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# AEROSPACE STRUCTURAL METALS HANDBOOK

LEVEL

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Nonferrous Alloys.

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10 S.S. Manson

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AEROSPACE STRUCTURAL METALS HANDBOOK

FOURTH QUARTER - DEC. 1978

1978 REVISION - SUPPLEMENT XI

INSERTION INSTRUCTIONS

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)

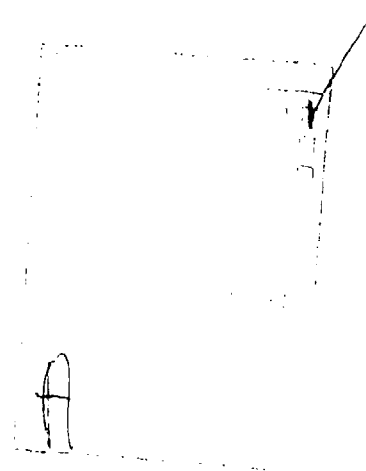
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AUTHOR: S. S. MANSON

## NONFERROUS ALLOYS

### 1. GENERAL

This nickel-base alloy, containing large additions of aluminum and titanium, achieves very high strength at elevated temperature. It has thus received considerable attention for application in components of high performance jet engines such as turbine blades, vanes and nozzles, and even integral turbine wheels.

Because of the large quantities of strengthening elements included in the composition, the alloy is not hot worked, and is therefore used in the as-cast condition. Recently, however, there has been considerable development of a powder metallurgy product which permits working of the alloy. At high temperatures the powder-consolidated product becomes superplastic, thus opening many possibilities in fabrication-to-shape of wrought complex components.

Also, because of the high content of gamma prime precipitate that constitutes one of the strengthening components of the alloy, the equilibrium solution temperature approaches the solidus, so the material is usually used in the as-cast condition, without heat treatment. However, it is subjected to heat treatment during the deposition of protective coatings. The powder metallurgy product is heat treated to achieve desirable properties.

The low oxidation and corrosion resistance of the alloy at the high temperatures where the strength of the alloy is most advantageously used, introduces the need for protective systems. A large number of coating types have been studied, and most have been found to provide sufficient protection to extend the useful life of the alloy, commensurate with its strength.

Exposure to high temperature and stress for long periods of time may also result in embrittlement due to precipitation of sigma phase. The alloy has been extensively studied to determine how to avoid such embrittlement. Maintaining a low content of aluminum plus titanium has been found effective, and the most recent specifications require bounds in the titanium content (in accordance with electron vacancy density calculations) to insure that no deleterious precipitates develop. Because of the interest in its potential use in advanced jet engine components, the alloy (especially the powder product) has also been extensively studied in relation to its fatigue characteristics, particularly fatigue crack growth during cyclic loading.

#### 1.01 Commercial Designation IN-100

#### 1.02 Alternate Designations

(17p) 122, (13m) 36, Austenal 100, AMS 5397 IN-100, Udimet IN-100, Haynes Alloy IN-100, All-vac IN-100, Vertex IN-100.

#### 1.021 Special designations of modifications of basic compositions to achieve freedom from sigma phase proneness.

International Nickel Co., -INCO 731X  
General Electric Co., -Rene' 100

#### 1.03 Specifications

AMS5397, Investment cast  
G.E. (original spec.) C50T77A.  
G.E. (Rene' 100 modification) C50T77C.

#### 1.031 G.E. Spec. C50T77C specifies that the electron vacancy number $N_v$ be calculated by the Pha Comp concept, using the procedure of Woodvatt - Sims - Reatlie (15). A maximum value of 2.47 is allowed for each heat.

#### 1.032 AMS 5397 specifies minimum values as follows:

$F_{tu}$  - 115 ksi  
 $F_{ty}$  - 95 ksi

$\epsilon$ (percent in 1 in or 4D) - 5 percent

#### 1.033 AMS 5397 Spec. for creep rupture test at 1800F, 29 ksi, rupture time minimum of 23 hrs, and elongation, (ln 4D) after rupture shall be 4 percent minimum.

#### 1.04 Composition Table 1.04

#### 1.05 Heat Treatment (See also 3.023)

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

1.052 Heating for 2 - 4 hr at 1900 to 2000F can re-solution sigma phase precipitated by creep exposure at lower temperature, and also makes alloy more resistant to sigma phase precipitation upon subsequent exposure to long-time creep conditions at lower temperatures (12).

1.053 Coating applications may expose alloy to temperatures 1600 - 2000F for periods up to 25 hrs (19, p. 9). INCO recommends that if the coating is to be diffused at 1900-1950F, the alloy should receive a preliminary high temperature solutioning at 2100-2150F, followed by aging at 1500-1600F.

This should provide the alloy with a capability of maintaining a consistently high level of mechanical properties.

For the powder metallurgy product, Pratt & Whitney Aircraft (R&I, 19, p. 6) recommends solutioning at 2050F, stabilization at 1600 and 1800F, and precipitation hardening at 1200 and 1300F. Typical heat treatment used (see Table 3.023) 221a) 1 hrs - 2000F, 4 hrs - 1550F, 16 hrs.

#### 1.06 Hardness

1.061 AMS specifies hardness RC 30-34 or equivalent.

1.062 Effect of temperature on hardness, Fig. 1.062

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, Fig. 1.063.

#### 1.07 Forms and Conditions Available

Investment Castings

Caterized (Trade Mark, Pratt & Whitney Aircraft for creep formed powder product hydrostatically pressed at elevated temperature) turbine disks and other shapes.

#### 1.08 Melting and Casting Practice Vacuum melted and cast

#### 1.09 Special Considerations

1.091 Because of the low chromium content, as well as the presence of Vanadium, oxidation resistance is not adequate at the high temperatures where the strength of the alloy assumes 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 apparently obtained without impairing the tensile and creep properties at high temperature. (5)(6)(7)(10)(11) to (14).

1.092 The high hardener content of the alloy makes it particularly prone to the precipitation of embrittling phases, such as sigma, upon prolonged exposure to high temperature, especially if stress is simultaneously applied. Special compositions, low in titanium content have been found advantageous for avoiding such embrittlement. The International Nickel Company, original developers of IN 100, has developed a modification designated as IN 731X, (13) and the General Electric Company has developed Rene' 100 for this purpose, (13). Both use Pha Comp techniques (wherein electron vacancy of the remaining matrix after the major hardening precipitates have formed, is used as a basis for the determination of whether sigma will form). Every heat requires a separate computation to determine sigma-proneness because of the large variations permitted in the chemistry of individual heats; however, in general, the revised composition limits with lower titanium contents, are usually sigma free within the specified limits of the other elements. The tendency toward sigma-proneness was first reported in reference (11) to be a result of exposure to high temperatures for long times, especially at stress. Reference (14) demonstrates more extensively the effects of exposure to temperature, and simultaneous exposure

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

IN-100

|      |    |
|------|----|
|      | Ni |
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| 0.95 | V  |

