stress-strain diagrams.
3.033 Impact, see 3.023.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration, see Figures 3.0541 and 3.0542.
3.038 Combined properties.

3.04 Creep and Creep-Rupture Properties
3.041 Creep.
3.0411 Creep of conventionally cast alloy.
3.04111 Typical creep curves at 1400 F for conventionally cast alloy as determined by alloy developer, Figure 3.04111.
3.04112 Typical creep curves at 1600 F for conventionally cast alloy as determined by alloy developer, Figure 3.04112.
3.04113 Typical creep curves at 1700 F for conventionally cast alloy as determined by alloy developer, Figure 3.04113.
3.04114 Typical creep curves at 1800 F for conventionally cast alloy as determined by alloy developer, Figure 3.04114.
3.04115 Stress/time combinations to produce percent creep strain at temperatures from 1400 to 1800 F for conventionally cast alloy, as determined by alloy developer, Figure 3.04115.
3.0412 Creep of hafnium-modified alloy.
3.04121 Creep curve for Mar-M-246 (hafnium) at 1340 F, 100 ksi, Figure 3.04121.
3.04122 Creep curve for Mar-M-246 (hafnium) at 1500 F, 70 ksi, Figure 3.04122.
3.04123 Creep curve for Mar-M-246 (hafnium) at 1600 F, 57 ksi, Figure 3.04123.
3.04124 Creep curve for Mar-M-246 (hafnium) at 1650 F, 53 ksi, Figure 3.04124.
3.0413 Creep correlations.
3.04131 Arrhenius relation between second stage creep rate and temperature at 67 ksi for conventionally cast alloy, Figure 3.04131.
3.04132 Relation between stress and strain rate for conventionally cast Mar-M-246 at 1650 F, with comparison to several other materials at various temperatures, Figure 3.04132.
3.04133 Correlation of steady-state creep rate data for several materials including Mar-M-246 according to a universal equation, Figure 3.04133.
3.042 Creep rupture.
3.0421 General. Alloy is among the most resistant to rupture at high temperature of the nickel-base alloys.
3.04211 Comparison of strength of Mar-M-246 with other nickel-bearing alloys according to temperature capability to support 20 ksi for 100 and 1000 hr, Figure 3.04211.
3.0422 Creep rupture of conventionally cast alloy.
3.04221 Stress for creep rupture in 100 and 1000 hr for conventionally cast alloy from 1400 to 1900 F, Figure 3.04221.
3.04222 Typical creep-rupture properties for conventionally cast alloy from 1400 to 2100 F, as supplied by developer, Figure 3.04222.
3.04223 Relative performance of various time-temperature parameters in correlating and extrapolating creep-rupture data, Table 3.04223.
3.04224 Computer-determined constants for analysis of creep-rupture data of conventionally cast alloy by seven time-temperature parameters, Table 3.04224.
3.0423 Creep rupture of hafnium-modified alloy.
3.04231 Creep rupture at 1500 F for hafnium-modified Mar-M-246 in single-crystal and directionally solidified form. Figure also shows comparison of longitudinal properties with limited data on transverse properties, Figure 3.04231.
3.04232 Creep-rupture properties of hafnium-modified alloy as determined from cast bars and specimens machined from turbine blades, Table 3.04232.
3.0424 Effects of coatings.
3.04241 Creep-rupture test results for alloy with various coatings and in uncoated condition evaluated at 1800 F, 35 ksi, Table 3.04241.
3.04242 Creep-rupture data at 1800 F for uncoated alloy and with various coatings, Figure 3.04242.

3.05 Fatigue Properties
3.051 Low cycle fatigue.
3.0511 Room temperature low cycle fatigue tests in 5000 psig helium and in 2000 and 5000 psig hydrogen for directionally solidified Mar-M-246, Figure 3.0511.
3.0512 Comparison of low cycle fatigue behavior of single-crystal and directionally solidified alloy at 1400 F in 5000 psig hydrogen, Figure 3.0512.
3.0513 Low cycle fatigue in 15 psig argon at 1250 and 1500 F for directionally solidified hafnium-modified Mar-M-246, Figure 3.0513.
3.0514 Low cycle fatigue at 1400 F for alloy in uncoated condition and coated with codeposited aluminum-manganese system, Table 3.0514.
3.052 High cycle fatigue.
3.0521 Low frequency high cycle fatigue at 1550 F in completely reversed axial loading for directionally solidified, hafnium-modified Mar-M-246, Figure 3.0521.
3.0522 High cycle fatigue of hafnium-modified Mar-M-246 alloy at 1500 F, R = 0.03, with comparison of longitudinal and transverse properties of directionally solidified alloy, Figure 3.0522.
3.0523 High cycle fatigue of hafnium-modified Mar-M-246 at 1500 F, R = 0.03, with comparison of longitudinal and transverse properties of single-crystal alloy, Figure 3.0523.

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

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3.0524 High cycle fatigue of hafnium-modified Mar-M-246 at 1600 F, R = 0.20, with comparison between longitudinal properties of directionally solidified and single-crystal alloys, Figure 3.0524.

3.0525 High cycle fatigue of hafnium-modified Mar-M-246 at 1700 F, R = 0.20, with comparison between longitudinal properties of directionally solidified and single-crystal alloys, Figure 3.0525.

3.0526 High cycle fatigue of hafnium-modified Mar-M-246 at 1800 F, R = 0.20, with comparison between longitudinal properties of directionally solidified and single-crystal alloys, Figure 3.0526.

3.053 Thermal fatigue.

3.0531 Thermal fatigue cracking for small turbine blades of single-crystal and directionally solidified hafnium-modified Mar-M-246 alternately immersed in fluidized beds at 77 and 1742 F, Table 3.0531.

3.0532 Effect of various coatings on thermal fatigue resistance of conventionally cast Mar-M-246, Table 3.0532.

3.054 Fatigue crack growth.

3.0541 Fatigue crack growth curves for conventionally cast hafnium-modified Mar-M-246 at 1000 F in 5000 psig hydrogen, and at 1600 F in 5000 psig hydrogen, or in 5000 psig mixture of hydrogen and 50 percent water vapor, Figure 3.0541.

3.0542 Fatigue crack growth curves for directionally solidified, hafnium-modified Mar-M-246 at 1000 F in 5000 psig hydrogen, and at 1600 F in 5000 psig hydrogen, or in 5000 psig mixture of hydrogen and 50 percent water vapor, Figure 3.0542.

3.06 Elastic Properties

3.061 Poisson's ratio from room temperature to 2000 F, Figure 3.061.

3.062 Modulus of elasticity.

3.0621 Dynamic modulus of elasticity of conventionally cast alloy, Figure 3.0621.

3.0622 Elastic modulus at room and elevated temperatures for directionally solidified hafnium-modified Mar-M-246 in 5000 psig helium and hydrogen, Figure 3.0622.

3.063 Modulus of rigidity from room temperature to 2000 F for conventionally cast alloy, Figure 3.063.

4 FABRICATION

4.01 Forming

4.011 Alloy is usually cast to shape, including directionally solidified turbine blades.

4.012 For alloy with hafnium addition special gating and pouring practice should be considered in evaluating the tendency of hafnium to increase shrinkage characteristics, see also 4.0131 Code 4213.

4.02 Machining and Grinding

4.021 As with other gamma-prime-strengthened nickel-base superalloys of similar composition, Mar-M-246 can be machined successfully only when careful attention to proper machining techniques is employed. Variables such as part configuration, condition of machine, type of fixturing, and surface finish requirements all affect machining performance. Rigid equipment and flood cooling with soluble oils or water-base chemical coolants are required. Feeds and speeds are generally lower than values used for steel machining. Sharp, hard cutting tools are recommended.

4.022 Material can be machined in standard operations such as end-milled, face-milled, drilled, or turned. For recommended machining parameters, see reference 22, p. 6.2–6.6.

4.023 Conventional surface grinding operations are common, including electrical discharge machining (EDM) and electrochemical machining (ECM) (22, 25).

4.03 Joining

Repair welding in inert atmospheres using GTA process can be applied to alloy. Inertia welding of Mar-M-246 to steel has been successfully achieved (26).

4.04 Surface Treating

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Ni	
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

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Alloy	MAR-M-246, Hf Modified	
Property[a]	Typical Values	Suggested Minimum for Spec
Room Temperature Tensile		
F_{tu}, ksi	150	135
F_{ty}, ksi	130	115
E (2 in.), percent	4.5	3.0
Creep Rupture		
At 1800 F, 34 ksi		
Rupture Time, hr	34	23
Prior Creep, percent[b]	4.5	2.0
Elongation at Rupture, percent	6.4	4.0
At 1400 F, 105 ksi		
Rupture Time, hr	68	23
Prior Creep, percent[b]	3.5	1.8

(a) Heat treatment at 1550 F for 50 hours; air cool.
(b) Extension measured within 2 hours of failure.

TABLE 1.031. SPECIFICATIONS FOR STANDARD ALLOY SUGGESTED BY ALLOY DEVELOPER (22)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

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Alloy	MAR-M-246, Hf Modified		
Composition	Weight Percent		
	Nominal	Min	Max
Co	10.0	9.0	11.0
W	10.0	9.0	11.0
Cr	9.0	8.0	10.0
Al	5.5	5.25	5.75
Mo	2.5	2.25	2.75
Ti	1.5	1.25	1.75
Ta	1.5	1.25	1.75
C	0.15	0.13	0.17
Fe	0.15	–	1.0
Mn	0.10	–	0.20
Zr	0.05	0.03	0.08
Si	0.05	–	0.20
B	0.015	0.01	0.02
Cu	0.008	–	0.10
S	0.005	–	0.015
Ni	Bal	–	–

(a) Hafnium-modified alloy percentages are 1.75, 1.5, and 2.0, respectively.

TABLE 1.041. COMPOSITION LIMITS SPECIFIED BY ALLOY DEVELOPER[a] (22)

Alloy	MAR-M-246, Hf Modified	
Composition	Weight Percent	
	Heat Used by Pratt & Whitney Aircraft (23)	Heat Used by Rocketdyne (24)
Co	10.20	10.63
W	10.10	9.23
Cr	8.85	8.30
Al	5.50	5.53
Mo	2.70	2.49
Ti	1.55	1.62
Ta	1.51	1.46
Hf	1.85	1.96
C	0.14	0.14
Fe	0.19	0.05
Mn	<0.10	0.01
Zr	0.04	0.04
Si	0.06	0.05
B	0.014	0.016
Cu	<0.10	<0.01
Mg	0.0006	–
Ni	Bal	Bal

TABLE 1.042. COMPOSITION OF TWO HAFNIUM-MODIFIED HEATS USED IN ALLOY CHARACTERIZATION (23)(24)

Alloy	MAR-M-246, Hf Modified					
Form	Small Turbine Blades, Aluminide Coated With Codeposited Mn					
Test Conditions	Exposed 1950 F, 100 to 2000 hr in Argon to Establish Interdiffusion of Aluminum and Alloy Substrate Elements					
	Total Coating Thickness, mils		Diffusion Zone Thickness, mils		Depth of Sigma Phase Needles in Substrate Beneath Coating, mils	
Exposure Time at 1950 F, hr	B-1900	MAR-M-246	B-1900	MAR-M-246	B-1900	MAR-M-246
0	2.3	2.0	0.5	0.4	0	0
100	4.0	4.75	1.75	2.0	0	2
500	3.75	4.75	1.75	2.25	4	8
1000	3.75	4.25	2.25	1.75	8	8
1500	3.75	5.0	2.25	2.5	12	12
2000	3.75	5.0	2.0	2.5	12	12

TABLE 2.0315. VARIATION OF ALUMINIDE LAYER THICKNESS AND SIGMA PHASE DEPTH WITH EXPOSURE TIME IN ARGON FOR CONVENTIONALLY CAST TURBINE BLADES, WITH COMPARISON TO ANOTHER NICKEL-BASE ALLOY, B-1900 (20)

Alloy	MAR-M-246, Hf Modified					
Composition	See Table 1.042, Pratt & Whitney Heat					
Heat Treatment	See 1.052					
	Specimens Cast to Size 27 Specimens			Specimens Machined From Blades 5 Specimens		
	Min	Max	Avg	Min	Max	Avg
F_{tu}, ksi	123	150	134.5	124	132	127.6
F_{ty}, ksi	116	125	121.9	120	123	121.2
E, percent	3.5	7.5	5.1	4.0	6	5.2
RA, percent	3.2	15.5	7.2	4.0	7.7	5.3

TABLE 3.0212. ROOM TEMPERATURE MECHANICAL PROPERTIES OF HAFNIUM-MODIFIED ALLOY CAST TO TEST SPECIMEN SHAPE OR MACHINED FROM TURBINE BLADES (5)

Ni	
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

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Alloy	MAR-M-246, Hf Modified						
Form	Coated Specimen, 50 mil, Using Various Coatings, as Shown						
Test Conditions	Impacted With 0.156 diam Steel Ball at 340 ft/sec (Impact Energy 4.6 - 4.7 ft-lb) at RT or 1950 F. After Impact, Specimens Coated With 10 w/o NaCl and 90 w/o Na_2SO_4 Salt Mixture and Oxidized With Air at 1800 F to Failure.						
MAR-M-246				B-1900			
Coating System	Temp at Impact, F	Condition After Impact	Oxidation Life, hr	Coating System	Temp at Impact, F	Condition After Impact	Oxidation Life, hr
				Al (Cr)	Not Impacted	(Standard)	22
Al (Cr)	80	(a)	43	Al (Cr)	80	(a)	43
Al (Cr)	80	(b)	43	Al (Cr)	80	(b)	43
Al (Cr)	1950	(b)	21(c)	Al (Cr)	1950	(b)	21
Al (Cr)	1950	(b)	>87	Al (Cr)	1950	(b)	21
Mg Codep	80	(a)	43	Mg Codep	80	(a)	22
Mg Codep	80	(b)	43	Mg Codep	80	(b)	63
Mg Codep	1950	(b)	87	Mg Codep	1950	(b)	21(c)
Mg Codep	1950	(b)	>87	Mg Codep	1950	(b)	61
Mn Codep	80	(b)	>63	Si Codep	80	(b)	43
Mn Codep	80	(b)	>63	Si Codep	80	(b)	43
Mn Codep	1950	(b)	61	Si Codep	1950	(b)	87
Mn Codep	1950	(b)	87	Si Codep	1950	(b)	87
Mn-Al	80	(a)	63	Mn Codep	–	(b)	63
Mn-Al	80	(b)	>63	Mn Codep	–	(b)	>63
Mn-Al	1950	(b)	21(c)	Mn Codep	–	(b)	66(c)
Mn-Al	1950	(b)	>87	Mn Codep	–	(b)	87(c)

(a) Coating spalled adjacent to impacted area.
(b) No cracking or spalling of coating.
(c) Specimen corroded overall.

