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## NONFERROUS ALLOYS

1. GENERAL  
This cobalt-base alloy, containing chromium for oxidation resistance, and tungsten and columbium as high-temperature strengthening agents, is commonly used for first-stage turbine guide vanes (1). It has excellent castability and foundry characteristics (2), very good repairability, and moderately good creep and fatigue strength, oxidation and hot-corrosion resistance. Recently developed nickel-base alloys (e.g. B-1900) tend to be superior in oxidation and corrosion resistance, and in thermal fatigue resistance, resulting in replacement of the alloy for some applications involving high temperatures.
- The alloy is commonly used in the as-cast condition although it may be strengthened by heat treatment. Above 1700-1800F surface protection is needed for use in an oxidizing environment. The oxidation mechanisms have been extensively studied, and many protective systems have been investigated, among them various coatings and claddings.
- 1.01 Commercial Designation  
WI-52
- 1.02 Alternate Designations  
Haynes Alloy 152, HA-152, PWA 653, CF 239 (1, p. 1).
- 1.03 Specifications  
There are no formal specifications; company specifications such as PWA 653-A (29) may be used as guide.
- 1.04 Composition  
Table 1.04.
- 1.05 Heat Treatment  
1.051 Normally used in as-cast condition.  
1.052 Alloy is, however, age hardenable through formation of columbium carbide at temperatures above 1200F. While strengthening the alloy, such heat treatment reduced high temperature ductility. Aging 50 hours at 1475F is one recommendation (7).
- 1.06 Hardness  
1.061 Maximum hardness in as-cast condition, RC 38, or equivalent (1, p. 18).  
1.062 As precipitation hardened; 1475F, 50 hours, maximum hardness RC 45 or equivalent.
- 1.07 Forms and Conditions Available  
1.071 Normally used in as-cast condition.  
1.072 Columnar-grained turbine vanes have been produced by directional solidification (27, p. 29).
- 1.08 Melting and Casting Practice  
1.081 Electric furnace air melt in combination with standard investment casting procedures (7, p. 1), and air cast (6, p. 1).  
1.082 In some cases there is insufficient creep-rupture strength improvement by vacuum melting and casting to warrant the increased processing cost (27, p. 47).
- 1.09 Special Considerations  
1.091 For use above 1800F the alloy definitely requires surface protection against oxidation, corrosion and erosion. Recent intense activity to establish the oxidation mechanism and to develop coatings and claddings (9-15)(19)(21) (24) may result in methods for adequate surface protection. However, newly developed nickel-base alloys, such as B-1900, IN-100 and TAZ-8A, are considerably more oxidation resistant than WI-52, and should be considered for stringent service at very high temperature. (See Figures 2.03233, 2.03234). WI-52 may, however, be very acceptable for service at and below 1700F especially if properly coated. (See Figure 2.03241, extrapolating to lower temperatures.)  
1.092 Oxidation resistance is extremely sensitive to surface air velocity (Figure 2.03232); hence static furnace tests are inadequate to rate material for specific service application not properly simulated by furnace test.
- 1.093 Thermal fatigue cracking and bowing for this alloy are only moderate to poor compared to newly developed nickel-base alloys. (See Figures 3.053, 3.055.)  
1.094 Decreases in thermal fatigue life due to 1500F exposure have been observed (27, p. 51).
2. PHYSICAL AND CHEMICAL PROPERTIES
- 2.01 Thermal Properties  
2.011 Melting range, approximately 2400 to 2450F (4, p. 2).  
2.012 Phase changes.  
2.0121 Carbide precipitation occurs above 1200F (5, p. 1).  
2.013 Thermal conductivity, Figure 2.013.  
2.014 Thermal expansion, Figure 2.014.  
2.015 Specific heat, Figure 2.015.  
2.016 Thermal diffusivity.
- 2.02 Other Physical Properties  
2.021 Density, 0.321 lb per cu in, 8.88 gr per cu cm (4, p. 2).  
2.022 Electrical properties.  
2.023 Magnetic properties.  
2.024 Emissivity.  
2.025 Damping capacity.
- 2.03 Chemical Properties  
2.031 General. Alloy has good oxidation and corrosion resistance at temperatures below 1700F; but must be protected above this temperature by coatings or claddings, particularly if exposed to high air velocities (see Section 1.09). Alloy is best in oxidation resistance in a static air furnace, becomes much more susceptible to oxidation if temperature is cycled, even in a static-air furnace environment, due to spalling of oxide formed at the higher temperatures of the range covered, and is poorest if exposed to a high air velocity, due to erosion. Its hot-corrosion resistance with respect to sulfur and salt is not as good as many other nickel and cobalt-base alloys (Figures 2.03251 and 2.03252). The striated hot corrosion attack is believed to be due to the preferential attack of the high-columbium MC-type carbides and interdendritic regions (27, p. 41). Its oxidation characteristics are also significantly affected by surface preparation (Figures 2.03211 and 2.03212), believed to be associated with residual stresses (11).  
2.032 Oxidation.  
2.0321 Static furnace oxidation. (See also 2.0322.)  
2.03211 Effect of surface preparation on weight gain during oxidation in air at 1800F, Figure 2.03211.  
2.03212 Effect of surface preparation on weight gain during oxidation in air at 2000F, Figure 2.03212.  
2.03213 Phases developed during air oxidation at 1600 to 2000F for alloy in ground condition, Figure 2.03213.  
2.03214 Phases developed during air oxidation at 1800 and 2000F for alloy in ground and lapped condition, Figure 2.03214.  
2.0322 Cyclic furnace oxidation.  
2.03221 Weight change during heating portions of successive 5-hour cycles of furnace oxidation at 2000F of ground and lapped  
2.03222 Weight change during heating portions of successive 20-hour cycles of furnace oxidation at 2000F of ground and lapped castings, Figure 2.03222.  
2.03223 Net weight change during combined heating and cooling portions of 1900 and 2000F tests under cyclic furnace oxidation conditions, and comparison with weight change during isothermal oxidation, Figure 2.03223.  
2.03224 Effect of cyclic frequency on furnace oxidation of aluminumized alloy tested at 2000F, Figure 2.03224.  
2.03225 Effect of frequency of cyclic furnace oxidation at 1900 and 2000F on surface recession, Figure 2.03225.  
2.0323 High velocity burners.  
2.03231 Weight change at 1800, 1900 and 2000F for airfoil section in Mach 1 gas stream, Figure 2.03231.  
2.03232 Comparison of weight change during cyclic oxidation (1 hr cycle) between static furnace test and high velocity burner test, Figure 2.03232.  
2.03233 Comparison of weight loss for as-cast alloy with other nickel and cobalt-base alloys tested for 100 hours in a high velocity gas stream, Figure 2.03233.