## IN-100

- to stress and temperature. Reference (12) reveals that life in creep-rupture at 1500F could be reduced by factors as high as 4 to 8 when sigma phase precipitates as compared to extrapolated values for sigma free material. It was also shown in reference (12) that sigma formed at 1650F could be solutioned at 1900 - 2000F, in 2 - 4 hrs and that a 2000F, 2 hour heat treatment delayed sigma formation. This heat treatment was observed to delay sigma formation whether applied to an as-cast bar or whether applied to a bar previously exposed to 1650F, containing sigma. This observation points to the possibility of beneficial effects of heat treatment, in contrast to the normally used as-cast structure. It also points to the possibility of removing creep damage by re-heat treatment for this alloy. The question of sigma phase precipitation has been extensively studied (Ref. 22 to 24), and effect on properties determined in detail.
- 1.093 The alloy in the powder metallurgy form has been extensively studied (Refs. (19)(20)(33)(34)(35)(36) both in regard to mechanical properties of fabricated products and especially in regard to crack growth.
- 1.094 High pressure hydrogen reduces tensile ductility, particularly at RT (see Table 3.03171).
2. PHYSICAL AND CHEMICAL PROPERTIES
- 2.01 Thermal Properties
- 2.011 Melting range 2305 - 2435F (3), p 7.
- 2.012 Phase changes. Structure consists of intragranular as well as eutectic or primary  $\text{Ni}_3(\text{Al}, \text{Ti})$ ,  $\text{Ti}(\text{C}, \text{N})$  and  $\text{M}_2\text{B}$ , also possibly perovskite carbide within  $\text{Ni}_3(\text{Al}, \text{Ti})$  islands. On aging precipitation of perovskite-like phase ( $\text{Ni}_3(\text{Al}, \text{Ti})\text{C}$ ) occurs at 1400F, and continues at 1600F where, 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 1800F. In the absence of stress, solution of  $\text{Ti}(\text{C}, \text{N})$  and  $\text{Ni}_3(\text{Al}, \text{Ti})\text{C}$  and the resultant precipitation of  $\text{M}_{23}\text{C}_6$  are the main structural changes at 1800F, (11). The tendency toward the formation of sigma phase can be eliminated by keeping the electron vacancy number  $N_V$  below 2.47.
- 2.0120 Effect of aging time and temperature on minor phase concentration, Fig. 2.0120.
- 2.0121 Effect of exposure for 5000 hours at various temperatures on minor phase concentration, Fig. 2.0121.
- 2.0122 Transformation to sigma phase for as-cast and forged alloy for two levels of electron vacancy concentration, Fig. 2.0122.
- 2.0123 Time-temperature relation for the onset of sigma phase precipitation for medium and high electron vacancy concentration ( $N_V$ ) compositions, and in fine or coarse grain size structure, Fig. 2.0123.
- 2.013 Thermal conductivity, Fig. 2.013.
- 2.014 Coefficient of thermal expansion, Fig. 2.014.
- 2.015 Specific heat, Fig. 2.015.
- 2.016 Thermal diffusivity.
- 2.02 Other Physical Properties
- 2.021 Density 0.280 lb per cu in, 7.75 gm per cu cm (4) p 2
- 2.022 Electrical Properties
- 143.0 microhm - cm at RT (4, p 2)
- 2.023 Magnetic Properties
- 2.03 Chemical Properties
- 2.031 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 intended use range is above that of many other nickel base alloys. Thus, where an oxidizing or sulfidizing environment is present as in turbojet applications, a protective coating is usually applied. Common coatings are of the aluminum and aluminum base types. These can substantially improve the sulfidation resistance, oxidation resistance and thermal shock characteristics. While only limited data are available at present, it appears that these coatings do not reduce the creep rupture strength, rupture elongation, or room temperature fatigue strength of the as-cast alloy. The oxidation characteristics in a high velocity gas stream containing oxygen is very complex, particularly if steady load and thermal shock cycles are superimposed. Depending on temperature, a weight gain or weight loss may occur under the same velocity conditions, (see Figure 2.034). An uncoated material may first gain weight and subsequently lose weight in the same test, due to the fact that heavy build-up of oxide (weight gain) may be followed by spalling (weight loss), as shown in Figure 2.035. Coating may reduce oxidation and thus prevent spalling, as also shown in Figure 2.035. Surface effects may also be important, Figure 2.036. At present the process is regarded as too complex to be predictable from thermodynamic principles. This complexity is the result of the interplay among heterogeneous oxide growth, oxide interactions, oxide vaporization, and spalling, especially in the presence of creep strain and cyclic plastic strain due to thermal shock (6) p 3. Caution is advised against extrapolating behavior from one set of conditions to another. Rather, it is suggested that tests be conducted under conditions closely simulating operation.
- 2.032 Summary of main stages of oxidation, Figure 2.032.
- 2.033 Typical plot of weight gain versus time in static oxidation Figure 2.033.
- 2.034 Dynamic oxidation tests at 1600 and 1800F indicating complexity of process. Weight gain occurs at 1600F, loss at 2000F, Figure 2.034.
- 2.035 Cyclic oxidation behavior with and without protective aluminum base diffusion coating, Figure 2.035.
- 2.0312 Platinum-Aluminum coatings.
- 2.03121 Typical weight change pattern for coated alloy cycled for one hour intervals at 2000F, followed by cooling to RT in 3 minutes. Figure shows data for Pt-Al alloy, with summary of results for several other alloys, Fig. 2.03121
- 2.0313 Corrosion.
- 2.03131 Effect of corrosive environment on weight change in bare and coated condition, Table 2.03131.
- 2.03132 Relative corrosion of various superalloys for two fuels of different sulfur content and two salt/air ratio contents, Fig. 2.03132.
- 2.03133 Correlation showing that low corrosion resistance of alloy is related to its low chromium content, Fig. 2.03133.
- 2.03134 Correlation showing that the low threshold temperature for corrosion is principally related to its low chromium content, Fig. 2.03134.
- 2.03135 Corrosion (as measured by depth of attack) for alloy in 700 FPS velocity gas jet using low sulfur fuel (JP4) with 4ppm and 8 ppm sea salt in inlet air, Fig. 2.03135.
- 2.03136 Corrosion (as measured by depth of attack) for alloy in 700 FPS velocity gas jet using high sulfur fuel (JP-4R) with 4 ppm and 8 ppm sea salt in inlet air, Fig. 2.03136.
- 2.03137 Hot corrosion resistance of thinwall alloy with two proprietary coatings in 1900F cyclic temperature test, Table 2.03137.
- 2.03138 Comparison of hot-corrosion behavior in a marine turbine simulator with other nickel - and cobalt-base alloys, Fig. 2.03138.
- 2.036 Dynamic oxidation at 1800F of alloy in two conditions of surface finish. Rougher surface promotes more rapid oxidation, Fig. 2.036.
- 2.037 Slurry coatings.
- 2.0371 Cyclic furnace oxidation in 20 hour cycles at 2000F of FeAl + Fe-Cr-Al aluminized slurry of average composition Fe-25Cr-Al, and comparison with oxidation of alloy protected by cladding of Fe-25Cr-4Al-1Y, Fig. 2.0371.
- 2.0372 Cyclic furnace oxidation in 20 hour cycles at 2000F of NiAl slurry coated alloy with comparison to oxidation of commercial conversion coating, Fig. 2.0372.
- 2.0373 Oxidation of NiAl aluminized slurry coating in Mac1 jet at 2000F, with comparison to commercial aluminide coating, Fig. 2.0373.
- 2.038 Metallized coatings.
- 2.0381 High gas velocity oxidation and thermal fatigue cracking at 1900F of alloy coated by an electrolytic fused salt process

- (metallized), and comparison with oxidation of bare alloy and pack aluminum coated alloy, Fig. 2.0381.
- 2.0382 High velocity oxidation and thermal fatigue cracking at 2000°F of alloy coated by an electrolytic fused salt process (metallized), and comparison with bare alloy and pack aluminum coated alloy, Fig. 2.0382.
- 2.0383 Static oxidation at 2000 and 2100°F of alloy coated by electrolytic fused salt process (metallizing), Fig. 2.0383.
- 2.0384 Comparison of static oxidation with oxidation in high velocity jet (Mach 1) at 2100°F for metallized coating, Fig. 2.0384.
- 2.039 Claddings
- 2.0391 Effect of cladding thickness on cyclic oxidation of Fe-25Cr-4Al-1Y clad alloy at 1900 and 2000°F, Fig. 2.0391.
- 2.0392 Effect of cladding thickness on cyclic oxidation of Ni-20Cr-4Al-1.2Si clad alloy at 1900 and 2000°F, Fig. 2.0392.
- 2.0393 Effect of cladding thickness on cyclic oxidation of Ni-30Cr-1.4Si at 1900 and 2000°F, Fig. 2.0393.
- 2.0310 Vapor deposited coatings.
- 2.03101 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, Fig. 2.03101.
- 2.0311 Embedded alumina particle coatings.
- 2.03111 Weight change and thermal fatigue cracking tendencies of alloy with EAPA (embedded alumina-particle aluminide) subjected to 1 hour cycles at 2000°F in Mach 1 jet burner, and comparison with performance of bare alloy and other types of coatings, Fig. 2.03111.
- 2.04 Nuclear Properties
3. MECHANICAL PROPERTIES
- 3.01 Specified Mechanical Properties  
See 3.032 and 3.033.
- 3.02 Mechanical Properties at Room Temperature  
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- 3.021 Room temperature tensile properties of as cast alloy in three levels of electron vacancy concentration, and at two levels of grain size, Table 3.021.
- 3.022 Mechanical properties at room temperature of forged alloy in three conditions of proneness to sigma phase precipitation. Properties shown after normal heat treatment and after heat treatment followed by exposure to elevated temperature, Table 3.022.
- 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,  $\bar{N}_v$ , relating to propensity toward sigma formation), Table 3.023.
- 3.024 Effect of exposure at 1550°F for 250 hour and for 2500 hour on room temperature tensile properties of alloy with Al-Ti composition varied to achieve 3 levels of electron vacancy concentration,  $\bar{N}_v$ , Fig. 3.024.
- 3.025 Room temperature tensile properties and hardness of powder metallurgy product prepared from powders of various compositions and grain size and consolidated by several processes, Table 3.025.
- 3.026 Tensile properties of superplastically formed pancake forging used in fatigue crack growth studies, Table 3.026.
- 3.027 Comparison of tensile properties of alloy with Ni-20Cr-4Al-1.2Si cladding alloy before and after oxidation, Fig. 3.027.
- 3.028 Stress-strain curves, See Fig. 3.03111
- 3.029 Impact
- 3.0291 Unnotched Charpy impact strength at room temperature after held for 500 or 1000 hours at elevated temperature, Fig. 3.0291.
- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension
- 3.0311 Stress-strain curves
- 3.03111 Stress-strain curves for as cast alloy at room and elevated temperatures, Fig. 3.03111
- 3.03112 Stress-strain curves for JoCoated alloy at room and elevated temperatures, Fig. 3.03111.
- 3.0312 Tensile properties
- 3.03121 Effect of test temperature on mechanical properties as cited by alloy developer, Fig. 3.03121.
- 3.03122 Tensile properties of as cast bar at room and elevated temperatures, Fig. 3.03122.
- 3.03123 Tensile properties of JoCoated bar at room and elevated temperatures, Fig. 3.03123.
- 3.0313 Heat treatment effects
- 3.03131 Effect of several solution heat treatments on the tensile properties at 1300°F, Table 3.03131.
- 3.0314 Coating and coating repair effects.
- 3.03141 Tensile properties at room and elevated temperatures of thinwall alloy coated with two proprietary coatings, Table 3.03141.
- 3.03142 Effect of coating, high temperature exposure, and several repair processes on tensile and yield strength at 1800°F compared to as cast uncoated base material, Fig. 3.03142
- 3.03143 Effect of coating, high temperature exposure, and several repair processes on elongation at 1800°F compared to as cast uncoated base material, Fig. 3.03143.
- 3.0315 Powder metallurgy product.
- 3.03151 Effect of reduction practice and heat treatment on the tensile properties at RT and 1200°F of powder metallurgy alloy, Table 3.03151.
- 3.03152 Tensile properties of specimen from powder alloy pancake at RT and 1300°F, with comparison to Pratt & Whitney specifications for alloy, Fig. 3.03152.
- 3.03153 Flow characteristics in the range of low strain rates and temperatures where superplasticity can be achieved, Fig. 3.03153.
- 3.03154 Relation between stress and high deformation rate at 1900 to 2100°F for alloy directly extruded from powder, Fig. 3.03154.
- 3.03155 High strain rate effect on elongation at fracture at 1900 to 2100°F for alloy directly extruded from powder, Fig. 3.03155.
- 3.03156 Superplasticity exhibited by powder metallurgy alloy, Fig. 3.03156.
- 3.0317 High pressure gas effects.
- 3.03171 Tensile properties at RT and 1250°F in 5000 psig helium and hydrogen, Table 3.03171.
- 3.032 Compression
- 3.0321 Effect of test temperature on compression yield strength for air melted and cast alloy and for vacuum melted and cast alloy, Fig. 3.0321.
- 3.033 Impact
- 3.0331 Effect of temperature on Charpy V impact energy, Fig. 3.0331.
- 3.034 Bending
- 3.035 Torsion and shear
- 3.036 Bearing
- 3.037 Stress concentration, (see also 3.05)
- 3.0371 Notch properties
- 3.0372 Fracture toughness
- 3.038 Combined properties
- 3.04 Creep and creep rupture properties, (see also 3.054)
- 3.041 Creep curves at various temperatures.
- 3.0411 Creep curves of as cast alloy at 1562°F, Fig. 3.0411.
- 3.0412 Creep curves for JoCoated alloy at 1562°F, Fig. 3.0412.
- 3.0413 Creep curves of as cast alloy at 1697°F, Fig. 3.0413.
- 3.0414 Creep curves for JoCoated alloy at 1697°F, Fig. 3.0414.
- 3.0415 Creep curves of as cast alloy at 1832°F, Fig. 3.0415.
- 3.0416 Creep curves for JoCoated alloy at 1832°F, Fig. 3.0416.
- 3.0417 Alloy developer's suggested design curves for creep strain and creep rupture at 1300°F, Fig. 3.0417.
- 3.0418 Alloy developer's suggested design curves for creep strain and creep rupture at 1500°F, Fig. 3.0418.
- 3.0419 Alloy developer's suggested design curves for creep strain and creep rupture at 1700°F, Fig. 3.0419.
- 3.04110 Alloy developer's suggested design curves for creep strain and creep rupture at 1800°F, Fig. 3.04110.
- 3.04111 Alloy developer's suggested design curves for creep strain and creep rupture at 1900°F, Fig. 3.04111.
- 3.04112 Minimum creep rate curves for temperatures from 1350 to 1900°F, Fig. 3.04112.
- 3.042 Creep of superplastically formed product.
- 3.0421 Creep and creep rupture properties of superplastically formed pancake forging used in fatigue crack growth