TABLE 3.0231. BALLISTIC IMPACT EFFECTS ON SUBSEQUENT CORROSION EXPOSURE FOR CONVENTIONALLY CAST MAR-M-246, WITH COMPARISON TO ANOTHER NICKEL-BASE ALLOY, B-1900 (20)

Alloy	MAR-M-246, Hf Modified			
Composition	See Table 1.042, Pratt & Whitney Heat			
Heat Treatment	See 1.052			
	Directionally Solidified		Single Crystal	
Test Temperature(d)	Longitudinal	Transverse	Longitudinal	Transverse
1500 F				
F_{tu}, ksi	152.2(a)	165.6(a)	–	166.8(a)
1600 F				
F_{tu}, ksi	137.8(b)	–	133.3(c)	–
F_{ty}, ksi	125.0(b)	–	117.4(b)	–
1700 F				
F_{tu}, ksi	117.1(b)	–	–	–
F_{ty}, ksi	96.2(b)	–	–	–
1800 F				
F_{tu}, ksi	93.1(b)	–	–	–
F_{ty}, ksi	77.1(b)	–	–	–

(a) Average of four tests.
(b) Average of two tests.
(c) Average of three tests.
(d) All tests conducted at strain rate 0.1 in./minute.

TABLE 3.0313. TENSILE PROPERTIES AT 1500 TO 1800 F FOR HAFNIUM-MODIFIED MAR-M-246 IN DIRECTIONALLY SOLIDIFIED AND SINGLE-CRYSTAL FORM (5)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

Alloy	MAR-M-246, Hf Modified				
Condition	Conventionally Cast + Age (Presumably 1550 F, 50 hr)				
Parametric Form and Order of Polynomial Representing Master Curve (See Also Table 3.04214 for Parametric Forms and Constants)	Standard Deviation of Regression for Correlation of All Data, log hr	Average Percent Deviation For: Stress for Correlation of All Data	Rupture Time for Correlation of All Data	Stress for Extrapolated Points[a]	Rupture Time for Extrapolated Points[a]
Larson-Miller,					
2nd Degree Polynomial	0.124	4.04	20.90	13.31	41.12
3rd Degree Polynomial	0.115	3.23	19.46	9.40	46.90
Manson-Haferd,					
2nd Degree Polynomial	0.109	3.25	19.51	8.77	55.51
3rd Degree Polynomial	0.108	2.93	18.87	8.46	54.12
Orr-Sherby-Dorn,					
2nd Degree Polynomial	0.160	5.86	27.24	20.09	31.12
3rd Degree Polynomial	0.136	4.11	23.87	10.25	35.39
Goldhoff-Sherby					
2nd Degree Polynomial	0.111	3.17	19.45	9.47	76.09
3rd Degree Polynomial	0.110	3.03	19.23	9.29	71.05
Manson-Succop					
2nd Degree Polynomial	0.116	3.68	19.75	11.07	39.11
3rd Degree Polynomial	0.106	2.91	18.17	8.68	47.09
Conrad	–	–	–	9.52	28.12
Korchynsky	–	–	–	12.28	62.61

(a) Five points were "internally extrapolated", i.e., the master curve did not need to be extrapolated to make the extrapolation on time.

TABLE 3.04223. RELATIVE PERFORMANCE OF VARIOUS TIME-TEMPERATURE PARAMETERS IN CORRELATING AND EXTRAPOLATING CREEP-RUPTURE DATA (16)

Alloy	MAR-M-246, Hf Modified		
Condition	Conventionally Cast + Age (Presumably 1550 F, 50 hr)		
Parameter Designation and Form		Computer-Evaluated Constants: Master Curve 2nd Degree Polynomial	Master Curve 3rd Degree Polynomial
Larson-Miller $P = (T+460)(\log t_r + C)$,	T = F t_r = Rupture Time, hr	$C = 20.09$	$C = 21.43$
Manson-Haferd $P = \frac{\log t_r - \log t_a}{T - T_a}$	T = F t_r = Rupture Time, hr	$\log t_a = -21.33$ $T_a = 4000$	$\log t_a = -32.75$ $T_a = 5000$
Orr-Sherby-Dorn $P = t_r e^{(-\Delta H/RK)}$	K = Temperature in Kelvin t_r = Rupture Time, hr	$\Delta H = 57,310$ R = Universal Gas Constant	$\Delta H = 65,260$
Manson-Succop $P = \log t_r + AT$	T = F t_r = Rupture Time, hr	$A = .010$	$A = .011$
Goldhoff-Sherby $P = \frac{\log t_r - \log t_b}{1/T - 1/T_b}$	T = F t_r = Rupture Time, hr	$\log t_b = -6.42$ $\frac{1}{T_b} = .0003$	$\log t_b = -6.58$ $\frac{1}{T_b} = .0003$
Conrad $t_r = Be^{-\sigma/\sigma_o} e^{\Delta H/RK}$	K = Temperature in Kelvin t_r = Rupture Time, hr R = Universal Gas Constant	$\Delta H = 156,470$ No polynomial assumed for master curve, stress form is $Be^{-\sigma/\sigma_o}$	
Korchynsky $t_r = D\sigma^b e^{\frac{E}{K}}$	K = Temperature in Kelvin t_r = Rupture Time, hr	$E = 969,420$ No polynomial assumed for master curve, stress form is $D\sigma^b$	

TABLE 3.04224. COMPUTER-DETERMINED CONSTANTS FOR ANALYSES OF CREEP-RUPTURE DATA OF CONVENTIONALLY CAST ALLOY BY SEVEN TIME-TEMPERATURE PARAMETERS (16)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

Alloy	MAR-M-246, Hf Modified					
Composition	See Table 1.042, Pratt & Whitney Heat					
Heat Treatment	See 1.052					
	Life, hr			RA, percent		
Test Condition	Cast To Size	Machined From Oversized Bar	Machined From Blades	Cast To Size	Machined From Oversized Bar	Machined From Blades
1800 F, 32 ksi	45.7(a)	32.9(c)	44.4(d)	7.0(a)	4.0(d)	6.5(d)
1800 F, 31 ksi	49.9(b)	–	–	7.1(b)	–	–
1800 F, 30 ksi	57.7(c)	–	–	4.4(c)	–	–
1700 F, 42 ksi	92.8(d)	–	–	6.1(d)	–	–
1400 F, 105 ksi	60.1(c)	34.9(b)	–	4.0(d)	5.1(b)	–
1400 F, 100 ksi	86.8(d)	–	–	4.1(d)	–	–
1400 F, 97.5 ksi	24.6(d)	40.3(c)	24.2(d)	4.8(d)	3.6(c)	4.0(d)

(a) Average of 10 tests.
(b) Average of four tests.
(c) Average of two tests.
(d) One test.

TABLE 3.04232. CREEP-RUPTURE PROPERTIES OF HAFNIUM-MODIFIED ALLOY AS DETERMINED FROM CAST BARS AND SPECIMENS MACHINED FROM TURBINE BLADES (5)

Alloy	MAR-M-246, Hf Modified				
Form	As Cast 1/4-inch diam Creep Rupture Spec				
		Coating System			
Condition	Uncoated	Mg Codeposited	Al(Cr)	Mn-Al	Mn Codeposited
Rupture Time, hr	6.7, 4.5	3.1, 4.4	16.2, 4.9, 7.8	15.0, 7.2	15.4, 8.7
E (1-1/4 in.), percent	5.3, 5.5	11.3, 9.3	4.2, 9.3, 6.6	2.8, 5.9	9.9, 5.6
RA, percent	3.1, 2.7	12.1, 12.8	6.5, 25.2, 11.7	8.4, 7.4	11.0, 7.6

TABLE 3.04241. CREEP-RUPTURE TEST RESULTS FOR ALLOY WITH VARIOUS COATINGS AND IN UNCOATED CONDITION EVALUATED AT 1800 F, 35 KSI (20)

Alloy	MAR-M-246, Hf Modified	
Form	Conventionally Cast Bar	
Condition	Uncoated or Coated With Codeposited Al-Mn Tested at 1400 F	
	Cycles to Failure	
Plastic Strain Range	Uncoated	Al-Mn Codeposited Coatings
0.008	11	–
0.015	9	–
0.031	–	8
0.037	–	9

TABLE 3.0514. LOW CYCLE FATIGUE AT 1400 F FOR ALLOY IN UNCOATED CONDITION AND COATED WITH CODEPOSITED ALUMINIDE-MANGANESE SYSTEM (20)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

Alloy	MAR-M-246, Hf Modified				
Condition	Directionally Solidified and Single-Crystal Turbine Blades				
Form	Airfoil Section Approx 85-inch Length by 3/4-inch Chord				
Test Conditions	Alternate Immersion in Fluidized Beds at 77 F and 1742 F for 180 sec Each. Observation for Cracks at 25, 50, 100, 200, 300, 500, 700, 1000, 1500, 2000, and 3000 Heating/Cooling Cycles. Cracking Defined at Avg Between Cycles When no Cracking Observed and Cycles When Crack First Observed.				
Blade Number	Microstructure Single Crystal (SC) or Dir Sol (DS)	Crack No.	No. of Cycles to Produce Crack	Crack Size, mils	Location of Crack Dist from Blade Tip, inch
12	DS	1	2750	10	0.20
		2	2750	10	0.86
13	DS	1	850	20	0.95
		2	>3000	–	–
14	DS	1	>3000	–	–
15	SC	1	1250	20	0.95
		2	2250	10	0.55
16	SC	1	850	20	0.95
		2	>3000	–	–
17	SC	1	1250	10, Growth to	0.95
		2	>3000	20 at 3000 Cycles	
18	DS	1	400	10, Growth to	0.95
	(Etched)	2	>3000	40 at 3000 Cycles	
19		1	2750	20	0.93
		2	>3000		
20		1	400	10	0.71
		2	850	30	0.95
21		1	>3000	–	–
22		1	>3000	–	–
23		1	400	10, Growth to 20 at 3000 Cycles	0.90
		2	400	10, No Growth to 3000 Cycles	0.76
24		1	2750	10	0.86
		2	>3000	–	–

TABLE 3.0531. THERMAL FATIGUE CRACKING FOR SMALL TURBINE BLADES OF SINGLE-CRYSTAL AND DIRECTIONALLY SOLIDIFIED Hf-MODIFIED MAR-M-246 ALTERNATELY IMMERSED IN FLUIDIZED BEDS AT 77 AND 1742 F (17)

Alloy	MAR-M-246, Hf Modified				
Form	Wedge Bar, as Shown(b)				
Condition	Uncoated	Al(Cr) Coated	Mn-Al Coated	Mn Codeposited	Mg Codeposited
Cycles to Failure(a)	700,800	>1042 >1000	1000 1000	440 1000	>1000 1000
Nature of Failure	Moderate Erosion; Deep Oxide Penetration at 1140 Cycles	No Failure	Transverse Cracks	Cracks	Transverse Cracks

(a) Tested in neutral oxygen acetylene torch, 2200 F, 15 sec followed by air blast for 15 sec.

