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NONFERROUS ALLOYS

1. **GENERAL**
 VM-103 is a NASA wrought cobalt-base alloy which has useful strength at temperatures as high as 2200F. The addition of 10 percent nickel to the standard composition improves both hot and cold formability, ductility, impact strength and metallurgical stability with only a slight loss in strength properties. Strength properties produced by vacuum induction melting (VIM) are slightly higher at elevated temperatures than those produced by electroslag remelting (ESR). Electroslag remelting, however, significantly improves fabricability and ductility. The alloy has demonstrated considerable high temperature gas erosion resistance. Based on limited data the alloy appears to be castable but further development effort will be needed to characterize casting parameters and cast properties.
- 1.01 Commercial Designation
 VM-103
- 1.02 Alternate Designations
- 1.03 Specifications
 NASA procurement specification, (4).
- 1.04 Composition
 Table 1.04.
- 1.05 Heat Treatment
- 1.051 Solution treat.
- 1.0511 For minimum hardness, minimum grain growth, and minimum carbide precipitation: 2200F (in circulating air), 30 min., water quench. Grit blast to remove oxide scale (4).
- 1.052 Age. The alloy was designed to be solid-solution strengthened. Limited data, however, indicate a potential aging response (4).
- 1.0521 Effect of aging time and temperature on hardness of sheet in solution treated condition, Figure 1.0521.
- 1.0522 Effect of aging time and temperature on hardness of sheet in solution treated plus 15 percent cold reduced condition, Figure 1.0522.
- 1.0523 Effect of aging time and temperature on hardness of sheet in solution treated plus 25 percent cold reduced condition. Figure 1.0523.
- 1.06 Hardness
 See also Figures 1.0521, 1.0522 and 1.0523.
- 1.061 Effect of cold work on hardness of sheet. Figure 1.061.
- 1.062 Hardness of sheet in various conditions at room and elevated temperatures, Table 1.062.
- 1.063 Specified maximum hardness. 363 Brinell (4).
- 1.07 Forms and Conditions Available
- 1.071 General. VM-103 has not as yet been produced in production quantities. However, a significant amount of research and development work has been done on this alloy and it could be produced in production quantities with a minimum of scale-up efforts. Procurement specifications have been prepared to cover bar, forgings, plate and sheet (4).
- 1.08 Melting and Casting Practice
- 1.081 Melting practice. The alloy is produced by vacuum induction melting (VIM) plus vacuum arc remelting (VAR) or VIM plus electroslag remelting (ESR) (4).
- 1.082 Casting. Based on limited data, the alloy appears to be castable.
- 1.09 Special Considerations
- 1.091 Thermomechanical processing studies of the VM-103 alloy show that combinations of cold work and aging can be effective in increasing room temperature hardness and probably also its room temperature and intermediate temperature strength. However, tensile tests performed at 2000 and 2200F showed no beneficial effect (4).
- 1.092 The high strain rate tests have indicated that this alloy is strain rate sensitive at room and elevated temperatures (1).
2. **PHYSICAL AND CHEMICAL PROPERTIES**
- 2.01 Thermal Properties
- 2.011 Melting range. Incipient melting at 2550F (2).
- 2.012 Phase changes. The nature of phases present in VM-103, Table 2.012.
- 2.0121 Time-temperature-transformation diagrams, Figure 2.0121.
- 2.013 Thermal conductivity.
- 2.014 Thermal expansion. Average coefficient of linear thermal expansion over range from 77 to 1832F. 7.75×10^{-6} in per in per F (4).
- 2.015 Specific heat.
- 2.016 Thermal diffusivity.
- 2.02 Other physical properties
- 2.021 Density. 0.357 lb per cu in. . 9.89 gr per cu cm (4).
- 2.022 Electrical properties.
- 2.023 Magnetic properties.
- 2.024 Emissivity.
- 2.025 Damping capacity.
- 2.03 Chemical Properties
- 2.04 Nuclear Properties
3. **MECHANICAL PROPERTIES**
- 3.01 Specified Mechanical Properties
 Specified minimum tensile properties, Table 3.011.
- 3.02 Mechanical Properties at Room Temperature
- 3.021 Tension. See Table 3.0311 and Table 3.0312.
- 3.0211 Stress-strain diagrams.
- 3.0212 Effect of exposure at elevated temperature on tensile properties of cast specimens at room temperature. Table 3.0212.
- 3.022 Compression.
- 3.023 Impact.
- 3.0231 Impact strength at room and low temperature. Table 3.0231.
- 3.024 Bending.
- 3.0241 Minimum bend radii of annealed sheet. Table 3.0241.
- 3.025 Torsion and shear.
- 3.026 Bearing.
- 3.027 Stress concentration.
- 3.0271 Notch properties.
- 3.0272 Fracture toughness.
- 3.028 Combined properties.
- 3.029 Other static properties.
- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension.
- 3.0311 Tensile properties of ESR sheet at temperatures from 75 to 2000F for various conditions, Table 3.0311.
- 3.0312 Tensile properties of VIM sheet at temperatures from 75 to 2000F for various conditions, Table 3.0312.
- 3.0313 Tensile properties of solution treated sheet tested at elevated temperatures with conventional strain rate. Figure 3.0313.
- 3.0314 Tensile properties of solution treated sheet tested at elevated temperatures with high strain rate. Figure 3.0314.
- 3.032 Compression.
- 3.033 Impact. See Table 3.0231.
- 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.
- 3.039 Other static properties.