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

IN-100

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

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- 3.0433 studies, Table 3.0421.
- 3.0434 Relation of creep to creep rupture.
- 3.0435 Relation among start of third stage creep, time to 1% creep, and rupture time for as cast alloy, Fig. 3.0431.
- 3.0436 Relation among time of third stage creep, time to 1% creep, and rupture time for JoCoated alloy, Fig. 3.0432.
- 3.044 Effects of repair coatings on creep and creep rupture.
- 3.0441 Creep and rupture properties of alloy after repair of oxidation and mechanical damage effects, Fig. 3.0441.
- 3.045 Creep rupture, general.
- 3.0451 Typical creep rupture properties in life range from 10 to 10,000 hours at temperatures from 1300 to 2000F, Fig. 3.0451.
- 3.0452 Creep rupture curves for as cast alloy at 1562F, 1697F, and 1832F, Fig. 3.0452.
- 3.0453 Creep rupture data for as cast alloy as determined by developer, Fig. 3.0453.
- 3.046 Creep rupture, heat treatment effects.
- 3.0461 Effect of several solution heat treatments on the creep-rupture life at 1800F, 29 ksi, Table 3.0461.
- 3.047 Creep rupture, coating effects.
- 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, Table 3.0471.
- 3.0472 Creep rupture curves for JoCoated alloy at 1562F, 1697F and 1832F, Fig. 3.0472.
- 3.0473 Correlation between ductility and rupture time at 1562F, 1697F, and 1832F for JoCoated alloy, Fig. 3.0473.
- 3.0474 Creep rupture lives and elongations at 1450F and 1800F for thinwall alloy coated with two proprietary coatings, Table 3.0474.
- 3.048 Creep rupture, sigma phase instability effects.
- 3.0481 Beneficial effects on creep rupture behavior achieved by avoiding sigma phase precipitation, Table 3.0481.
- 3.0482 Creep rupture properties of forged alloy in three conditions of proneness to sigma phase precipitation, Table 3.0482.
- 3.0483 Creep rupture curves for fine grain alloy of composition sufficiently low in Al and Ti to avoid sigma precipitation, Fig. 3.0483.
- 3.0484 Creep rupture curves at 40ksi 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 1650F for 250 and 2500 hours, Fig. 3.0484.
- 3.0485 Creep rupture curves for fine grain alloys of low, medium and high electron vacancy concentration (Nv), representing progressively increasing tendency toward sigma phase precipitation. Curves show that strong tendency for sigma precipitation results in reduction of creep rupture strengths, Fig. 3.0485.
- 3.049 Creep rupture, powder metallurgy product.
- 3.0491 Creep rupture properties in very short time range at 1900 to 2100F for extruded alloy prepared from two lots of powder, Fig. 3.0491.
- 3.0492 Creep rupture curves at 1800F for cast alloy of various grain sizes and for alloy extruded from powders, Fig. 3.0492.
- 3.0410 Creep rupture in special environments.
- 3.04101 Creep rupture of alloy in helium, hydrogen, and hydrogen/water vapor at 1250F and 5000 psig pressure, Fig. 3.04101.
- 3.05 Fatigue properties.
- 3.051 Mechanically induced fatigue.
- 3.0511 Effect of aluminum base coating on rotating bending fatigue properties at room temperature, Table 3.0511.
- 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, Fig. 3.0512.
- 3.0513 Low cycle fatigue characteristics at 1700F of hollow specimen with two sets of diagonal holes, Fig. 3.0513.
- 3.0514 Strain-range partitioning life relationships for cast alloy at 1700F, Fig. 3.0514.
- 3.0515 Axial fatigue at 1650F of simulated hollow airfoils coated with proprietary coatings, Fig. 3.0515.
- 3.052 Thermally induced fatigue.
- 3.0521 Thermal shock fatigue characteristics of airfoil shape with and without aluminum base coating, Table 3.0521.
- 3.0522 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, Fig. 3.0522.
- 3.0523 Thermal fatigue crack initiation of as cast or directionally solidified alloy with and without JoCoat tested in alternate fluidized beds at 1990 and 600F, Fig. 3.0523.
- 3.0524 Thermal fatigue crack initiation of as cast or directionally solidified alloy with and without JoCoat tested in alternate fluidized beds at two sets of temperatures, Fig. 3.0524.
- 3.0525 Effect of cycle time on thermal fatigue cracking of coated and uncoated wedges alternately immersed in fluidized beds at 600 and 1990F, Fig. 3.0525.
- 3.0526 Effect of maximum cycle temperature 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.
- 3.0527 Relation between crack growth rate and resistance to initial cracking in thermal cycling, Fig. 3.0527.
- 3.0528 Thermal fatigue of thinwall alloy with two proprietary coatings subjected to 10.5 ksi tensile mean stress and to temperature cycling from 2050F, Table 3.0528.
- 3.0529 Correlation of time to initiate thermal cracking with weight gain slope parameter for alloy coated in various ways, Fig. 3.0529.
- 3.053 Mechanical loading of powder metallurgy product.
- 3.0531 Stress range variation during low cycle fatigue tests at 1200F of powder metallurgy bars prepared by Pratt & Whitney Aircraft Gatorizing process, Fig. 3.0531.
- 3.0532 Low cycle fatigue at 1200F of powder metallurgy bars prepared by Pratt and Whitney Gatorizing process. Data points represent cycles to complete fracture, Fig. 3.0532.
- 3.0533 Low cycle fatigue at 1200F of powder metallurgy bars prepared by Pratt and Whitney Aircraft Gatorizing process. Data points represent cycles to 5 percent load drop, Fig. 3.0533.
- 3.0534 Low cycle fatigue at 1200F of specimen from powder metallurgy compressor disk, Fig. 3.0534.
- 3.054 Crack growth in steady loading or continuous cycling.
- 3.0541 Basic crack growth curves at RT, 1200F and 1350F for constant amplitude loading of WOL specimen, Fig. 3.0541.
- 3.0542 Effect of net section stress on crack growth rate at 1200F, Fig. 3.0542.
- 3.0543 Effect of temperature and specimen thickness on sustained load crack propagation rate, Fig. 3.0543.
- 3.0544 Effect of specimen thickness on crack growth rate at RT, Fig. 3.0544.
- 3.0545 Effect of frequency on crack growth rate in continuous cycling at 1200F, Fig. 3.0545.
- 3.0546 Effect of temperature on crack growth rate at 10cpm, R = 0.1, Fig. 3.0546.
- 3.0547 Effect of stress ratio on crack growth rate at 1200F, 10cpm, Fig. 3.0547.
- 3.0548 Effect of stress ratio on crack growth rate at 1200F, 20cps, Fig. 3.0548.
- 3.0549 Effect of specimen thickness on crack growth rate at 1200F, continuous cycling at 10cpm, Fig. 3.0549.
- 3.055 Crack growth-overload effects.
- 3.0551 Crack growth at 1200F under continuous cycling and with 50 percent overload every 5, 20, or 40 cycles, Fig. 3.0551.
- 3.0552 Crack growth at 1200F under continuous cycling and with 25 percent or 50 percent overloads every 21 cycles, Fig. 3.0552.
- 3.0553 Crack growth at 1200F under sustained load and with 25 percent or 50 percent overloads every 2 minutes, Fig. 3.0553.
- 3.056 Crack growth-dwell periods.
- 3.0561 Effect of net section stress on crack growth rate for 2 minute dwell at peak stress at 1200F, Fig. 3.0561.
- 3.0562 Effect of specimen thickness on crack growth rate at 1200F. Two minute dwell at max load, 10cpm during variable stress period, Fig. 3.0562.
- 3.0564 Effect of dwell time at peak stress on crack growth rate at 1200F, R = 0.1, Fig. 3.0563.
- 3.0565 Crack growth at 1350F under continuous cycling, or with 25 and 50 percent overload, or with 2 minute dwell at the

