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GENERAL DISCUSSION OF HANDBOOK CONTENTS

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2. PHYSICAL AND CHEMICAL PROPERTIES
3. MECHANICAL PROPERTIES
4. FABRICATION

CODE DESIGNATION REVISED

CARBON AND LOW ALLOY STEELS (FeC)

1103 Fe-(0.15C)-0.9Mn-0.8Ni-0.25Cr-0.25Mo-0.2Cu-0.25Si-0.25Al

ULTRA HIGH STRENGTH STEELS (FeUH)

1201 Fe-(0.30C)-0.95Cr-0.30Mo .......................................................... 4130 Dec 73
1203 Fe-(0.4C)-1Cr-0.4Mo .................................................................. 4140 Sep 74
1204 Fe-(0.5C)-1.8Ni-0.8Cr-0.2Mo .................................................. 6230 V Mod Mar 69
1205 Fe-(0.55C)-1.8Cr-0.3Mo-0.25 ............................. 4335 V Mod Mar 65
1206 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 4340 (4337) Dec 63
1207 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 52100 Jun 75
1208 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 8630 Sep 74
1209 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 12310 Mar 63
1210 Fe-(0.5C)-1.8Ni-0.3Cr-0.25Mo .................................................. 17-22X (17-22X) Mar 75
1211 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 2680A Dec 64
1212 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 6170A Jun 74
1213 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 6170A Jun 74
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1218 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 6170A Jun 74
1219 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 6170A Jun 74
1220 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 6170A Jun 74
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1224 Fe-(0.4C)-1.8Ni-0.3Cr-0.25Mo .................................................. 6170A Jun 74
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<td>Al-751-0.3Mg-0.8Fe</td>
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<td>Al-4.7Cu-0.8Mg-0.25Mn</td>
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### ALUMINUM ALLOYS; Wrought, Heat Treatable (AIWT)

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### MAGNESIUM ALLOYS; Cast (MgWT)

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### MAGNESIUM ALLOYS; Wrought, Heat Treatable (MgWT)

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### NICKEL BASE ALLOYS (<5%Co)(Ni)

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## APPENDICES

### ABBREVIATIONS

### GLOSSARY OF HEATING AND HEAT TREATING TERMS

### FRACTURE PROPERTIES

### SI CONVERSION FACTORS AND TABLES

### CROSS INDEX OF ALLOYS

- 1977, référence n°. Inc.
The attached Fourth Quarter of 1978 Revision Supplement XI may be incorporated into your Handbook as follows:

1. Observe the numerical sequence of the alloy code numbers and pages.

2. Replace the 1968 Chapter Code 4212 (Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V) with the December 1978 revision.

The addenda to the Table of Contents and Cross Index of Alloys on the reverse side of this sheet should be retained until the Fourth Quarter when they will be included in the revised sections.
FOURTH QUARTER INDEX ADDENDA
(Dec. 1978)

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NONFERROUS ALLOYS

1.01 Commercial Designation
IN-713

1.02 Alternate Designations
(YP) 713,713-D, Nicroalloy 100, ALAM 5397 IN-140, VoltaRail 16, N16 Alloy IN-160, All-vac IN-100, Vendor IN-100.

1.03 Specifications
ASM5397, Investment cast
G-E, original spec. 317GTTA.
G-E, spec. 198 mod. cast 198777C.

1.04 Compositions
Table 1.01

1.05 Heat Treatment
(see at 3.062)

1.06 Compositions
Commonly used in as-cast condition with no further heat treatment.

1.07 Heating, for 2 - 4 h at 1800 to 2000°F can re-solutionize the precipitated as-cast condition at lower temperatures, and also makes alloy more resistant to sigma phase precipitation upon subsequent exposure to long-time creep conditions at lower temperatures (121).

1.08 Coating applications may expose alloy to temperatures 1600 - 2200°F for periods up to 23 hrs (10). ISO recommends that if its coating is to be diffused at 1800-1950°F, the alloy should receive a preliminary high temperature solution treatment at 2100-2350°F, followed by aging at 1600-1650°F. This should provide the alloy with a capability of maintaining a consistently high level of mechanical properties.

For the powder metallurgy product, Pratt and Whitney Aircraft (105, 39, 74) recommends solutionizing at 2000°F, followed by the powder metallurgy precipitation hardening at 1200 and 1250°F. Typical heat treatment used Table 4.02 is 250 h, 1 hr 2000°F, 1 hr 1600°F, 3 hrs 1500°F, 16 hrs.

1.09 Hardness
AMS specimen if residues 0.30 - 0.35 or equivalent.

1.10 Effect of temperature on hardness, Fig. 1.062
1.101 Effect of heat treatment on hardness, Fig. 1.062

1.11 Forming and Welding
Investment Castings
Ceramalloy (Trade Mark), Pratt & Whitney Aircraft for creep formed powder product technologically processed at elevated temperatures, in its welded and other shapes.

1.12 Melting and Casting Practice
Vacuum melted and cast

1.13 Special Considerations
1.122 Because of the high chromium content, as well as the presence of vanadium, oxidation resistance is not adequate at high temperatures above the strength of the alloy assumes a special advantage. The problem is usually overcome by the use of aluminum or aluminum-base coatings. Many of these are proprietary, and the compositions as well as heat treatments are not revealed. Information provided by the coating producers show beneficial effects of coatings as protection against oxidation and sulfidation, and improvement of thermal shock resistance. These benefits are typically obtained without impairing the tensile and creep properties at high temperatures. (55995541)(5541) to 1.122.

1.123 The high chromium content of the alloy makes it particularly prone to the precipitation of carbide phases, such as sigma, upon prolonged exposure to high temperature, especially at stress is simultaneously applied. Special compositions, low in chromium content have been found advantageous for avoiding such embrittlement. The International Nickel Company, original developers of IN-100, have developed a modification designated as IN-721X, 15% and the General Electric Company has developed NIM-100 for this purpose, 1241. Both use P/M techniques to obtain the electronic structure of the remaining metal, after the major forming pretreatments have been done, as well as a means for the determination of whether sigma will form. Every heat requires a separate determination to determine the proportions of the large volume elements in the matrices of individual heats; however, in general, the revised composition limits with lower chromium content, must usually upset to a minimum of the other elements. The tendency toward sigma is somewhat sensitive to a heat treatment which is based in the presence of exposure to high temperatures for long times, especially at stresses. It is demonstrated that the presence of the effects of exposure to high temperatures, and simultaneous exposure...
NONFERROUS ALLOYS

REVISED: DECEMBER 1978

1. NiCo

15 NiCo 15 Co
10 10 Cr
5.1 Al
4.7 Ti
3 3 Mo
0.95 0.95 In
IN-100 V

1.093
The alloy in the powder metallurgy form has been extensively studied (Ref. 21) to reveal any beneficial effects of heat treatment. In contrast to the normally used cast structure, it also points to the possibility of removing creep damage by re-heat treatment for this alloy. The transition to a sigma phase precipitation has been extensively studied (Ref. 22 to 24), and effect on properties determined in detail.

1.034
High pressure hydrogen reduces tensile ductility, particularly at RT (see Table 2.0117).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01
Thermal Properties

2.011 Melting range 2025 - 2050°F (938 - 1065°C) at 1.85 to 1.90% Ti.

2.012 Phase changes. Structure consists of intergranular as well as eutectic or primary Ni(Cr, Ti). TiC, (N) and Ni3Al, possibly perovskite carbide within NiAl or TiN islands. On aging precipitation of perovskite-like phase (Ni3Al or TiC) occurs at 1400°F and continues at 1600°F while, after about 100 hr, an acicular sigma phase also begins to nucleate at grain and phase boundaries. The formation of sigma phase appears to be promoted by stress to 1400°F. In the absence of stress, solution of TiC(N) and Ni3Al or TiC and the resultant precipitation of Ni3AlC, are the main structural changes at 1400°F (11). The tendency toward the formation of sigma phase can be eliminated by "peeling" the vacuum electron number to 2.47.

2.0120 Effect of aging time and temperature on sigma phase precipitation, Fig. 2.0121.

2.0121 Effect of exposure for 5000 hours at various temperatures on sigma phase concentration, Fig. 2.0121.

2.0122 Transformation to sigma phase for as-cast and forged alloy for two levels of electron vacuum concentration, Fig. 2.0122.

2.0123 Time-temperature relation for the onset of sigma phase precipitation for medium and high electron vacuum concentration (700 µA/cm2), and in time and coarse grain size structure, Fig. 2.0123.

2.0124 Thermal conductivity, Fig. 2.0124.

2.0125 Coefficient of thermal expansion, Fig. 2.0125.

2.0126 Specific heat, Fig. 2.0126.

2.0127 Thermal diffusivity.

2.0128 Other Physical Properties

2.0129 Density 7.390 to 7.395 lbs容积 ft3, 7.75 gms per cc cm (4) (p. 2)

2.0130 Electrical Properties

3.043 Micro ohm - cm at RT (4, p. 2)

2.013 Magnetic Properties

2.0131 Electrical resistivity, Fig. 2.0131.

2.0132 Magnetic permeability.

2.0133 Chemical Properties

2.0134 Because of the lower chromium content of this alloy compared to other high temperature, high strength nickel base alloys, oxidation resistance is somewhat reduced. However, since it retains strength at high temperature, its interdendritic range is above that of many other nickel base alloys. Thus, when an oxidizing or sulfidizing environment is present in turbine applications, a protective coating is usually applied. Common coatings are the aluminum and aluminum base type. These can substantially improve the oxidation resistance, oxidation resistance and thermal shock characteristics. When only limited results are available at present, it appears that these coatings do not reduce the creep rupture strength, rupture elongation, or oxidation resistance for temperature in the 1400°F to 2500°F range.

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NONFERROUS ALLOYS

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See also 3.03.

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NiCo

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Ni 15 Co 10 Cr 5.5 Al 4.7 Ti 3 Mo 0.95 V

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3.0458 Effect of aluminum coating on rotating bending fatigue properties at room temperature, Table 3.0511.
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Effect of cycle time on thermal fatigue cracking of coated and uncoated airfoils simulating turbine blades subjected to Mach 1 gas flow followed by rapid air jet cooling, Fig. 3.0526.

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Effect of cycle time on thermal fatigue cracking of coated and uncoated airfoils simulating turbine blades subjected to Mach 1 gas flow followed by rapid air jet cooling, Fig. 3.0526.
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3.0566 Interaction of low cycle fatigue with dwell periods at max.
load for tests at 1200°F. R = 0.1, Fig. 3.0566.
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3.05143 Strainrange partitioning life relationship at 1522°F for
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powder metallurgy bars prepared by Pratt & Whitney
Gatling, a process and tested under rapid strain
cycling, tensile stress-hold, and tensile strain-hold.
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4.221 Room temperature tensile strength of brazed attachment
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4.231 Tensile properties at 1200°F for TLP bond between cast
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NiCo

NONFERROUS ALLOYS

REvised: December 1978

Ni 15 Co 10 Cr 5.5 Al 4.7 Ti 3 Mo 0.95 V

IN-100

Table 1.04 Composition

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FIG. 1.062 EFFECT OF TEMPERATURE ON HARDNESS
(A, p. 11)

FIG. 1.063 EFFECT OF TEST TEMPERATURE ON BRINELL HARDNESS, AS DETERMINED BY MUTUAL INDENTATION. FOR AIR MELTED AND CAST ALLOY AND FOR VACUUM MELTED AND CAST ALLOY
(12, FIGS. 1, 2)

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NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V
AS CAST + AGE AS INDICATED

AGING TIME AND TEMPERATURE

FIG. 3.0120 EFFECT OF AGING TIME AND TEMPERATURE ON MINOR PHASE CONCENTRATION (G, FIG. 1)

Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V
AS CAST, \( \bar{\eta} = 2.60 \) (V ELECTRON VACANCY DENSITY)
EXPOSED 5000 HR AT TEMP INDICATED

FIG. 2.0121 EFFECT OF EXPOSURE FOR 5000 HR AT VARIOUS TEMPERATURES ON MINOR PHASE CONCENTRATION (G1.15, 92.84)
NiCo

NONFERROUS ALLOYS

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Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V (NOMINAL)
ACTUAL COMPOSITION FOR 2 LEVELS OF Nv
MEd Nv (2.49): Ni-13.3Co-10.14Cr-5.5Al-4.29Ti-3.5Mo-0.96V
HIGH Nv (2.65): Ni-13.3Co-10.12Cr-5.5Al-4.29Ti-3.5Mo-0.95V

ALL ALLOYS MADE FROM SAME MASTER HEAT, ADDITIONS OF Al AND Ti MADE DURING CASTING TO ACHIEVE DESIRED LEVEL OF ELECTRON VACANCY CONCENTRATION (Nv)
TESTED AS CAST OR FORGED TO PANCAKE IN FOLLOWING STEPS:
1. EXTRUSION AT 2050°F FROM 5 IN DIAM INGOT TO 3 1/8 IN STEEL PIPE
2. FLATTENED AT 2050°F TO 1 3/4 IN DIAM PIPE
3. FLATTENED AT 2050°F TO 1 IN DIAM PANCAKE
4. FLATTENED AT 2050°F TO 5/8 IN DIAM PANCAKE

TEST SPECIMEN 1/4 IN DIAM x 1 1/4 IN GAGE LENGTH EXPOSED WITHOUT STRESS FOR TIMES AND TEMPS SHOWN

FIG. 2.0123 TIME-TEMPERATURE RELATION FOR THE ONSET OF SIGMA PHASE PRECIPITATION FOR MEDIUM AND HIGH ELECTRON VACANCY (Nv) COMPOSITIONS, AND IN FINE AND COARSE GRAIN SIZE STRUCTURES. (23, pp. 14, 19, 23)

FIG. 2.0122 TRANSFORMATION TO SIGMA PHASE FOR AS CAST AND FORGED ALLOY FOR TWO LEVELS OF ELECTRON VACANCY CONCENTRATION (22, pp. 14, 19, 23)

FIG. 2.013 THERMAL CONDUCTIVITY (21, p. 14)
FIG. 2.014 COEFFICIENT OF THERMAL EXPANSION

0.14
11
364
AS CAST
15
Cr
10
5.5
Al
4.7
Ti
3
Mo
0.95
V
IN-100

FIG. 2.015 SPECIFIC HEAT

0.15
0.14
13
74
MCF PER LB.-F

FIG. 2.016 SUMMARY OF MAJOR STAGES OF OXIDATION

NiCo

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NiCo

NONFERROUS ALLOYS

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Ni 15 Cr 10 Al 4.7 Ti 3 Mo 0.95 V
IN-100

FIG. 2.635 TYPICAL PLOT OF WEIGHT GAIN VS TIME IN STATIC OXIDATION

AS CAST

TESTED IN CYCLIC OXIDATION:
55 MIN IN OXYACETYLENE FLAME + 5 MIN COOL TO 750°F + REPEAT TEST EACH HOUR

CEMENTATION WITH NC-101, AN ALUMINUM BASE DIFFUSION COATING (SYLCO IRV, SYLVANIA ELECTRIC PRODUCTS, infrared, N.Y.)