	Co
21	Cr
11	W
2	Fe
1.75	Ta
+	Cb

WI-52

21	Co
11	Cr
2	W
1.75	Fe
+	Ta
	Cb

WI-52

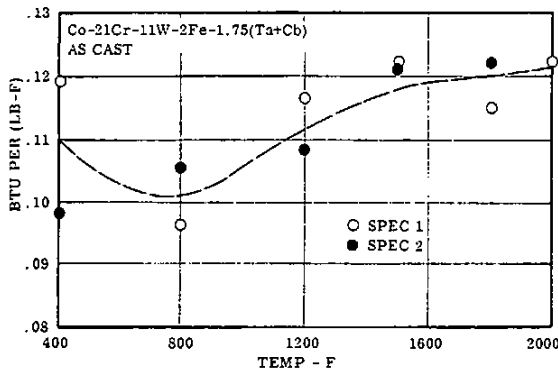
- 2.03234 Surface recession of as-cast airfoil tested in a high velocity gas stream with metal temperature of 2000F, and comparison with other nickel and cobalt-base alloys similarly tested. Figure 2.03234.
- 2.0324 Coatings and claddings for oxidation.
- 2.03241 Effect of test temperature on life of conventional aluminate coating on wedge specimen tested in a Mach 1 gas burner. Figure 2.03241.
- 2.03242 Effect of temperature on life of three proprietary coatings tested in a high velocity combustion gas rig. Figure 2.03242.
- 2.03243 Comparison of oxidation in a Mach 1 combustion gas stream at 1900 and 2000 F for wedge specimens either aluminate coated or FeCrAlY clad. Figure 2.03243.
- 2.03244 Effect of various coatings and claddings on weight change during 20 hour cyclic furnace oxidation. Figure 2.03244.
- 2.03245 Effect of cladding on cyclic oxidation at 1900 and 2000 F. Figure 2.03245.
- 2.03246 Effect of cladding thickness on furnace oxidation of bare castings and castings with cladding of Ni-20Cr-4Al (DH 245). Figure 2.03246.
- 2.03247 Effect of cladding thickness and exposure cycle frequency on furnace oxidation of alloy with cladding of Ni-30Cr (Tophet 30). Figure 2.03247.
- 2.03248 Effect of cladding thickness and exposure cycle frequency on furnace oxidation of alloy with cladding of Fe-25Cr-4Al (GE 2541). Figure 2.03248.
- 2.03249 Effect of cladding and of exposure to furnace oxidation conditions subsequent to cladding on tensile properties at 2000 F. Figure 2.03249.
- 2.0325 Corrosion.
- 2.03251 Relative hot corrosion resistance of alloy compared to other cobalt-base alloys when tested in a burner using Diesel oil with 1 percent sulfur and 5 ppm sea salt in combustion air. Figure 2.03251.
- 2.03252 Comparison of hot-corrosion behavior in a marine turbine simulator with other nickel and cobalt-base alloys. Figure 2.03252.
3. MECHANICAL PROPERTIES
- 3.01 Specific Mechanical Properties
- 3.011 Specified mechanical properties, Table 3.011 and Table 3.012.
- 3.02 Mechanical Properties at Room Temperature (See also 3.03).
- 3.021 Tension.
- 3.0211 Stress-strain diagrams.
- 3.022 Compression.
- 3.0221 Stress-strain diagrams.
- 3.023 Impact.
- 3.024 Bending.
- 3.025 Torsion and shear.
- 3.026 Bearing.
- 3.027 Stress concentration.
- 3.0271 Notch properties.
- 3.0272 Fracture toughness.
- 3.028 Combined properties.
- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension.
- 3.0311 Stress-strain diagrams.
- 3.03111 Stress-strain curves at 1700 F and 2000 F. Figure 3.03111.
- 3.0312 Tensile properties.
- 3.03121 Tensile properties at room and elevated temperature for alloy cast by various methods. Figure 3.03121.
- 3.03122 Effect of test temperature on tensile properties of cast bar. Figure 3.03122.
- 3.032 Compression.
- 3.0321 Stress-strain diagrams.
- 3.033 Impact.
- 3.034 Bending.
- 3.035 Torsion and shear.
- 3.036 Bearing.
- 3.037 Stress concentration.
- 3.0371 Notch properties.
- 3.0372 Fracture toughness.
- 3.038 Combined properties.
- 3.04 Creep and Creep-Rupture Properties
- 3.041 Creep deformation.
- 3.0411 Creep curves at 25 ksi, 1600 F and at 20 ksi, 1700 F to times in range of 50 hours. Figure 3.0411.
- 3.0412 Creep curves at 20 ksi, 1600 F and at 15 ksi, 1700 F to times in range of 1000 hours. Figure 3.0412.
- 3.0413 Stress-time relation to produce 0.2 percent and 0.5 percent creep at 1600 to 2000 F. Figure 3.0413.
- 3.0414 Stress-time relation to produce 1 percent creep for alloy in bare, aluminized and chromized coated condition. Figure 3.0414.
- 3.042 Creep-rupture.
- 3.0421 Effect of temperature on stress to cause rupture in 100 and 1000 hours for cast bar. Figure 3.0421.
- 3.0422 Creep-rupture properties at 1600, 1700 and 1800 F for Haynes Alloy 152. Figure 3.0422.
- 3.0423 Creep-rupture properties at 1700, 1800 and 2000 F showing scatterband from various lots tested at 15 ksi, 1800 F. Figure 3.0423.
- 3.05 Fatigue
- 3.051 Maximum tensile stress developed during in-phase temperature and strain cycling. Figure 3.051.
- 3.052 Low-cycle fatigue under mechanical straining while cycling temperature between 400 and 1800 F. Figure 3.052.
- 3.053 Number of thermal stress cycles required to produce cracking in wedge-shaped specimens alternately transferred from hot (1990 F) to cold (600 F) fluidized beds. and comparison with thermal fatigue resistance of other commonly used alloys. Figure 3.053.
- 3.054 Thermal fatigue resistance of square plate rapidly heated and cooled at periphery of central hole. and comparison with thermal fatigue resistance of other commonly used cast alloys. Figure 3.054.
- 3.055 Trailing edge bow produced by combining bend stress of 5 ksi with programmed thermal cycling. Figure 3.055.
- 3.056 Thermal fatigue cracking performance of as-cast airfoil wedge specimen. Table 3.056.
- 3.06 Elastic Properties
- 3.061 Poisson's ratio.
- 3.062 Static modulus of elasticity. Figure 3.062.
- 3.063 Modulus of rigidity.
4. FABRICATION
- 4.01 Formability
- 4.02 Machining and Grinding
- The alloy is considered to be difficult to machine. Use cutting speeds of 10-15 sfpm with high speed steel and 30-50 sfpm with carbide tools. Machining should be done at low feeds and speeds using a positive cut to prevent work-hardening of the surface. Carbide-tipped cutting tools give satisfactory machining when ground to 0 degree back rake, 6 degree side rake, 0 degree side cutting-edge angle, 6 degree end cutting-edge angle, 6 degree relief angle, and 0.020 inch nose radius. No cutting fluid is necessary with carbide cutting tools. Maximum tool life is obtained with cutting solution-treated material by using a feed of 0.011 in per rev at a cutting speed of 100 sfpm with Grade K6 carbide. At lower cutting speeds such as 50 sfpm, the tool life of K6 carbide, measured in cubic inches of metal removed, is in the ratio of approximately 23 for the solution treated material to 34 for the fully age-hardened material(7).
- 4.03 Welding
- 4.031 Great care in welding is necessary. However, when proper care is exercised alloy can be welded by all usual methods. especially arc and atomic hydrogen welding (7).
- 4.04 Heat Treatment
- 4.05 Surface Treatment

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Source	WaiMet (2,p.4)		Haynes (4,p.2) PWA 653A (29)	
	Percent		Percent	
	Min	Max	Min	Max
Carbon	0.40	0.50	0.40	0.50
Chromium	20.0	22.0	20.00	22.00
Columbium + Tantalum	1.50	2.00	1.5	2.5
Iron	-	0.60	1.0	2.5
Manganese	-	0.50	-	0.50
Nickel	-	1.0	-	1.0
Silicon	-	0.50	-	0.50
Tungsten	10.0	12.0	10.00	12.00
Phosphorus	-	0.040	-	0.040
Sulfur	-	0.040	-	0.040
Cobalt	Balance		Balance	

TABLE 1.04 COMPOSITION.



Co  
21 Cr  
11 W  
2 Fe  
1.75 Ta  
+ Cb  
WI-52

FIG 2.015 SPECIFIC HEAT.

(1,p.4)

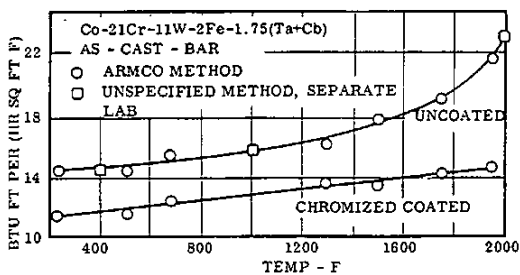


FIG 2.013 THERMAL CONDUCTIVITY.

(1,p.6)(8,p.9)

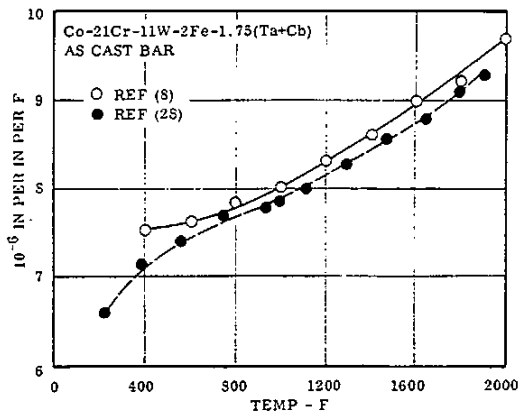


FIG 2.014 THERMAL EXPANSION.

(8,p.10)(28,p.3)

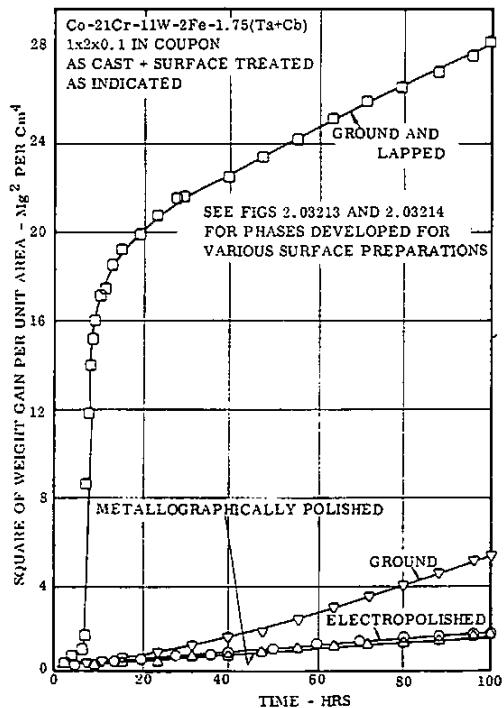


FIG 2.03211 EFFECT OF SURFACE PREPARATION ON WEIGHT GAIN DURING OXIDATION IN AIR AT 1800F.