- 3.0565 50 percent overload condition, Fig. 3.0564.  
Interaction of low cycle fatigue with dwell periods at max load for tests at 1290F,  $R = 0.1$ , Fig. 3.0565.
- 3.0566 Interaction of low cycle fatigue with dwell periods at max load for tests at 1250F,  $R = 0.1$ , Fig. 3.0566.
- 3.057 Crack growth-delay effects due to overloads.
- 3.0571 Delay cycles prior to resumption of basic crack growth after single cycle of overload. Baseline  $K_{max} = 23.2 \text{ ksi } \sqrt{\text{in}}$ , Fig. 3.0571.
- 3.0572 Delay cycles prior to resumption of basic crack growth after single cycle of overload. Baseline  $K_{max} = 35.2 \text{ ksi } \sqrt{\text{in}}$ , Fig. 3.0572.
- 3.058 Helium and hydrogen effects at high pressure.
- 3.0581 Low cycle fatigue at 1250F in high pressure hydrogen and helium, Fig. 3.0581.
- 3.0582 High cycle axial fatigue in high pressure hydrogen and helium at 1250F, Fig. 3.0582.
- 3.05141 Inelastic strain range vs. low-cycle fatigue life for each partitioned strain range component for as-cast thinwall tubing at 1700F, Fig. 3.05141.
- 3.05142 Strainrange partitioning life relationships at 1652F and 1832F for as-cast aluminum-coated alloy, Fig. 3.05142.
- 3.05143 Inelastic strainrange vs. low-cycle fatigue life for each partitioned strainrange component at 1409F. Specimens from creep-formed (Gatorized<sub>TM</sub>) turbine disk, Fig. 3.05143.
- 3.05144 Total strain range vs. low-cycle fatigue life at 1200F of powder metallurgy bars prepared by Pratt & Whitney Gatorizing<sub>TM</sub> process and tested under rapid strain cycling, tensile stress-hold, and tensile strain-hold, Fig. 3.05144.
- 3.05145 Inelastic strainrange vs. low cycle fatigue life at 1200F of powder metallurgy bars prepared by Pratt and Whitney Gatorizing<sub>TM</sub> process and tested under rapid strain cycling, tensile stress-hold, and tensile strain-hold, Fig. 3.05145.
- 3.06 Elastic properties
- 3.061 Poisson's ratio, 0.298
- 3.062 Dynamic modulus of elasticity, Fig. 3.062.
- 3.063 Modulus of rigidity
- 4.0 FABRICATION
- 4.1 Strength of shaped parts
- 4.11 Mechanical properties from RT to 1360F of specimens from the 10-12th stage compressor of F100/F401 engine, Fig. 4.11.
- 4.12 Room temperature tensile strength of fir tree simulating turbine blade attachment, Table 4.12.
- 4.13 Creep rupture at 1409F of fir tree simulating turbine blade attachment, Fig. 4.13.
- 4.14 Fatigue at RT under combined static and vibratory stress of turbine blade fir tree fastening, Table 4.14.
- 4.2 Welding and joining
- 4.21 Weldments
- 4.211 Room temperature tensile strength of weldment to Waspaloy, Table 4.211.
- 4.212 Creep rupture at 1409F of electron beam weldment to Waspaloy, Table 4.212.
- 4.213 Fatigue at RT under combined static and vibratory stress of electron beam weldment to Waspaloy, Table 4.213.
- 4.22 Brazed joints
- 4.221 Room temperature tensile strength of brazed attachment to Waspaloy, Table 4.221.
- 4.222 Fatigue at RT under combined static and vibratory stress of brazed joint simulating turbine blade fastening to Waspaloy, Table 4.222.
- 4.23 TLP bonding
- 4.231 Tensile properties at 1409F for TLP bond between cast alloy and wrought Udimet 700, Table 4.231.

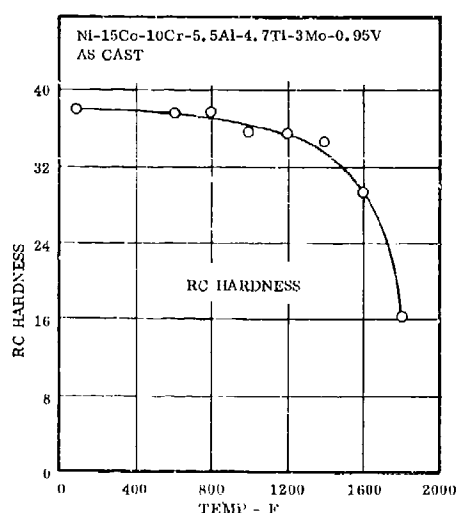
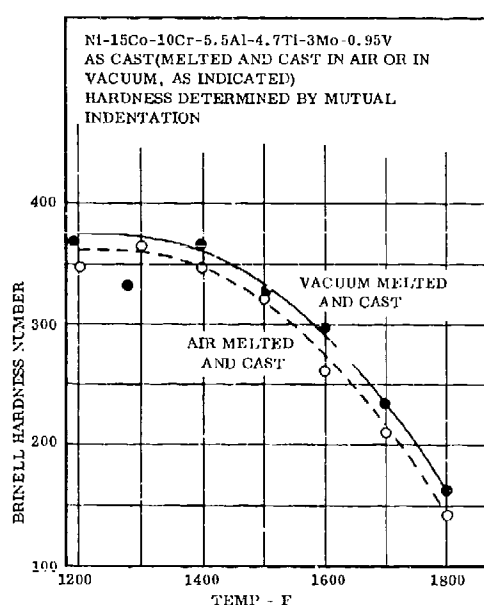
|      |    |
|------|----|
|      | Ni |
| 15   | Co |
| 10   | Cr |
| 5.5  | Al |
| 4.7  | Ti |
| 3    | Mo |
| 0.95 | V  |

IN-100

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

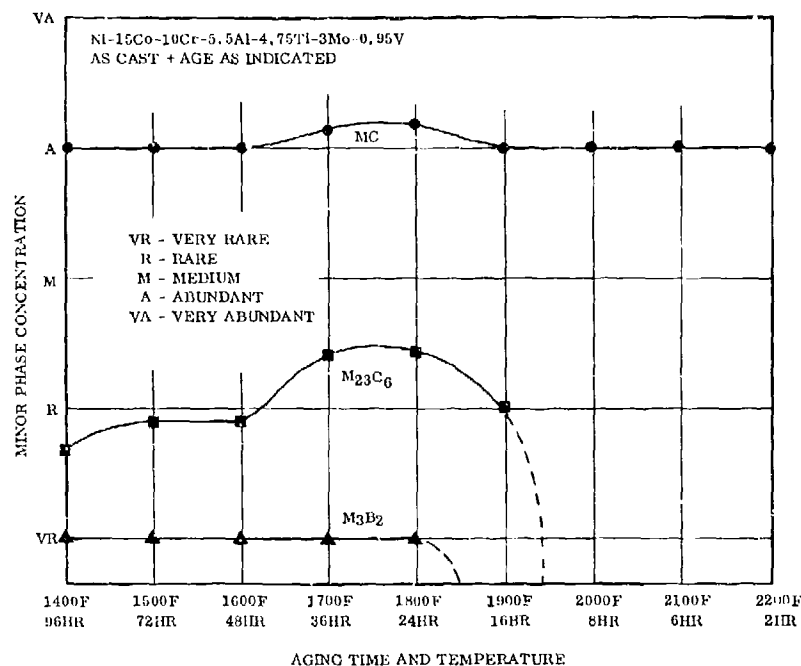
| Alloy               | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                   |     |                             |      |                           |     |
|---------------------|------------------------------------------------------|-----|-----------------------------|------|---------------------------|-----|
| Condition           | As Cast                                              |     |                             |      |                           |     |
| Source              | Original Inco spec. (1960-1965) also GE spec C50T77A |     | New Inco spec. also AMS5397 |      | GE Rene' 100 spec C50T77C |     |
|                     | Percent                                              |     | Percent                     |      | Percent                   |     |
|                     | Min                                                  | Max | Min                         | Max  | Min                       | Max |
| Cobalt              | 13                                                   | 17  | 13                          | 17   | 14                        | 16  |
| Chromium            | 8                                                    | 11  | 8                           | 11   | 9                         | 10  |
| Aluminum            | 5                                                    | 6   | 5                           | 6    | 5.3                       | 5.7 |
| Titanium            | 4.5                                                  | 5.5 | 4.5                         | 5.0  | 4.0                       | 4.4 |
| Aluminum + Titanium | -                                                    | -   | 10                          | 11   | -                         | -   |
| Molybdenum          | 2                                                    | 4   | 2                           | 4    | 2.7                       | 3.3 |
| Iron                | 0                                                    | 1   | 0                           | 1    | 0                         | 1   |
| Vanadium            | .7                                                   | 1.2 | .7                          | 1.2  | .9                        | 1.1 |
| Boron               | .01                                                  | .02 | .01                         | .02  | .01                       | .02 |
| Carbon              | .15                                                  | .20 | .15                         | .20  | .15                       | .20 |
| Manganese           | -                                                    | -   | -                           | .10  | -                         | -   |
| Sulfur              | -                                                    | -   | -                           | .015 | -                         | -   |
| Silicon             | -                                                    | -   | -                           | .15  | -                         | -   |
| Nickel              | Balance                                              |     | Balance                     |      | Balance                   |     |