	Co
25	W
3	Cr
1	Ti
0.5	Zr
0.5	C

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	Co
25	W
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1	Ti
0.5	Zr
0.5	C

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- 3.04 Creep and Creep Rupture Properties
- 3.041 Creep rupture properties of wrought solution treated sheet. Figure 3.041.
- 3.042 Creep rupture properties of cast solution treated sheet. Figure 3.042.
- 3.043 Typical creep strain curves at 1600, 1800 and 2000F. Figure 3.043.
- 3.044 Stress-rupture curves for cast specimens tested in helium at 2000 and 2125F. Figure 3.044.
- 3.05 Fatigue Properties
- 3.051 Tension-tension fatigue properties for 0.012 inch VAR and ESR sheet. Table 3.051.
- 3.06 Elastic Properties
- 3.061 Poisson's ratio.
- 3.062 Modulus of elasticity.
- 3.063 Modulus of rigidity.

4. FABRICATION

- 4.01 Formability
- 4.011 Forging. Condition cast ingots for forging by grit blasting to remove surface impurities and to allow assessment of ingot quality. Remove surface imperfections by grinding or rough turning. Soak at 2175F for 30 minutes. Forge with initial reductions of 8 to 10 percent. Return to furnace after each reduction; soak at temperature for 15 minutes. Subsequent reductions 15 to 20 percent. Return to furnace after each reduction; soak at temperature for 10 minutes. After last pass, soak at 2200F, 10 minutes and water quench. Inspect after each reduction and grind or crop any surface defects as required. This forging technique has been used successfully to reduce 4 inch diameter ingots to 1 inch square bar using a 3500 lb. hammer forge (4).
- 4.012 Rolling. One inch bar has been successfully reduced to 0.10 inch using the following rolling techniques: Preheat at 2175F, 30 minutes. Roll initial passes 12-15 percent with subsequent reductions of 15 to 35 percent. Reheat between passes at 2175F for 3 to 10 minutes, depending on material thickness. After last pass, soak at 2200F for 10 minutes and water quench (4).
- 4.02 Machining and Grinding
- 4.021 General. This alloy, like most other cobalt-base alloys, is difficult to machine. Electrochemical and electrode discharge machining techniques have been used successfully in limited applications (4).
- 4.03 Welding
- 4.04 Heat Treatment
- 4.05 Surface Treatment