(11,p.9)

	Co
21	Cr
11	W
2	Fe
1.75	Ta
+	Cb

WI-52

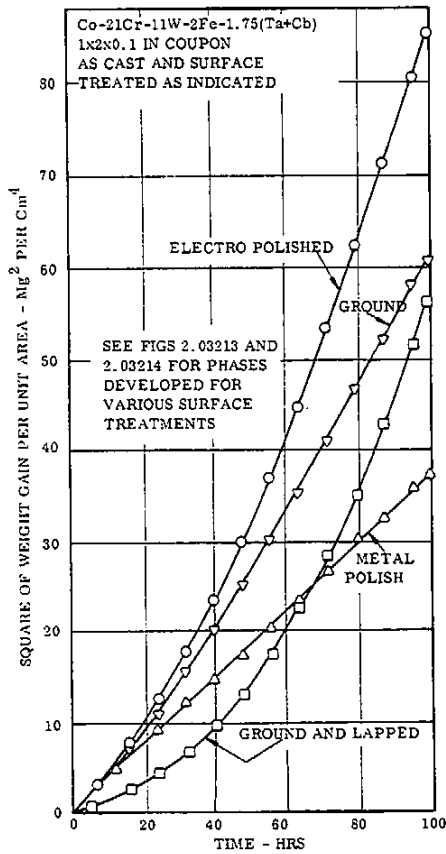


FIG 2.03212 EFFECT OF SURFACE PREPARATION ON WEIGHT GAIN DURING OXIDATION IN AIR AT 2000F. (11, p. 10)

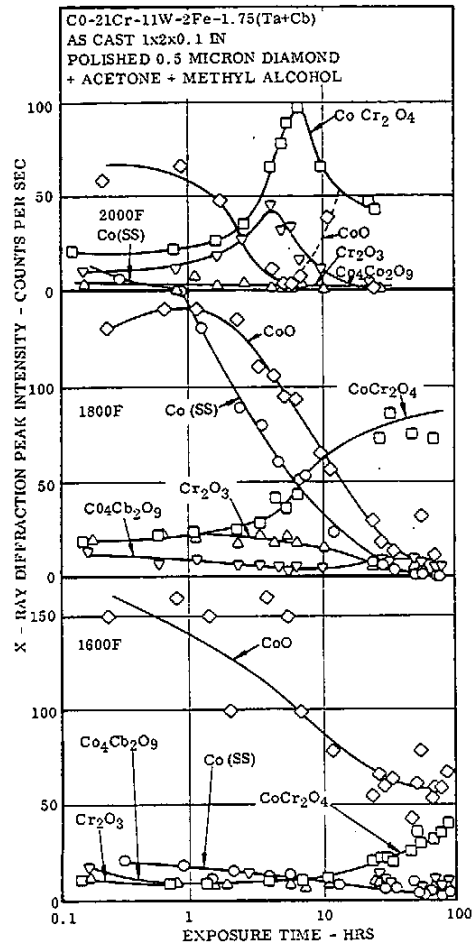


FIG. 2.03213 PHASES DEVELOPED DURING AIR OXIDATION AT 1600 TO 2000 F FOR ALLOY IN GROUND CONDITION. (15, p. 8,9)

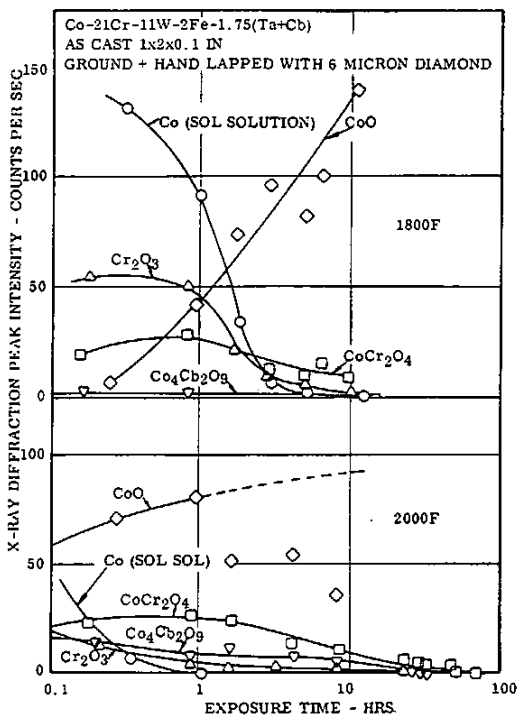


FIG. 2.03214 PHASES DEVELOPED DURING AIR OXIDATION AT 1800 AND 2000 F FOR ALLOY IN GROUND AND LAPPED CONDITION. (15, p. 10)

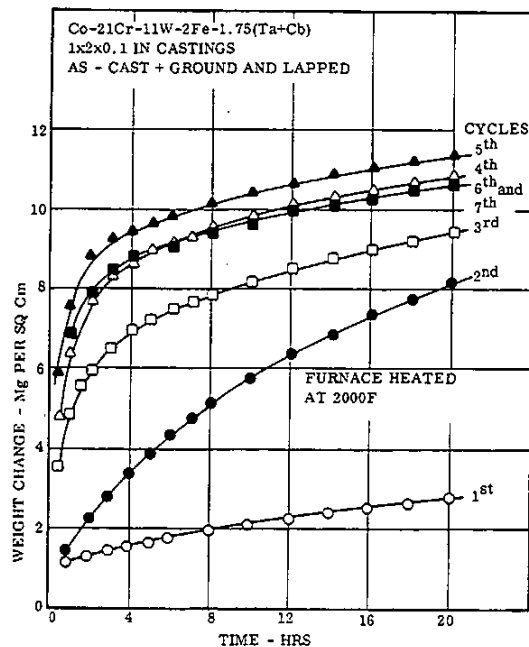


FIG 2.03222 WEIGHT CHANGE DURING HEATING PORTIONS OF SUCCESSIVE 20 - HR CYCLES OF FURNACE OXIDATION AT 2000F OF GROUND AND LAPPED CASTINGS. (14, p. 21)

Co
21 Cr
11 W
2 Fe
1.75 Ta
+ Cb
WI-52

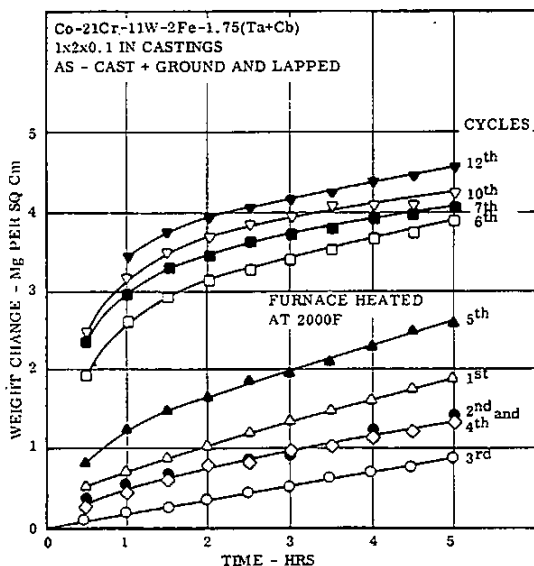


FIG 2.03221 WEIGHT CHANGE DURING HEATING PORTIONS OF SUCCESSIVE 5 - HOUR CYCLES OF FURNACE OXIDATION AT 2000F OF GROUND AND LAPPED CASTINGS. (14, p. 22)

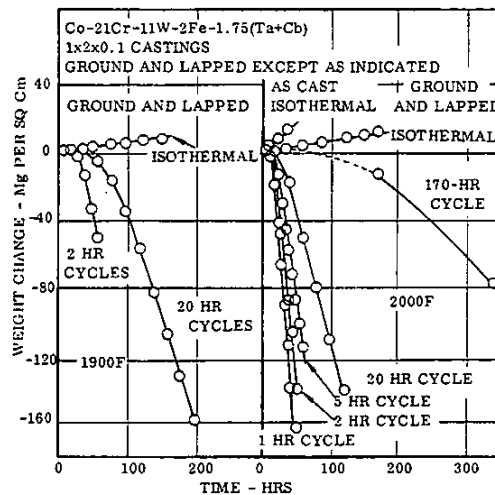


FIG. 2.03223 NET WEIGHT CHANGE DURING COMBINED HEATING AND COOLING PORTIONS OF 1900 AND 2000 F TESTS UNDER CYCLIC FURNACE OXIDATION CONDITIONS, AND COMPARISON WITH WEIGHT CHANGE DURING ISOTHERMAL OXIDATION. (14, p. 20)