Ni-16Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
AS CAST

TESTED IN HIGH VELOCITY STREAM OF NATURAL GAS COMBUSTION PRODUCTS

Ni 15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
AS CAST

FIG. 2.634 DYNAMIC OXIDATION TESTS AT 1800°F AND 1900°F INDICATING COMPLEXITY OF PROCESS. WEIGHT GAIN OCCURS AT 1500°F, LOSSES AT 2000°F

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NONFERROUS ALLOYS

NiCo

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Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

AS CAST

HIGH VELOCITY NATURAL GAS COMBUSTION PRODUCTS AT 1800°F

WEIGHT CHANGE - Mg per cm²

0.1 0.5 1 2 3 4 5 6 7 8 9 10

0 100 200 300 400

GUT BLOWED (55H=10 RMS)

FINE GROUND (5g = 2 RMS)

TIME - HR

FIG. 2.365 DYNAMIC OXIDATION AT 1800°F OF ALLOY IN TWO CONDITIONS OF SURFACE FINISH. NONFERROUS SURFACE PROMOTES MORE RAPID OXIDATION (14, p. 162)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

0.1 x 1 x 2 CASTINGS

Fe-25Cr-20Al- COATING APPLIED IN TWO STAGES:

(a) Fe-Cr Slurry Sprayed onto Surface, Cold Biostatically Pressed at 70 PSI Pressure and Sintered at 10-7 Torr, 200°F, 4 HR

(b) Surface Then Pack Aluminized in Flowing Argon (0.01 ft³ per min) at 200°F, In Pack of 38 Percent Al₂O₃ (-100 Mesh Powder), 1 Percent AI (-100 Mesh Powder) and 1 Percent NaCl Activator for 18 HR. In This Way 10 mg/cm² Was Deposited to Produce a FeAl + Fe-Cr-Al Coating of Average Composition Fe-25Cr-20Al, AVERAGE COATING THICKNESS 5 MILS TESTED IN STATIC FURNACE AT 200°F FOR 15 CYCLES OF 20 HR AIRFLOW THROUGH FURNACE, 0.01 ft³ per min, Inspected and Weighed After Each Cycle

Fe-25Cr-4AI-LY CLADDING FOR REFERENCE SEE ALSO FIG. 3.2831

TESTED AT 2000°F

Fe 25Cr-4Al-LY CLAD

FeAl-Fe-Cr-Al ALUMINIZED SLURRY COATING

FIG. 2.3671 CYCLIC FURNACE OXIDATION IN 20 HR CYCLES AT 2000°F OF FeAl-Fe-Cr-Al ALUMINIZED SLURRY OF AVERAGE COMPOSITION Fe-25Cr-4AI, AND COMPARISON WITH OXIDATION OF ALLOY PRODUCED BY CLADDING OF Fe-25Cr-4Al-LY (41, p. 3,4,18)

Ni

15 Co

10 Cr

5.5 Al

4.7 Ti

3 Mo

0.95 V

IN-100

FIG. 2.3672 CYCLIC FURNACE OXIDATION IN 20 HR CYCLES AT 2000°F OF NaAl Slurry Coated Alloy with Comparison to Oxidation of Commercial Conversion Coating (41, pp. 3,4,18)
NiCo

NONFERROUS ALLOYS

REVISED: DECEMBER 1978

Ni-15Co-18Cr-5.5Al-4.7Ti-3Mo-0.95V
SIMULATED AIRFOIL SPECIMEN, SEE FIG. 2.03111
COATED WITH NiAI SLURRY COATING APPLIED IN TWO STAGES:
a) Ni POWDER SPRAYED ONTO SURFACE, COLD
SINTERED AT 1000 F, 4 HR
b) SURFACE THEN PACK ALUMINIZED IN FLOWING ARCON (0.018 FT³ PER MIN) AT 2000F IN
PACK OF 98 PERCENT Al₂O₃ (-100 MESH POWDER), 1 PERCENT NaCl ACTIVATOR FOR 1 HR.
IN THIS MANNER 13 Mg PER CM² Al WAS DEPOSITED TO CONVERT Ni TO NiAl, AVERAGE
COATING THICKNESS 1.6 MILS + DIFFUSION ZONE OF 1.6 MILS
TESTED IN HIGH VELOCITY (MACH 1) JET AT 2000 F
IN CYCLES OF 1 HR AT 1500F + 3 MIN COOLING IN AIR JET. SEE FIG 2.03111 FOR DETAILS
COMMERCIAL COATING SHOWN FOR COMPARISON IS WIDELY USED PROPRIETARY ALUMINIDE CONVERSION COATING

1 HR CYCLES

WEIGHT CHANGE, %

0 100 200 300

EXPOSURE TIME, HR

FiguRe. 2.0373
Oxidation of NiAl Slurry Coating in MACH 1 Jet at 2000F with Comparison to Commercial Aluminide Coating (41, pp. 3, 4, 20)

Ni-15Co-18Cr-5.5Al-4.7Ti-3Mo-0.95V
AS CAST WEDGE SPECIMEN AS SHOWN IN FIG.
2.03113 BARE OR COATED BY ELECTROLYTIC FUSED SALT (EFS) PROCESS WHICH METALLIZES ALUMINUM DIRECTLY INTO SURFACE, PRODUCING AN ALUMINUM-RICH NiAl LAYER, ON COATED BY COMMERCIAL ALUMINIDE COATING.
TESTED IN MACH 1 JET AT 1500F USING CYCLE OF 1 HR FOLLOWED BY AIR COOLING TO RT IN 3 MINUTES
SEE FIG. 2.03114 FOR SKETCH OF SPECIMEN
NO TEST DETAILS

FiguRe. 2.0391
High Gas Velocity Oxidation and Thermal Fatigue Cracking at 1500F of Alloy Coated by Electrolytic Fused Salt Process, (metallic) and Comparison with Oxidation of Bare Alloy and Pack Aluminiun Coated Alloy

(41, pp. 2, 3, 29)
NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.05V
AS CAST WEDGE SPECIMEN AS SHOWN IN FIG. 2.03111 BARE, COATED BY COMMERCIAL ALUMINIDE COATING, OR COATED ELECTROLYTIC FUSED SALT PROCESS(EFSP) WHICH METALLIDIES ALUMINUM DIRECTLY INTO SURFACE PRODUCING AN ALUMINUM-RICH NICKEL LAYER

TESTED IN MACH 1 JET AT 2000°F USING CYCLE OF ONE HOUR FOLLOWED BY AIR COOLING TO RT IN 3 MINUTES

SEE FIG. 2.03111 FOR SKETCH OF SPECIMEN AND TEST DETAILS

**Fig. 2.0312** HIGH VELOCITY OXIDATION AND THERMAL FATIGUE CRACKING AT 2000°F OF ALLOY COATED BY AN ELECTROLYTIC FUSED SALT PROCESS(METALLIDED), AND COMPARISON WITH BARE ALLOY AND PACK ALUMINIZED ALLOY COATED ALLOY.(13, pp.2,3,21)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.05V
AS CAST WEDGE SPECIMEN AS SHOWN IN FIG. 2.03111 COATED WITH ELECTROLYTIC FUSED SALT PROCESS WHICH METALLIDIES ALUMINUM DIRECTLY INTO SURFACE PRODUCING AN ALUMINUM-RICH NICKEL LAYER

TESTED IN EITHER STATIC FURNACE OR IN HIGH VELOCITY JET AT MACH 1. SEE FIGURES 2.03111 AND 2.0312

SPECIMEN FOR STATIC TESTS 1 x 2 x 0.1 PLATES SPECIMEN FOR HIGH VELOCITY JET TESTS WEDGES AS SHOWN IN FIG. 2.03111

**Fig. 2.0314** COMPARISON OF STATIC OXIDATION WITH OXIDATION IN HIGH VELOCITY JET (MACH 1) AT 2100°F FOR METALLIDED COATING (13, pp.2,22)
NiCo

NONFERROUS ALLOYS

REVISED: DECEMBER 1978

Ni-15Co-10Cr-5.5A1-4.7Ti-3Mo-0.95V

COUPONS 2 x 1 x 0.1 IN

CLAD WITH FOILS OF Fe-25Cr-4Al-1Y OF THICKNESS .005 AND .01 IN USING FACE SHEETS AND EDGE STRIPS. PRESSURE BONDED 2 HR AT 2000 F, 15 KS PRESSURE.

TESTED IN FURNACE AT 1900 F AND 2000 F USING 1 HR OR 20 HR EXPOSURES. AFTER EACH EXPOSURE SPECIMENS WERE COOLED TO 212 F IN 10 MIN BEFORE REINSERTION INTO FURNACE.

TESTS ALSO CONDUCTED ON CLAD SPECIMENS OF CLADDING ALLOY.

ALL DATA 20 HR CYCLE EXCEPT AS NOTED.

FIG. 2.0391 EFFECT OF CLADDING THICKNESS ON CYCLIC OXIDATION OF Fe-25Cr-4Al-1Y CLAD ALLOY AT 1900 AND 2000 F (42, pp. 2,3,25)

Ni-15Co-10Cr-5.5A1-4.7Ti-3Mo-0.95V

COUPONS 2 x 1 x 0.1 IN

CLAD WITH FOILS OF Ni-20Cr-4Al-1.25Y OF THICKNESS .002, .005, AND .01 INCH USING FACE SHEETS AND EDGE STRIPS. PRESSURE BONDED 2 HR AT 2000 F, 15 KS PRESSURE.

TESTED IN FURNACE AT 1900 F AND 2000 F USING 1 HR AND 20 HR EXPOSURE. AFTER EACH EXPOSURE SPECIMENS WERE COOLED TO 212 F IN 10 MIN BEFORE REINSERTION INTO FURNACE.

△ BARE 1 HR CYCLE
○ .01 CLAD 1 HR
□ .005 1 HR
■ .002 1 HR
□ .01 CLAD 20 HR
□ .005 20 HR
■ .002 CLAD 20 HR

FIG. 2.0392 EFFECT OF CLADDING THICKNESS ON CYCLIC OXIDATION OF Ni-20Cr-4Al-1.25Y CLAD ALLOY AT 1900 F AND 2000 F (42, pp. 2, 3, 25)

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NiCo

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NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

COUPONS 2x3x0.1 in.

CLAD WITH FOILS OF Ni-30Cr-1.4Si OF THICKNESS .002, .005 AND .01 IN USING FACE SHEETS AND EDGE STRIPS PRESSURE BONDED 2 HR AT 2000°F, 1500 psi.

TESTED IN FURNACE AT 1900 AND 2000°F USING 20 HR EXPOSURES. AFTER EACH EXPOSURE SPECIMENS WERE COOLED TO 212°F IN 10 MIN BEFORE REINSERTION INTO FURNACE.

TESTS ALSO CONDUCTED ON CLAD SPECIMENS OF CLADDING ALLOY.

FIG. 2.032 EFFECT OF CLADDING THICKNESS ON CYCLIC OXYDATION OF Ni-30Cr-1.4Si AT 1900 AND 2000°F.