TABLE 1.04 COMPOSITION

FIG. 1.062 EFFECT OF TEMPERATURE ON HARDNESS  
(4, 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  
(32, FIGS. 1, 2)

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## NONFERROUS ALLOYS



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

FIG. 2.0120 EFFECT OF AGING TIME AND TEMPERATURE ON MINOR PHASE CONCENTRATION (2, FIG. 1)

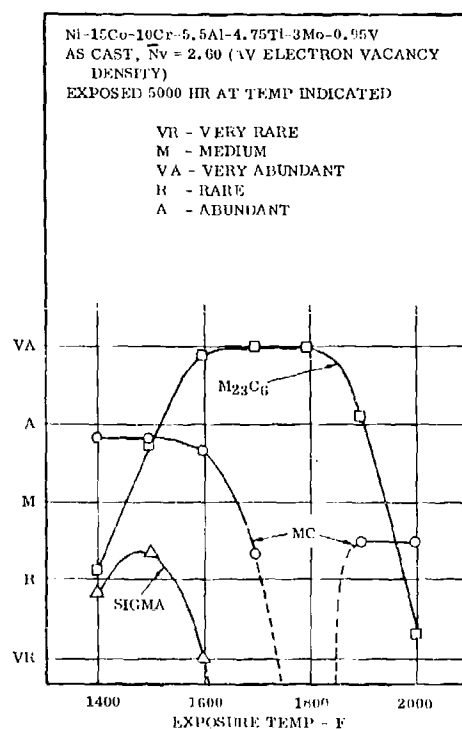


FIG. 2.0121 EFFECT OF EXPOSURE FOR 5000 HR AT VARIOUS TEMPERATURES ON MINOR PHASE CONCENTRATION (21, 14, 82, 84)

|      |    |
|------|----|
|      | 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)  
ACTUAL COMPOSITION FOR 2 LEVELS OF  $\bar{N}_v$   
MED  $\bar{N}_v$  (2.49): NI-13.3Co-10.14Cr-5.5Al-4.29Ti-3.55Mo-0.96V  
HIGH  $\bar{N}_v$  (2.65): NI-13.3Co-10.12Cr-5.6Al-4.69Ti-3.51Mo-0.97V

ALL ALLOYS MADE FROM SAME MASTER HEAT. ADDITIONS OF AL AND TI MADE DURING CASTING TO ACHIEVE DESIRED LEVEL OF ELECTRON VACANCY CONCENTRATION ( $\bar{N}_v$ )  
TESTED AS CAST OR FORGED TO PANCAKE IN FOLLOWING STEPS:

1. EXTRUSION AT 2050F FROM 5 IN DIA INGOT TO 3 1/8 IN STEEL PIPE
2. FLATTENED AT 2050F TO 1 3/4 IN DIA PANCAKE
3. FLATTENED AT 2050F TO 1 IN DIA PANCAKE
4. FLATTENED AT 2050F TO 5/8 IN DIA PANCAKE

TEST SPECIMEN 1/4 IN DIA BAR x 1 1/4 IN GAGE LENGTH EXPOSED WITHOUT STRESS FOR TIMES AND TEMP SHOWN

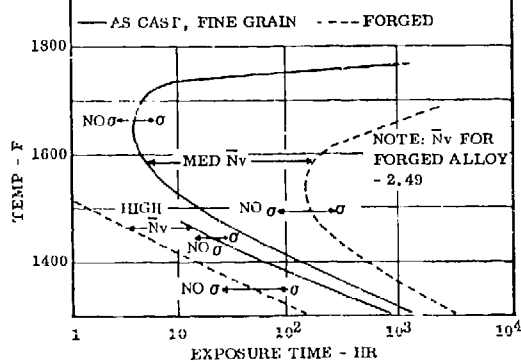


FIG. 2.0122 TRANSFORMATION TO SIGMA PHASE FOR AS CAST AND FORGED ALLOY FOR TWO LEVELS OF ELECTRON VACANCY CONCENTRATION (22, pp. 14, 19, 23)

NI-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V (NOMINAL)  
ACTUAL COMPOSITION FOR TWO LEVELS OF  $\bar{N}_v$

MEDIUM  $\bar{N}_v$  (2.49): NI-13.3Co-10.14Cr-5.5Al-4.29Ti-3.55Mo-0.96V  
HIGH  $\bar{N}_v$  (2.65): NI-13.3Co-10.12Cr-5.6Al-4.69Ti-3.51Mo-0.97V

ALL ALLOYS MADE FROM SAME MASTER HEAT. ADDITIONS OF AL AND TI MADE DURING CASTING TO ACHIEVE DESIRED LEVEL OF ELECTRON VACANCY CONCENTRATION  $\bar{N}_v$   
COARSE GRAIN ALLOYS PREPARED BY NORMAL INVESTMENT CASTING PROCEDURES; FINE GRAIN ALLOYS PREPARED BY MOLD INNOCULATION

TEST SPECIMEN 1/4 IN DIA x 1 1/4 IN GAGE LENGTH

EXPOSED WITHOUT STRESS FOR TIMES AND TEMPERATURES INDICATED

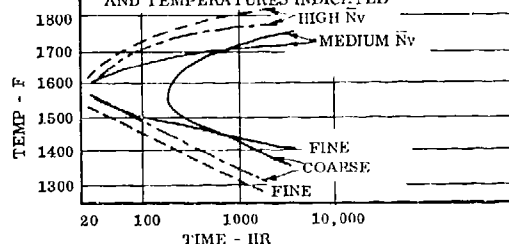


FIG. 2.0123 TIME-TEMPERATURE RELATION FOR THE ONSET OF SIGMA PHASE PRECIPITATION FOR MEDIUM AND HIGH ELECTRON VACANCY ( $\bar{N}_v$ ) COMPOSITIONS, AND IN FINE AND COARSE GRAIN SIZE STRUCTURE. (23, pp. 3, 7, 8)

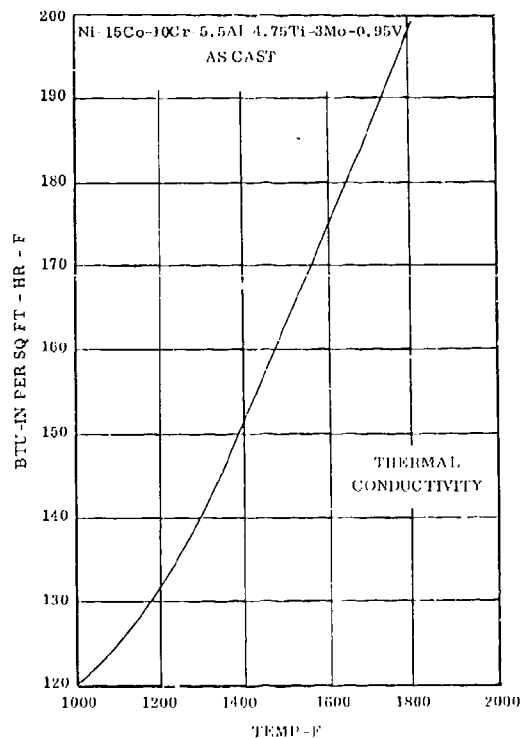


FIG. 2.013 THERMAL CONDUCTIVITY (11p.C-15)

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NONFERROUS ALLOYS

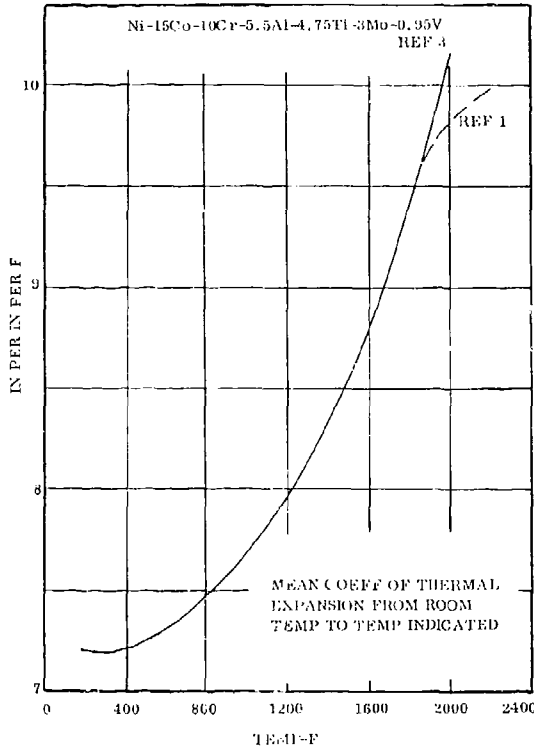


FIG. 2.014 COEFFICIENT OF THERMAL EXPANSION  
(1,p.C-14)(3,p.10)