(b)

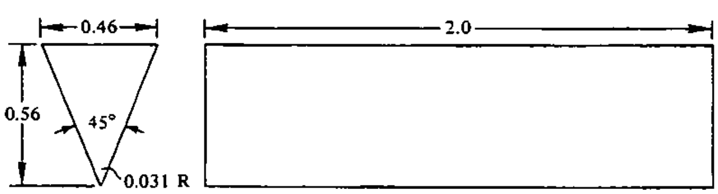

TABLE 3.0532. EFFECT OF VARIOUS COATINGS ON THERMAL FATIGUE RESISTANCE OF CONVENTIONALLY CAST MAR-M-246 (20)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

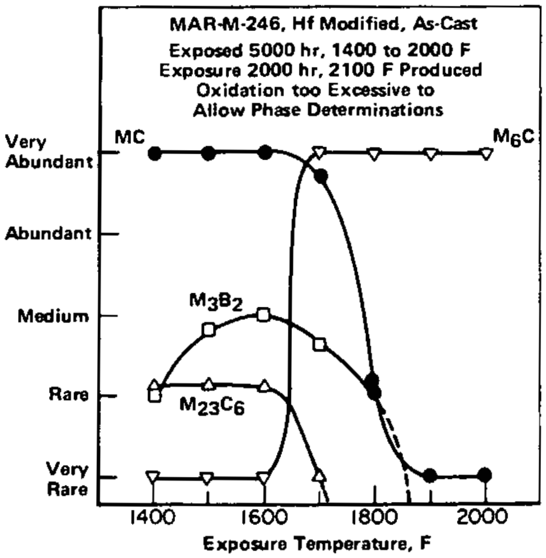

FIGURE 2.0121. MINOR PHASE CONCENTRATIONS FOR ALLOY AT LONG EXPOSURE OF 5000 HR AT VARIOUS HIGH TEMPERATURES (6)

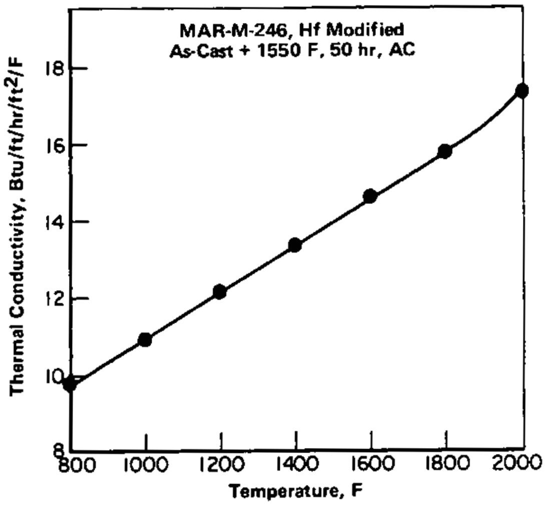

FIGURE 2.0131. THERMAL CONDUCTIVITY OF CONVENTIONALLY CAST ALLOY (1)

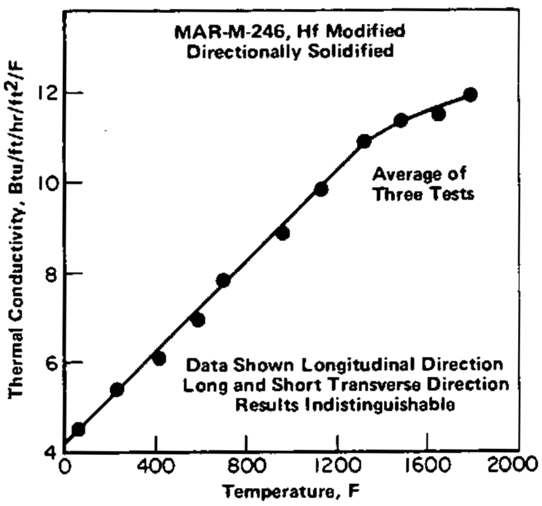

FIGURE 2.0132. THERMAL CONDUCTIVITY OF DIRECTIONALLY SOLIDIFIED ALLOY (4)

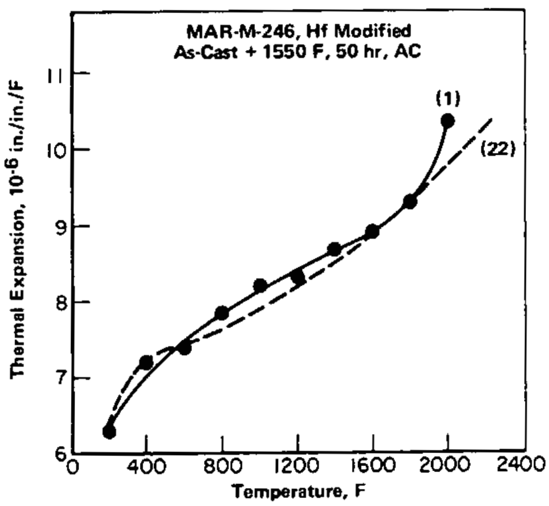

FIGURE 2.014. THERMAL EXPANSION (1) (22)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

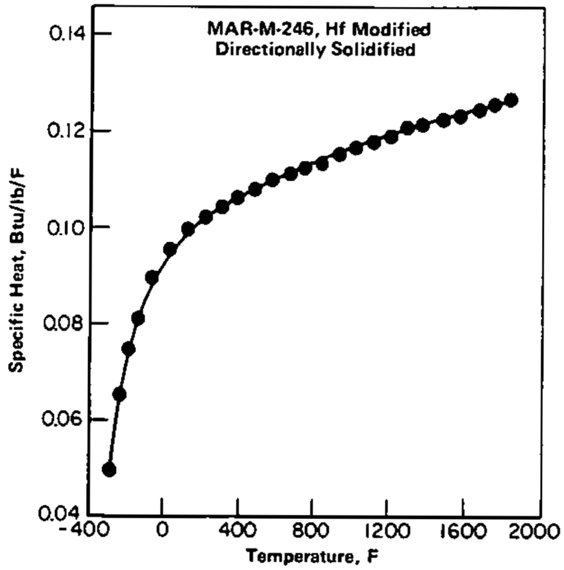

FIGURE 2.015. SPECIFIC HEAT OF DIRECTIONALLY SOLIDIFIED ALLOY (4)

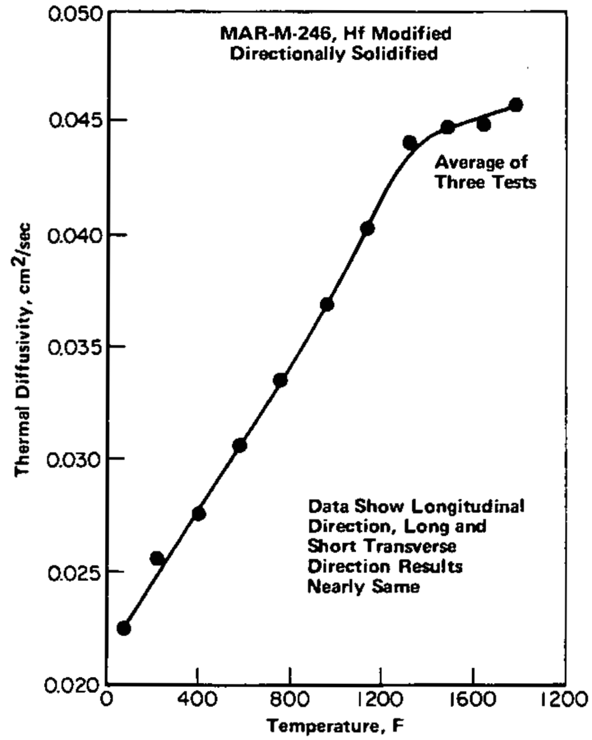

FIGURE 2.016. THERMAL DIFFUSIVITY OF DIRECTIONALLY SOLIDIFIED ALLOY (4)

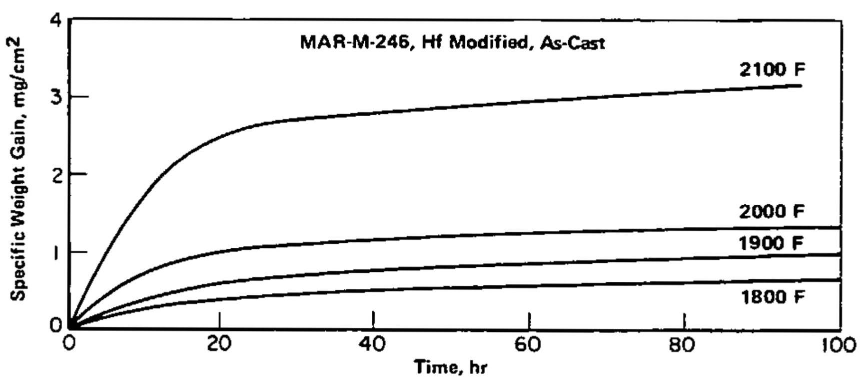

FIGURE 2.0311. OXIDATION CHARACTERISTICS OF CONVENTIONALLY CAST ALLOY IN STATIC AIR (22)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

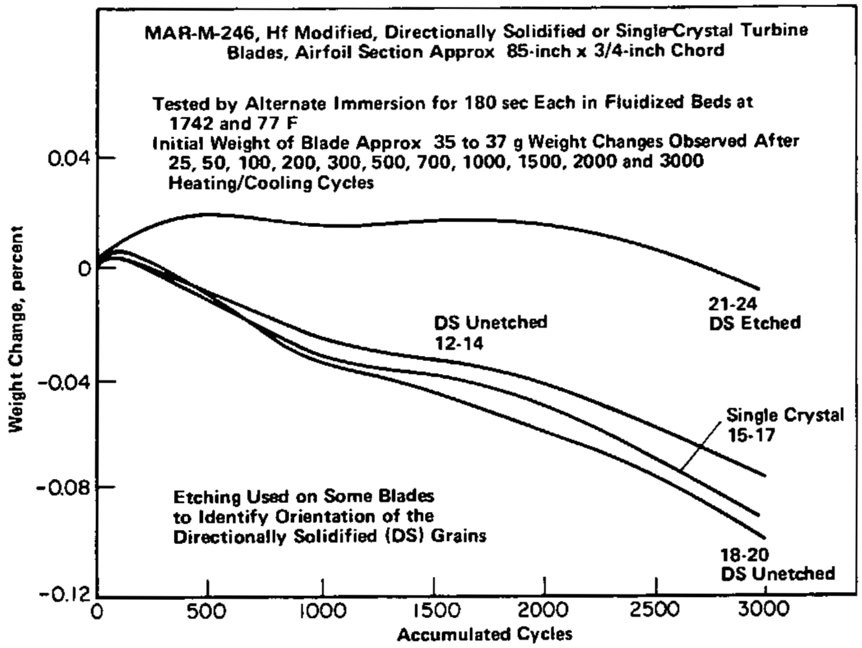

FIGURE 2.0312. WEIGHT CHANGE FOR DIRECTIONALLY SOLIDIFIED AND SINGLE CRYSTAL HAFNIUM-MODIFIED MAR-M-246 TURBINE BLADES THERMALLY CYCLED BY ALTERNATE IMMERSION IN TWO FLUIDIZED BEDS (17)

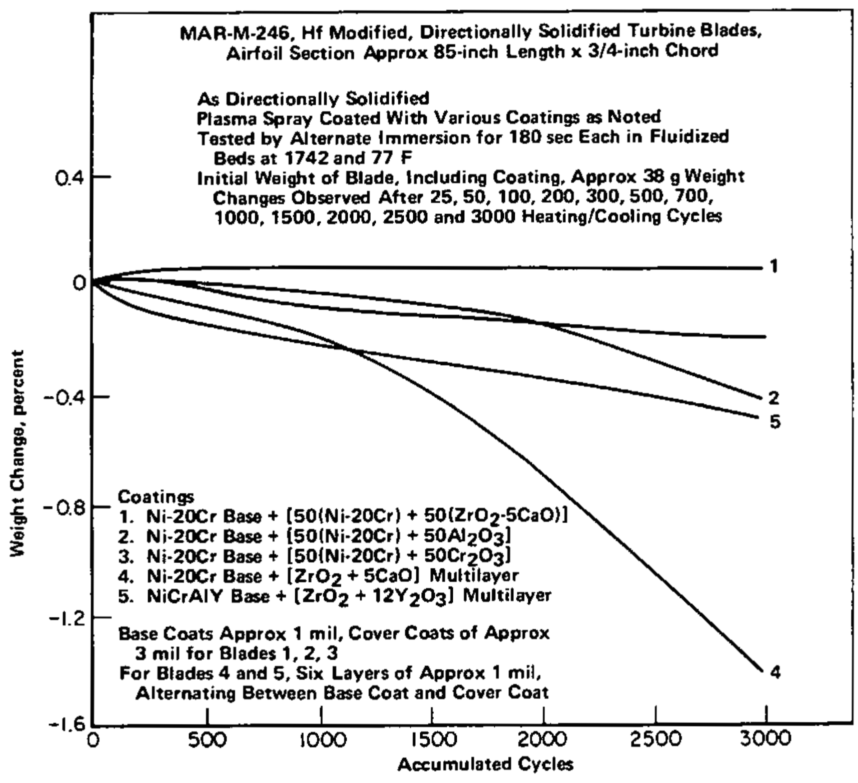

FIGURE 2.0313. WEIGHT CHANGE, DURING THERMAL CYCLING IN FLUIDIZED BEDS, OF DIRECTIONALLY SOLIDIFIED TURBINE BLADES OF HAFNIUM-MODIFIED MAR-M-246 PROTECTED BY VARIOUS PLASMA SPRAY COATINGS (17)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