Co  
21 Cr  
11 W  
2 Fe  
1.75 Ta  
+ Cb  
WI-52

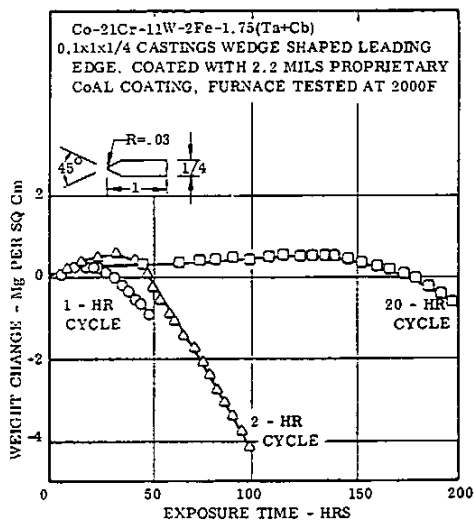


FIG 2.03224 EFFECT OF CYCLIC FREQUENCY ON FURNACE OXIDATION OF ALUMINIZED ALLOY TESTED AT 2000F. (21, p. 13)

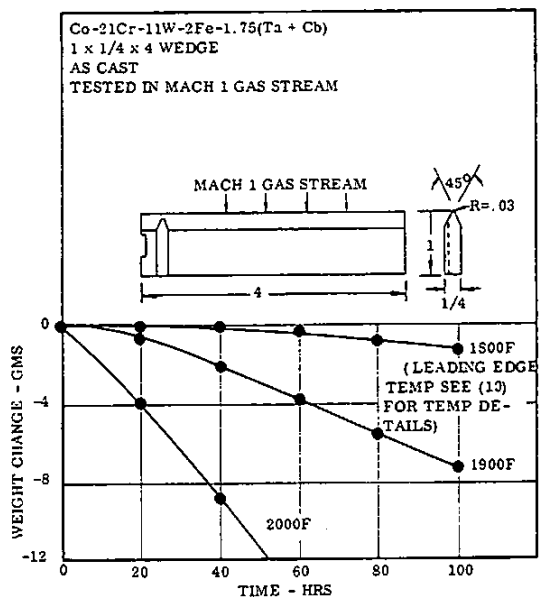
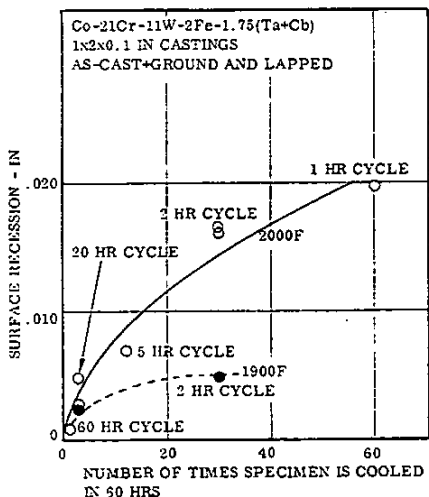


FIG. 2.03231 WEIGHT CHANGE AT 1800, 1900, AND 2000F FOR AIRFOIL SECTION IN MACH 1 GAS STREAM. (10, p. 31)



2.03225 EFFECT OF FREQUENCY OF CYCLIC FURNACE OXIDATION AT 1900 AND 2000F ON SURFACE RESSION. (14, p. 23)

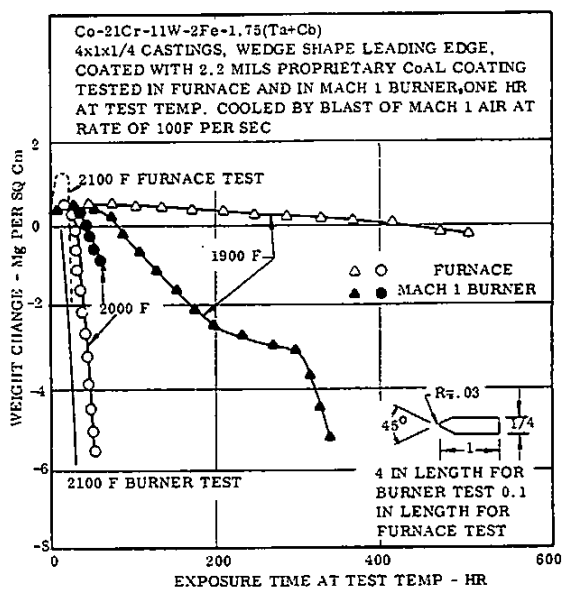


FIG 2.03232 COMPARISON OF WEIGHT CHANGE DURING CYCLIC OXIDATION (1-HR CYCLE) BETWEEN STATIC FURNACE TEST AND HIGH VELOCITY BURNER TEST (21, p. 20)

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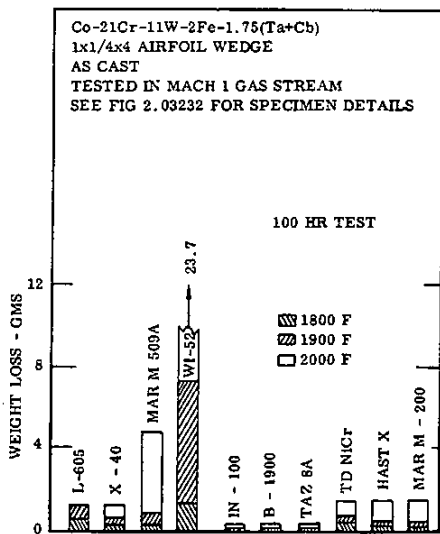
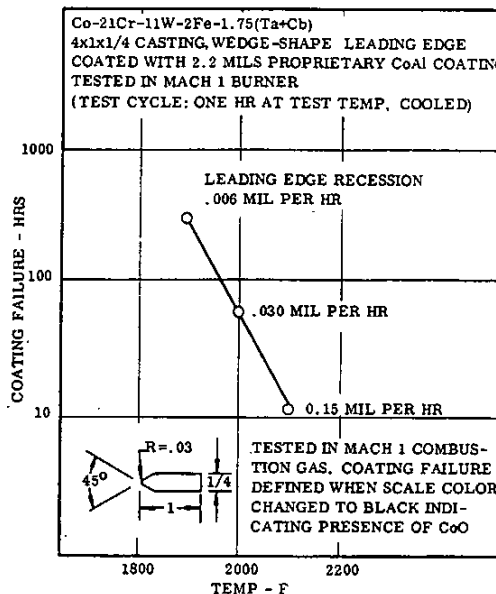


FIG 2.03233 COMPARISON OF WEIGHT LOSS FOR AS-CAST ALLOY WITH OTHER NICKEL-AND COBALT-BASE ALLOYS TESTED FOR 100 HRS IN A HIGH VELOCITY GAS STREAM. (10, p. 32)



Co  
21 Cr  
11 W  
2 Fe  
1.75 Ta  
+ Cb  
WI-52

FIG 2.03241 EFFECT OF TEST TEMPERATURE ON LIFE OF CONVENTIONAL ALUMINIDE COATING ON WEDGE SPECIMEN TESTED IN A MACH 1 GAS BURNER. (21, p. 23)

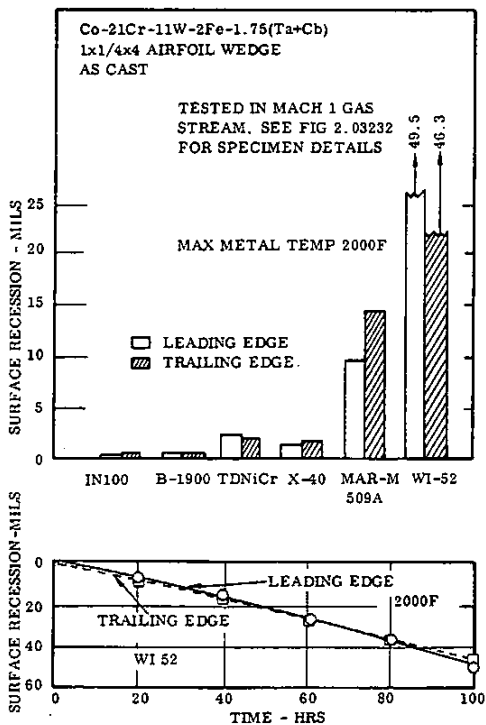


FIG. 2.03234 SURFACE RESSION OF AS-CAST AIRFOIL TESTED IN A HIGH VELOCITY GAS STREAM WITH METAL TEMPERATURE OF 2000 F AND COMPARISON WITH OTHER NICKEL-AND-COBALT-BASE ALLOYS SIMILARLY TESTED. (10, p. 34)

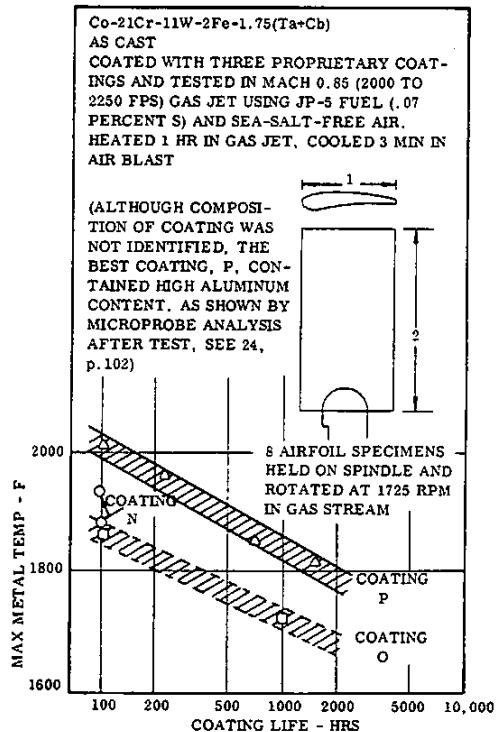


FIG 2.03242 EFFECT OF TEMPERATURE ON LIFE OF THREE PROPRIETARY COATINGS TESTED IN A HIGH VELOCITY COMBUSTION GAS RIG. (24, p. 103)