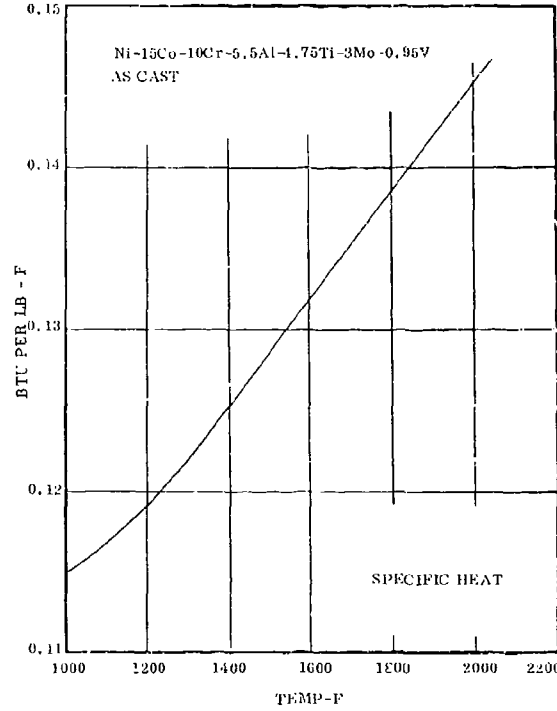


FIG. 2.016 SPECIFIC HEAT (1) p.C-15

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

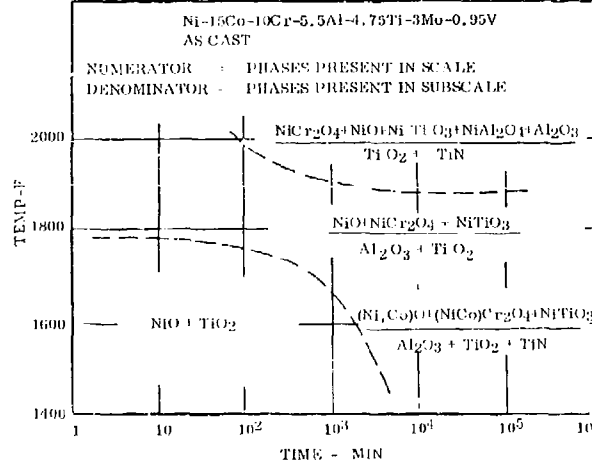


FIG. 2.032 SUMMARY OF MAIN STAGES OF OXIDATION (6)p.98

Ni  
 15  
 10  
 5.5  
 4.7  
 3  
 0.95 V  
 IN-100

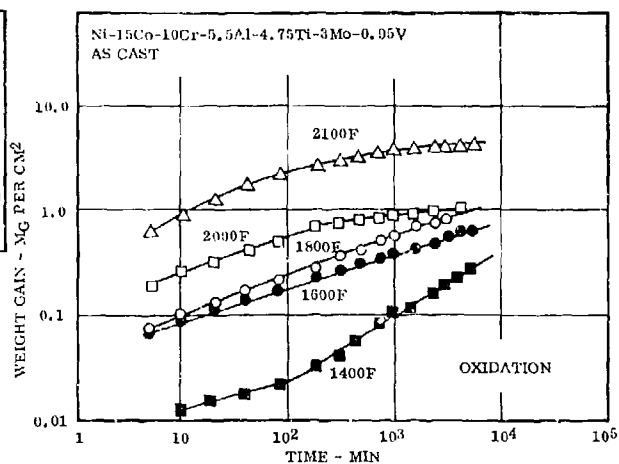


FIG. 2.033 TYPICAL PLOT OF WEIGHT GAIN VS TIME IN STATIC OXIDATION (6, p. 38)

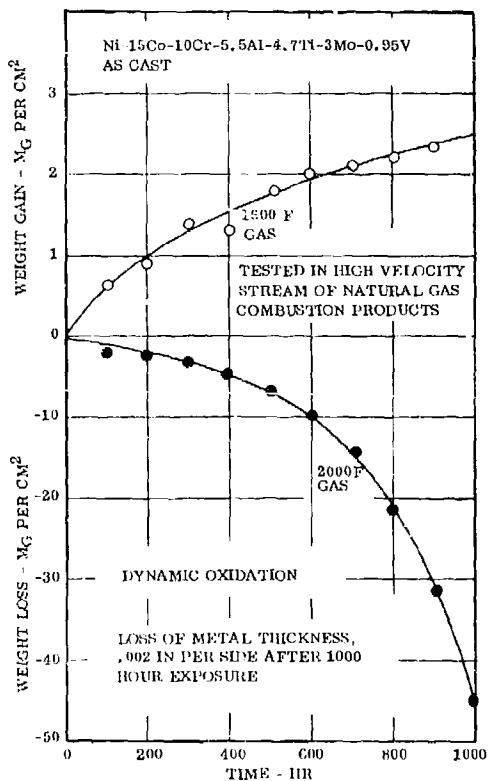


FIG. 2.034 DYNAMIC OXIDATION TESTS AT 1600F AND 1800F INDICATING COMPLEXITY OF PROCESS. WEIGHT GAIN OCCURS AT 1600F, LOSS AT 2000 F (6, pp. 131, 132)

Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V  
 AS CAST  
 TESTED IN CYCLIC OXIDATION:  
 55 MIN @ 2000F IN OXYACETYLENE FLAME + 5 MIN  
 COOL TO 750F + REPEAT TEST EACH HOUR

CEMENTATION WITH NC-101, AN ALUMINUM BASE  
 DIFFUSION COATING (SYLCOR DIV. SYLVANIA  
 ELECTRIC PRODUCTS, HICKSVILLE, N.Y.)

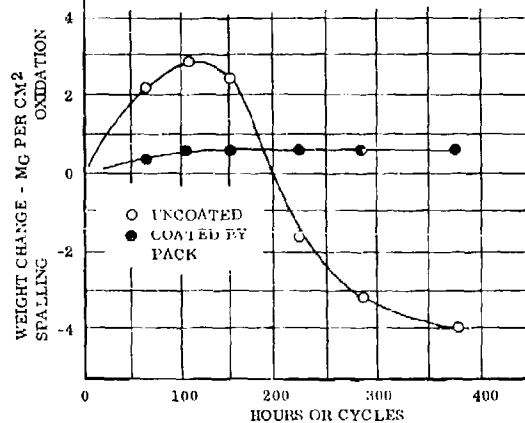


FIG. 2.035 CYCLIC OXIDATION BEHAVIOR WITH AND WITHOUT PROTECTIVE ALUMINUM BASE DIFFUSION COATING (7, pp. 33)(8)(9)

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## NONFERROUS ALLOYS

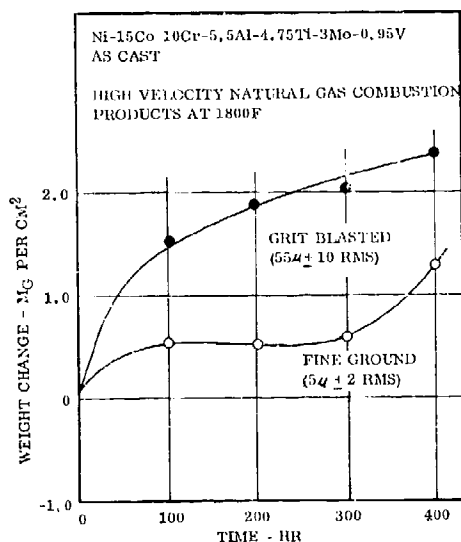


FIG. 2.036 DYNAMIC OXIDATION AT 1800F OF ALLOY IN TWO CONDITIONS OF SURFACE FINISH. ROUGHER SURFACE PROMOTES MORE RAPID OXIDATION (G. p. 162)

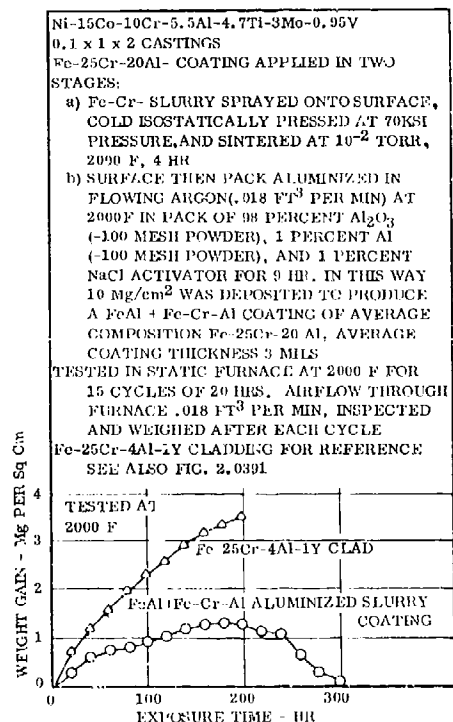


FIG. 2.0371 CYCLIC FURNACE OXIDATION IN 20 HR CYCLES AT 2000 F OF FeAl+Fe-Cr-Al ALUMINIZED SLURRY OF AVERAGE COMPOSITION Fe-25Cr-Al, AND COMPARISON WITH OXIDATION OF ALLOY PROTECTED BY CLADDING OF Fe-25Cr 4Al 1Y (41, pp. 3,4,18)

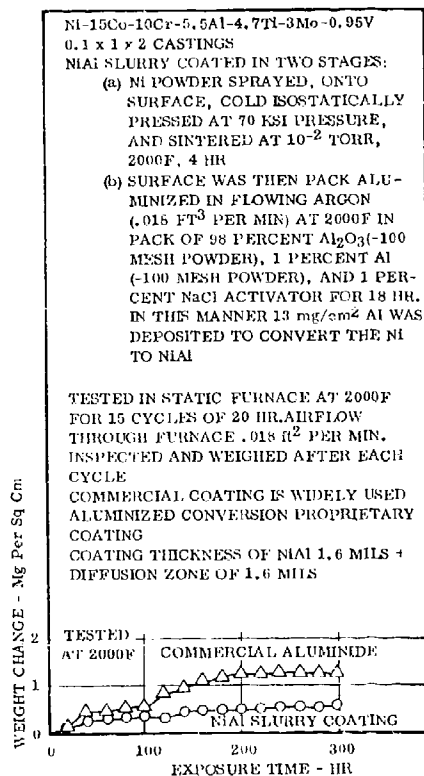


FIG. 2.0372 CYCLIC FURNACE OXIDATION IN 20 HR CYCLES AT 2000F OF NIAI SLURRY COATED ALLOY WITH COMPARISON TO OXIDATION OF COMMERCIAL CONVERSION COATING (41, pp. 3,4,14)