Source	(4)	(4) (a)		(4)	(4) (b)
	Standard	Specification		Standard	Modified
Composition	Percent Nominal	Percent Min.	Percent Max.	Percent Typical	Percent Typical
Tungsten	25	24	26	25.0	24.70
Chromium	3	2.5	3.5	3.16	2.98
Titanium	1	0.75	1.25	1.07	1.10
Zirconium	0.5	0.4	0.6	0.52	0.42
Carbon	0.5	0.48	0.52	0.52	0.55
Iron	0.1 max.	-	0.1	0.12	0.12
Nickel	-	-	-	0.13	10.30
Manganese	-	-	-	0.04	0.04
Silicon	-	-	-	0.10	0.10
Hydrogen	-	-	-	0.0001	0.0001
Oxygen	-	-	-	0.002	0.002
Nitrogen	-	-	-	0.0055	0.0055
Cobalt	Balance	Balance	Balance	Balance	Balance

(a) Procurement specification.
 (b) Modified by addition of 10 percent Nickel.

TABLE 1.04 COMPOSITION

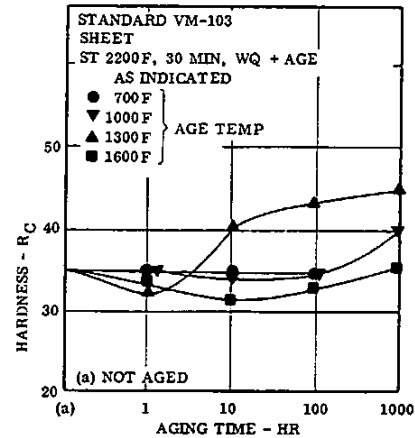


FIG. 1.0521 EFFECT OF AGING TIME AND TEMPERATURE ON HARDNESS OF SHEET IN SOLUTION TREATED CONDITION. (4)

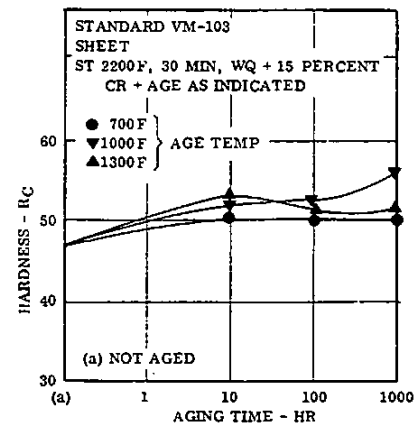


FIG. 1.0522 EFFECT OF AGING TIME AND TEMPERATURE ON HARDNESS OF SHEET IN SOLUTION TREATED PLUS 15 PERCENT COLD REDUCED CONDITION. (4)

NONFERROUS ALLOYS

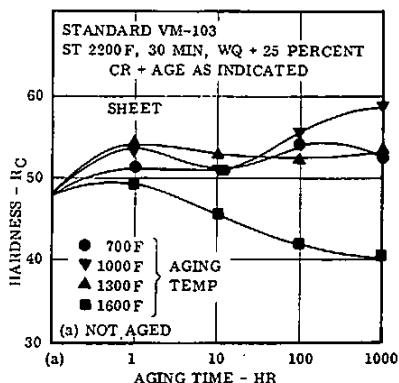


FIG. 1.0523 EFFECT OF AGING TIME AND TEMPERATURE ON HARDNESS OF SHEET IN SOLUTION TREATED PLUS 25 PERCENT COLD REDUCED CONDITION. (4)

Source	(4)				
Alloy	VM-103				
Condition (a)	Heat No. (b)	Hot Hardness Test Temp. - F			
		RT	1000	1200	1400
ST	B3	31 RC	92 RB	90 RB	86 RB
ST	B4	38 RC	96 RB	95 RB	92 RB
ST + Age	B3	35 RC	99 RB	98 RB	86 RB
ST + Age	B4	42 RC	35 RC	30 RC	100 RB
ST + 25 percent CR	B3	48 RC	41 RC	39 RC	31 RC
ST + 25 percent CR	B4	49 RC	48 RC	43 RC	29 RC
ST + 25 percent CR + age	B3	55 RC	47 RC	41 RC	24 RC
ST + 25 percent CR + age	B4	54 RC	47 RC	41 RC	28 RC

(a) ST: 2200F, 30 min., WQ.
25 percent CR: 25 percent reduction at 75F.
Age: 1300F, 10 hr., air cool.
(b) Heat B3 - Modified VM-103 (ESR)
Heat B4 - Standard VM-103 (ESR)