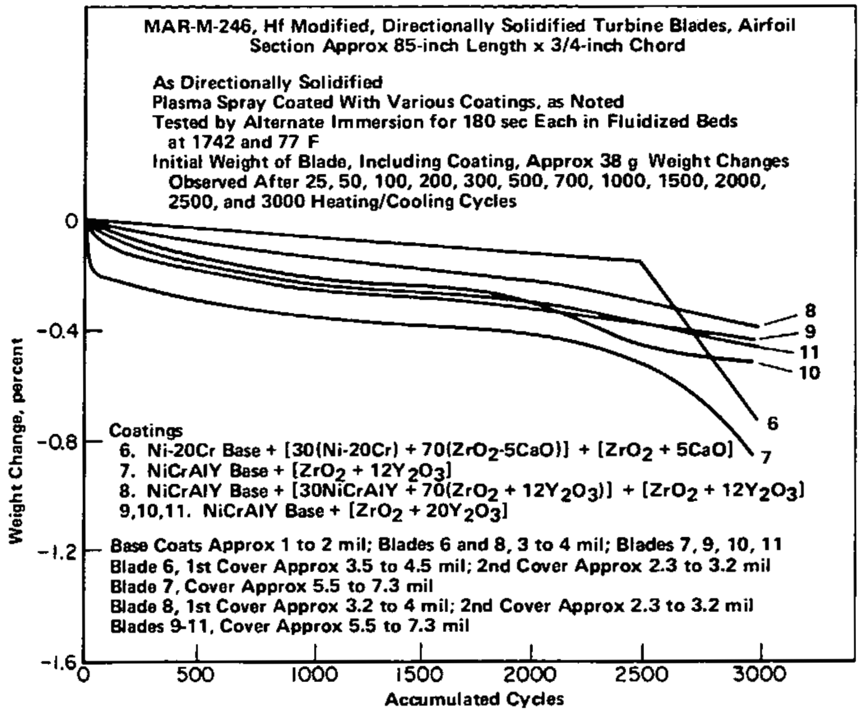

FIGURE 2.0314. WEIGHT CHANGE, DURING THERMAL CYCLING IN FLUIDIZED BEDS, OF DIRECTIONALLY SOLIDIFIED TURBINE BLADES OF HAFNIUM-MODIFIED MAR-M-246 PROTECTED BY SEVERAL ADDITIONAL PLASMA SPRAY COATINGS (17)

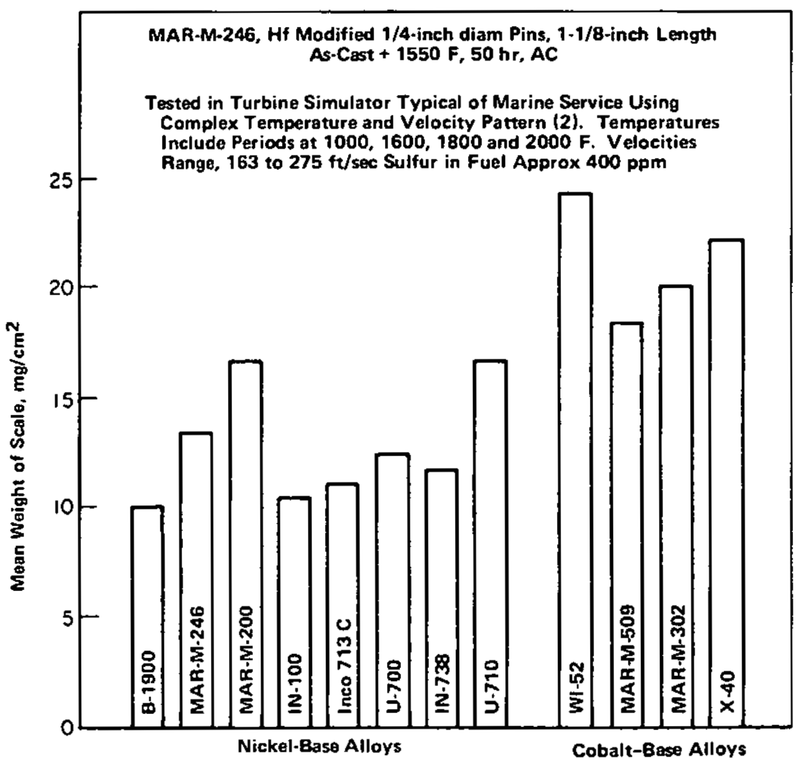

FIGURE 2.0321. COMPARISON OF HOT CORROSION BEHAVIOR OF MAR-M-246 IN A MARINE TURBINE SIMULATOR WITH OTHER NICKEL- AND COBALT-BASE ALLOYS (2)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

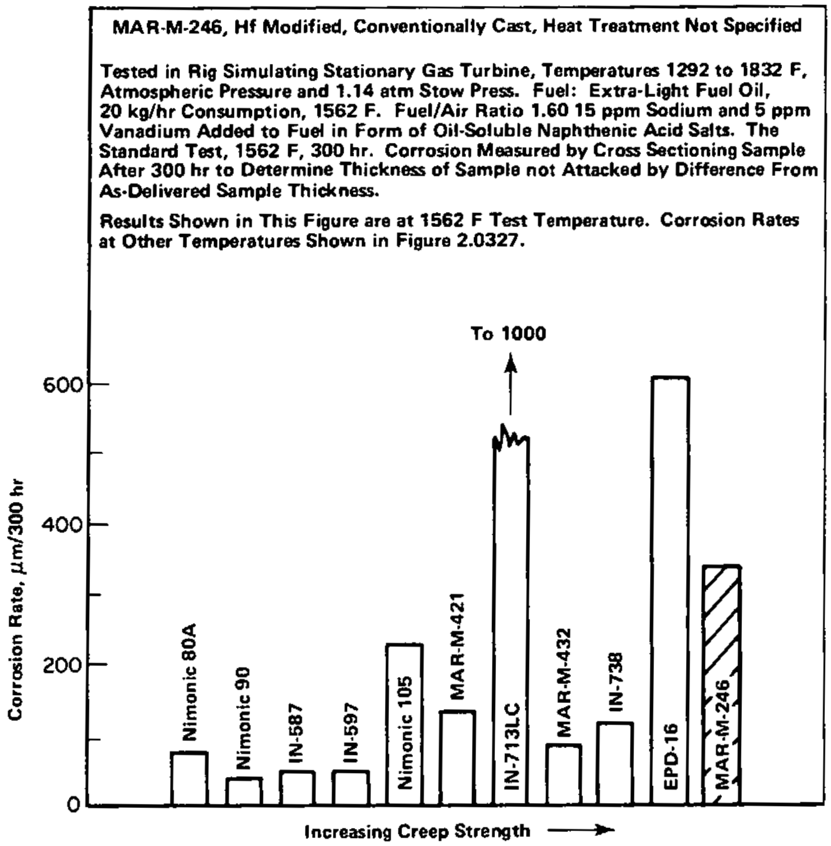

FIGURE 2.0322. CORROSION RATES FOR A SERIES OF NICKEL-BASE ALLOYS AS DETERMINED IN A TEST RIG SIMULATING STATIONARY GAS TURBINE OPERATING CONDITIONS. ALLOYS ARE ORDERED ACCORDING TO INCREASING CREEP STRENGTH, SHOWING MAR-M-246 TO BE STRONGEST OF THOSE TESTED (14)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

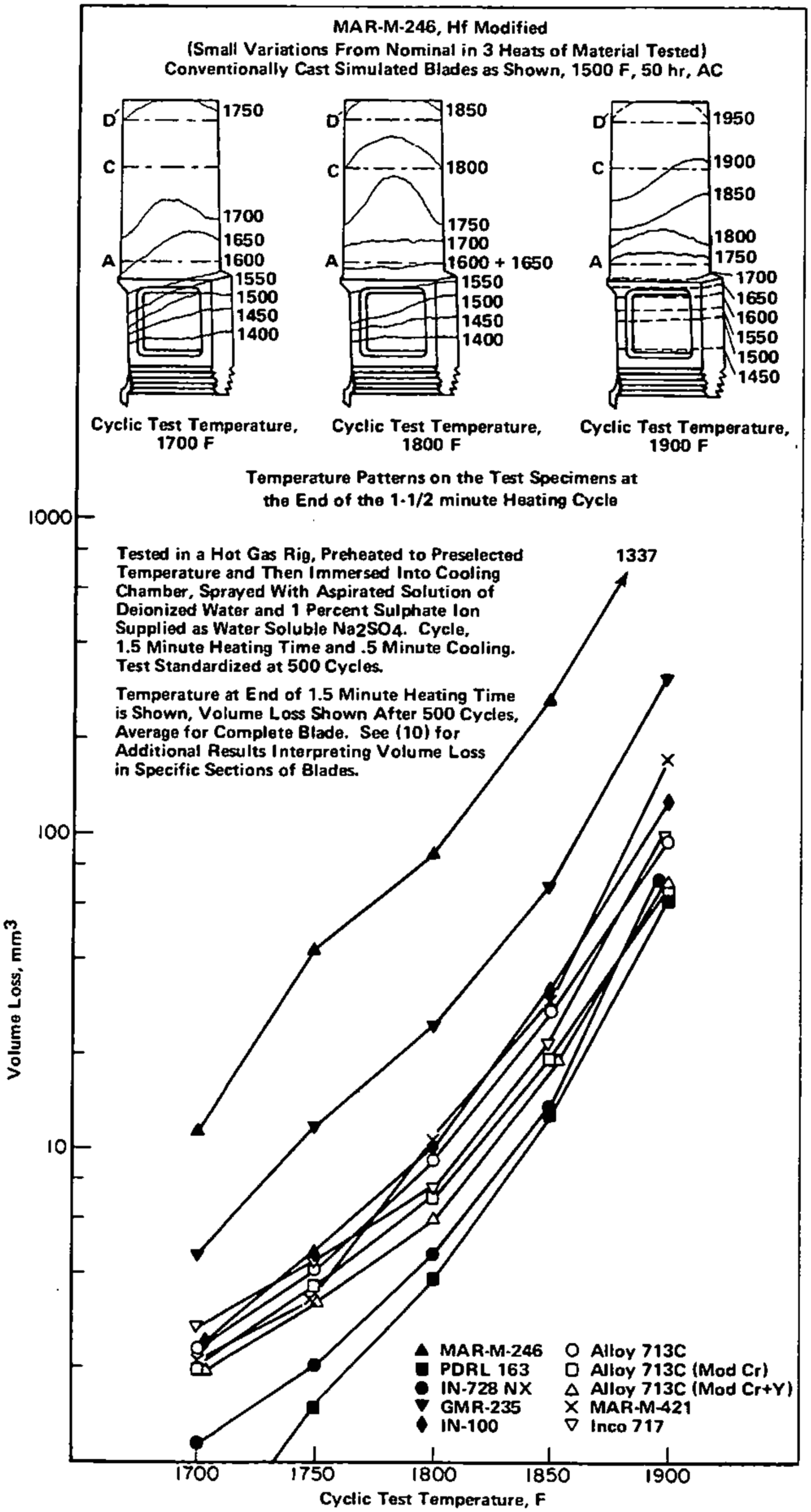

FIGURE 2.0323. COMPARISON OF HOT CORROSION RESISTANCE OF CONVENTIONALLY CAST SMALL TURBINE BLADES OF MAR-M-246 WITH RESISTANCE OF OTHER NICKEL-BASE ALLOYS TESTED IN A HOT GAS TURBINE RIG (9)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

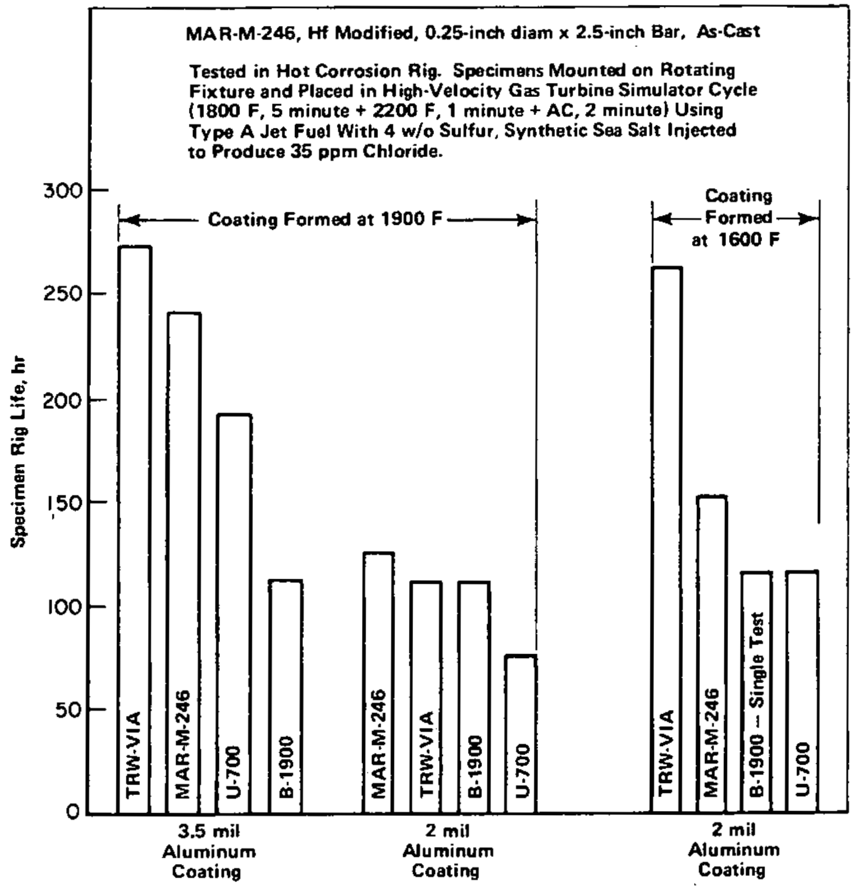

FIGURE 2.0324. HOT CORROSION RESISTANCE FOR ALLOY PROTECTED BY 2 OR 3.5 MIL STANDARD ALUMINIDE COATING, AND COMPARISON WITH THREE OTHER ALLOYS TESTED UNDER SIMILAR CONDITIONS (20)