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

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

IN-100

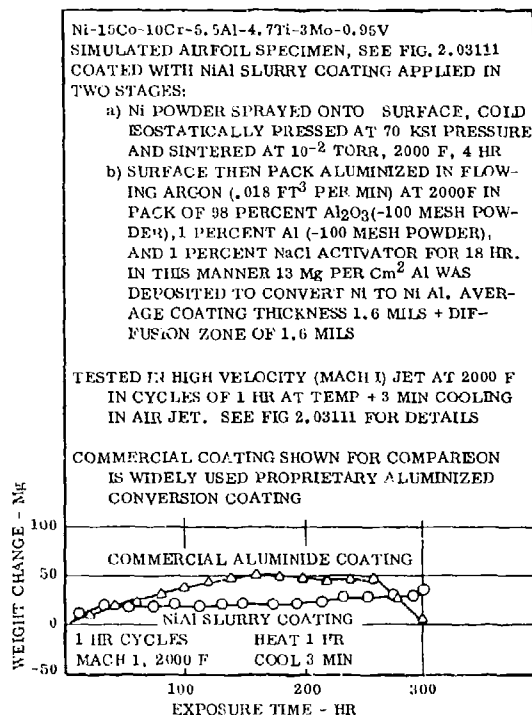


FIG. 2.0373 OXIDATION OF NIAI SLURRY COATING IN MACH 1 JET AT 2000F WITH COMPARISON TO COMMERCIAL ALUMINIDE COATING (41, pp. 3,4,20)

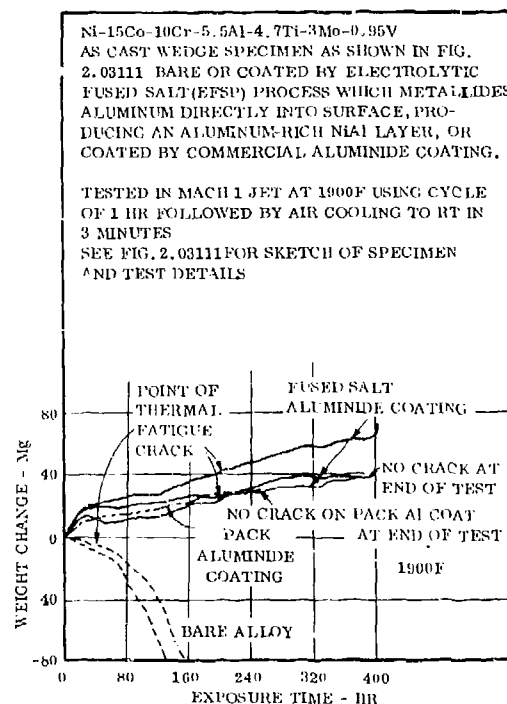


FIG. 2.0381 HIGH GAS VELOCITY OXIDATION AND THERMAL FATIGUE CRACKING AT 1900F OF ALLOY COATED BY AN ELECTROLYTIC FUSED SALT PROCESS (METALLIZED), AND COMPARISON WITH OXIDATION OF BARE ALLOY AND PACK ALUMINUM COATED ALLOY. (43, pp.2,3,20)

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## NONFERROUS ALLOYS

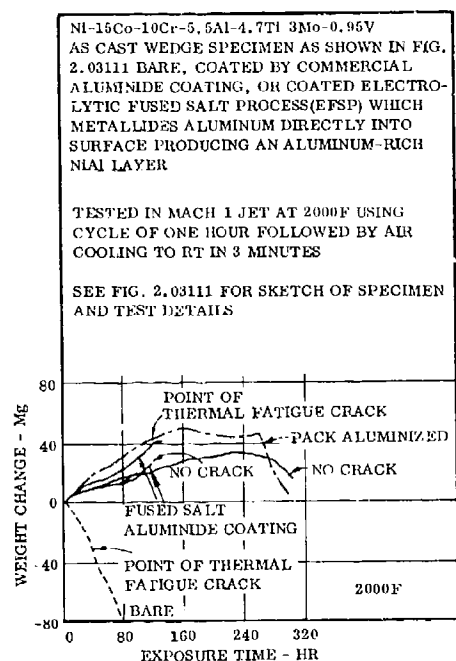


FIG. 2.0382 HIGH VELOCITY OXIDATION AND THERMAL FATIGUE CRACKING AT 2000F OF ALLOY COATED BY AN ELECTROLYTIC FUSED SALT PROCESS(METALLIDED), AND COMPARISON WITH BARE ALLOY AND PACK ALUMINUM COATED ALLOY. (43, pp.2,3,21)

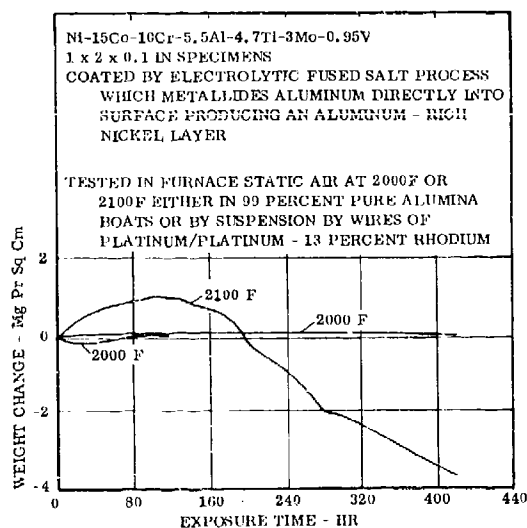


FIG 2.0383 STATIC OXIDATION AT 2000 AND 2100F OF ALLOY COATED BY ELECTROLYTIC FUSED SALT PROCESS (METALLIDING) (43, pp.2,22)

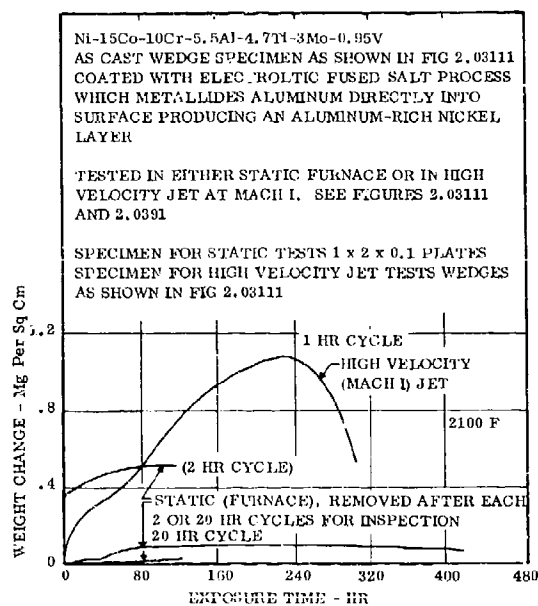


FIG. 2.0384 COMPARISON OF STATIC OXIDATION WITH OXIDATION IN HIGH VELOCITY JET (MACH 1) AT 2100 F FOR METALLIDED COATING (43, pp.2,22)

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

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

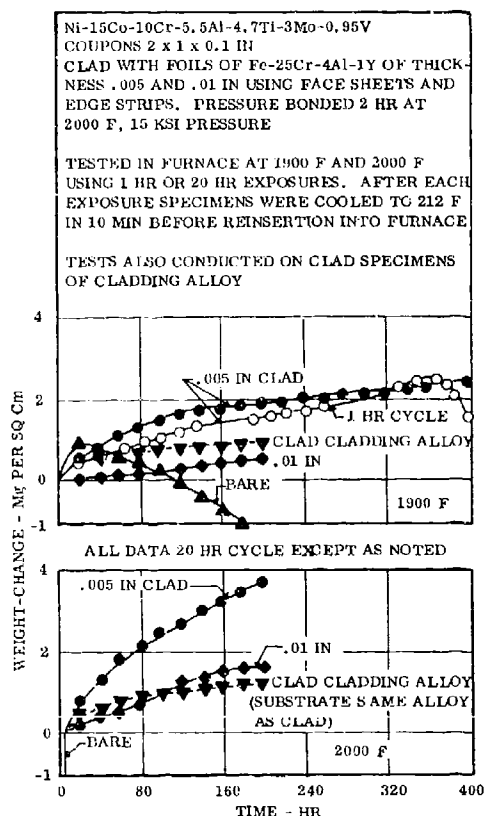


FIG. 2.0391 EFFECT OF CLADDING THICKNESS ON CYCLIC  
 OXIDATION OF Fe-25Cr-4Al-1Y CLAD ALLOY  
 AT 1900 AND 2000 F (42, pp. 2,3,29)