Co
25 W
3 Cr
1 Ti
0.5 Zr
0.5 C
VM-103

TABLE 1.062 HARDNESS OF SHEET IN VARIOUS CONDITIONS AT ROOM AND ELEVATED TEMPERATURES

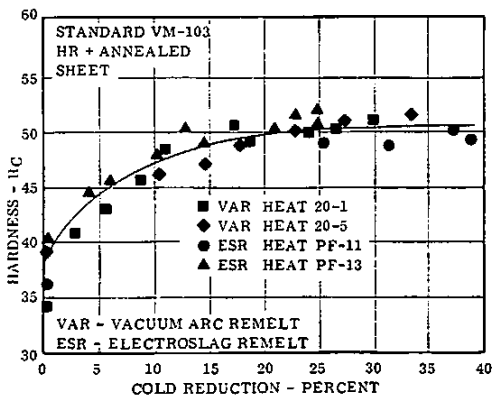


FIG. 1.061 EFFECT OF COLD WORK ON HARDNESS OF SHEET. (3)

Source	(3)	
Alloy	Standard VM-103	
Phase	Structure	Lattice Parameters
		A
α -Co	fcc	a = 3.544
ϵ -Co	hcp	a = 2.514 c = 4.105 c/a = 1.6329
TiC	B1, fcc	a = 4.341 (a)
ZrC	B1, fcc	a = 4.645 (a)
MgC	fcc	a = 10.905 (a)
W ₂ C	hcp	a = 2.99 c = 4.72 c/a = 1.58
α -Co ₃ W	L1 ₂ , ordered, fcc	a = 3.57
β -Co ₃ W	DO ₁₉ , ordered hexagonal	a = 5.134 (a) c = 4.115 (a) c/a = 0.80
Laves	C14, hexagonal	a = 4.73 c = 7.70
Co ₂ W		c/a = 1.63
μ Co ₇ W ₆	D8 ₅ , hexagonal (rhombohedral)	a = 4.73 c = 25.5 c/a = 5.39

(a) Calculated values.

TABLE 2.012 THE NATURE OF PHASES PRESENT IN VM-103

NONFERROUS ALLOYS

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	Co
25	W
3	Cr
1	Ti
0.5	Zr
0.5	C
VM-103	

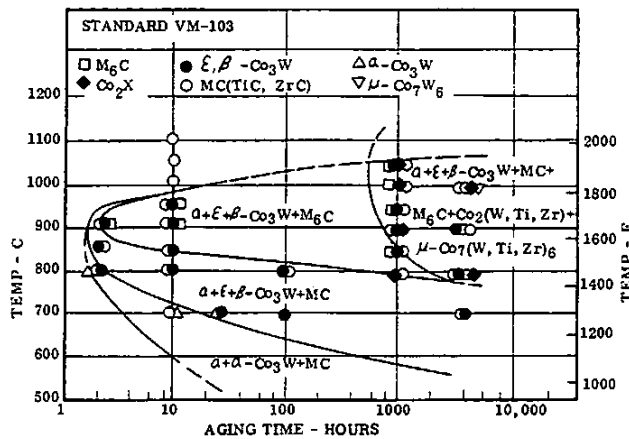


FIG. 2.0121 TIME-TEMPERATURE-TRANSFORMATION DIAGRAM FOR VM-103. (3)

Source	(4)
Alloy	Standard VM-103
Condition	Solution-treated
Form	Bars, forgings, plate and sheet
F _u , min (ksi)	135
F _y , min (ksi)	80
e (in 4D) (percent)	7
Hardness - Brinell	363 or less

TABLE 3.011 SPECIFIED MINIMUM TENSILE PROPERTIES

Source	(2)		
Alloy	Standard VM-103 Cast Specimens (a)		
Exposure time and temperature (b)	Test temp. (F)	F _u (ksi)	e (in 1.2 in) (percent)
As cast	Room	97.7	2
1200F, 192 hr.	Room	118.7	1
		114.1	1
1400F, 192 hr.	Room	141.5	0
		141.9	1
1600F, 192 hr.	Room	140.5	1
		134.5	0
1800F, 192 hr.	Room	88.3	2
		89.4	2
2000F, 192 hr.	Room	89.6	3
		90.3	3
(a) Specimens were cast to final dimensions; conical shoulders with 20 degree included angle. Gage section - 1.20 inches long and 0.25 inch diameter.			
(b) Exposure and testing were performed in air.			