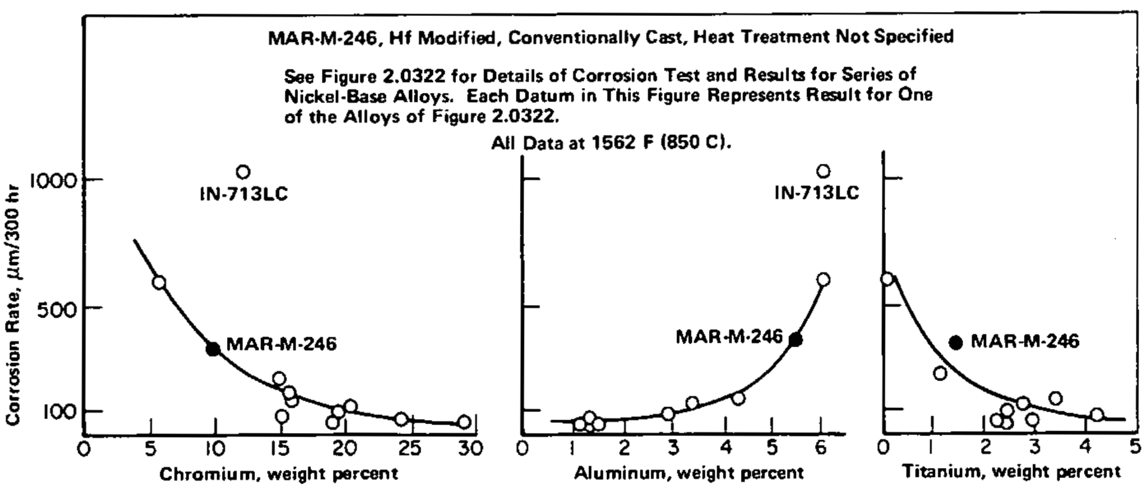

FIGURE 2.0325. CORRELATION OF CORROSION RESISTANCE IN A TEST RIG SIMULATING GAS TURBINE CONDITIONS FOR A SERIES OF NICKEL-BASE ALLOYS INCLUDING MAR-M-246. FIGURE SHOWS CORROSION PERFORMANCE AT 1562 F (850 C) IN RELATION TO CONTENT OF ELEMENTS CHROMIUM, ALUMINUM AND TITANIUM (14)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

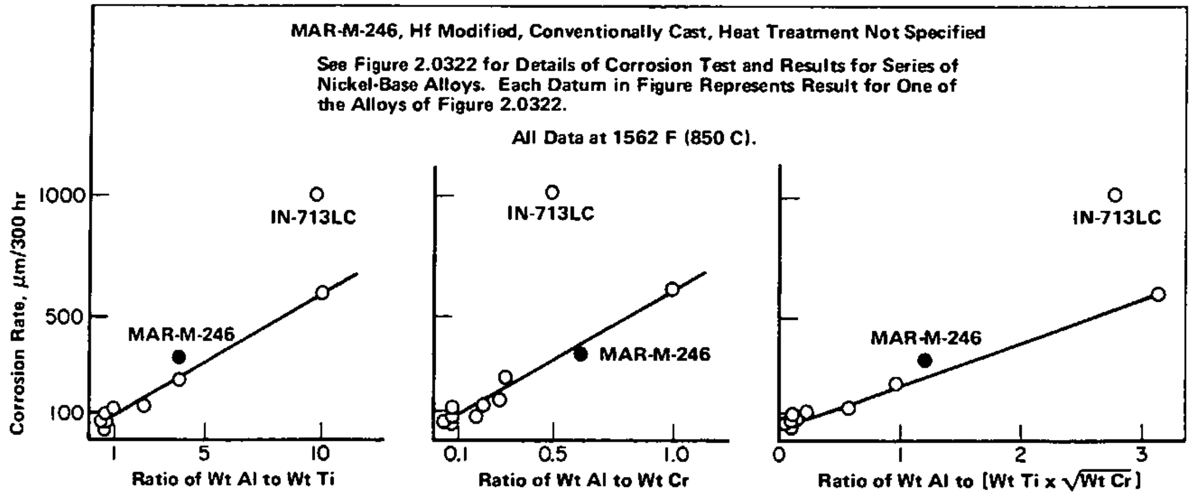

FIGURE 2.0326. CORRELATION OF CORROSION RESISTANCE IN A TEST RIG SIMULATING GAS TURBINE CONDITIONS FOR A SERIES OF NICKEL-BASE ALLOYS INCLUDING MAR-M-246. FIGURE SHOWS CORROSION PERFORMANCE AT 1562 F (850 C) IN RELATION TO SEVERAL RATIOS OF THE ELEMENTS CHROMIUM, ALUMINUM AND TITANIUM (14)

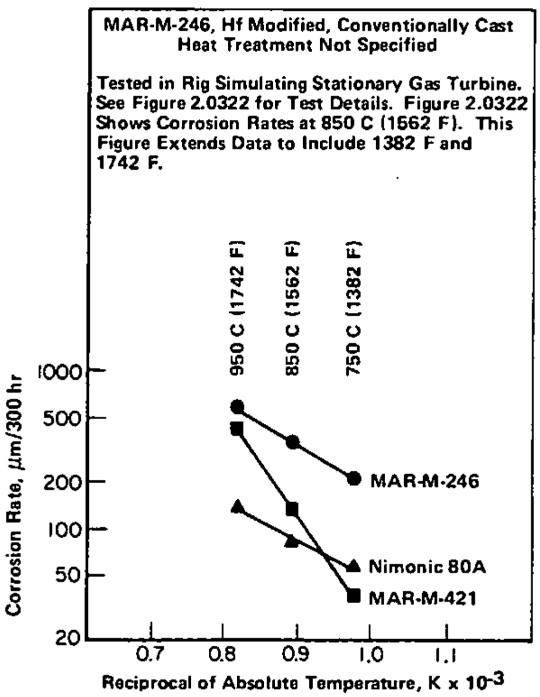

FIGURE 2.0327. CORROSION RATES FOR THREE NICKEL-BASE ALLOYS INCLUDING MAR-M-246 SHOWING LINEARITY OF ARRHENIUS PLOT OF RATE VERSUS RECIPROCAL OF ABSOLUTE TEMPERATURE IN TEMPERATURE RANGE 1382 TO 1742 F. OTHER NICKEL-BASE ALLOYS DO NOT NECESSARILY SHOW SUCH LINEARITY (14)

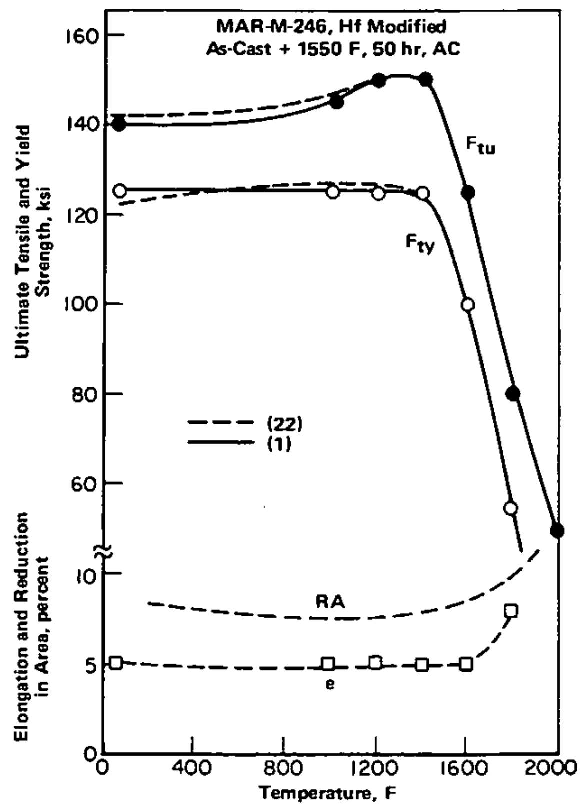

FIGURE 3.0312. AVERAGE TENSILE PROPERTIES OF CONVENTIONALLY CAST ALLOY FROM ROOM TEMPERATURE TO 2000 F (1) (22)

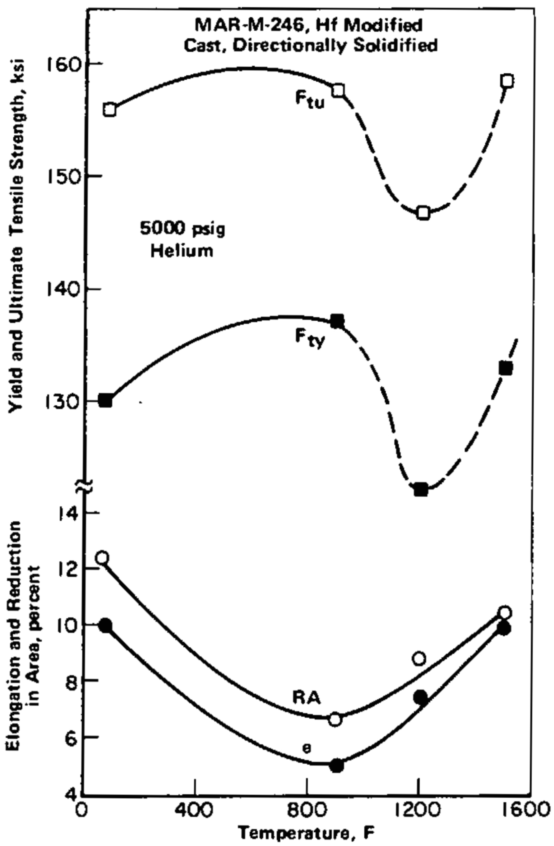

FIGURE 3.0314. TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURES OF DIRECTIONALLY SOLIDIFIED HAFNIUM-MODIFIED MAR-M-246 IN 5000 PSIG HELIUM (19)

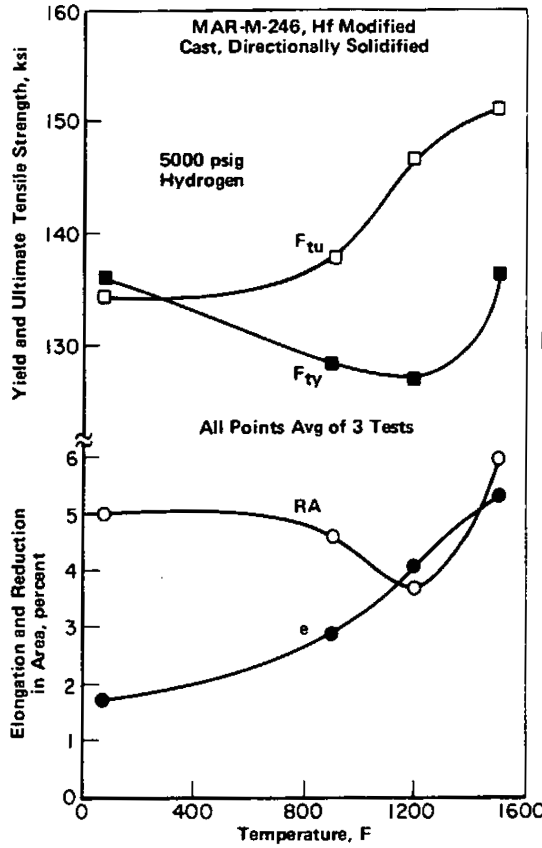

FIGURE 3.0315. TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURES FOR DIRECTIONALLY SOLIDIFIED HAFNIUM-MODIFIED MAR-M-246 IN 5000 PSIG HYDROGEN (19)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

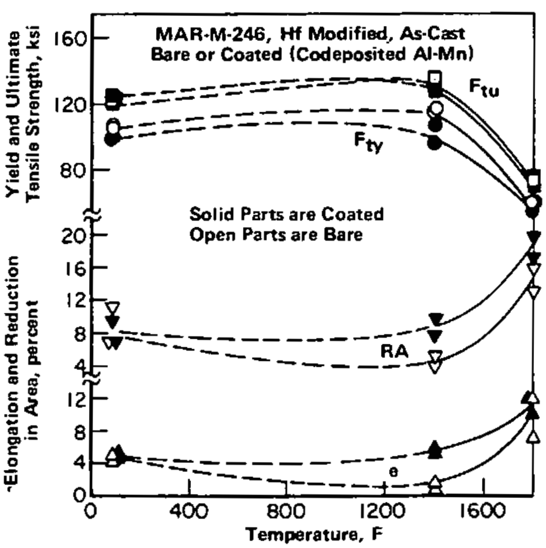

FIGURE 3.0316. EFFECT OF ALUMINUM MANGANESE COATING ON TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURES (20)

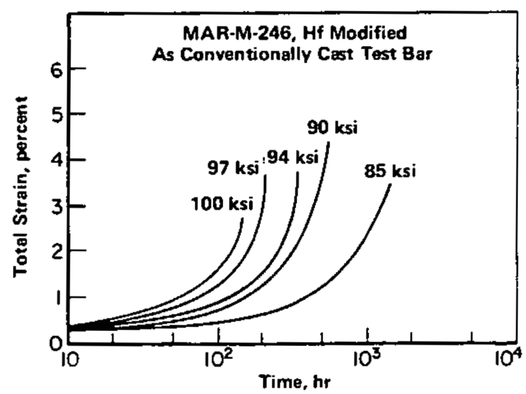

FIGURE 3.04111. TYPICAL CREEP CURVES AT 1400 F FOR CONVENTIONALLY CAST ALLOY AS DETERMINED BY ALLOY DEVELOPER (22)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