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NiCo

NONFERROUS ALLOYS

NiCo

15 Co
10 Cr
5.5 Al
4.7 Ti
3 Mo
0.95 V

IN-100

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

AS CAST ALLOY MACHINED TO WEDGE BAR AS SHOWN IN FIG. 2.03111

COATED WITH CoCrAlY BY ELECTRON-BEAM-HEAT-SOURCE, PHYSICAL-

VAPOR DEPOSITION PROCESS, NOMINAL COMPOSITION OF COATING:
Co-22Cr-14Al-0.1Y

TESTED IN MACH 1 JET AT 2000 F IN HEATING CYCLES OF 1 HR,
FOLLOWED BY COOLING TO RT IN 3 MIN

<table>
<thead>
<tr>
<th>TYPE OF COATING</th>
<th>TOTAL THICKNESS OF COATING IN</th>
<th>THICKNESS OF OUTER LAYER IN</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoCrAlY</td>
<td>.0040 .0045</td>
<td>.004 .0048</td>
</tr>
<tr>
<td>COMMERCIAL PACK ALUMINIDE</td>
<td>.0031</td>
<td>.0017</td>
</tr>
<tr>
<td>NO PARTICLE EMBEDMENT</td>
<td>.0017</td>
<td>.0012</td>
</tr>
</tbody>
</table>

SEE FIG. 2.03111 FOR DESCRIPTION OF SPECIMEN

SPECIMEN EXPOSED TO CYCLE CONSISTING OF 1 HR IN MACH 1 JET AT
2000 F + 3 MIN COOLING TO RT

FIG. 2.03111 WEIGHT CHANGE AND THERMAL FATIGUE CRACKING TENDENCIES
OF ALLOY WITH VAPOR DEPOSITED CoCrAlY COATING AND
COMPARISON WITH PERFORMANCE OF ALLOY COATED BY
COMMERCIAL PACK ALUMINIDE PROCESS

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NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.7Ti-5Mo-0.95V

AS CAST ALLOY MACHINED TO WEDGE BAR, AS SHOWN

EAPA(EMBEDDED ALUMINA-PARTICLE ALUMINIDE) COATING
APPLIED BY DUAL CYCLE, MODIFIED-PACK-CEMENTATION,
ALUMINIZING PROCESS. APPROX 15 V/0 OF 2 MICROMETER
ALUMINA PARTICLES ENTRAPPED IN COATING
TESTED IN 2000F, MACH 1 JET, HEAT 1 HR, COOL 3 MIN

<table>
<thead>
<tr>
<th>TYPE OF COATING</th>
<th>THICKNESS OF COATING - IN</th>
<th>THICKNESS OF OUTER NIAL LAYER - IN</th>
</tr>
</thead>
<tbody>
<tr>
<td>◯ NO COATING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ EMBEDDED ALUMINA-PARTICLE ALUMINIDE</td>
<td>0.0005 TO 0.0015</td>
<td>0.0002 TO 0.0007</td>
</tr>
<tr>
<td>◯ FUSED SALT, ALUMINIZED</td>
<td>0.0025</td>
<td>0.0015</td>
</tr>
<tr>
<td>△ COMMERCIAL PACK ALUMINIDE,</td>
<td>0.0033</td>
<td>0.0017</td>
</tr>
<tr>
<td>◊ NO PARTICLE EMBEDMENT</td>
<td>0.0017</td>
<td>0.0012</td>
</tr>
</tbody>
</table>

FIG. 2.00111 WEIGHT CHANGE AND THERMAL FATIGUE CRACKING TENDENCIES OF ALLOY WITH EAPA(EMBEDDED ALUMINA-PARTICLE ALUMINIDE) SUBJECTED TO 1 HR CYCLES AT 2000F IN MACH 1 JET BURNER, AND COMPARISON WITH PERFORMANCE OF DARK ALLOY AND OTHER TYPES OF COATINGS (44, pp. 2,10,22)

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NONFERROUS ALLOYS

NiCo

Ni - 15 Co - 10Cr - 5.5Al - 4.7Ti - 3Mo - 0.95V

AS CAST ALLOY MACHINED TO WEDGE BAR AS SHOWN IN FIG. 2.03111
COATED WITH Pt-Al BY APPLYING A .0003 LAYER OF Pt BY ELECTROPLATING
AND ALUMINIZING BY PACK PROCESS.

FINAL COATING THICKNESS APPROX. .602 IN

CERMET (1): Ni-Cr-Si ALLOY CONTAINING TiB₂ AND TiN PARTICLES
CERMET (2): Ni-Co-ALLOY CONTAINING TiS₂ PARTICLES
CERMET (3): NiCo ALLOY CONTAINING Pt-Al PACK TREATMENT - (PACK: 2Al-2NaCl-Al₂O₃, 2000°F, 1.5 Hr)

FACEAV: PLASMA SPRAYED Fe-25Cr-13Al-0.8Y, FOLLOWED BY OVER-
SPRAY WITH Al POWDER ø (100) F, 6 HR IN ARGON, THICKNESS
(.018) IN

Ni-CrAl (1): PROPRIETARY ALLOY CONTAINING NO ADDED OXIDES
Ni-CrAl (2): PROPRIETARY ALLOY CONTAINING Y₂O₃ PARTICLES

CERMET (3): CERMET (1) + ALUMINIZING PACK TREATMENT

ALLOY WITH Pt-Al COATING

FIG. 2.03111 TYPICAL WEIGHT CHANGE PATTERN FOR COATED ALLOY CYCLED FOR
ONE HR INTERVALS AT 2000°F, FOLLOWED BY COOLING TO RT IN 3 MIN
AND FACING SHOWS DATA FOR Pt-Al ALLOY WITH SUMMARY OF RESULTS
FOR SEVERAL OTHER ALLOYS

(45, 46, 2.13, 14)
NiCo

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NONFERROUS ALLOYS

TABLE 2.0333 EFFECT OF CORROSIVE ENVIRONMENT ON WEIGHT CHANGE IN DARE AND COATED CONDITION

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Cr-10Co-5.5Al-4.7Ti-2Mo-0.05V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Haynes (110 p. 5)</td>
</tr>
<tr>
<td>Condition</td>
<td>As Cast, Corrosion Tested (a)</td>
</tr>
<tr>
<td>Wt. Change (a) 2 Mg per cm. (Loss)</td>
<td></td>
</tr>
<tr>
<td>Bare</td>
<td>71.3</td>
</tr>
<tr>
<td>Coating C - 3</td>
<td>9.5</td>
</tr>
<tr>
<td>Coating C - 9</td>
<td>9.4</td>
</tr>
<tr>
<td>(a) Exposed 1 hr in Na2SO4 + 0.5 percent. NaCl at 100°F.</td>
<td></td>
</tr>
</tbody>
</table>

FIG. 2.0333 RELATIVE COMPOSITION OF VARIOUS SUPER-ALLOYS FOR TWO FUELS OF DIFFERENT SULPHUR CONTENT AND TWO SALT AIR RATE (b) CONDITIONS (27, p. 133)

FIG. 2.0334 CORRELATION SHOWING THAT LOW CORROSION RESISTANCE OF ALLOY IS RELATED TO ITS LOW CHROMIUM CONTENT (27, p. 33)

Ni-15Cr-10Co-5.5Al-4.7Ti-2Mo-0.05V

SINGULATED AIRFLO SECTION 1 IN CHORD, 2 IN SPAN, APPROX 1/8 IN THICKNESS AT LEADING EDGE

AS CAST

TESTED IN HIGH VELOCITY GAS 760 FPS

SEE FIG. 2.0335 FOR ADDITIONAL DETAILS OF TEST AND MEASUREMENT PROCEDURES

Ni-15Cr-10Co-5.5Al-4.7Ti-2Mo-0.05V

SINGULATED AIRFLO SECTION 1 IN CHORD, 2 IN SPAN, APPROX 1/8 IN THICKNESS AT LEADING EDGE

AS CAST

TESTED IN HIGH VELOCITY GAS 760 FPS

SEE FIG. 2.0335 FOR ADDITIONAL DETAILS OF TEST AND MEASUREMENT PROCEDURES
NiCo

NONFERROUS ALLOYS

REVISED: DECEMBER 1976

Ni-15Co-10Cr-5.5Al-4, 731Ti-3Mo-0.95 V
SIMULATED AIRFOIL SECTION, 1 IN CHORD, 2 IN SPAN, APPROXIMATELY 1/8 IN THICK AT LEADING EDGE
TESTED IN HIGH VELOCITY GAS JET (700 FPS) USING LOW SULPHUR FUEL (JP-11 with .025) SYNTHETIC SEA WATER ADDITION TO CONDUCION GAS PRODUCED 4 & 8 PPM SOLID SEA SALT AT INLET TEMPERATURES, MEASURED BY .030 IN DIAMETER PLUGS IN CONTROL TECHNIQUE
SPEC. CHECKED BY THERMOCOUPLES.
CYCLE: 1 MIN TO MAX TEMP * 10 MIN AT TEMP + 1 MIN AIR COOLING TO REACH 1000°F OR BELOW, TOTAL TEST TIME 120 HOURS
DEPTH OF ATTACK MEASUREMENTS MADE BY METALLOGRAPHIC AND OPTICAL OBSERVATIONS ON SECTIONS 1/4, 1, AND 1 1/2 IN FROM TIP OF AIRFOIL
○ ○ PEAK METAL TEMP 1600°F
△ △ PEAK METAL TEMP 1750°F
TWO TESTS AT EACH TEMP

Fig. 2.03134 CORROSION (AS MEASURED BY DEPTH OF ATTACK) FOR ALLOY IN 700 FPS VELOCITY GAS JET USING LOW SULPHUR FUEL (JP-11) WITH 4 PPM AND 8 PPM SEA SALT IN INLET AIR
(27, pp. 1-6, 76, 88)

Source: (466) pp. 2, 3, 7, 16, 18
Alloy Ni-15Co-10Cr-5.5Al-4, 731Ti-3Mo-0.95 V
Condition
Cooling Al-Cr-Mn: 1500°F, 1.5 hr + 2 hr soak from peak +
1600°F, 50 hr.
Cooling AEP No. 34: 11°F application + 2000°F, 2 hr + 1600°F, 50 hr.
Specimen Standard T65-A-9 solid turbine blades
Test Heat blades rotating at 1800 rpm in citric acid solution heating solution to 750°F, spray with artificial solution of deionized water and 1.4 percent water soluble sodium sulfate
Condition 1.5 min heat + 0.5 min spray, observe every 100 cycles
Remove when total corrosion area of .64 IN²
(0.1 IN² on each side)
Av. Nos. cycles to hot corrosion failure (6 specimens)
Coated with Al-Cr-Mn: 713
Coated with AEP No. 34: 561

Table 2.03134 Hot Corrosion Resistance of Thin Wall Alloy with Two Proprietary Coatings in 1800°F Cycle Temperature Test

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NONFERROUS ALLOYS

NiCo

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NONFERROUS ALLOYS

Ni

Co

15

10

Cr

5.5

Al

4.7

Ti

3

Mo

0.95

V

IN-100

SURFACE SCALE REMOVED AFTER TEST. SCALE WEIGHTS CALCULATED FROM WEIGHT MEASUREMENTS BEFORE AND AFTER SCALE REMOVAL.

FIG. 2.0138 COMPARISON OF HOT-CORROSION BEHAVIOR IN A MARINE TURBINE SIMULATOR WITH OTHER NICKEL- AND COBALT-BASE ALLOYS (29, pp. 1-17)

TABLE 3.022 ROOM TEMPERATURE TENSILE PROPERTIES OF AN CAST ALLOY IN THREE LEVELS OF ELECTRON VACANCY CONCENTRATION, AND AT TWO LEVELS OF GRAIN SIZE

NOMINAL: Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

1/4 DIA VINS, 1 1/8 IN LONG

AS CAST

TESTED IN A TURBINE SIMULATOR TYPICAL OF MARINE SERVICE USING COMPLEX TEMPERATURE AND VELOCITY PATTERN (SEE REF 29)

TEMPERATURES INCLUDE PERIODS AT 1600, 1609, 1400 AND 2000 F

VELOCITIES RANGE FROM 100 TO 760 FT PER SEC. SULFUR IN FUEL APPROX 400 PPM

AS CAST. VARIOUS COMPOSITIONS

and Grain Sizes Shown

Level of electron vacancy concentration, %, and grain size

Low %, Fine Grain Size

Medium %, Fine Grain Size

High %, Fine Grain Size

Low %, Coarse Grain Size

Medium %, Coarse Grain Size

High %, Coarse Grain Size

Min required by AMS 5677

641.2

112.5

142.2

142.2

128.7

128.7

114.0

140.9

112.5

142.2

142.2

142.2

114.0

12

9.0

9.0

9.0

9.0

5.9

11

9.0

9.0

9.0

9.0

5.9

(1) These alloys with minor variations in composition, achieved by additions of Al & Ti to same master heat. Several levels of electron vacancy concentration, %, designating tendency to form sigma precipitate, as defined in figures.

(2) All values shown average of two tests except as designated.

(3) One test only.

TABLE 3.022 ROOM TEMPERATURE TENSILE PROPERTIES OF AN CAST ALLOY IN THREE LEVELS OF ELECTRON VACANCY CONCENTRATION, AND AT TWO LEVELS OF GRAIN SIZE

(1) These alloys with minor variations in composition, achieved by additions of Al & Ti to same master heat. Several levels of electron vacancy concentration, %, designating tendency to form sigma precipitate, as defined in figures.

(2) All values shown average of two tests except as designated.

(3) One test only.

FIG. 2.0138 COMPARISON OF HOT-CORROSION BEHAVIOR IN A MARINE TURBINE SIMULATOR WITH OTHER NICKEL- AND COBALT-BASE ALLOYS (29, pp. 1-17)
NiCo

NONFERROUS ALLOYS

REVISED: DECEMBER 1978

NiCo

<table>
<thead>
<tr>
<th>Ni</th>
<th>Co</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mo</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>15</td>
<td>10</td>
<td>5.5</td>
<td>4.7</td>
<td>3</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IN-100</td>
</tr>
</tbody>
</table>

TABLE 3.022 MECHANICAL PROPERTIES AT ROOM TEMPERATURE OF FORGED ALLOY IN THREE CONDITIONS OF PROPRNESS TO SIGMA PHASE PRECIPITATION.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V (nominal), 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>(24) pp. 3, 4, 6, 8</td>
</tr>
<tr>
<td>Condition</td>
<td>Forged(1) and Heat Treated(2)(3) as Indicated</td>
</tr>
<tr>
<td>Ti + Al Content (3)</td>
<td>Heat Treated</td>
</tr>
<tr>
<td>Low</td>
<td>Med</td>
</tr>
<tr>
<td>$V_{in}$ (ksi)</td>
<td>185.5</td>
</tr>
<tr>
<td>$V_{so}$ (ksi)</td>
<td>139.5</td>
</tr>
<tr>
<td>$e$ (1.2% Ni) - percent</td>
<td>10</td>
</tr>
<tr>
<td>HA - percent</td>
<td>15</td>
</tr>
</tbody>
</table>

(1) $5$ in dia casting extruded to 3.15dia @ 2050F. Flattened at 2050F to $3/4$ in thick pancake, then to $1$ in thick pancake, then to $3/8$ in thick pancake. Machined to $1/4$ in dia specimens x $1/2$ in gage length specimen.