TABLE 3.0212 EFFECT OF EXPOSURE AT ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF CAST SPECIMENS AT ROOM TEMPERATURE

Source	(4)			
Alloy	VM-103			
Condition (a)	Heat No. (b)	Test Temp. F		
		-65	RT	
		IE Charpy V		
		Ft-lbs	Ft-lbs	
SHT	B3	27.1	30.4	
SHT	B3	19.4	17.7	
SHT + age	B4	26.9	30.5	
SHT + age	B4	14.5	20.8	
SHT + 25 percent CR	B3	5.8	7.3	
SHT + 25 percent CR	B4	4.4	4.5	
SHT + 25 percent CR + age	B3	5.3	2.7	
SHT + 25 percent CR + age	B4	3.0(c)	1.7	
(a) SHT = 2200F, 30 min., WQ 25 percent CR = 25 percent reduction at 75F Age = 1300F, 10 hr., air cool				
(b) Heat B3 - Modified VM-103 (ESR) Heat B4 - Standard VM-103 (ESR)				
(c) One specimen failed during machining.				

TABLE 3.0231 IMPACT STRENGTH AT ROOM AND LOW TEMPERATURE

NONFERROUS ALLOYS

Source	(1)
Alloy	Standard VM-103 (0.030 inch)
Condition	Hot rolled and annealed
Test	3 point bend tests (ASTM E290-66)
Heat number	Minimum 90° bend radius without cracking (T = 0.030 inch)
VAR 20-1	> 4T
VAR 20-5	4T
ESR PF-11	1T
ESR PF-13	4T
VAR = Vacuum arc remelted. ESR = Electroslag remelted. Specimen: Bend specimens with 20:1 width to thickness ratio.	

TABLE 3.0241 MINIMUM BEND RADII OF ANNEALED SHEET

Source	(4)			
Alloy	VM-103 0.040 in. sheet			
Heat No.	A-1 Standard VM-103 (VM)			
Condition	Test Temp. (F)	F _{TU} (ksi)	F _{TY} (ksi)	e (1 in) (percent)
ST (a)	75	138.7	86.2	9.5
	1200	109.4	79.9	9.0
	1600	82.1	63.2	3.3
	1800	47.6	33.7	22.5
	2000	20.4	17.3	11.5
ST + Age (b)	75	174.8	144.4	2.5
	2000	19.3	12.5	23.5
ST + 25 percent CR	75	204.1	152.9	4.3
ST + Age (c)	75	156.7	99.3	1.5
	1600	77.3	48.0	10.5
(a) ST: Solution treat 2200F, 30 min., water quench. (b) Age: 1300F, 10 hr., air cool. (c) Age: 1600F, 192 hr., air cool.				

25	Co
3	W
1	Cr
0.5	Ti
0.5	Zr
0.5	C

VM-103

TABLE 3.0312 TENSILE PROPERTIES OF VM SHEET AT TEMPERATURES FROM 75 TO 2000F FOR VARIOUS CONDITIONS.