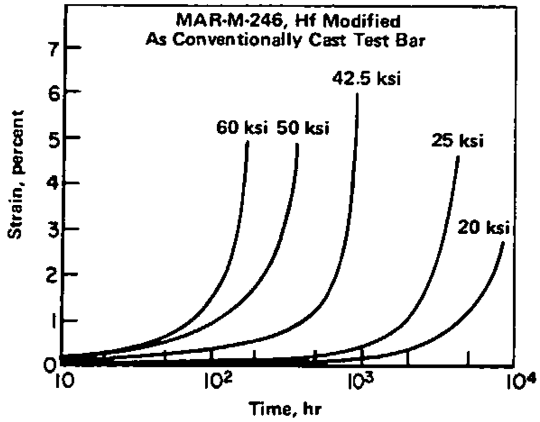

FIGURE 3.04112. TYPICAL CREEP CURVES AT 1600 F FOR CONVENTIONALLY CAST ALLOY AS DETERMINED BY ALLOY DEVELOPER (22)

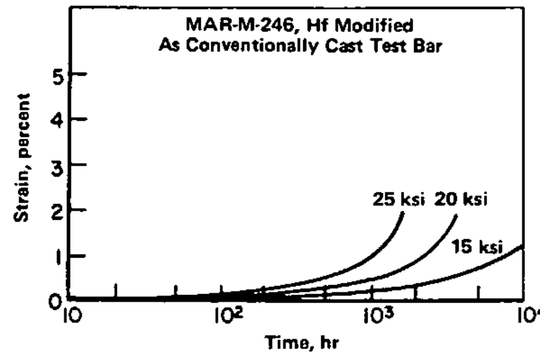

FIGURE 3.04113. TYPICAL CREEP CURVES AT 1700 F FOR CONVENTIONALLY CAST ALLOY AS DETERMINED BY ALLOY DEVELOPER (22)

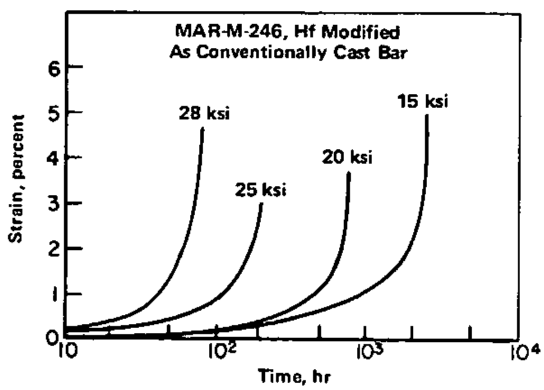

FIGURE 3.04114. TYPICAL CREEP CURVES AT 1800 F FOR CONVENTIONALLY CAST ALLOY, AS DETERMINED BY ALLOY DEVELOPER (22)

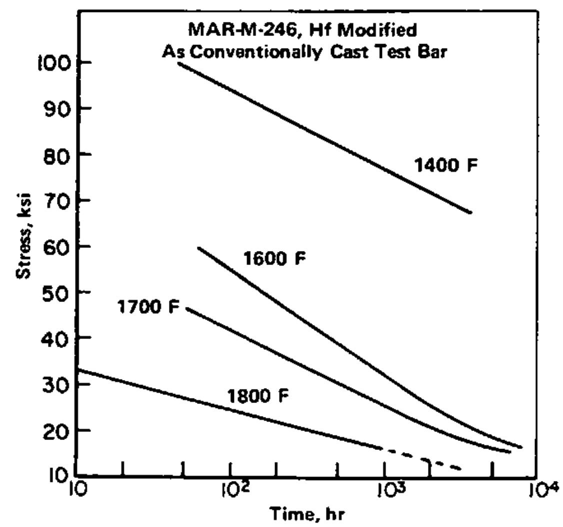

FIGURE 3.04115. STRESS/TIME COMBINATIONS TO PRODUCE 1 PERCENT CREEP STRAIN AT TEMPERATURES FROM 1400 TO 1800 F FOR CONVENTIONALLY CAST ALLOY, AS DETERMINED BY ALLOY DEVELOPER (22)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

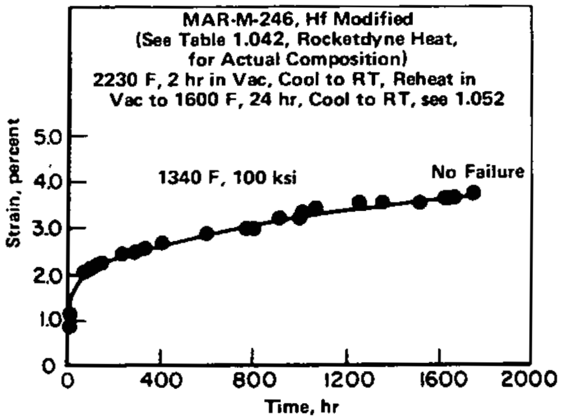

FIGURE 3.04121. CREEP CURVE FOR MAR-M-246 (HAFNIUM) AT 1340 F, 100 KSI (5)

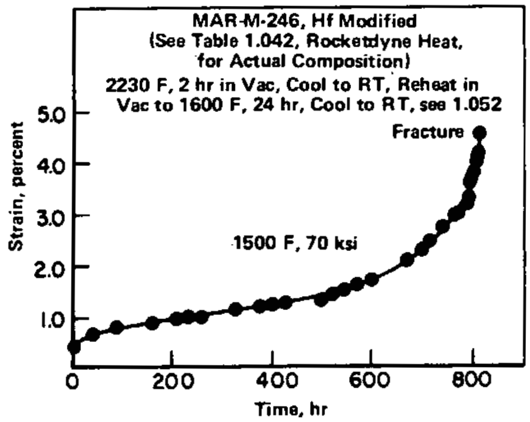

FIGURE 3.04122. CREEP CURVE FOR MAR-M-246 (HAFNIUM) AT 1500 F, 70 KSI (5)

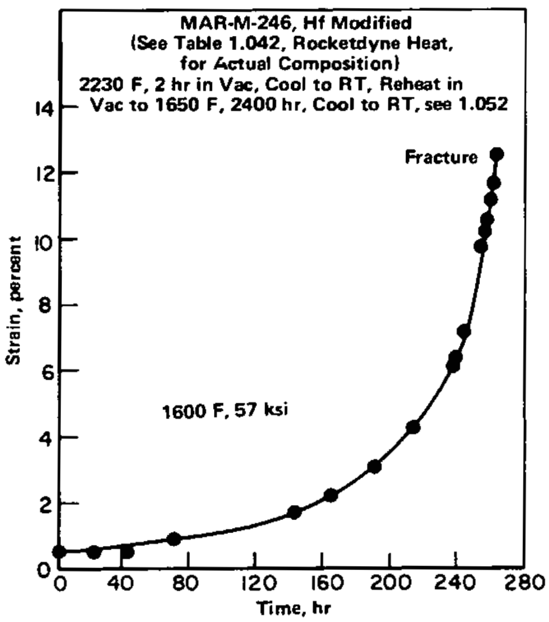

FIGURE 3.04123. CREEP CURVE FOR MAR-M-246 (HAFNIUM) AT 1600 F, 57 KSI (5)

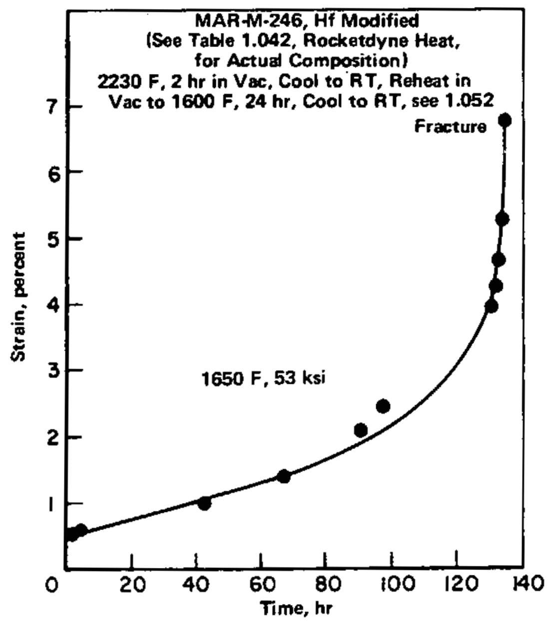

FIGURE 3.04124. CREEP CURVE FOR MAR-M-246 (HAFNIUM) AT 1650 F, 53 KSI (5)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

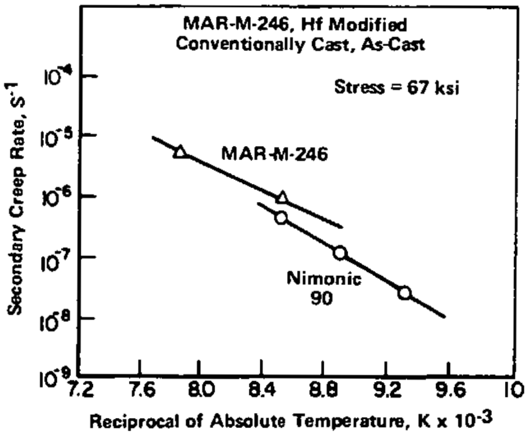

FIGURE 3.04131. ARRHENIUS RELATION BETWEEN SECOND STAGE CREEP RATE AND TEMPERATURE AT 67 KSI FOR CONVENTIONALLY CAST ALLOY (15)

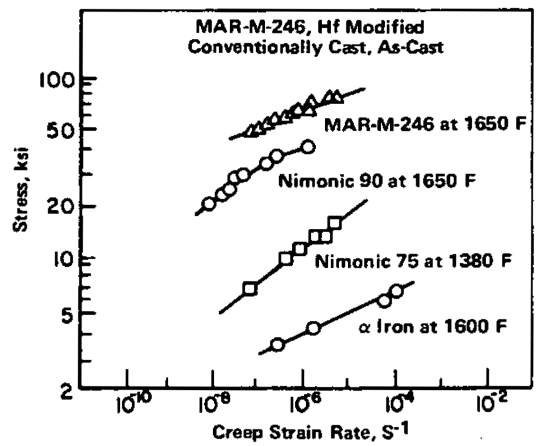

FIGURE 3.04132. RELATION BETWEEN STRESS AND STRAIN RATE FOR CONVENTIONALLY CAST MAR-M-246 AT 1650 F, WITH COMPARISON TO SEVERAL OTHER MATERIALS AT VARIOUS TEMPERATURES (15)

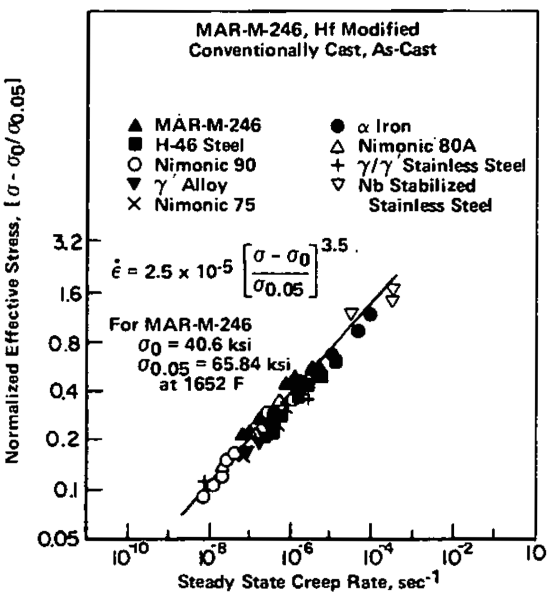

FIGURE 3.04133. CORRELATION OF STEADY-STATE CREEP RATE DATA FOR SEVERAL MATERIALS INCLUDING MAR-M-246 ACCORDING TO A UNIVERSAL EQUATION (15)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