(2) $2215F, 4$ hrs + $2000F, 4$ hrs + $1500F, 16$ hrs + $1400F, 24$ hrs.

(3) All three alloys from same master heat. Additions of Ti & Al to form alloys of varying degree of proneness to sigma phase precipitation, by controlling average electron vacancy concentration, $N_v$.

Low $N_v = 2.2$: Ni-13.73Co-10.26Cr-4.95Al-4.04Ti-3.19Mo-0.94V Median $N_v = 2.4$: Ni-13.41Co-10.15Cr-5.30Al-4.09Ti-3.5Mo-0.91V High $N_v = 2.59$: Ni-13.42Co-10.13Cr-5.46Al-4.13Ti-3.58Mo-0.91V

TABLE 3.023 EFFECT OF THERMAL EXPOSURE SUBSEQUENT TO HEAT TREATMENT ON ROOM TEMPERATURE TENSILE PROPERTIES FOR FORGED ALLOY WITH THREE LEVELS OF Al + Ti CONTENT (ELECTRON VACANCY CONCENTRATION, $N_v$, RELATING TO PROPRNESS TOWARD SIGMA FORMATION).
**NONFERROUS ALLOYS**

**NiCo**

**Source:** (28) pp 24-27

**Alloy:** Ni5.0r0.010Cr-0.4Al-4.76Ti-3.5Mo-0.95V (Nominal, see actual below)

**Composition:**
- As Cast: Ni15.4Cr10.5Al1.75Ti1.35Mo0.95V
- FM Powder: Ni15.4Cr10.5Al1.75Ti1.35Mo0.95V
- HM Powder: Ni15.4Cr10.5Al1.75Ti1.35Mo0.95V
- NM Powder: Ni15.4Cr10.5Al1.75Ti1.35Mo0.95V

**Powder Size:**
- HM Powder: 250 to 44 microns
- NM Powder: 200 to 44 microns

**Powder Consolidation:**
- HIP HM Powder: Prepared at 2320°F, 25,000 psi for 1 hr to achieve 1 x 1.5 x 20 in
- HIP HM Powder: Extruded to 3/4 in dia. rod, Prepared at 2320°F, 15,000 psi 1 hr.

**Specimen Size:**
- 3/8 in dia. by 2 ft

**Hardness:**
- Rockwell C: 48

**Table 3.025 ROOM TEMPERATURE TENSILE PROPERTIES AND HARDNESS OF POWDER METAL ALLOY IN BAR-PRESERVED FROM POWDERS OF VARIOUS COMPOSITIONS AND GRAIN SIZE AND CONSOLIDATED BY SEVERAL PROCESSES**

**Ni** 15
**Co** 10
**Cr** 5.5
**Al** 4.7
**Ti** 3
**Mo** 0.95
**V**

**IN-100**
Table 3.22. Tensile properties of superplastically formed pancake forging used in fatigue crack growth studies.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Co-15Cr-5.5Al-4.7Ti-3Mo-0.05V</th>
<th>Source: ASTM grain size 12-14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Solutionized at 2050°F, stabilized at 1600°F and 1800°F + precipitation hardened at 1200°F and 1400°F</td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>Superplastically forged</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASTM grain size 12-14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tested Solutionized at 2050°F, Stabilized at 1600°F and 1800°F +</td>
<td></td>
</tr>
<tr>
<td></td>
<td>precipitation hardened at 1200°F and 1400°F</td>
<td></td>
</tr>
</tbody>
</table>

Typical composition: Ni-16.5Co-12.4Cr-4.9Al-4.32Ti-3.2Mo-0.75V-0.6Zr-0.28 for time indicated.

(2) By patented Gatorizing process.

FIG. 3.027. Comparison of tensile properties of alloy with Ni-20Cr-4Al-1.2Si cladding alloy before and after oxidation.

FIG. 3.029. Unnotched Charpy impact strength at room temperature after 500 or 1000-hr at elevated temperature.

FIG. 3.031. Stress-strain curves for as-cast alloy at room and elevated temperatures.
Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN DIA BAR SPECIMEN x 2 IN GAGE LENGTH
COATED BY TRW WITH PWA A47 COATING PLUS
1975F, 4 HRS IN VAC, 4 RAPID ARGON QUENCH

Fig. 3.0312 Stress-strain curves for 40 coated alloy
AT ROOM AND ELEVATED TEMPERATURES
(16, pp. 7, 10, 123)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN DIA BAR SPECIMEN x 2 IN GAGE LENGTH
AS CAST

Fig. 3.03121 Effect of test temperature on
Mechanical properties as cited
by alloy developer (4, p.5)
NiCo

NONFERROUS ALLOYS

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NiCo

Ni 15 Co 10 Cr 5.5 Al 4.7 Ti 3 Mo 0.95 V

IN-100

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN DIA BAR SPECIMEN X 2 IN GAGE LENGTH
JOCOATED BY THR WITH PWA 470 COATING PLUS
1975 F, 4 HRS IN VAC + RAPID AROON QUENCH

Source (16 pp. 2, 3, 7, 66, 69)

Alloy Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

Condition As Cast + Coated with Two Proprietary Coatings:

Al-Co-Mn or Al5V No. 27

See Fig. 3.0315 for Coating Conditions

TABLE 3.0341 TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURES OF THINWALL ALLOY COATED WITH TWO PROPRIETARY COATINGS

<table>
<thead>
<tr>
<th>Specimen Type</th>
<th>Simulated Airlow</th>
<th>See Fig. 3.0345</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/E No. 32 Coating</td>
<td>A/C-Mn Coating</td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>1600°F</td>
<td>1800°F</td>
</tr>
<tr>
<td>Fp (ksi)</td>
<td>114</td>
<td>126.8</td>
</tr>
<tr>
<td>Fy (ksi)</td>
<td>105.9</td>
<td>101.9</td>
</tr>
<tr>
<td>Yield percent</td>
<td>3.7</td>
<td>3.7</td>
</tr>
</tbody>
</table>

(1) Average of two tests

TABLE 3.0331 EFFECT OF SEVERAL SOLUTION HEAT TREATMENTS ON THE TENSILE PROPERTIES AT 1300°F

<table>
<thead>
<tr>
<th>Condition</th>
<th>As Cast</th>
<th>2150°F 2 hr</th>
<th>2050°F 24 hr</th>
<th>1900°F 24 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fp (ksi)</td>
<td>156</td>
<td>138</td>
<td>129.3</td>
<td>126.7</td>
</tr>
<tr>
<td>Fy (ksi)</td>
<td>121.5</td>
<td>119</td>
<td>114.7</td>
<td>115.3</td>
</tr>
<tr>
<td>RA percent</td>
<td>8.8</td>
<td>6.0</td>
<td>4.5</td>
<td>3.7</td>
</tr>
<tr>
<td>RA percent</td>
<td>14.3</td>
<td>7.0</td>
<td>8.1</td>
<td>5.8</td>
</tr>
</tbody>
</table>

(1) All values average of 3 tests.

FIG. 3.03123 TENSILE PROPERTIES OF JOCOATED BAR AT ROOM AND ELEVATED TEMPERATURES (16 pp. 13, 121, 122)

FIG. 3.03142 EFFECT OF COATING, HIGH TEMPERATURE EXPOSURE, AND SEVERAL REPAIR PROCESSES ON TENSILE AND YIELD STRENGTH AT 1600°F COMPARED TO AS CAST UNCOATED BASE MATERIAL (16 pp. 13, 115, 116)

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Ni 15Co 10Cr 5.5Al 4.7Ti 3Mo 0.95V

PARTIAL STRIP BY LOCALIZED GRIND BLAST

COMPLETE STRIP BY IMMERSION IN SOLUTION OF 30V/0 HNO₃ + 1V/0 TURCO 4104
FOR 1 HOUR, RECOATING WITH VACUUM-FIRED ALLOY SLIP PACK OF 56 Cr-44 Al

OXIDIZED 150 HRS, 1700F
TINTED AT 1800F
ELONGATION OF UNCOATED ALLOY AT 1800F - 5.5 PERCENT

PERCENT OF ENCOATED ELONGATION

FIG. 3.03143 EFFECT OF COATING, HIGH TEMPERATURE EXPOSURE, AND SEVERAL REPAIR PROCESSES ON ELONGATION AT 1800F COMPARED TO AS CAST UNCOATED BASE MATERIAL (25, pp. 36, 113, 118)

Source

(20) vs. Mean

Alloy
Ni 15Co 10Cr 5.5Al 4.7Ti 3Mo 0.95V

Condition
Powder Metallurgy Product, deformed and heat treated as shown

<table>
<thead>
<tr>
<th>RT</th>
<th>Extruded 10.6 to 1 at 2000°F</th>
<th>Rolled 3 to 1 at 2000°F + 2150°F, 4 hr, oil quench + 1500°F, 22 hr, air cool + 2275°F, 56 hr, air cool</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL (ksi)</td>
<td>310</td>
<td>234.6</td>
</tr>
<tr>
<td>FY (ksi)</td>
<td>290.8</td>
<td>177.8</td>
</tr>
<tr>
<td>NA percent</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>RA percent</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>1200°F</td>
<td>Extruded 10.6 to 1 at 2000°F + 2150°F, 4 hr, oil quench + 1500°F, 22 hr, air cool + 1400°F, 8 hr air cool</td>
<td></td>
</tr>
<tr>
<td>FL (ksi)</td>
<td>237.4</td>
<td>204.8</td>
</tr>
<tr>
<td>FY (ksi)</td>
<td>241.8</td>
<td>186.6</td>
</tr>
<tr>
<td>NA percent</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>RA percent</td>
<td>16</td>
<td>12</td>
</tr>
</tbody>
</table>

TABLE 3.03151 EFFECT OF REDUCTION PRACTICE AND HEAT TREATMENT ON THE TENSILE PROPERTIES AT RT AND 1200°F OF POWDER METALLURGY ALLOY

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NiCo

NONFERROUS ALLOYS
REVISED: DECEMBER 1978

Ni 15 Co
10 Cr
5.5 Al
4.7 Ti
3 Mo
0.95 V
IN-100

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
1/2 IN DIA BAR
AS EXTRUDED
SEE TABLE 7, p.25 FOR DETAILS OF POWDER
COMPOSITION, CONSOLIDATION
PARAMETERS, AND R.T. PROPERTIES OF
ALLOY

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
3/4 LTA BARSTOCK
PREPARED BY "ALL INERT" P&W PROCESS
HEAT TREATED BY MODIFICATION TO PWA 1028
SPECIFICATIONS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
0.5 IN DIA BAR
AS FORGED
SEE TABLE 7, p.25 FOR DETAILS OF POWDER
COMPOSITION, CONSOLIDATION
PARAMETERS, AND R.T. PROPERTIES OF
ALLOY

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
1/2 IN DIA BAR
AS EXTRUDED
SEE TABLE 7, p.25 FOR DETAILS OF POWDER
COMPOSITION, CONSOLIDATION
PARAMETERS, AND R.T. PROPERTIES OF
ALLOY

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
3/4 LTA BARSTOCK
PREPARED BY "ALL INERT" P&W PROCESS
HEAT TREATED BY MODIFICATION TO PWA 1028
SPECIFICATIONS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
0.5 IN DIA BAR
AS FORGED
SEE TABLE 7, p.25 FOR DETAILS OF POWDER
COMPOSITION, CONSOLIDATION
PARAMETERS, AND R.T. PROPERTIES OF
ALLOY

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
3/4 LTA BARSTOCK
PREPARED BY "ALL INERT" P&W PROCESS
HEAT TREATED BY MODIFICATION TO PWA 1028
SPECIFICATIONS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
0.5 IN DIA BAR
AS FORGED
SEE TABLE 7, p.25 FOR DETAILS OF POWDER
COMPOSITION, CONSOLIDATION
PARAMETERS, AND R.T. PROPERTIES OF
ALLOY

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
3/4 LTA BARSTOCK
PREPARED BY "ALL INERT" P&W PROCESS
HEAT TREATED BY MODIFICATION TO PWA 1028
SPECIFICATIONS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
0.5 IN DIA BAR
AS FORGED
SEE TABLE 7, p.25 FOR DETAILS OF POWDER
COMPOSITION, CONSOLIDATION
PARAMETERS, AND R.T. PROPERTIES OF
ALLOY

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
(Nominal)
3/4 LTA BARSTOCK
PREPARED BY "ALL INERT" P&W PROCESS
HEAT TREATED BY MODIFICATION TO PWA 1028
SPECIFICATIONS

FIG. 3.03152 FLOW CHARACTERISTICS IN THE RANGE
AT LOW STRAIN RATES AND TEMPERATURES WHERE
SUPERPLASTICITY CAN BE ACHIEVED
(28 p.2-24)

FIG. 3.03154 RELATION BETWEEN STRESS AND HIGH
DEFORMATION RATE AT 1900 TO 2100°F
FOR ALLOY EXTRUDED DIRECTLY FROM
POWDERS
(28, p.2-22)
NONFERROUS ALLOYS

NiCo

REVISED: DECEMBER 1978

TABLE 3.6517 TENSILE PROPERTIES AT RT AND 1200°F IN 5000 PSI HELIUM AND HYDROGEN

<table>
<thead>
<tr>
<th>Source</th>
<th>Cu VIB - 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy</td>
<td>Ni-15Co-10Cr-5, 5Al-4, 77Ti-3Mo-0.25V</td>
</tr>
<tr>
<td>Test Condition</td>
<td>As Cast - 1200°F, 4 hrs, AC</td>
</tr>
<tr>
<td>Cond.</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>1200°F</td>
<td>5000 psi</td>
</tr>
<tr>
<td>3.6135</td>
<td>Ni</td>
</tr>
<tr>
<td>118.5</td>
<td>161</td>
</tr>
<tr>
<td>107.5</td>
<td>87.3</td>
</tr>
</tbody>
</table>
| Fig. 3.6521 EFFECT OF TEST TEMPERATURE ON COMPRESSION YIELD STRENGTH FOR AIR MELTED AND CAST ALLOY AND FOR VACUUM MELTED AND CAST ALLOY (33, P1G 4-1.5)
NiCo

NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
AS CAST
CHARPY V SPECIMEN

Ni-Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN DIA BAR SPECIMEN x 2 IN GAGE LENGTH
JO COATED BY TRW WITH PWA A47 COATING
PLUS 1978, 4 HRS IN VAC + RAPID ARGON QUENCH
TESTED AT 1562°F

FIG. 3.031 EFFECT OF TEMPERATURE ON CHARPY V IMPACT ENERGY (4, p.12)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN DIA BAR SPECIMEN x 2 IN GAGE LENGTH
AS CAST
TESTED AT 1562°F

FIG. 3.0411 CREEP CURVES OF AS CAST ALLOY AT 1562°F
(16, pp. 13,112,114,117)

FIG. 3.0412 CREEP CURVES FOR JO COATED ALLOY AT 1562°F.
(16, pp. 13,112,114,117)

FIG. 3.0413 CREEP CURVES OF AS CAST ALLOY AT 1697°F
(16, pp. 13,112,114,117)

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NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN DIA BAR SPECIMEN x 2 IN GAGE LENGTH, JOCOATED BY TRW WITH PWA A47 COATING PLUS 1975F, 4 HRS IN VAC + RAPID ARGON QUENCH TESTED AT 1697 F

FIG. 3.0414 CREEP CURVES FOR JO COATED ALLOY AT 1697 F
(16 pp. 13, 111, 114, 119)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN DIA BAR SPECIMEN x 2 IN GAGE LENGTH AS CAST TESTED AT 1832 F

FIG. 3.0415 CREEP CURVES OF AS CAST ALLOY AT 1832 F
(16 pp. 13, 111, 114, 119)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN DIA BAR SPECIMEN x 2 IN GAGE LENGTH JO COATED BY TRW WITH PWA A47 COATING PLUS 1975F, 4 HRS IN VAC + RAPID ARGON QUENCH TESTED AT 1832 F

FIG. 3.0416 CREEP CURVES FOR JO COATED ALLOY AT 1832 F
(16 pp. 13, 111, 114, 119)

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NiCo

NONFERROUS ALLOYS

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Ni
15
Co
10
Cr
5.5
Al
4.7
Ti
3
Mo
0.95
V
IN-100

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

0.5 PERCENT CREEP
1 PERCENT CREEP
0.2 PERCENT CREEP
0.1 PERCENT CREEP

HEAT RESISTANCE

AS CAST

80
70
60
50
40
30
20
10
0

1000
2000
3000
4000
TIME - HR

FIG. 3.0417 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1500°F

FIG. 3.0418 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1500°F

(4)
NiCo

NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
AS CAST

FIG. 3.0419 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1700°F

FIG. 3.0419 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1100°F
NiCo

NONFERROUS ALLOYS

REVISED: DECEMBER 1978

NiCo

Ni 15 Co 10 Cr 5.5 Al 4.7 Ti 3 Mo 0.95 V
IN-100

FIG. 3.0411 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1000°F

(4)

FIG. 3.0412 MINIMUM CREEP RATE CURVES FOR TEMPERATURES FROM 1350 TO 1900°F

(5)
### NiCo

**Nonferrous Alloys**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Co-15Cr-5.5Al-4.7Ti-3Mo-0.95V (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>(16, 114)</td>
</tr>
<tr>
<td>Condition</td>
<td>Superplastically Forged (b)</td>
</tr>
<tr>
<td>Heat Treatment</td>
<td>Solutionized at 2600°F, Stabilized at 1600°F and 1680°F, * + Precipitation Hardened at 1200°F and 1400°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time to 0.1% Creep</th>
<th>130°F</th>
<th>1350°F</th>
<th>130°F</th>
<th>1350°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>250°F</td>
<td>145°F</td>
<td>145°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>350°F</td>
<td>150°F</td>
<td>150°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>450°F</td>
<td>155°F</td>
<td>155°F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Time to 0.2% Creep, hr
- Time to Rupture, hr
- Percent Creep, Percent
- Hardened at 1200°F

**TABLE 3.0421 Creep and Creep Rupture Properties of Superplastically Formed Pancake Forging Used in Fatigue Crack Growth Studies**

**FIG. 3.0431 Relation Among Start of Third Stage Creep, Time to 1 Percent Creep, and Rupture Time for As Cast Alloy**

(a) Typical composition: Ni-18.5Co-15Cr-4.5Al-4.5Ti-3.5Mo-0.78V-0.78C-0.92Zr-0.07B

(b) By patented GATORIZING Process

---

**Note:**

- Time to 0.1% Creep
- Time to 0.2% Creep
- Time to Rupture
- Percent Creep
- Hardened at 1200°F

---

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NiCo

NONFERROUS ALLOYS

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| Ni  | 15 |
| Co  | 10 |
| Cr  | 5.5 |
| Al  | 4.7 |
| Ti  | 3  |
| Mo | 0.95 |

IN-100

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

2 x 1/4 x 1,000 IN SHEET

AS CAST + CODEP C-2 COATING (APPROX 2 MIL)
PARTIAL STRIP BY LOCALIZED Grit BLAST
COMPLETE STRIP BY IMMERGION IN SOLUTION
OF 80% HNO3 + 10% H2SO4 FOR 1 HR

REPAIRED BY RECOATING WITH VACUUM
FIRST SLURRY SLIP PACK OF 56 Cr-44 Al

OXIDIZED 150 HRS, 1750°F
TESTED AT 1900°F, 20 KSI

σ flowing of uncoated alloy at 1800°F - 56.3 KSI
σ flowing of uncoated alloy at 1900°F - 41.2 KSI
σ flowing of uncoated alloy at 1850°F -

2.8 PERCENT

| CODE | 4212 |
| PAGE | 36 |
FIG. 3.0451 TYPICAL CREEP RUPTURE PROPERTIES IN LIFE RANGE FROM 10 TO 10,000 HRS AT TEMPERATURES FROM 1300 TO 2000 F (4)
NiCo

NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST TO 1/4 IN. DIA. BAR SPECIMEN X 2 IN
GAGE LENGTH
AS CAST

Fig. 3.0453 CREEP RUPTURE CURVES FOR AS CAST ALLOY
AT 1500°F, 1670°F, AND 1830°F (46, pp. 11, 116 120)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
AS CAST
O FINE GRAIN (1/16 IN)
• COARSE GRAIN (2/1/8 IN)

Fig. 3.0453 CREEP RUPTURE DATA FOR AS CAST ALLOY AS DETERMINED BY
DEVELOPER (4, p. 6)

Source: 4212

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>As Cast</td>
</tr>
<tr>
<td>Tested at</td>
<td>1000°F, 20 kpsi</td>
</tr>
<tr>
<td>Life loss</td>
<td>31.6%</td>
</tr>
<tr>
<td>Percent of</td>
<td>6.9%</td>
</tr>
<tr>
<td>RA, percent</td>
<td>8.9%</td>
</tr>
</tbody>
</table>

(1) All values average of 3 tests

Table 3.0451 EFFECT OF SEVERAL SOLUTION HEAT TREATMENTS ON THE CREEP RUPTURE LIFE AT 1600°F.
NONFERROUS ALLOYS

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Haynes (19 p. 13)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>As Cast (Bare or Coated As Indicated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 ksi 1700°F</td>
<td>Bare</td>
</tr>
<tr>
<td>22 ksi 1800°F</td>
<td>Bare</td>
</tr>
<tr>
<td>17 ksi 1850°F</td>
<td>Bare</td>
</tr>
<tr>
<td>13 ksi 1900°F</td>
<td>Bare</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Creep Rupture Life, Hours (2in), percent</th>
<th>Bare</th>
<th>Coated</th>
</tr>
</thead>
<tbody>
<tr>
<td>69.4</td>
<td>53.7</td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>129</td>
<td></td>
</tr>
<tr>
<td>224</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>190</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>5.2</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>8.4</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>9.0</td>
<td></td>
</tr>
</tbody>
</table>

(a) Haynes C-9 coating

TABLE 3.0471 EFFECT OF COATING ON CREEP RUPTURE PROPERTIES AT STRESSES AND TEMPERATURES YIELDING CREEP RUPTURE LIVES IN THE RANGE OF 50 TO 200 HOURS

FIG. 3.0472 CREEP RUPTURE CURVES FOR 30 COATED ALLOY AT 1562°F, 1697°F, AND 1832°F (56, 10, 12, 13, 126)

FIG. 3.0473 CORRELATION BETWEEN DUCTILITY AND RUPTURE TIME AT 1562°F, 1697°F, AND 1832°F FOR 30 COATED ALLOY (36, 33, 23, 24)
Ni 15 Co 5.5 Al 4.7 Ti 3 Mo 0.95 V
IN-100

NONFERROUS ALLOYS
REVISED: DECEMBER 1978

Table 3.021

<table>
<thead>
<tr>
<th>Source</th>
<th>(15) pp 2, 3, 7, 61</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy</td>
<td>Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V</td>
</tr>
</tbody>
</table>
| Condition | As Cast + Coated With Two Proprietary Coatings
| AEP No. and AEP No. 32 (see Fig. 3.815) |

Table 3.0474 CREEP RUPTURE LIVES AND ELONGATIONS AT 14150F AND 1800F FOR THE WALL ALLOY COATED WITH TWO PROPRIETARY COATINGS

<table>
<thead>
<tr>
<th>Source</th>
<th>General Electric, (12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>A. CGato 1500</td>
</tr>
<tr>
<td>Life with sigma formation, hrs.</td>
<td>20 kSi 14150F</td>
</tr>
<tr>
<td>Estimated life, no sigma formation, hrs.</td>
<td>8000</td>
</tr>
</tbody>
</table>

Table 3.0881 BENEFICIAL EFFECTS ON CREEP RUPTURE BEHAVIOR ACHIEVED BY AVOIDING SIGMA PHASE PRECIPITATION

<table>
<thead>
<tr>
<th>Source</th>
<th>(24) pp 2, 3, 4, 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>Ni-15Co-10Cr-5, 5Al-4.7Ti-3Mo-0.95V (Nominal)</td>
</tr>
<tr>
<td>Test Temp. &amp; Stress</td>
<td>Low Ns, 2.25</td>
</tr>
<tr>
<td>High Ns, 2.50</td>
<td></td>
</tr>
<tr>
<td>Medium Ns, 2.49</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.0482 CREEP RUPTURE PROPERTIES OF FORGED ALLOY IN THREE CONDITIONS OF FORMENESS TO SIGMA PHASE PRECIPITATION

(1) See Table 3.072 for actual compositions, forging parameters and heat treatment
(1) Based on Log Life (Average of Log Life)

TABLE 3.0474 CREEP RUPTURE LIVES AND ELONGATIONS AT 14150F AND 1800F FOR THE WALL ALLOY COATED WITH TWO PROPRIETARY COATINGS

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Co-10Cr-5, 5Al-4.7Ti-3Mo-0.95V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>General Electric, (12)</td>
</tr>
<tr>
<td>Condition</td>
<td>As Cast</td>
</tr>
<tr>
<td>Life with sigma formation, hrs.</td>
<td>20 kSi 14150F</td>
</tr>
<tr>
<td>Estimated life, no sigma formation, hrs.</td>
<td>8000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>(24) pp 2, 3, 4, 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>Ni-15Co-10Cr-5, 5Al-4.7Ti-3Mo-0.95V (Nominal)</td>
</tr>
<tr>
<td>Test Temp. &amp; Stress</td>
<td>Low Ns, 2.25</td>
</tr>
<tr>
<td>High Ns, 2.50</td>
<td></td>
</tr>
<tr>
<td>Medium Ns, 2.49</td>
<td></td>
</tr>
</tbody>
</table>

(1) See Table 3.072 for actual compositions, forging parameters and heat treatment
(1) Based on Log Life (Average of Log Life)
NiCo

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NONFERROUS ALLOYS

Ni-15Co-13Cr-5.5Al-4.7Ti-3Mo-0.95V (nominal)
ACTUAL: Ni-13, Co-16, 2Cr-4.99Al-4.4Ti-3.55Mo-9.99V
AV ELECTRON VACANCY CONCENTRATION,
\( N_v \) : 2.29
CRITICAL VALUE OF \( N_v \) FOR SIGMA FORMATION, ACCORDING TO METHOD OF WOODYATT, SIMS, AND BEATTIE: 2.32
ACCORDINGLY, ALLOY OF THIS COMPOSITION IS NOT EXPECTED TO FORM SIGMA.
FINE GRAIN ALLOY PREPARED BY MOLD INOCULATION
TEST SPECIMEN 1/4 IN Dia x 1 1/4 IN GAGE LENGTH TESTED AS CAST

FIG. 3.010: CREEP Rupture CURVES FOR FINE GRAIN ALLOY OF COMPOSITION SUFFICIENTLY LOW IN AI AND Ti TO AVOID SIGMA PRECIPITATION

FIG. 3.040: CREEP RUPTURE CURVES AT 40 KSI FOR ALLOY IN THREE LEVELS OF ELECTRON VACANCY CONCENTRATION ACHIEVED BY ADDITIONS OF AL-TI TO A SINGLE HEAT, TESTED IN AS CAST CONDITION OR AFTER EXPOSURE AT 1550F FOR 250 AND 2500 HRS. (23, pp. 1-3, 12)

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NONFERROUS ALLOYS

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Ni
15 Co
10 Cr
5.5 Al
4.7 Ti
3 Mo
0.95 V

IN-100

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V (NOMINAL)

SEE FIGURE 3.0464 FOR ACTUAL COMPOSITIONS OF ALLOYS OF LOW,
MEDIUM, AND HIGH ELECTRON VACANCY CONCENTRATION, ACHIEVED
BY VARIATIONS OF Al AND Ti.