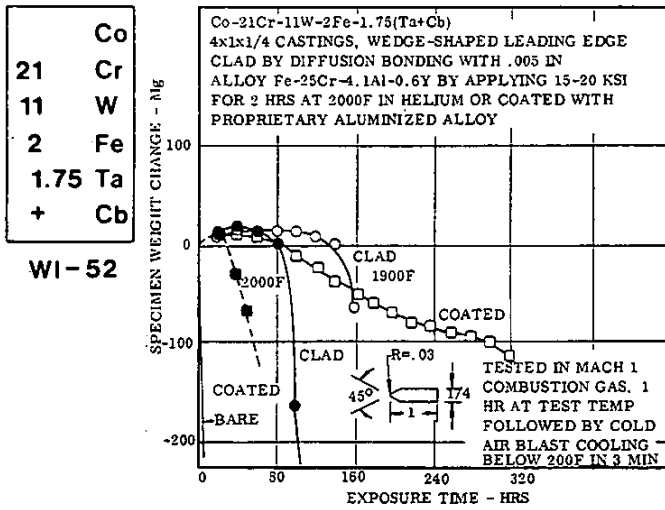


FIG 2.03243 COMPARISON OF OXIDATION IN A MACH 1 COMBUSTION GAS STREAM AT 1900 AND 2000F FOR WEDGE SPECIMENS EITHER ALUMINIDE COATED OR FeCrAlY CLAD. (13, FIG 7)

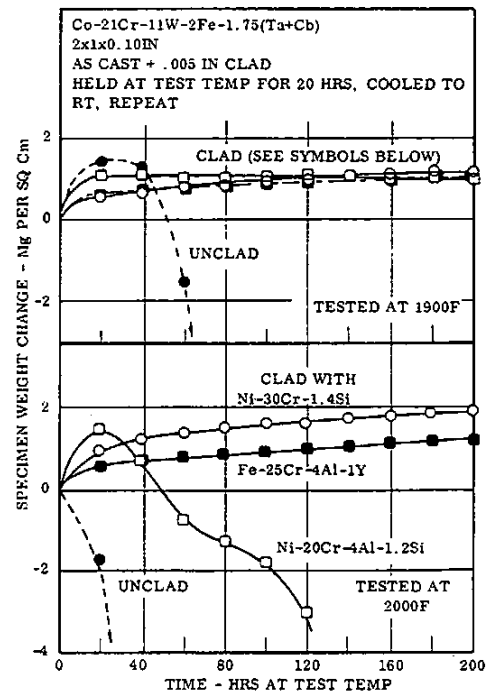


FIG 2.03245 EFFECT OF CLADDING ON CYCLIC OXIDATION AT 1900 AND 2000F. (9, p. 16)

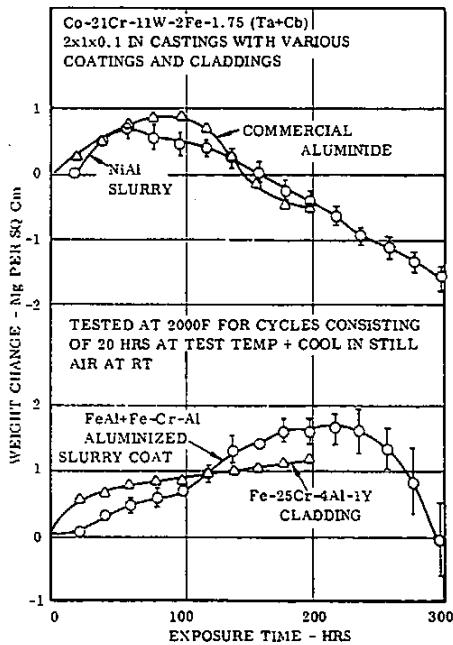


FIG 2.03244 EFFECT OF VARIOUS COATINGS AND CLADDINGS ON WEIGHT CHANGE DURING 20 - HOUR CYCLIC FURNACE OXIDATION. (12, p. 14, 18)

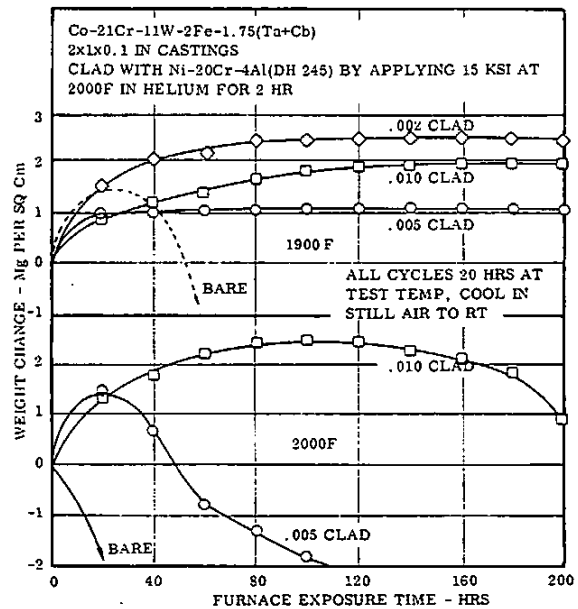


FIG. 2.03246 EFFECT OF CLADDING THICKNESS ON FURNACE OXIDATION OF BARE CASTINGS AND CASTINGS WITH CLADDING OF Ni-20Cr-4Al(DH245). (19)

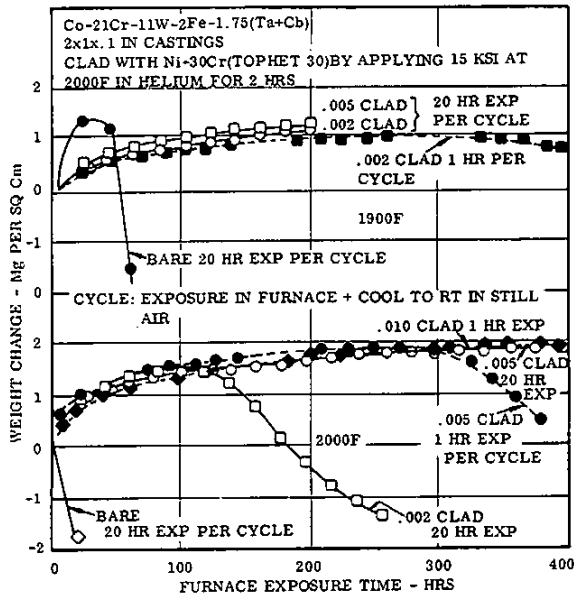


FIG. 2.03247 EFFECT OF CLADDING THICKNESS AND EXPOSURE CYCLE FREQUENCY ON FURNACE OXIDATION OF ALLOY WITH CLADDING OF Ni-30Cr(TOPHET 30). (19)

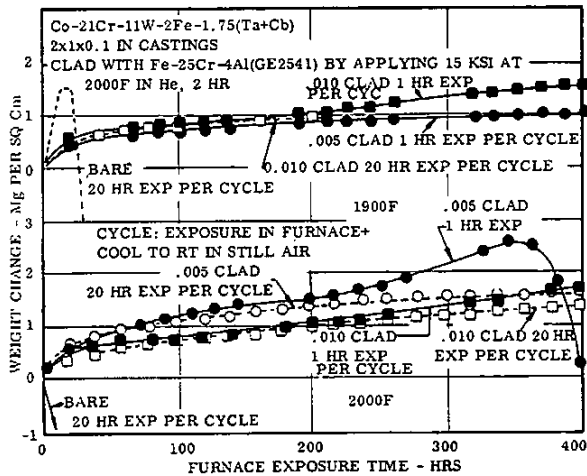


FIG. 2.03248 EFFECT OF CLADDING THICKNESS AND EXPOSURE CYCLE FREQUENCY ON FURNACE OXIDATION OF ALLOY WITH CLADDING OF Fe-25Cr-4Al (GE 2541). (19)