Source	(4)				
Alloy	VM-103 0.040 in. sheet				
Condition	Heat No. (d)	Test Temp. (F)	F _{TU} (ksi)	F _{TY} (ksi)	e (1 in) (percent)
ST (a)	B3	75	156.2	76.5	35.5
	B4	75	150.8	90.5	15.0
	B3	1200	97.8	61.7	12.0
	B4	1200	101.2	85.1	4.8
	B3	1600	52.4	48.4	10.8
	B4	1600	68.1	53.7	9.5
	B3	1800	38.5	23.6	21.0
	B4	1800	41.9	27.9	32.0
	B3	2000	16.7	10.2	41.0
	B4	2000	18.7	13.7	31.5
ST + age (b)	B3	75	176.0	110.9	13.2
	B4	75	167.2	133.1	3.0
	B3	2000	16.1	10.5	33.5
	B4	2000	19.6	13.2	22.0
ST + 25 percent CR	B3	75	204.9	166.3	10.0
	B4	75	251.4	165.7	2.5
ST + age (c)	B3	75	127.5	80.5	4.7
	B4	75	155.4	92.4	1.2
	B3	1600	64.1	39.8	16.0
	B4	1600	80.6	51.4	10.8
(a) ST: Solution treat 2200F, 30 min., water quench. (b) Age: 1300F, 10 hr., air cool. (c) Age: 1600F, 192 hrs., air cool. (d) Heat B3: Modified VM-103 (ESR) Heat B4: Standard VM-103 (ESR)					

TABLE 3.0311 TENSILE PROPERTIES OF ESR SHEET AT TEMPERATURES FROM 75 TO 2000F FOR VARIOUS CONDITIONS

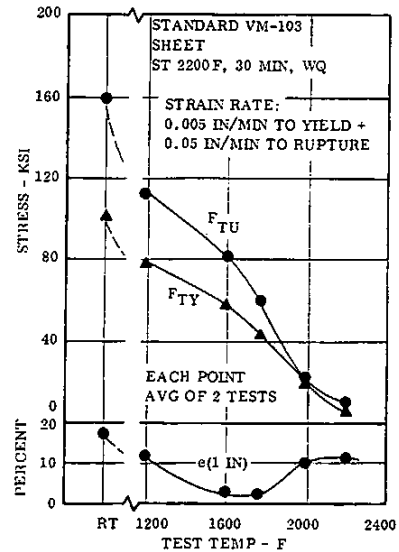


FIG. 3.0313 TENSILE PROPERTIES OF SOLUTION-TREATED SHEET TESTED AT ELEVATED TEMPERATURES WITH CONVENTIONAL STRAIN RATE. (4)

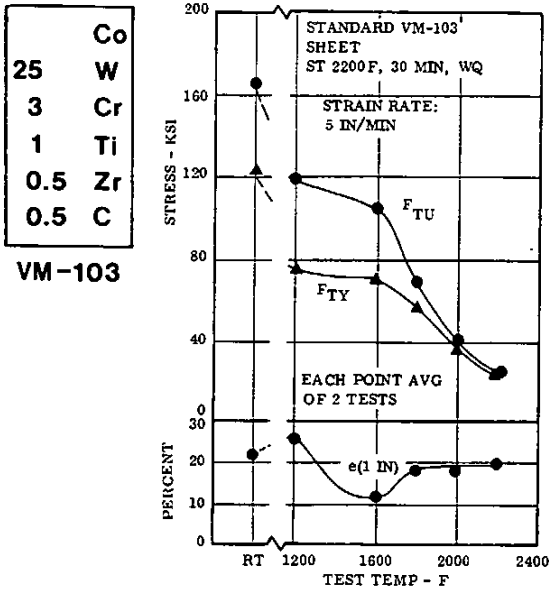


FIG. 3.0314 TENSILE PROPERTIES OF SOLUTION TREATED SHEET TESTED AT ELEVATED TEMPERATURES WITH HIGH STRAIN RATE. (4)

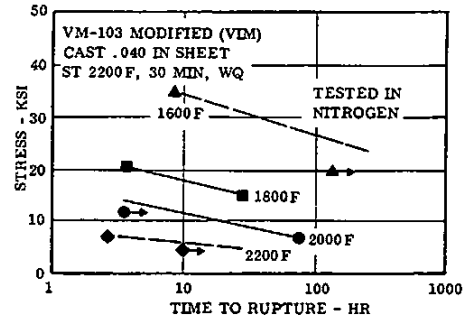


FIG. 3.042 CREEP-RUPTURE PROPERTIES OF CAST SOLUTION-TREATED SHEET. (4)