SEE ALSO TABLE 3.028 FOR OTHER DETAILS OF ALLOY PREPARATION,
AND SPECIMEN DIMENSIONS. RESULTS SHOWN HERE REFER TO FINE
GRAIN ALLOY STRUCTURES.

DATA POINTS SHOWN ARE FOR ALLOYS OF MEDIUM AND HIGH ELECTRON
VACANCY CONCENTRATION. DOTTED CURVES ARE FOR REFERENCE
FROM THE LOW Ni ALLOY WHEREIN NO SIGMA FORMS IN THE TIMES
SHOWN. ACTUAL DATA ARE SHOWN IN FIGURE 3.0463

CURVES FOR ONSET OF SIGMA PRECIPITATION ARE BASED ON EQUATION 3.0463
BUT CORRECTED BY ESTIMATION TO ACCOUNT FOR EFFECT OF STRESS.

FIG. 3.0465 CREEP RUPTURE CURVES FOR FINE GRAIN ALLOYS OF LOW, MEDIUM,
AND HIGH ELECTRON VACANCY CONCENTRATION, REPRESENTING
PROGRESSIVELY INCREASING TENDENCY TOWARD SIGMA PHASE
PRECIPITATION. CURVES SHOW THAT STRONG TENDENCY FOR SIGMA
PRECIPITATION RESULTS IN REDUCTION OF CREEP RUPTURE STRENGTH.

(21, 14, 3, 7, 8, 12, 13)
NONFERROUS ALLOYS

Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V (Nominal)
Ni-13.8Co-0.5Cr-5.5Al-4.75Ti-3.70Mo-0.17C-0.44H-10ppm O (Actual FM)
Ni-15.18Co-0.9Cr-5.4Al-4.8Ti-3.86Mo-0.95V-1180°C-0.65-744pm O (Actual FM)
FM POWDER PARTICLE SIZE: <250 TO >444
NM POWDER PARTICLE SIZE: 500 TO 444

EXTRUDED AT 2100°F WITH 20% REDUCTION TO BAR 1/4 IN Dia x 7 FT

SEE TABLE 3.025 FOR RT TENSILE PROPERTIES OF ALLOYS

Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V
AS CAST + 1600°F, 12 HR, AC

0.204 IN THICKNESS (CONSTANT CROSS SECTION) x 1 IN GAGE LENGTH

O HELIUM
O HYDROGEN
O HYDROGEN/WATER VAPOR

FIG. 3.0401 CREEP-RUPTURE OF ALLOY IN HELIUM, HYDROGEN,
AND HYDROGEN/WATER VAPOR AT 1250°F AND 5000 PSIG PRESSURE

1/2 IN Dia 1 BAR X 1 IN GAGE LENGTH
CAST OR EXTRUDED AS INDICATED
SEE TABLE 3.025 FOR DETAILS OF POWDER COMPOSITION, CONSOLIDATION PARAMETERS, AND RT PROPERTIES OF ALLOY

O CAST: COARSE GRAIN (3000 MICRON)
O CAST: FINE GRAIN (1500 MICRON)
O CAST - CONSOLIDATED FM POWDER (100 MICRON)
O EXTRUDED - OVERAGED FM POWDER (8 MICRON)
O EXTRUDED - OVERAGED NM POWDER (5 MICRON)

FIG. 3.0402 CREEP-RUPTURE CURVES AT 1800°F FOR CAST ALLOY OF VARIOUS GRAIN SIZE, AND FOR ALLOY EXTRUDED FROM POWDER (28, pp. 3-7, 2-21)

FIG. 3.0403 EFFECT OF ALUMINUM BASE COATING ON ROTATING BENDING FATIGUE PROPERTIES AT ROOM TEMPERATURE

TABLE 3.0511 EFFECT OF ALUMINUM BASE COATING ON ROTATING BENDING FATIGUE PROPERTIES AT ROOM TEMPERATURE

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NiCo NONFERROUS ALLOYS

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Ni-15Co-20Cr-5.5Al-4.75Ti-3Mo-0.95V
AS CAST + COATED WITH PWA 47-14L COATING,
COATING HEAT TREAT: 1975F, 20 Min + 1975F, 4 HR (B.)
+ AGED 1000F, 12 HR

FIG. 3.0512 LOW CYCLE FATIGUE CHARACTERISTICS OF SMOOTH HOLLOW SPECIMEN WITH ONE INCH GAGE LENGTH OF UNIFORM CROSS SECTION AT TEMPERATURES FROM 1000 TO 2000F IN STRAIN-CONTROLLED CYCLING

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**NONFERROUS ALLOYS**

**FIG. 3.0514 STRAIN RANGE PARTITIONING LIFE RELATIONSHIPS FOR CAST ALLOY AT 1700°F**

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
Simulated Airfoil as shown coated with proprietary coatings as indicated.

**TABLE 3.0521 THERMAL NICKEL FATIGUE CHARACTERISTICS OF AIRFOIL SHAPE WITH AND WITHOUT ALUMINUM BASE COATING**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Ni (p. 7, p. 81)</td>
</tr>
<tr>
<td>Condition</td>
<td>As Cast, Tested in Thermal Shock (a)</td>
</tr>
<tr>
<td>Number of Cycles to Cracking</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>200</td>
</tr>
<tr>
<td>Coating C-9</td>
<td>&gt; 500 (a)</td>
</tr>
<tr>
<td>Coating C-3</td>
<td>-</td>
</tr>
</tbody>
</table>

(a) Two tests, stepped at 500 cycles, no cracking.
(b) Airfoil shape alternated for 50 seconds in furnace at test temperature, then 90 seconds in water spray.

**FIG. 3.0515 AXIAL FATIGUE AT 1600°F OF SIMULATED HOLLOW AIRFOILS COATED WITH PROPRIETARY COATINGS**

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NONFERROUS ALLOYS

Ni-5Co-10Cr-5.5Al-4-7Ti-3Mo-6.80V
CAST + JOCOAFT(ALUMINIDE COATING) 2000°F, 2 HR
6 MIN CYCLES IN FLUIDIZED BEDS
3 MIN AT 1000°F
3 MIN AT 600°F

NASA TAZ-7A 5095-50COAT
MAR-M 200-50COAT
NASAWAZ-20-50COAT
NX-16-50COAT
NX-18-50COAT
M-20-50COAT
U-700-50COAT
W-52-50COAT
MAR-M 200-50COAT
U-700 WROUGHT

SEE FIGS. 3.0523 AND 3.0529 FOR PROPERTIES OF AS CAST ALLOY

FIG. 3.0523 THERMAL FATIGUE CRACK INITIATION OF AS CAST OR DIRECTIONALLY SOLIDIFIED ALLOY WITH AND WITHOUT JOCOAT TESTED IN ALTERNATE FLUIDIZED BEDS AT 1900° AND 600°F.

FIG. 3.0524 THERMAL FATIGUE CRACK INITIATION OF AS CAST OR DIRECTIONALLY SOLIDIFIED ALLOY WITH AND WITHOUT JOCOAT TESTED IN ALTERNATE FLUIDIZED BEDS (150°C), FOLLOWED BY 3 MIN AT 1000°F OR 3 MIN AT 1700°F, FOLLOWED BY 3 MIN AT 1000°F.

SEE FIG. 3.0525 FOR CYCLE TIME SHOWING EFFECT OF CYCLE TIME ON THERMAL FATIGUE CRACKING OF COATED AND UNCOATED WROUGHT ALTERNATELY IMMERSED IN FLUIDIZED BEDS AT 600° AND 1900°F.
NONFERROUS ALLOYS

Figs. 3.0526 EFFECT OF MAXIMUM CYCLE TEMPERATURE ON THERMAL FATIGUE CRACKING OF COATED AND UNCOATED AIRFOILS SIMULATING TURBINE BLADES SUBJECT TO MACH 1 GAS FLOW FOLLOWED BY MACH 1 JET COOLING (Ref. p. 665)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST WEIGH SPECIMEN, SEE FIG. 3.0625
CAST + 2090F, 2 HRS + 1700F, 16 HRS.
AS PT OR COATED WITH COMMERCIAL COATING (40 COAT) TESTED IN FLUIDIZED BEDS, 3 MIN AT 600F, 3 MIN AT 1900F

CRACK GROWTH RATE REFERS TO AREA GROWTH AT EDGE OF WEDGE HAVING INITIAL RADIUS OF .024 IN
SEE FIG. 3.0228

FIG. 3.0527 RELATION BETWEEN CRACK GROWTH RATE AND RESISTANCE TO INITIAL CRACK G IN THERMAL CYCLING
(SEE TABLE II, FIG. 9)

-source- (40) pp. 2, 3, 42, 45
Alloy Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
Condition Coated with Al-Cr-Mn, see Fig. 3.0525 for Coating Type
Specimen Type Cast simulation hollow airfoil, see Fig. 3.0515
Test Mean tensile stress of 10.5 ksi, 60 sec, at Conditions 2600F + 40 sec, cooling with RT air. Specimen insulated with Fluorocarbon Paraffin wax every 100 cycles
Specimen Cycles to Fatigue Crack

<table>
<thead>
<tr>
<th>Number</th>
<th>Al-Cr-Mn</th>
<th>AES No.</th>
<th>AES No. 32 eq.</th>
<th>Dot Coat on NASA VI-A</th>
<th>U-799</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4080</td>
<td>4080</td>
<td>5566</td>
<td>626</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3500</td>
<td>4540</td>
<td>5340</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3500</td>
<td>4540</td>
<td>5340</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1540</td>
<td>1540</td>
<td>7018</td>
<td>260</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5540</td>
<td>1550</td>
<td>7018</td>
<td>260</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1250</td>
<td>1250</td>
<td>5018</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>605</td>
<td>605</td>
<td>2010</td>
<td>170</td>
<td></td>
</tr>
</tbody>
</table>

Av. trend on Log. cycles to failure 1834 1867 6405 296

TABLE 3.0628 THERMAL FATIGUE OF THINWALL ALLOY WITH TWO PROPRIETARY COATINGS SUBJECTED TO 16,000 TONNEL MEAN STRESS AND 10 TEMPERATURE CYCLING FROM 200F.

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
CAST ALLOY MACHINE TO WEDGE BAR AS SHOWN IN FIG. 3.0625
COATED WITH ALLOYS SHOWN IN FIG. 2.0623
TESTED IN MACH 1 JET AT 2000F PER CYCLE, CONSISTING OF 1 HR AT TEMP + COOL TO RT IN 3 MIN.

THERMAL CRACKING OBSERVED IN COATING AFTER TESTS SHOWN IN FIG. 2.0623
CORRELATION OF POINTS OF THERMAL CRACKING WITH SLOPE PARAMETER DEFINED IN SKETCH BELOW

FIG. 3.0629 CORRELATION OF TIME TO INITIATE THERMAL CRACKS WITH WEIGHT GAIN SLOPE PARAMETER FOR ALLOY COATED IN VARIOUS WAYS (Ref. 14.15)
NiCo

NONFERROUS ALLOYS

REvised: December 1978

Ni-15Co-15Cr-5.5Al-4.7Ti-3Mo-0.95V
WROUGHT BARS PREPARED FROM PREALLOyED POWDERS
SOLUTIONED AT 2050°F, STABILIZED AT 1600°F AND 1800°F, PRECIPITATION HARDENED AT 1200°F AND 1400°F
AT 1200°F

P'TY = 230 KSI
P'TY = 142 KSI
e = 24 PERCENT
RA = 25 PERCENT

1200°F
0.3" DEWELL
CONTINUOUS CYCLING, ZERO MEAN STRAIN

CONTINUOUS CYCLING
0.02" MAX STRAIN

0.04 PERCENT

0.80 PERCENT

1.0 PERCENT

1.42 PERCENT

1.46 PERCENT

1.55 PERCENT

FIG. 3.0533 LOW CYCLE FATIGUE AT 1200°F OF POWDER METALLURGY BARS PREPARED BY PRATT AND WHITNEY AIRCRAFT GATeRING PROCESS DATA POINTS REPRESENT CYCLES TO 5 PERCENT LOAD DROP (ST. FIG. 14)

Ni-15Co-15Cr-5.5Al-4.7Ti-3Mo-0.95V
WROUGHT BARS PREPARED FROM PREALLOYED POWDERS
SOLUTIONED AT 2050°F, STABILIZED AT 1600°F AND 1800°F, PRECIPITATION HARDENED AT 1200°F AND 1400°F
AT 1200°F
P'TY = 230 KSI
P'TY = 142 KSI
e = 24 PERCENT
RA = 25 PERCENT

15 MIN DEWELL
AT 1200°F
0.3" AT MAX STRAIN

1200°F

FIG. 3.0531 LOW CYCLE FATIGUE TESTS AT 1200°F OF POWDER METALLURGY BARS PREPARED BY PRATT AND WHITNEY AIRCRAFT GATeRING PROCESS (ST. FIG. 6)

Ni-15Co-15Cr-5.5Al-4.7Ti-3Mo-0.95V
WROUGHT BARS PREPARED FROM PREALLOYED POWDERS
SOLUTIONED AT 2050°F, STABILIZED AT 1600°F AND 1800°F, PRECIPITATION HARDENED AT 1200°F AND 1400°F
AT 1200°F
P'TY = 230 KSI
P'TY = 142 KSI
e = 24 PERCENT
RA = 25 PERCENT

15 MIN DEWELL
AT MAX STRAIN

0.3" AT MAX STRAIN

1200°F

FIG. 3.0532 LOW CYCLE FATIGUE tests AT 1200°F OF POWDER METALLURGY BARS PREPARED BY PRATT AND WHITNEY AIRCRAFT GATeRING PROCESS DATA POINTS REPRESENT CYCLES TO COMPLETE FRACTURE (ST. FIG. 15)

Ni-15Co-15Cr-5.5Al-4.7Ti-3Mo-0.95V
COMPRESSION DISK FROM 197 TGF 401 ENGINE, APPROX. 17 IN. DIAMETER, PRODUCED FROM "ALL-INERT" POWDER BY PRATT AND WHITNEY AIRCRAFT GATeRING PROCESS HEAT TREATED TO MEET REQUIREMENTS OF PWA 1029 SPECIFICATIONS

1200°F CYCLING FROM ZERO TO MAX STRAIN CONTINUOUS CYCLING, FREQUENCY NOT SPECIFIED

FIG. 3.0534 LOW CYCLE FATIGUE TESTS AT 1200°F OF COMPRESSION DISK FROM POWDER METALLURGY COMPRESSION DISK (ST. FIG. 3)

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Ni-Cr-10Co-15Fe-5Al-4.7Ti-3Mo-0.95V powder metallurgy turbine disk and flat disk forging produced by PWA GATORING forging process, with the following tensile properties:

- RT: 
  - Ftu = 230 ksi, Fty = 141 ksi, e = 24 percent, RA = 34 percent
- 1200°F: 
  - Ftu = 185 ksi, Fty = 142 ksi, e = 24 percent, RA = 35 percent
- 1350°F: 
  - Ftu = 160 ksi, Fty = 137 ksi, e = 32 percent, RA = 33 percent

Tested using WOl specimen as shown.