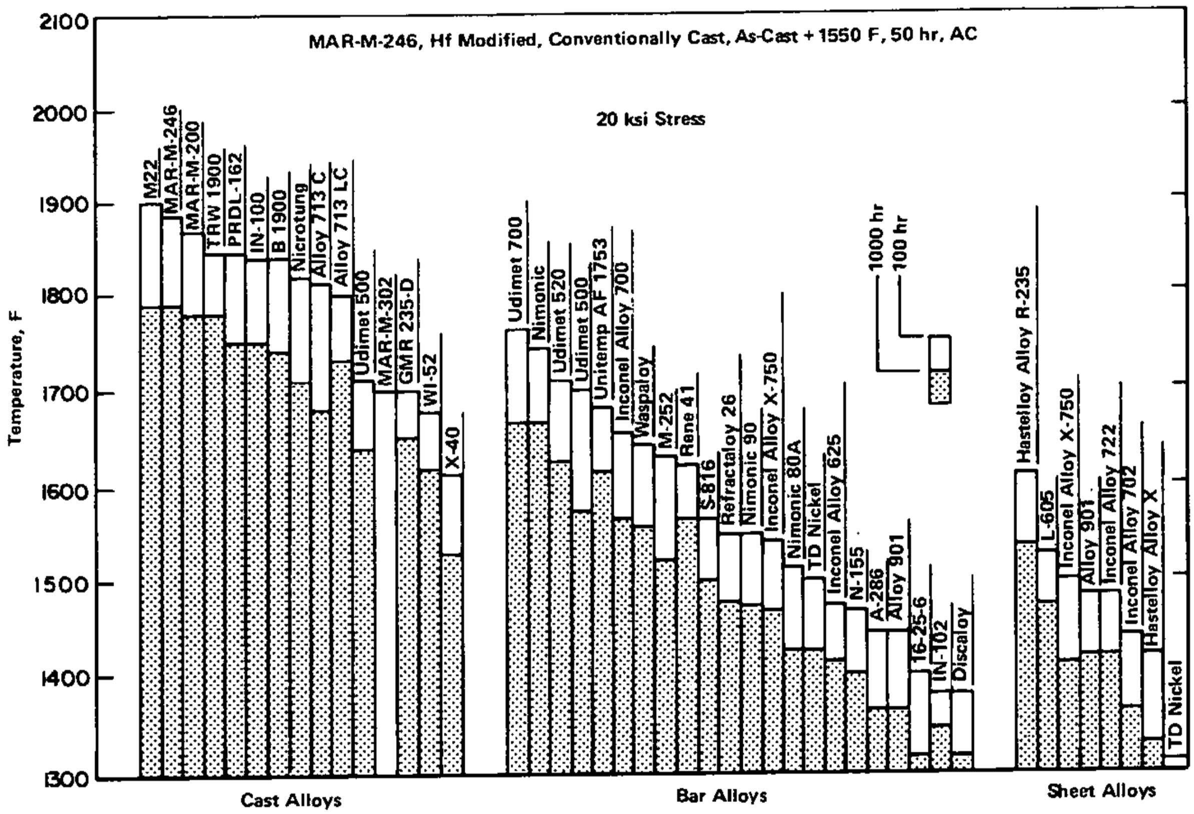

FIGURE 3.04211. COMPARISON OF STRENGTH OF MAR-M-246 WITH OTHER NICKEL-BEARING ALLOYS ACCORDING TO TEMPERATURE CAPABILITY TO SUPPORT 20 KSI FOR 100 AND 1000 HR (18)

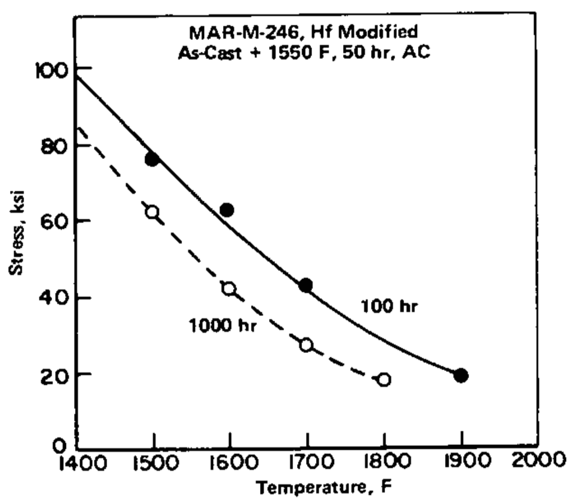

FIGURE 3.04221. STRESS FOR CREEP RUPTURE IN 100 AND 1000 HR FOR CONVENTIONALLOY CAST ALLOY FROM 1400 TO 1900 F (1)

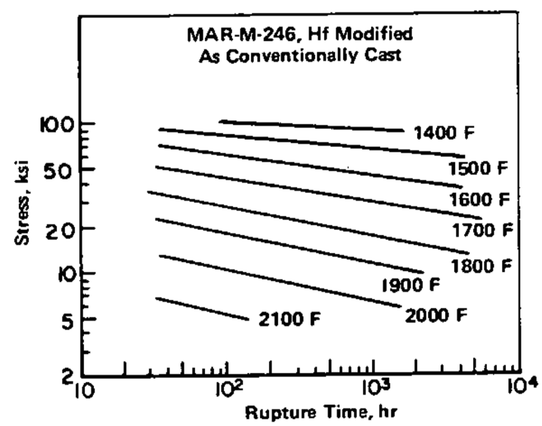

FIGURE 3.04222. TYPICAL CREEP-RUPTURE PROPERTIES FOR CONVENTIONALLY CAST ALLOY FROM 1400 TO 2100 F, AS SUPPLIED BY DEVELOPER (22)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

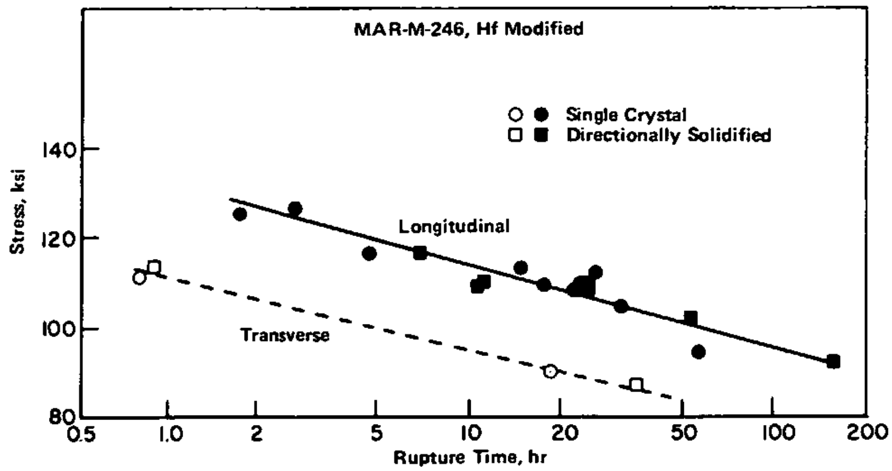

FIGURE 3.04231. CREEP RUPTURE AT 1500 F FOR HAFNIUM-MODIFIED MAR-M-246 IN SINGLE-CRYSTAL AND DIRECTIONALLY SOLIDIFIED FORM. FIGURE ALSO SHOWS COMPARISON OF LONGITUDINAL PROPERTIES WITH LIMITED DATA ON TRANSVERSE PROPERTIES (5)

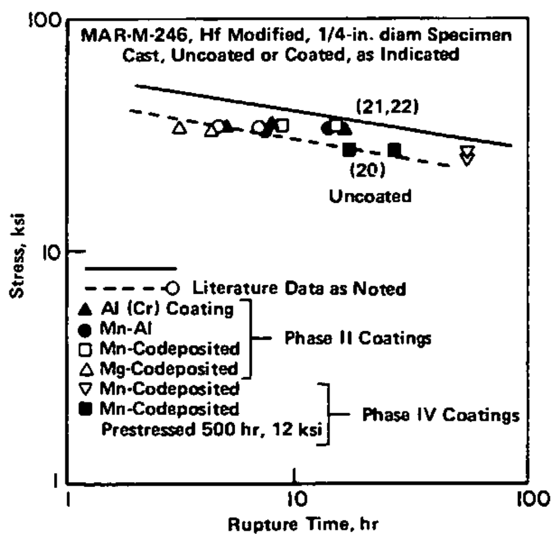

FIGURE 3.04242. CREEP-RUPTURE DATA AT 1800 F FOR UNCOATED ALLOY AND WITH VARIOUS COATINGS (20,21,22)

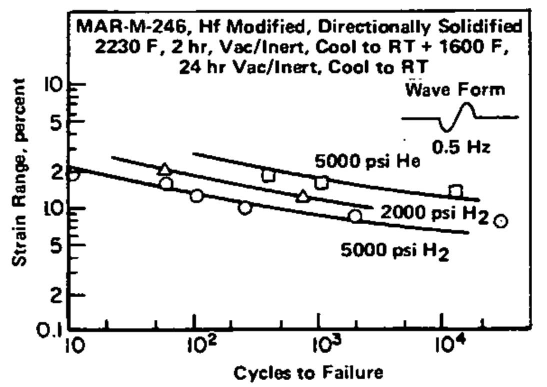

FIGURE 3.0511. ROOM TEMPERATURE LOW CYCLE FATIGUE TESTS IN 5000 PSIG HELIUM AND IN 2000 AND 5000 PSIG HYDROGEN FOR DIRECTIONALLY SOLIDIFIED MAR-M-246 (11)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

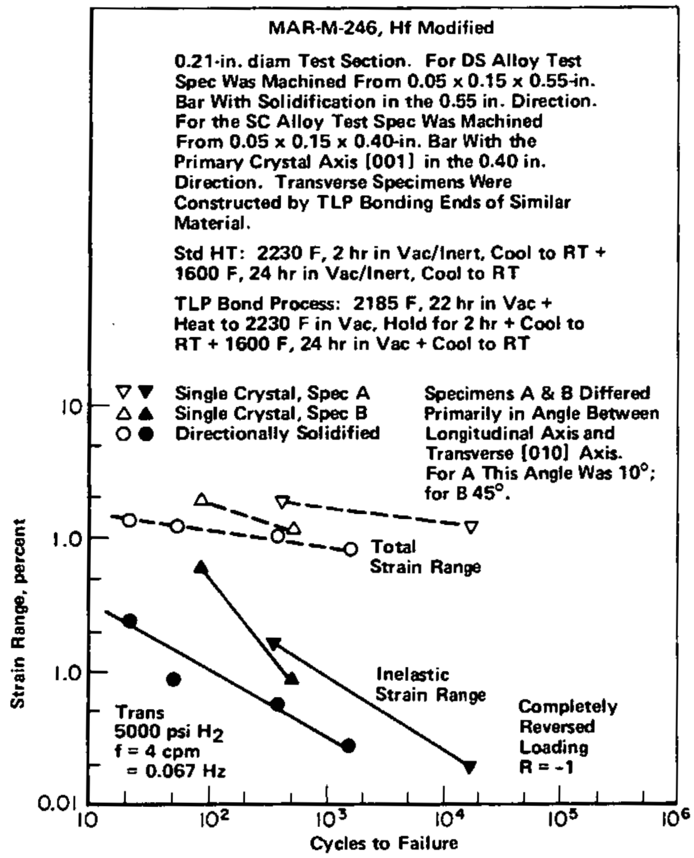

FIGURE 3.0512. COMPARISON OF LOW CYCLE FATIGUE BEHAVIOR OF SINGLE-CRYSTAL AND DIRECTIONALLY SOLIDIFIED ALLOY AT 1400 F IN 5000 PSIG HYDROGEN (3)

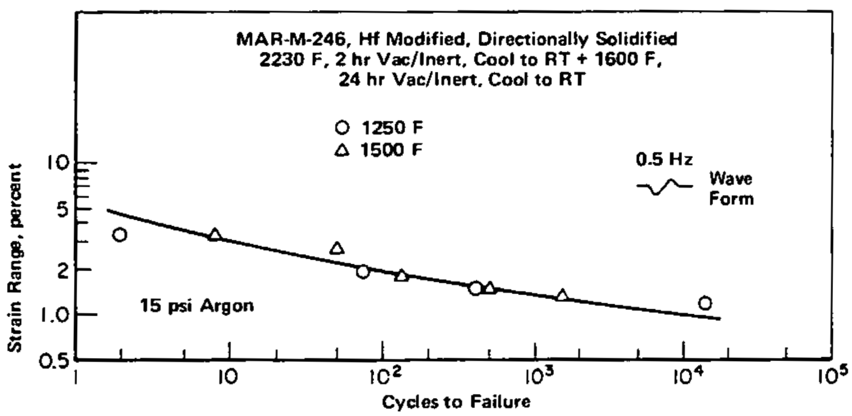

FIGURE 3.0513. LOW CYCLE FATIGUE IN 15 PSIG ARGON AT 1250 AND 1500 F FOR DIRECTIONALLY SOLIDIFIED HAFNIUM-MODIFIED MAR-M-246 (11)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

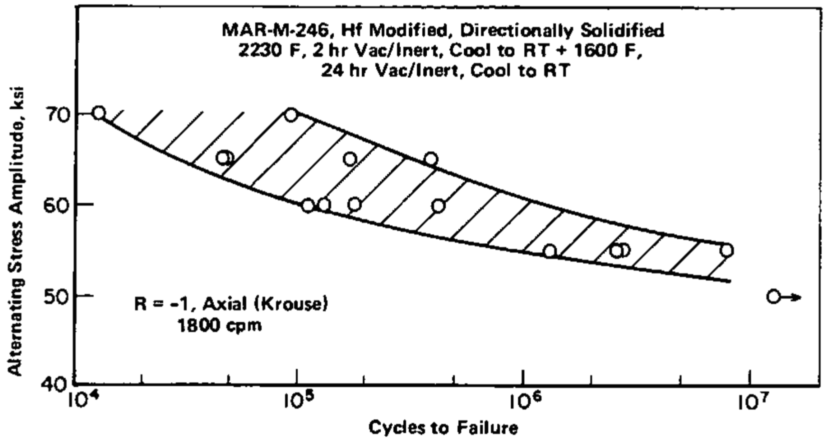

FIGURE 3.0521. LOW FREQUENCY HIGH CYCLE FATIGUE AT 1550 F IN COMPLETELY REVERSED AXIAL LOADING FOR DIRECTIONALLY SOLIDIFIED HAFNIUM-MODIFIED MAR-M-246 (10)