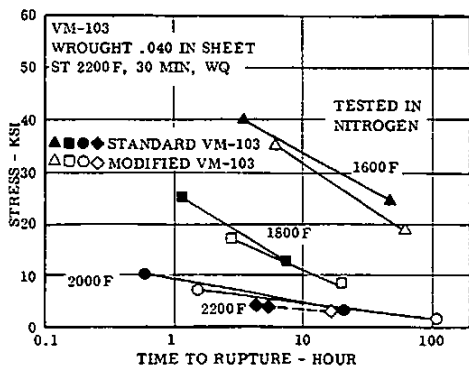


FIG. 3.041 CREEP-RUPTURE PROPERTIES OF WROUGHT SOLUTION-TREATED SHEET. (4)

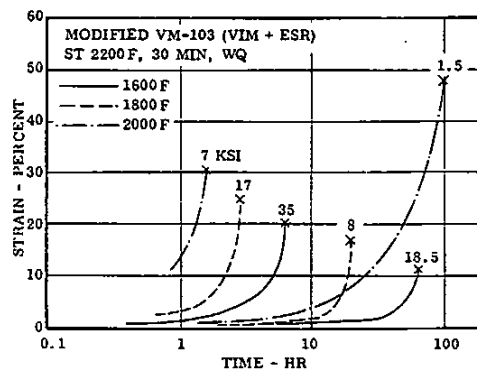
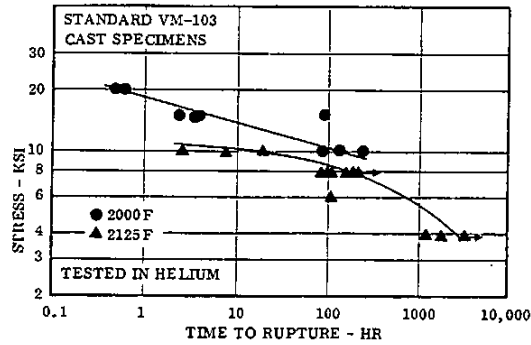


FIG. 3.043 TYPICAL CREEP STRAIN CURVES AT 1600, 1800 AND 2000 F. (4)

NONFERROUS ALLOYS

Co



	Co
25	W
3	Cr
1	Ti
0.5	Zr
0.5	C
VM-103	

FIG. 3.044 STRESS-RUPTURE CURVES FOR CAST SPECIMENS TESTED IN HELIUM AT 2000 AND 2125 F. (2)

Source	(1)	
Alloy	Standard VM-103 0.012 in sheet	
Condition	Cold rolled and annealed	
Test	Tension-tension fatigue (a)	
Heat No.	VAR 20-1	ESR PF-11
	Total Cycles to Failure (b)	
Stress range	37,000	212,400
0 - 75 ksi	576,000	18,600
	92,100	15,100
R = 0	130,900	138,000
	100,100	676,800
	25,300	-
Average	158,600	212,000
(a) All tests performed on a Budd (Tatnall-Krause) VSP-150 fatigue machine with a direct stress attachment.		
(b) Cyclic rate = 2000 cycles per minute.		

TABLE 3.051 TENSION-TENSION FATIGUE PROPERTIES FOR 0.012 INCH VAR AND ESR SHEET

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1. Harlow, R.A. and Gold, E. . "Development and Metallurgy Study of a NASA Cobalt-Base Superalloy", Final Report. Philco-Ford Corporation, Newport Beach, California. Prepared under NASA Contract NAS3-12421 Report No. NASA CR-72726 (April 1970).
2. Dreshfield, R.L., Freche, J.C. and Sandrock, G.D. . "Modification of High Temperature Cobalt-Tungsten Alloys for Improved Stability", NASA-TN-D-6147 (February 1971).
3. Drapier, J.M., Viatour, P. and Coutsouradis, D., "Structural Stability of a Co-W Heat Resisting Alloy". *Cobalt* No. 52 (September 1971).
4. Harlow, R.A. and Ritchey, E.E., "Further Development and Characterization of VM-103, A NASA Wrought Cobalt-Base Alloy". Report No. NASA CR-121189. Philco-Ford Corporation, Newport Beach, California. Prepared under NASA Contract NAS3-14329 (December 1972).