**Figure 3.0541** Basic crack growth curves at RT, 1200°F, 1350°F, for constant amplitude loading of WOl specimens (Table 1, Figure 3).

- Ni: 15 Co: 10 Cr: 5.5 Al: 4.7 Ti: 3 Mo: 0.95 V
- IN-100
NiCo

NONFERROUS ALLOYS

Ni 15 Co
10 Cr
5.5 Al
4.7 Ti
3 Mo
0.95 V
IN-100

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
MODIFIED COMPACT SPECIMEN AS SHOWN
IN FIG. 2.0641
THICKNESS AS INDICATED

5.5 Al
4.7 Ti
3 Mo
135OF
0.95 V
(0.5 c
2 -0.5IN
IN-100

FIG. 2.0643 EFFECT OF TEMPERATURE AND SPECIMEN
THICKNESS ON SUSTAINED LOAD CRACK
PROPAGATION RATE. (20, pp.4,8,13)

K - KSI/IN

FIG. 2.0644 EFFECT OF SPECIMEN THICKNESS ON
CRACK GROWTH RATE AT HT. (20, pp.4,8,9)

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Ni-Co 15 Cr 10 Co 5.5 Al 4.7 Ti 3 Mo 0.95 V

FIG. 3.0545 EFFECT OF FREQUENCY ON CRACK GROWTH RATE IN CONTINUOUS CYCLING AT 1200°F
(20, pp. 4,5,6,8,22)

FIG. 3.0546 EFFECT OF TEMPERATURE ON CRACK GROWTH RATE AT 10 CPM, R = 0.1
(20, pp. 4,5,6,8,28)

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Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
COMPACT TENSION SPECIMEN, SEE FIG. 3.0541
VARIOUS THICKNESSES

FIG. 3.0547 EFFECT OF STRESS RATIO ON CRACK GROWTH RATE AT 1200°F, 10 CPM
(20, pp. 4, 5, 6, 9, 26)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
MODIFIED COMPACT TENSION SPEC,
FIG. 3.0541, SEVERAL THICKNESS AS
INDICATED

FIG. 3.0549 EFFECT OF SPECIMEN THICKNESS ON CRACK GROWTH RATE AT 1200°F CONTINUOUS CYCLING AT 10 CPM
(20, pp. 4, 8, 11)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
COMPACT TENSION SPECIMEN, SEE FIG. 3.0541
VARIOUS THICKNESSES

FIG. 3.0548 EFFECT OF STRESS RATIO ON CRACK GROWTH RATE AT 1200°F, 20 CPM
(20, pp. 4, 5, 6, 8, 27)

FIG. 3.0551 CRACK GROWTH AT 1200°F UNDER CONTINUOUS CYCLING AND WITH 50 PERCENT OVERLOAD
EVERY 5, 20, 40 CYCLES (20, pp. 4, 5, 49)
NiCo

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NONFERROUS ALLOYS

FIG. 3.0552 CRACK GROWTH AT 1200°F UNDER CONTINUOUS CYCLING AND WITH 25 PERCENT OR 50 PERCENT OVERLOADS EVERY 21 CYCLES (See pp. 4, 5, 6, 47)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
COMPACT TENSION SPECIMEN, SEE FIG. 3.0541, THICKNESS 0.250 IN. INITIAL CRACK LENGTH 0.936 IN

FIG. 3.0551 CRACK GROWTH AT 1200°F UNDER SUSTAINED LOAD AND WITH 25 PERCENT OR 50 PERCENT OVERLOADS EVERY 2 MINUTES (See pp. 4, 5, 6, 47)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
COMPACT TENSION SPECIMEN, SEE FIG. 3.0541, THICKNESS 0.250 IN. INITIAL CRACK LENGTH 0.936 IN

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Ni 15 Co 10 Cr 5.5 Al 4.7 Ti 3 Mo 0.95 V IN-100

Ni-15Cr-10Co-5.5Al-4.7Ti-3Mo-0.95V

COMPACT TENSION SPEC., SEE FIG. 3.0541

CENTER CRACKED SPEC., SEE FIG. 3.0542
THICKNESS 0.125 IN, CRACK LENGTH 0.12 IN, NET SECT STRESS 0.05 ksi

1200°F
2 MIN DWELL AT PEAK STRESS

3Mo, 1.95V

FIG. 3.0541 EFFECT OF NATURAL STRESS ON CHOK GROWTH RATE FOR 2 MINUTE DWELL AT PEAK STRESS AT 1200°F (60, 10, 4, 5, 6, 8, 18)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V

MODIFIED COMPACT TENSION SPEC., FIG. 3.0541 SEVERAL THICKNESSES, AS INDICATED

THICKNESS

0.063 IN
0.125
0.250
0.44

2 MIN DWELL
1, 2, 5 MIN DWELL PERIODS

FIG. 3.0543 EFFECT OF NATURAL STRESS ON CHOK GROWTH RATE FOR 2 MINUTE DWELL AT 1200°F, R = 0.1, 0.125 IN

(20, 30, 4, 5, 6, 8, 32)

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NONFERROUS ALLOYS

Ni-15Co-16Cr-5.5Al-4.7Ti-3Mo-0.95V

COMPACT TENSION SPECIMEN, SEE FIG.

Fig. 3.064

THICKNESS 0.23 IN

INITIAL CRACK LENGTH APPROX .84 IN

2 MIN DWELL

50 PERCENT OVERLOAD

25 PERCENT OVERLOAD

CONTINUOUS CYCLING

NO OVERLOADS

1350F

CONTINUOUS CYCLING @

20 CPS, \( R = 0.8 \) WITH 25

PERCENT OR 50 PERCENT

OVERLOAD EACH 40 CYCLES,

OR WITH 2 MIN DWELL AT,

THE 50 PERCENT OVERLOAD.

\( \Delta K - \text{KN/IN} \)

\( \Delta K - \text{KN/IN} \)

2 MIN DWELL

10 CYCLES

10 CPM + 2 MIN DWELL

40 CYCLES

10 CPM + 2 MIN DWELL

1200F

R = 0.1

BASELINE

10 CYCLES

NO DWELL

\( \Delta K - \text{KN/IN} \)

\( \Delta K - \text{KN/IN} \)

Fig. 3.065

INTERACTION OF LOW CYCLE FATIGUE

WITH Dwell PERIODS AT MAX LOAD FOR

Tests AT 1200F, \( R = 0.1 \) (20, 40, 4, 6, 7, 33, 35)

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NONFERROUS ALLOYS

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NiCo

Ni 15Co 10Cr 5.5Al 4.7Ti 3Mo 0.95V
IN-100

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
COMPACT TENSION SPECIMEN, SEE
FIG. 3.0541

1 MISSION CYCLE

N CYCLES

2 MIN DWELL

10 CYCLES

h 10 CPM +
2 MIN DWELL

1.35 V

R = 0.1

10 CYCLES

10 CPM +
2 MIN DWELL

BASELINE

10 CPM

NO DWELL.

10-5

10-4

10-3

10-2

10-1

1 2 5 10 2 5 100 2 5 1000

σ - IN PER MISSION CYCLE

σ - ksi/√ft

FIG. 3.0666 INTERACTION OF LOW CYCLE FATIGUE WITH DWELL PERIODS AT MAX LOAD FOR TESTS AT 1350°F, R = 0.1(30, pp.4, 6, 7, 33, 35)

Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
POWDER METALLURGY WOL SPECIMEN
FROM TURNED DISK AS DESCRIBED IN
FIG. 3.0641

KσL SINGLE OVERLOAD

KσL INITIAL CRACK GROWTH

KσL CRACK LENGTH

KσL TO OVERLOAD

DELAY CYCLES

DELAY CYCLES PRIOR TO RESUMPTION OF
BASIC CRACK GROWTH AFTER SINGLE CYCLE
OF OVERLOAD, BASELINE Kσmax = 23.2 ksi/√ft

FIG. 3.0571 DELAY CYCLES PRIOR TO RESUMPTION OF
BASIC CRACK GROWTH AFTER SINGLE CYCLE
OF OVERLOAD, BASELINE Kσmax = 23.2 ksi/√ft

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NONFERROUS ALLOYS

Ni-55Co-16Cr-5.5Al-4.7Ti-3Mo-0.05V
POWDER METALLURGY VOL. SPECIMEN
FROM TURBINE DISK AS DESCRIBED IN FIG. 3.0641

FIG. 3.0672 DELAY CYCLES PRIOR TO RESUMPTION OF
BASIC CRACK GROWTH AFTER SINGLE CYCLE
OVERLOAD. BASELINE Kmax = 25.2 KSI√FT

Ni-55Co-16Cr-5.5Al-4.7Ti-3Mo-0.05V
AS CAST + 1400°F, 12 HR, AC
0.251 DIA NPTI AS SHOWN
AXIAL LOADING
R = 0.1
T = 1250°F

FIG. 3.0631 LOW CYCLE FATIGUE AT 1250°F IN
HIGH PRESSURE HYDROGEN AND
HELIUM

Ni-55Co-16Cr-5.5Al-4.7Ti-3Mo-0.05V
AS CAST + 1400°F, 12 HR, AC
0.159 IN DIA MIN SECTION, AS SHOWN

Ni-55Co-16Cr-5.5Al-4.75Ti-3Mo-0.05V
AS CAST + 1400°F, 12 HR, AC
0.189 IN DIA MIN SECTION, AS SHOWN

FIG. 3.0682 HIGH CYCLE AXIAL FATIGUE IN HIGH
PRESSURE HYDROGEN AND HELIUM
AT 1250°F

(See p. III-10, IV-4, 9)

FIG. 3.0641 INELASTIC STRAIN RANGE VS. LOW-CYCLE
FATIGUE LIFE FOR EACH PARTITION STRAIN
RANGE COMPONENT FOR AS-CAST THINWALL
TURBING AT 1700°F

(See p. 20, 62, 4 & FIG. 6)

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NONFERROUS ALLOYS

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Ni-15Co-5.5Al-4.7Ti-3Mo-0.95V

SOLID TUBULAR SPECIMEN APPROX 1/4 IN DIA
AS CAST + VAPOR PHASE ALUMINIZED COATING,
ALUMINIZED AT 2100°F, 3 HR + ARGON COOLED

Cycles to Failure

FIG. 3.05342 STRAIN-RANGE PARTITIONING LIFE RELATIONSHIPS
AT 1652°F AND 1832°F FOR AS-CAST ALUMINUM
COATED ALLOY

Ni-15Co-5.5Al-4.7Ti-3Mo-0.95V
WROUGHT BARS PREPARED FROM
PREALLOYED POWDERS
SOLUBILIZED AT 2400°F, STABILIZED AT 1600°F
AND 1800°F, PRECIPITATION HARDENED AT
1200°F AND 1400°F

FIG. 3.05441 TOTAL STRAIN RANGE VS LOW-CYCLE
FATIGUE LIFE AT 1200°F OF POWDER
METALLOGRAPHIC BARS PREPARED BY
PRATT & WHITNEY GATLINGING, IN
PROCESSED AND TESTED UNDER RAPID
STRAIN CYCLING, TENSILE STRESS-
HOLD, AND TENSILE STRAIN-HOLD.

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Ni-15Co-15Cr-5.5Al-4.7Ti-3Mo-0.95V
Wrought bars prepared from prealloyed powders

See Fig. 3.05344 for details of heat treatment and resulting tensile and creep properties.