Co
21 Cr
11 W
2 Fe
1.75 Ta
+ Cb

WI-52

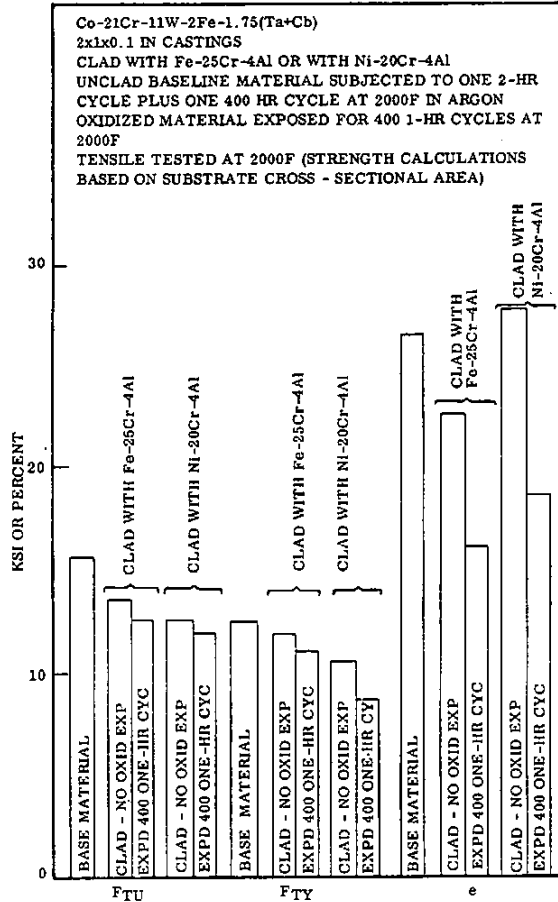


FIG. 2.03249 EFFECT OF CLADDING AND OF EXPOSURE TO FURNACE OXIDATION CONDITIONS SUBSEQUENT TO CLADDING ON TENSILE PROPERTIES AT 2000 F. (19)

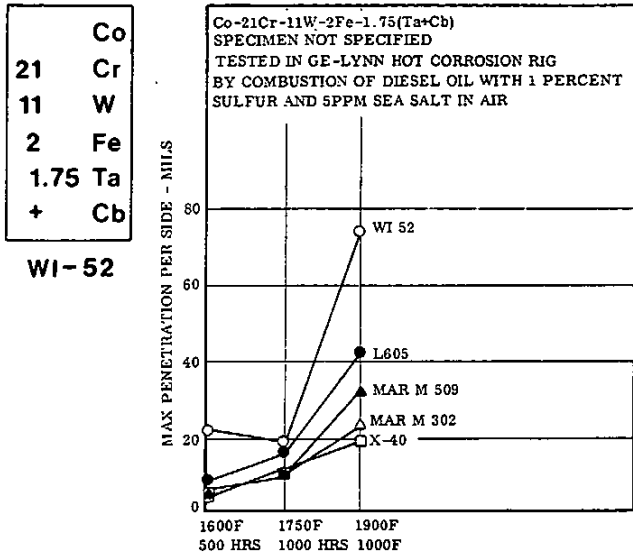


FIG 2.03251 RELATIVE HOT CORROSION RESISTANCE OF ALLOY COMPARED TO OTHER COBALT - BASE ALLOYS WHEN TESTED IN A BURNER USING DIESEL OIL WITH 1 PERCENT SULFUR AND 5 PPM SEA SALT IN COMBUSTION AIR. (17, p. 10)

Source	Wai Met (2)		
Alloy	Co-21Cr-11W-2Fe-1.75 (Ta + Cb)		
Form	Investment Casting		
Condition	As cast	1500 F	Aged 1475 F 50 hr
F <sub>tu</sub> - ksi	125	75	-
F <sub>ty</sub> - ksi	85	52	-
e (1 in)- percent	5	8	-
RA - percent	5	12.5	-
Hardness			
RC	≤ 38	-	≤ 45

TABLE 3.011 SPECIFIED MECHANICAL PROPERTIES.

Source	(1, p. 5)	
Requirement	23 hr life and 5 percent min elongation	
Form and Condition	As cast test specimen	
Spec	Temp - F	Stress - ksi
PWA 653-A	1800	15.0
PWA 654	1800	17.5
CF 239	1700	19.0
WI 52 (WaiMet)	1600	23.0

TABLE 3.012 SPECIFIED MECHANICAL PROPERTIES.

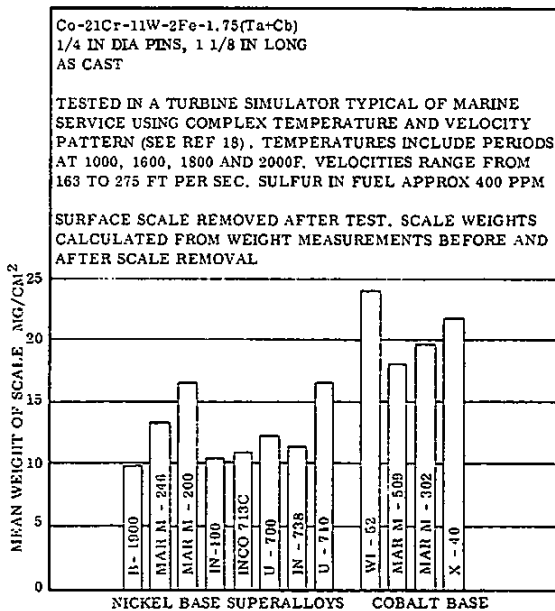


FIG 2.03252 COMPARISON OF HOT - CORROSION BEHAVIOR IN A MARINE TURBINE SIMULATOR WITH OTHER NICKEL - AND COBALT - BASE ALLOYS. (18, p. 1-17)

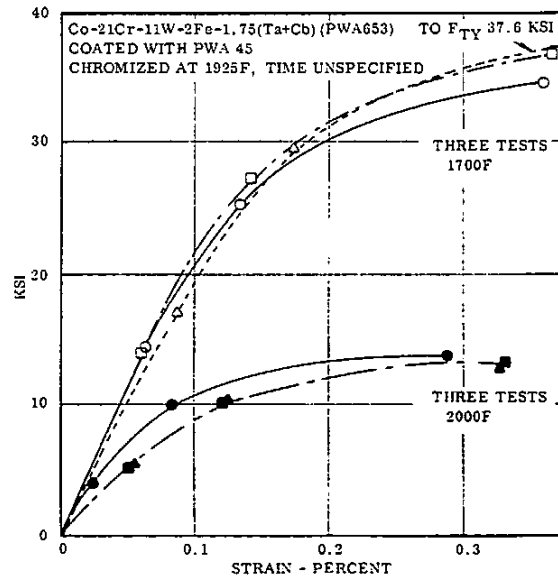


FIG 3.03111 STRESS - STRAIN CURVES AT 1700 AND 2000F.

(31)

NONFERROUS ALLOYS

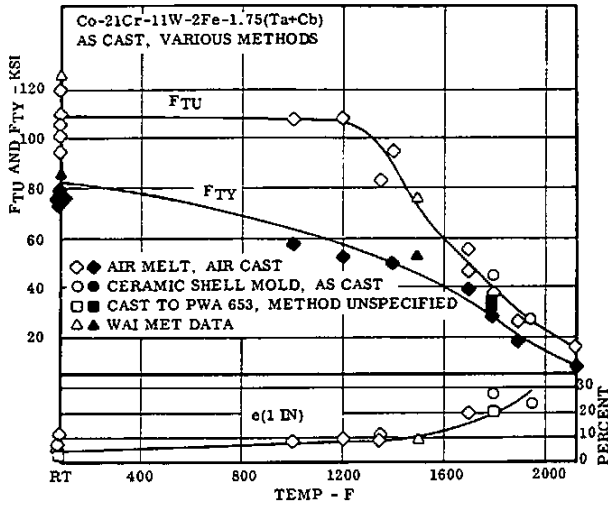


FIG 3.03121 TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURE FOR ALLOY CAST BY VARIOUS METHODS. (1, p7)

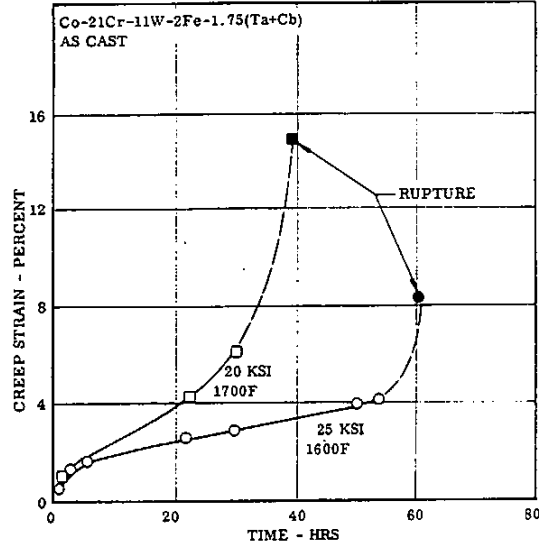


FIG. 3.041 CREEP CURVES AT 25 KSI, 1600F AND AT 20 KSI, 1700F TO TIMES IN RANGE OF 50 HOURS. (1, pp 15-16)