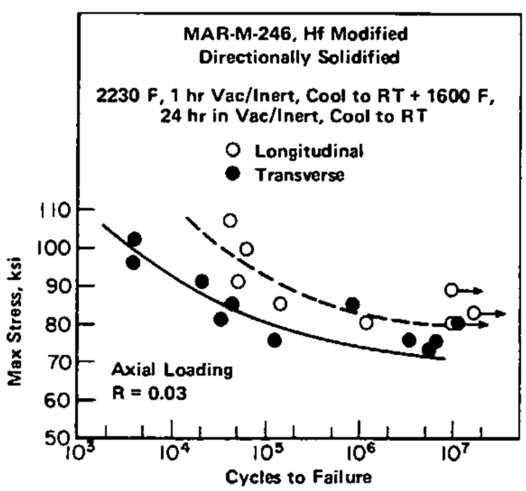

FIGURE 3.0522. HIGH CYCLE FATIGUE OF HAFNIUM-MODIFIED MAR-M-246 ALLOY AT 1500 F, R = 0.03, WITH COMPARISON OF LONGITUDINAL AND TRANSVERSE PROPERTIES OF DIRECTIONALLY SOLIDIFIED ALLOY (5)

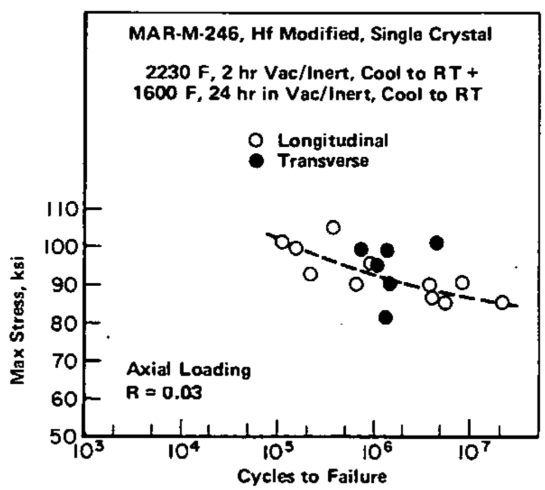

FIGURE 3.0523. HIGH CYCLE FATIGUE OF HAFNIUM-MODIFIED MAR-M-246 AT 1500 F, R = 0.03, WITH COMPARISON OF LONGITUDINAL AND TRANSVERSE PROPERTIES OF SINGLE-CRYSTAL ALLOY (5)

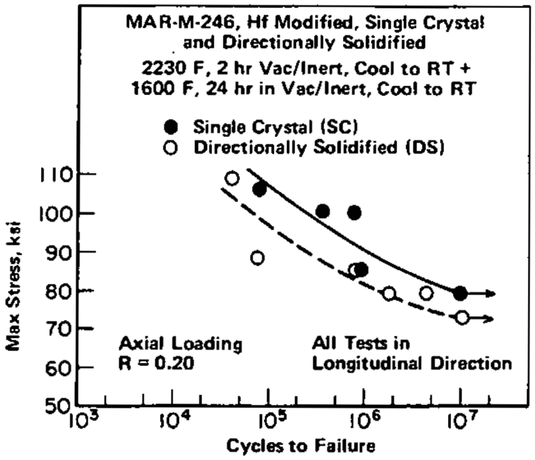

FIGURE 3.0524. HIGH CYCLE FATIGUE OF HAFNIUM-MODIFIED MAR-M-246 AT 1600 F, R = 0.20, WITH COMPARISON BETWEEN LONGITUDINAL PROPERTIES OF DIRECTIONALLY SOLIDIFIED AND SINGLE-CRYSTAL ALLOYS (5)

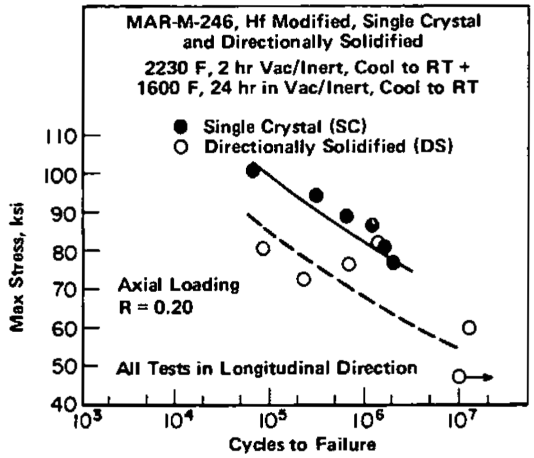

FIGURE 3.0525. HIGH CYCLE FATIGUE OF HAFNIUM-MODIFIED MAR-M-246 AT 1700 F, R = 0.20, WITH COMPARISON BETWEEN LONGITUDINAL PROPERTIES OF DIRECTIONALLY SOLIDIFIED AND SINGLE-CRYSTAL ALLOYS (5)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

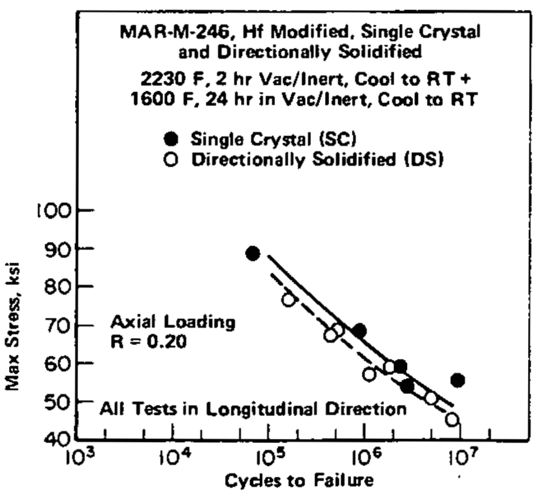

FIGURE 3.0526. HIGH CYCLE FATIGUE OF HAFNIUM-MODIFIED MAR-M-246 AT 1800 F, R = 0.20, WITH COMPARISON BETWEEN LONGITUDINAL PROPERTIES OF DIRECTIONALLY SOLIDIFIED AND SINGLE-CRYSTAL ALLOYS (5)

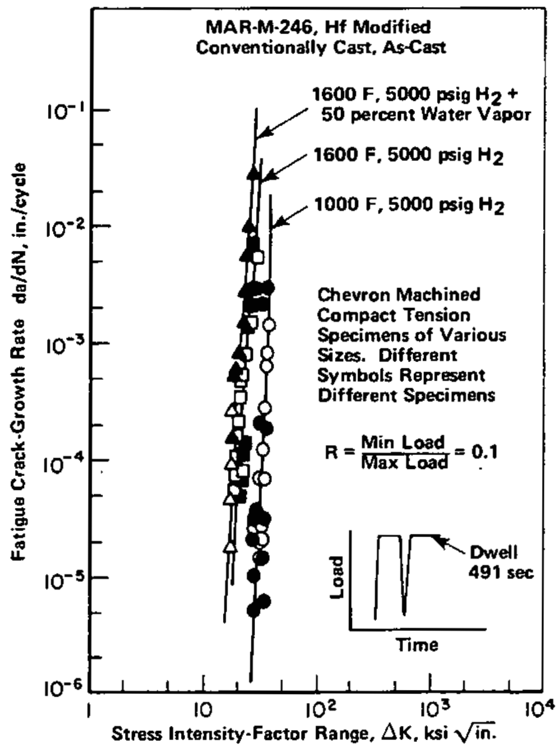

FIGURE 3.0541. FATIGUE CRACK GROWTH CURVES FOR CONVENTIONALLY CAST HAFNIUM-MODIFIED MAR-M-246 AT 1000 F IN 5000 PSIG HYDROGEN, AND AT 1600 F IN 5000 PSIG HYDROGEN, OR IN 5000 PSIG MIXTURE OF HYDROGEN AND 50 PERCENT WATER VAPOR (12)

	Ni
10	Co
10	W
9	Cr
5.5	Al
2.4	Mo
1.5	Ta
1.5	Ti

MAR-M-246

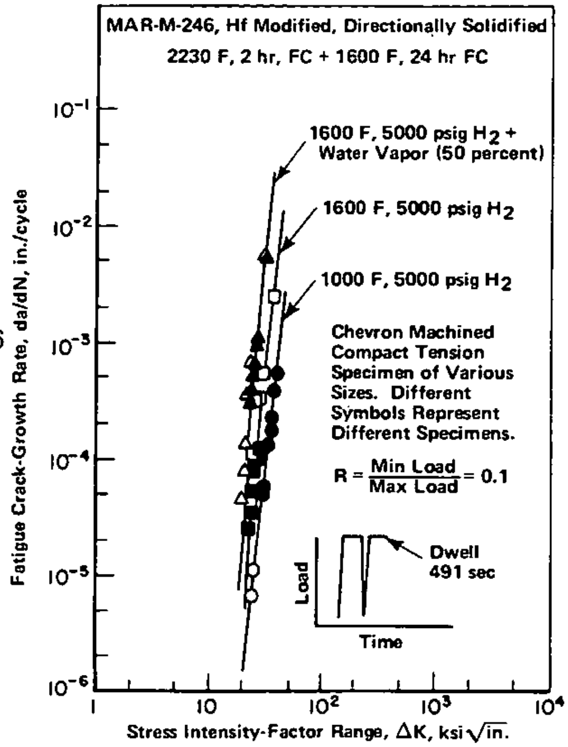

FIGURE 3.0542. FATIGUE CRACK GROWTH CURVES FOR DIRECTIONALLY SOLIDIFIED HAFNIUM-MODIFIED MAR-M-246 AT 1000 F IN 5000 PSIG HYDROGEN, AND AT 1600 F IN 5000 PSIG HYDROGEN OR IN 5000 PSIG MIXTURE OF HYDROGEN AND 50 PERCENT WATER VAPOR (12)

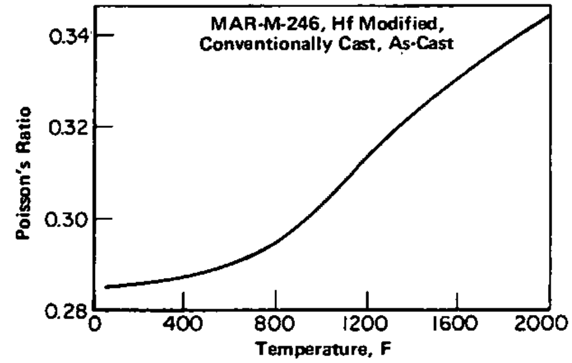

FIGURE 3.061. POISSON'S RATIO FROM ROOM TEMPERATURE TO 2000 F (13)

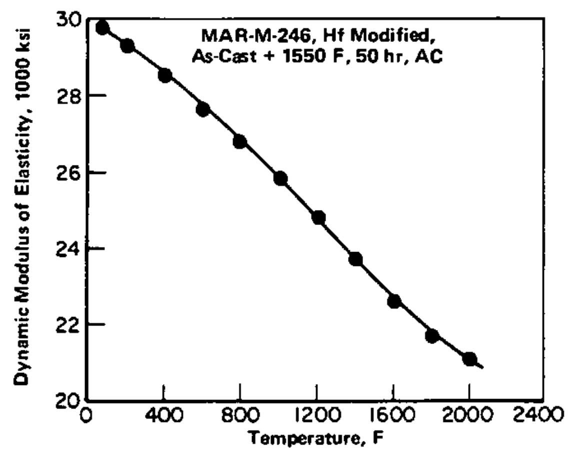

FIGURE 3.0621. DYNAMIC MODULUS OF ELASTICITY OF CONVENTIONALLY CAST ALLOY (1)

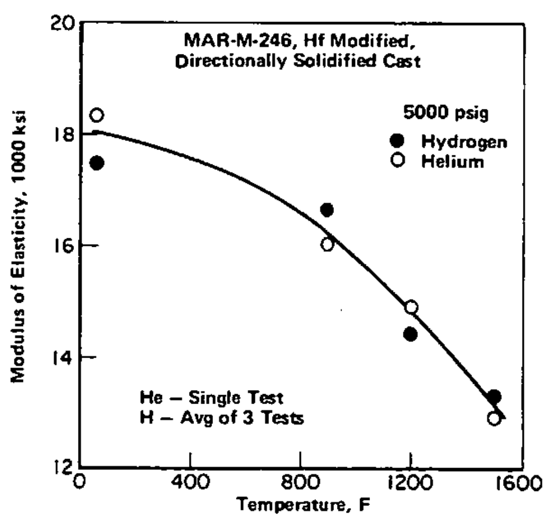

FIGURE 3.0622. ELASTIC MODULUS AT ROOM AND ELEVATED TEMPERATURES FOR DIRECTIONALLY SOLIDIFIED HAFNIUM-MODIFIED MAR-M-246 IN 5000 PSIG HELIUM AND HYDROGEN (19)

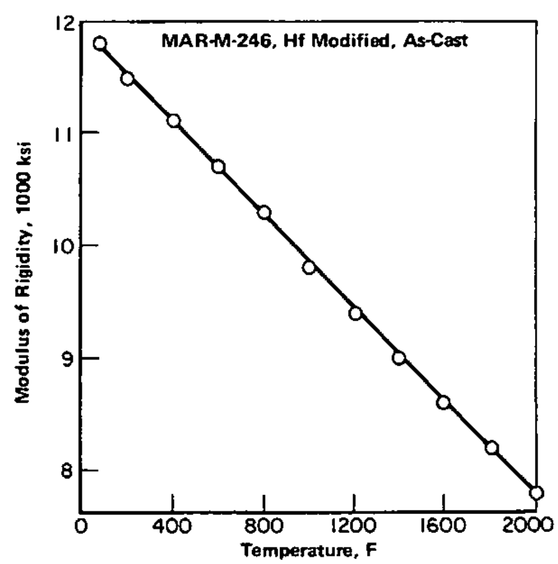

FIGURE 3.063. MODULUS OF RIGIDITY FROM ROOM TEMPERATURE TO 2000 F FOR CONVENTIONALLY CAST ALLOY (22)