Fig. 3.05345. Inelastic strain range vs low cycle fatigue life at 1200°F of powder metallurgy bars prepared by Pratt and Whitney Gattizing Process and tested under rapid strain cycling, tensile stress-hold, and tensile stress-hold. (58)

Fig. 3.062. Dynamic modulus of elasticity (6.5×10^6 psi) (15, p. 114)

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Ni-Co-10Cr-5.5Al-4.7Ti-3Mo-0.25V
COMPRRESSOR DISK FROM 10 - 12TH STAGE OF
F100/F401 ENGINE APPROX 17 IN DIAM
PRODUCED FROM "ALL INERT" POWDER BY
PRATT AND WHITNEY GATING PROCESS
HEAT TREATED BY MODIFICATION OF FWA
102B SPECIFICATIONS

FIG. 4.11 MECHANICAL PROPERTIES FROM RT TO 1300°F
OF SPECIMENS FROM THE 10 - 12TH STAGE
COMPRRESSOR OF F100/F401 ENGINE

(See, Fig. 2)

<table>
<thead>
<tr>
<th>Source</th>
<th>(Ti) pO.30, 83</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy</td>
<td>Ni-Co-10Cr-5.5Al-4.7Ti-3Mo-0.25V</td>
</tr>
<tr>
<td>Condition</td>
<td>As Cast and Machined To Fit Tree Specimen As Shown</td>
</tr>
<tr>
<td>Test Temperature</td>
<td>RT</td>
</tr>
</tbody>
</table>

Specimen
LOADING AX10
FAILURE SECTION

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Nominal Stress At Failure, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>136.5</td>
</tr>
<tr>
<td>2</td>
<td>129.9</td>
</tr>
</tbody>
</table>

TABLE 4.12 ROOM TEMPERATURE TENSILE STRENGTH OF FIT TREE SIMULATING TURBINE BLADE ATTACHMENT

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NONFERROUS ALLOYS

Ni 15 Co
10 Cr
5.5 Al
4.7 Ti
3 Mo
0.95 V
IN-100

Ni-15Co - 10Cr-5.5Al-4.7Ti-3Mo-0.95V
As cast + machined to fir tree shape
As shown
loaded in tension by mating Waspaloy fixture

Failure section

All stresses calculated from load
and failure section, no stress concen-
tration factor applied.

Fig. 4.13 Creep rupture at 1400°F of fir tree
simulating turbine blade attachment
(67, pp. 31,107)
Ni~V

NONFERROUS ALLOYS
REVISED: DECEMBER 1978

NiCo

15 Ni
10 Co
5.5 Al
4.7 Ti
3 Mo
0.95 V
IN-100

Source: Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
Alloy
Condition: As Cast and Machined To Fit Tree Specimen As Shown
Test Temperature: RT

Specimen Loaded in Tension + Vibratory Bending Moment. Stresses shown are nominal stresses across failure section (no correction for stress concentration) + bending stress at outer fibers of failure section.

<table>
<thead>
<tr>
<th>Static Stress, ksi</th>
<th>Alternating Stress, ksi</th>
<th>Cycles to Failure(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>15</td>
<td>3.1 x 10^6</td>
</tr>
<tr>
<td>20</td>
<td>30</td>
<td>8.7 x 10^5</td>
</tr>
<tr>
<td>20</td>
<td>5 for 10^6 cycles + 10 for 10^6 cycles + 15 to failure</td>
<td>3.8 x 10^5</td>
</tr>
<tr>
<td>25</td>
<td>5 for 10^6 cycles + 10 for 10^6 cycles + 15 to failure</td>
<td>2.04 x 10^6</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>9.6 x 10^6</td>
</tr>
</tbody>
</table>

(1) If failure did not occur in 10^6 cycles, alternating stress was increased for an additional 10^6 cycles, if necessary. If failure still did not occur in 10^6 cycles, nominal stress was again increased. Failure cycles shown are at the last alternating stress shown.

TABLE 4.14 FATIGUE AT RT UNDER COMBINED STATIC AND VIBRATORY STRESS OF TURBINE BLADE MR TREE FASTENING

Source: Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V
Alloy
Test Specimen: 4 x 1.5 x 0.5 bar Electron Beam Welded to Similar Waespalloy Bar, After Heat Treat, Machined to Specimen Described Below
Condition: As Cast + Welded + Heat Treat (to restriction Waespalloy): 1850°F, 1 hour + 1550°F, 4 hour + 1400°F, 16 hour + Machined to Approximately 0.3 x 0.3 at Test Section
Test Temperature: RT

Failure Strength (ksi): 110
Location of Failure: Weld
Weld Cracks:

TABLE 4.21 ROOM TEMPERATURE TENSILE STRENGTH OF WELDMENT TO WELDALLOY

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**NONFERROUS ALLOYS**

**Source**

(47) pp 25, 26, 35, 87, 94

**Alloy**

Ni-15Cr-10Ni-3Fe-1.7Si-3Mo-0.95V

**Test Specimen**

4 x 1.5 x 0.5 in. Electron Beam Welded in Similar Waspaloy Bar. After Heat Treat, Machined to Specimens described below.

**Condition**

As Cast + Welded + Heat Treat (to strengtheen Waspaloy): 1850°F, 1 hr + 1550°F, 4 hr + 1400°F, 16 hr + Machine To Approximately 0.3 x 0.3 in Test Section

<table>
<thead>
<tr>
<th>Test Temperature</th>
<th>Stress at Failure</th>
<th>Life</th>
<th>Location of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld Cracks(1)</td>
<td>91</td>
<td>0.1</td>
<td>Weld</td>
</tr>
<tr>
<td>Weld Cracks(1)</td>
<td>56.5</td>
<td>31</td>
<td>Weld</td>
</tr>
<tr>
<td>Good</td>
<td>61.6</td>
<td>7221.6(2)</td>
<td>Waspaloy</td>
</tr>
<tr>
<td>Weld Cracks(1)</td>
<td>45.5</td>
<td>76.5</td>
<td>Weld</td>
</tr>
<tr>
<td>Weld Cracks(1)</td>
<td>60.7</td>
<td>1.6</td>
<td>Weld</td>
</tr>
</tbody>
</table>

(1) Caused by loss of ductility in IN 100 as result of change in microstructure during welding.

(2) Failure in Waspaloy, weld still intact.

TABLE 4.212 CREEP RuptURE AT 1400°F OF ELECTRON BEAM WELDMENT TO WASPALOY

**Source**

(47) pp 25, 26, 35, 87

**Alloy**

Ni-15Cr-10Ni-3Fe-1.7Si-3Mo-0.95V

**Test Specimen**

4 x 1.5 x 0.5 in. Electron Beam Welded in Similar Waspaloy Bar + Heat Treatment as Shown Below + Machined to Specimen Shape Shown

approximately 0.12 x 0.05 Thick At Minimum Section

<table>
<thead>
<tr>
<th>Condition as Determined by X-Ray Prior to Test</th>
<th>Static Stress</th>
<th>Vibratory Stress</th>
<th>Cycles(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld Cracks(1)</td>
<td>62.2</td>
<td>9.8</td>
<td>2.3 x 10^6</td>
</tr>
<tr>
<td>Weld Cracks(2)</td>
<td>62.2</td>
<td>4.9</td>
<td>1.76 x 10^6</td>
</tr>
<tr>
<td>Good</td>
<td>62.2</td>
<td>4.9</td>
<td>&gt;10^7</td>
</tr>
<tr>
<td>Good</td>
<td>62.2</td>
<td>9.8</td>
<td>3.07 x 10^6</td>
</tr>
</tbody>
</table>

(1) All failures in weld
(2) Caused by loss of ductility in IN 100 as result of change in microstructure during welding

TABLE 4.211 FATIGUE AT RT UNDER COMBINED STATIC AND VIBRATORY STRESS OF ELECTRON BEAM WELDMENT TO WASPALOY
**NiCo**

**NONFERROUS ALLOYS**

**REVISED: DECEMBER 1978**

### Table 4.211 Room Temperature Tensile Strength of Brazed Attachment to Waspaloy

<table>
<thead>
<tr>
<th>Source</th>
<th>(47) pp 27, 28, 38, 91, 110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy</td>
<td>Ni-15Co-10Cr-5, 5AI-4Ti-Mo-0.95V</td>
</tr>
</tbody>
</table>

#### Test Specimen and Brazing

![Diagram of test specimen and brazing](Diagram)

- Fingers A and B are C and C1 mate, double.
- Brazing and welding of faces A and B into hollow C.
- Prior to brazing, 0.005 in. P-1130 plate deposited on sides at 1000°F, 20 min.
- To bond, for brazing clearance for 0.02 to 0.06 in. maintained.

Brazed in H13, At 2000°F, 20 min. Diffusion of brace 1900°F, 8 hr, 1950°F, 50 hr.

Following Brazing H13 to Restrengthen Waspaloy: Fast Cool From 1950°F to 1000°F At 40°F Per Min + 1950°F, 4 hr + Cool to 1000°F + 1450°F, 16 hr

<table>
<thead>
<tr>
<th>Test Temperature</th>
<th>HT</th>
<th>Min P 1100 1108 RS</th>
<th>Min P Waspaloy 190 RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brace Area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KSI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location of Failure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blade Radius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN 100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point F in sketch Above</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.222 Fatigue at HT Under Combined Static and Vibratory Stress of Brazed Joint Simulating Turbine Blade Fastening to Waspaloy

<table>
<thead>
<tr>
<th>Source</th>
<th>(47) pp 27, 28, 38, 91, 110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy</td>
<td>Ni-15Co-10Cr-5, 5Al-4Ti-Mo-0.95V</td>
</tr>
</tbody>
</table>

#### Test Specimen

WASPALOY FAILURE IN 100

![Diagram of test specimen](Diagram)

See Table 4.211 For Details of Geometry of Brazed Surfaces and Brazing Procedure.

- Axial Load Applied for Static Stress
- Alternating Stress Applied By Random Vibration

<table>
<thead>
<tr>
<th>Test Temperature</th>
<th>HT</th>
<th>Static Stress</th>
<th>Alternating Stress</th>
<th>Cycles To Failure(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Stress</td>
<td>KSI</td>
<td>(2)</td>
<td>(2)</td>
<td>(2)</td>
</tr>
<tr>
<td>25.8</td>
<td></td>
<td>10.2 for 10^6 cycles + 13.6 for 10^5 cycles</td>
<td>5 x 10^5</td>
<td>5 x 10^5</td>
</tr>
<tr>
<td>20.3</td>
<td></td>
<td>16.2 for 10^6 cycles + 26.4 for 10^5 cycles</td>
<td>1.9 x 10^5</td>
<td>1.9 x 10^5</td>
</tr>
<tr>
<td>37.3</td>
<td></td>
<td>13.6 for 10^5 cycles + 10.2 for 10^6 cycles</td>
<td>9.2 x 10^6</td>
<td>9.2 x 10^6</td>
</tr>
<tr>
<td>22.4</td>
<td></td>
<td>13.6 for 10^6 cycles + 13.6 for 10^5 cycles</td>
<td>10^7</td>
<td>10^7</td>
</tr>
</tbody>
</table>

(1) All failures at base cross section of IN 100
(2) If failure did not occur in 10^6 cycles, alternating stress was increased to 10^7 cycles.

If necessary at the next higher stress level shown, failure cycles shown are for last value of alternating stress listed.

**TABLE 4.222 FAITIGUE AT HT UNDER COMBINED STATIC AND VIBRATORY STRESS OF BRAZED JOINT SIMULATING TURBINE BLADE FASTENING TO WASPALOY**

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NONFERROUS ALLOYS

<table>
<thead>
<tr>
<th>Source</th>
<th>(51) p 208</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni-15Co-10Cr-5, 5AI-4, TI-3Mo-8, 6V</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>Cast and Bonded By TLP Process (1)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Base Metal</th>
<th>IN 100, Mn SSI F 115, F 95</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Requirements at 1400°F</th>
<th>11-22 Min SSI F 115, F 120</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Bonding Condition</th>
<th>FMS (ksi)</th>
<th>FF (ksi)</th>
<th>E (ksi)</th>
<th>GA</th>
<th>Failuere Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000°F, 4 Hrs</td>
<td>137.3</td>
<td>126.1</td>
<td>2.3</td>
<td>6.6</td>
<td>IN 100</td>
</tr>
<tr>
<td>2000°F, 4 Hrs</td>
<td>141.5</td>
<td>127</td>
<td>2.3</td>
<td>10.3</td>
<td>IN 100</td>
</tr>
<tr>
<td>2000°F, 4 Hrs</td>
<td>104.4</td>
<td>127</td>
<td>4.6</td>
<td>6.6</td>
<td>Bond Region</td>
</tr>
<tr>
<td>2100°F, 4 Hrs</td>
<td>136.1</td>
<td>124.4</td>
<td>4.2</td>
<td>10.3</td>
<td>IN 100</td>
</tr>
<tr>
<td>2100°F, 4 Hrs</td>
<td>134.2</td>
<td>128.4</td>
<td>1.7</td>
<td>2.3</td>
<td>IN 100</td>
</tr>
<tr>
<td>2100°F, 4 Hrs</td>
<td>109.6</td>
<td>121.6</td>
<td>8.5</td>
<td>9.5</td>
<td>IN 100</td>
</tr>
<tr>
<td>2100°F, 4 Hrs</td>
<td>134.8</td>
<td>121.6</td>
<td>3.8</td>
<td>10.3</td>
<td>IN 100</td>
</tr>
</tbody>
</table>

(1) TLP is Pratt and Whitney Aircraft Trade Name for Transition-Liquid-Phase Bond by adding this layer between austenite to be bonded and exposing to temperature near melting point in vacuum.

When temperature depression (10°F) is added to bonding alloy, some alloying elements of basic composition (i.e., Al, Ti, C) are restricted to prevent formation of stable interface phases.

<table>
<thead>
<tr>
<th>Ni</th>
<th>Co</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>10</td>
<td>5.5</td>
<td>4.7</td>
<td>3 Mo</td>
</tr>
<tr>
<td>0.95 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IN-100

REFERENCES


"© 1978, Delmar Publishers, Inc."
34. Anon., "TE-12 Stage F100/F401 Compressor Disk of IN-100 Forged From "All-Inert" Powder Billet", Pratt & Whitney Aircraft, F100/F401 Bulletin B700122-2 (Jan. 1970)
42. Gedwell, J.A., "Cyclic Oxidation Resistance of Clad IN 100 at High Velocity Oxidation Behavior of Yttrium-Aluminide Coatings on IN 100 and V4A Alloys at 1000°C", NASA TN D-2788 (June 1971)