Co
21 Cr
11 W
2 Fe
1.75 Ta
+ Cb
WI-52

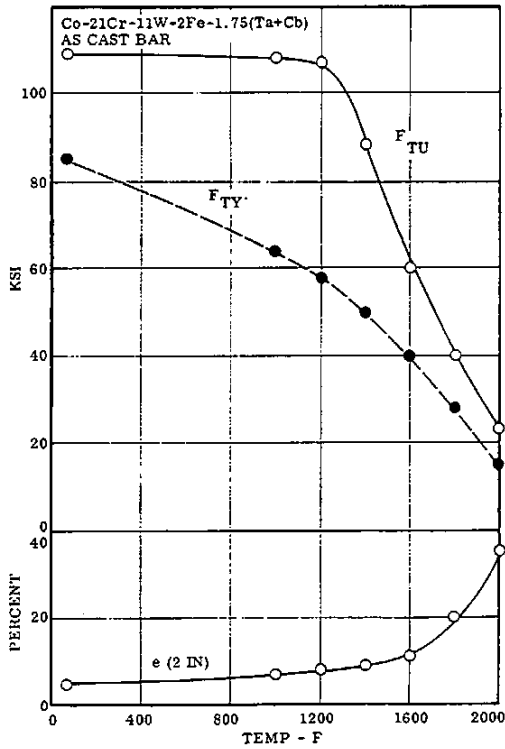


FIG. 3.03122 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF CAST BAR. (8, pp 13-15)

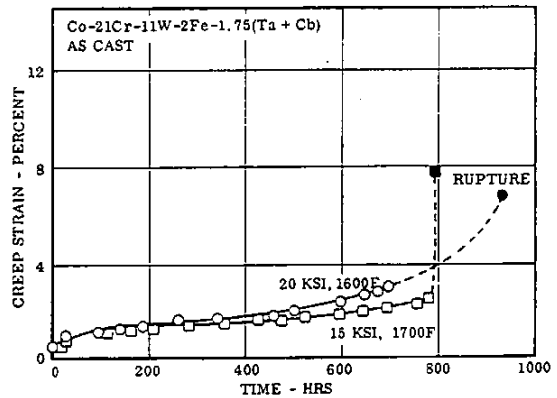


FIG 3.0412 CREEP CURVES AT 20 KSI, 1600F AND AT 15 KSI, 1700F TO TIMES IN RANGE OF 1000 HRS. (1, pp 15-16)

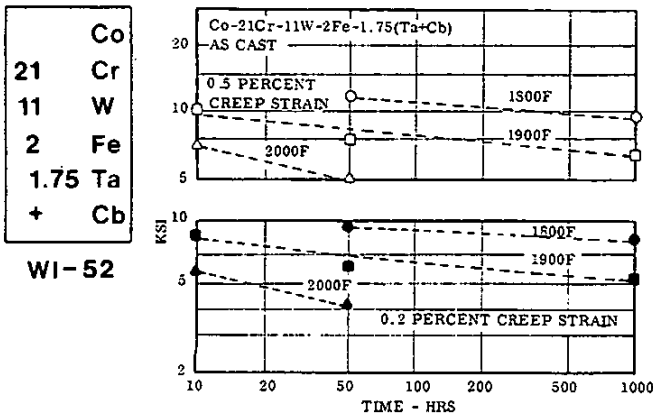


FIG 3.0413 STRESS - TIME RELATION TO PRODUCE 0.2 PERCENT AND 0.5 PERCENT CREEP AT 1800 TO 2000F. (1, p. 17)

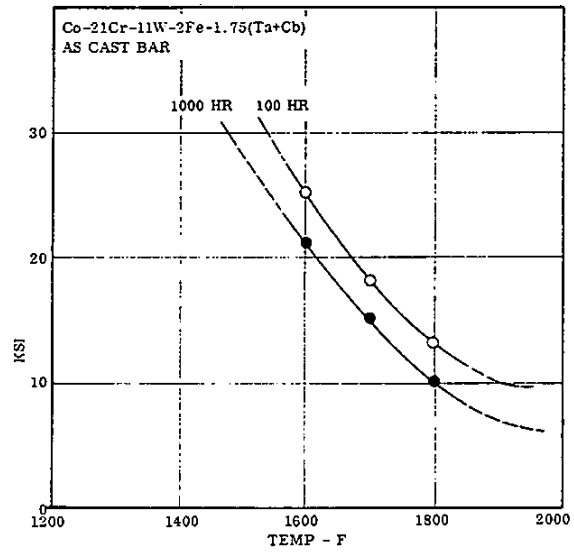


FIG. 3.0421 EFFECT OF TEMPERATURE ON STRESS TO CAUSE RUPTURE IN 100 AND 1000 HOURS FOR CAST BAR. (8, pp 11-12)

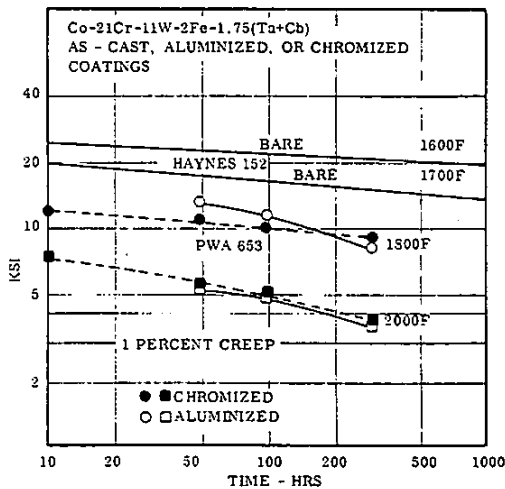


FIG 3.0414 STRESS - TIME RELATION TO PRODUCE 1 PERCENT CREEP FOR ALLOY IN BARE, ALUMINIZED AND CHROMIZED COATED CONDITION. (1, pp 18-19)

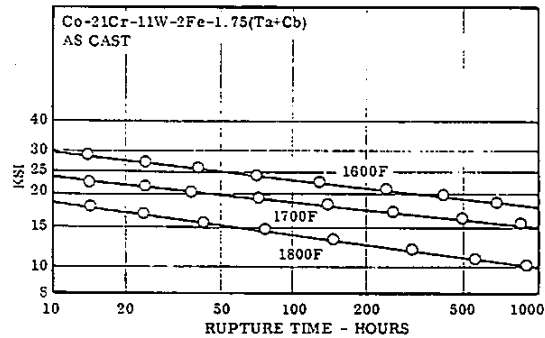


FIG. 3.0422 CREEP RUPTURE PROPERTIES AT 1600, 1700 AND 1800F FOR HAYNES ALLOY 152. (22, p. 60)

NONFERROUS ALLOYS

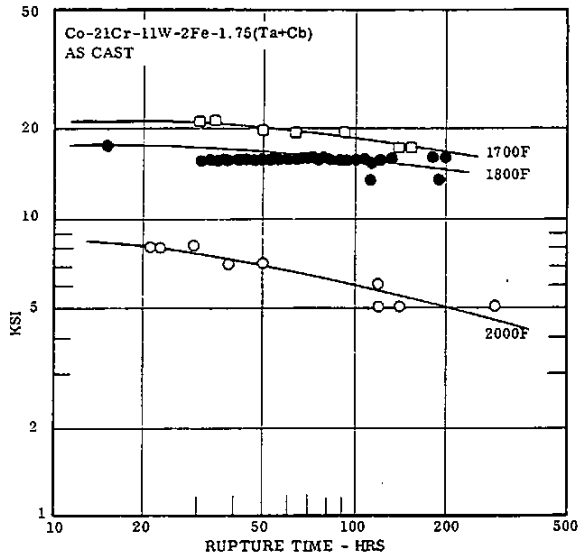


FIG 3.0423 CREEP - RUPTURE PROPERTIES AT 1700, 1800, AND 2000F. SHOWING SCATTERBAND FROM VARIOUS LOTS TESTED AT 15 KSI, 1800F. (23)

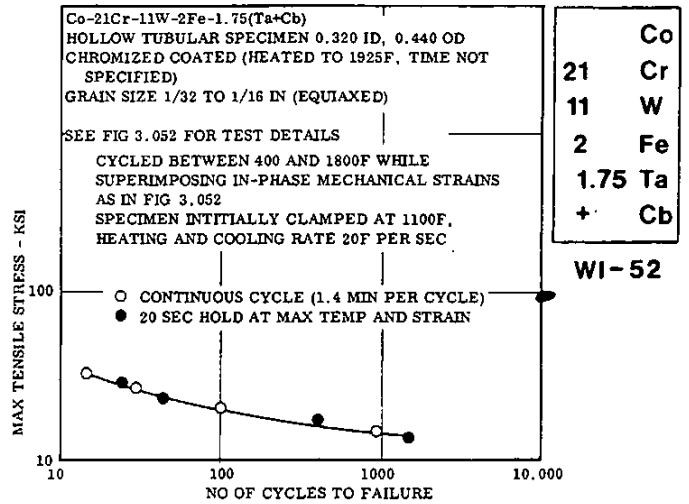


FIG. 3.051 MAXIMUM TENSILE STRESS DEVELOPED DURING IN-PHASE TEMPERATURE AND STRAIN CYCLING. (20, p.10)

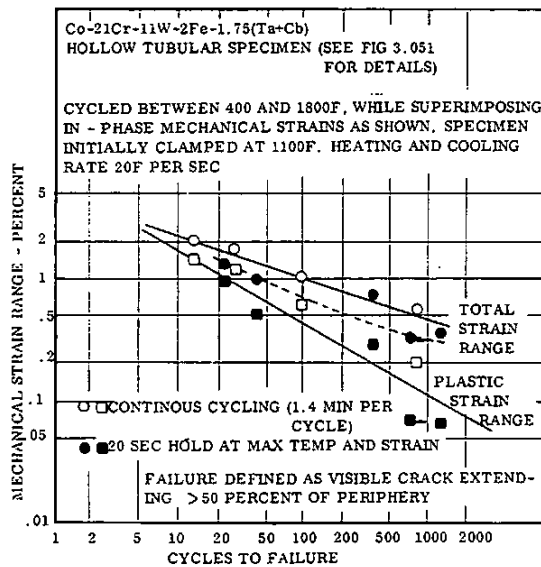


FIG 3.052 LOW CYCLE FATIGUE UNDER MECHANICAL STRAINING WHILE CYCLING TEMPERATURE BETWEEN 400 AND 1500F. (20, p.9)

Co  
21 Cr  
11 W  
2 Fe  
1.75 Ta  
+ Cb  
WI-52

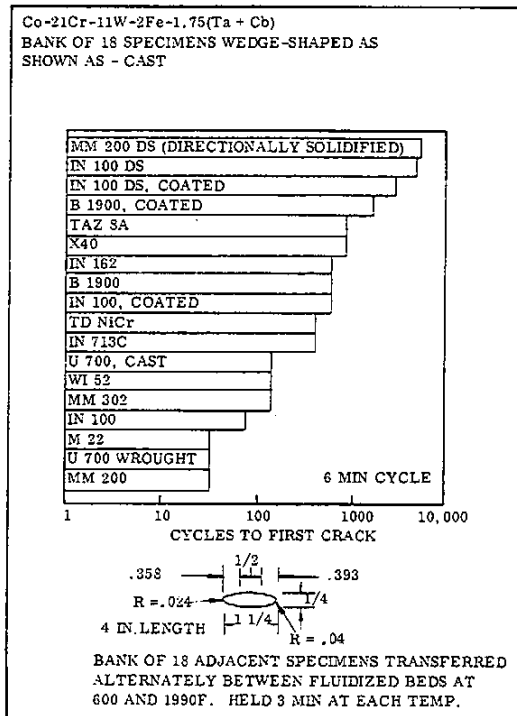


FIG 3. 053 NUMBER OF THERMAL STRESS CYCLES REQUIRED TO PRODUCE CRACKING IN WEDGE - SHAPED SPECIMENS ALTERNATELY TRANSFERRED FROM HOT (1990F) TO COLD (600F) FLUIDIZED BEDS, AND COMPARISON WITH THERMAL FATIGUE RESISTANCE OF OTHER COMMONLY USED ALLOYS. (16. FIG 5)

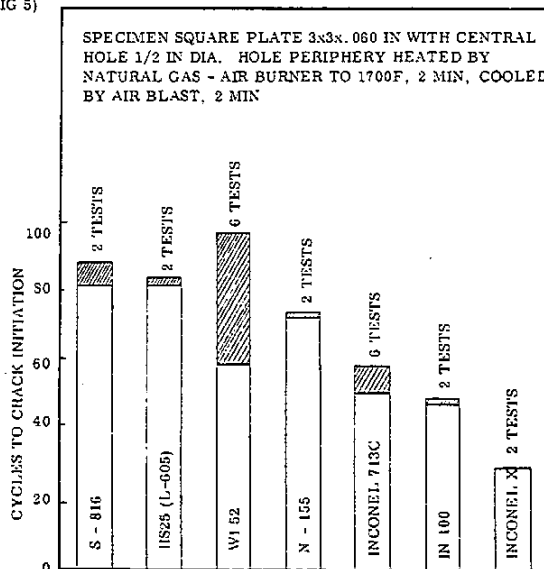
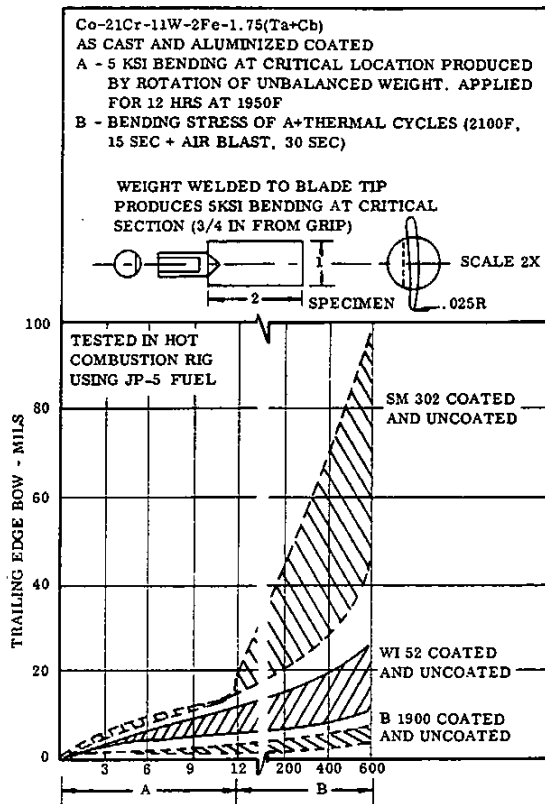


FIG 3.054 THERMAL FATIGUE RESISTANCE OF SQUARE PLATE RAPIDLY HEATED AND COOLED AT PERIPHERY OF CENTRAL HOLE, AND COMPARISON WITH THERMAL FATIGUE RESISTANCE OF OTHER COMMONLY USED CAST ALLOYS. (30, p. 15)

REVISED : MARCH 1973

NONFERROUS ALLOYS



Co  
 21 Cr  
 11 W  
 2 Fe  
 1.75 Ta  
 + Cb

WI-52

FIG 3.055 TRAILING EDGE BOW PRODUCED BY COMBINING BEND STRESS OF 5KSI WITH PROGRAMMED THERMAL CYCLING. (26, p.4)

Source	(10, pp. 35, 46)				
Alloy	Co-21Cr-11W-2Fe-1.75 (Ta + Cb)				
Form	As cast airfoil wedge (See Figure 2.03231)				
Test Condition	20 hr	40 hr	60 hr	80 hr	100 hr
2000 F combustion gas, Mach 1, force air cool to RT, 1 hr Cycle (7 specimens tested)	0	3	2	2	-
2000 F, Mach 0.7, force air cool to RT, 1 hr cycle (2 specimens tested)	0	0	0	0	0
2000 F, Mach 1, free air cool to RT, 10 hr cycle (2 specimens tested)	0	0	0	0	0
1900 F, Mach 1, force air cool to RT, 1 hr cycle (7 specimens tested)	0	0	0	0	7
1800 F, Mach 1, force air cool to RT, 1 hr cycle (7 specimens tested)	0	0	0	0	7
2000 F, Mach 1, force air cool to 1200 F, 1 hr cycle (1 specimen tested)	0	0	0	0	0

TABLE 3.056 THERMAL FATIGUE TESTS - NUMBER OF BLADES CRACKED AFTER VARIOUS TEST TIMES.

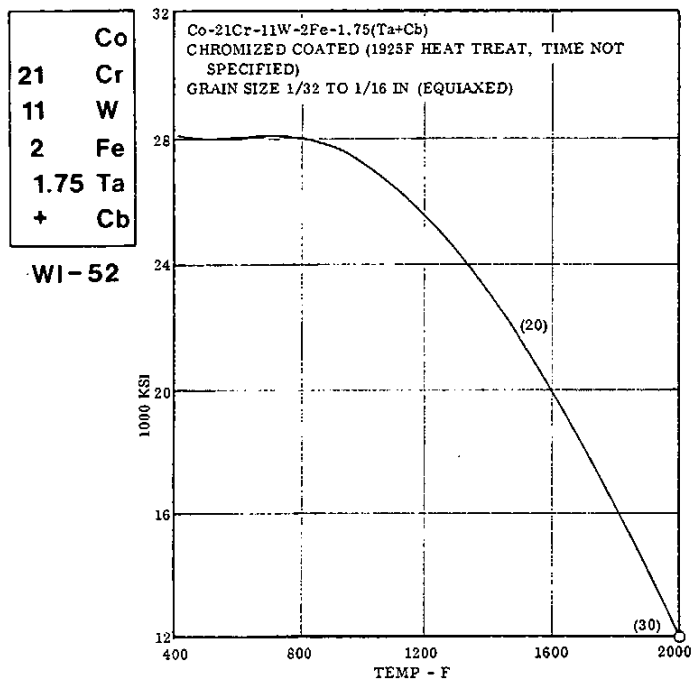


FIG. 3.062 STATIC MODULUS OF ELASTICITY. (20, p.4)(30)

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