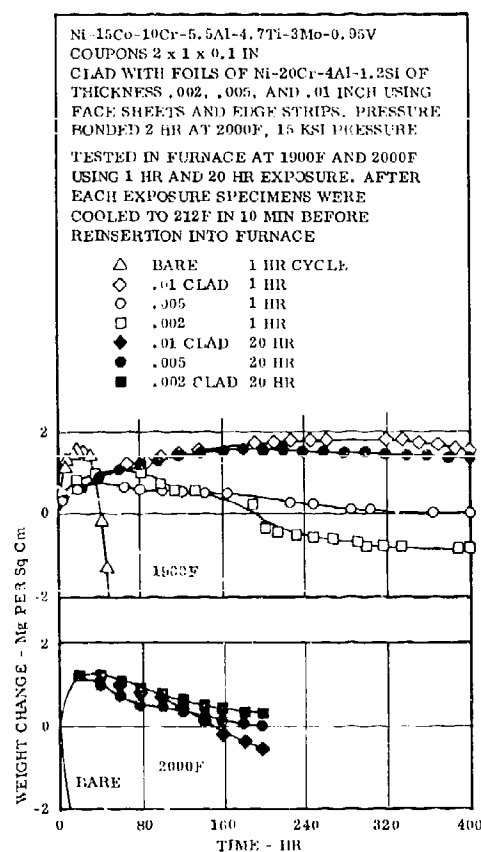


FIG. 2.0392 EFFECT OF CLADDING THICKNESS ON  
 CYCLIC OXIDATION OF Ni-20Cr-4Al-1.2Si  
 CLAD ALLOY AT 1900F AND 2000F  
 (42, pp. 2, 3, 25)

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

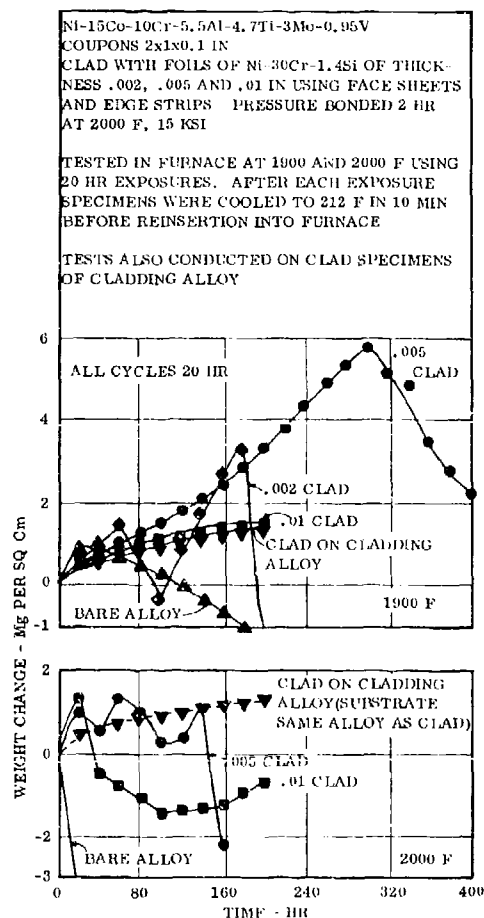


FIG. 2.0393 EFFECT OF CLADDING THICKNESS ON CYCLIC  
OXIDATION OF NI-30CR-1.4SI AT 1900 AND  
2000 F (42, pp. 2, 3, 33)

|      |    |
|------|----|
|      | 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 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

| TYPE OF COATING             | TOTAL THICKNESS<br>OF COATING<br>IN | THICKNESS OF<br>OUTER LAYER<br>IN |
|-----------------------------|-------------------------------------|-----------------------------------|
| □ CoCrAlY                   | .0040 TO .0055                      | .004 TO .0048                     |
| △ COMMERCIAL PACK ALUMINIDE | .0033                               | .0017                             |
| ○ NO PARTICLE EMBEDMENT     | .0017                               | .0012                             |

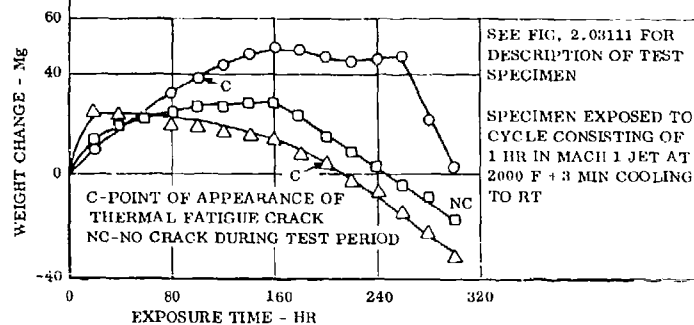


FIG. 2.03101 WEIGHT CHANGE AND THERMAL FATIGUE CRACKING TENDENCIES OF ALLOY WITH VAPOR DEPOSITED CoCrAlY COATING AND COMPARISON WITH PERFORMANCE OF ALLOY COATED BY COMMERCIAL PACK ALUMINIDE PROCESS (44, pp. 3, 18, 26)

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## NONFERROUS ALLOYS

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

IN-100

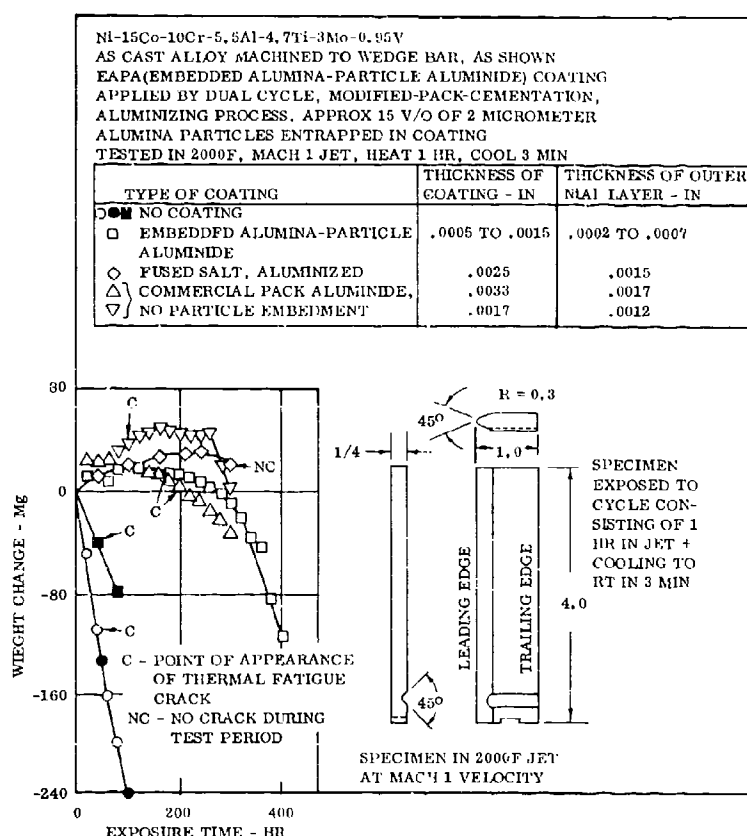


FIG. 2.03111 WEIGHT CHANGE AND THERMAL FATIGUE CRACKING TENDENCIES  
 OF ALLOY WITH EAPA(EMBEDDED ALUMINA-PARTICLE ALUMINIDE)  
 SUBJECTED TO 1 HR CYCLES AT 2000F IN MACH 1 JET BURNER, AND  
 COMPARISON WITH PERFORMANCE OF BARE ALLOY AND OTHER  
 TYPES OF COATINGS (44, pp. 2, 18, 22)

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

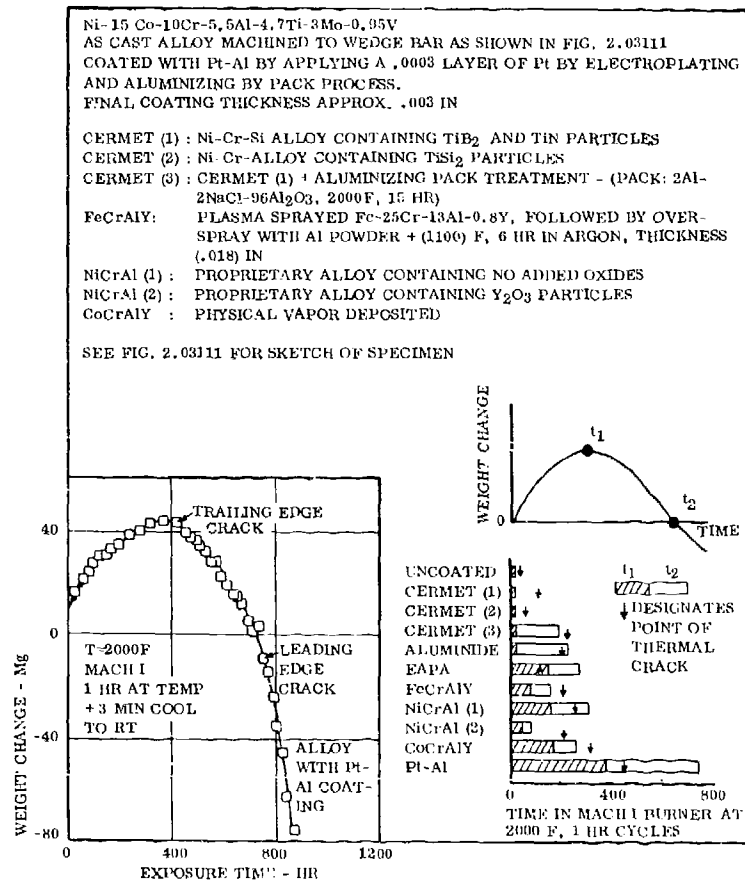


FIG. 2.03121 TYPICAL WEIGHT CHANGE PATTERN FOR COATED ALLOY CYCLED FOR ONE HR INTERVALS AT 2090 F, FOLLOWED BY COOLING TO RT IN 3 MIN  
 FIGURE SHOWS DATA FOR Pt-Al ALLOY WITH SUMMARY OF RESULTS FOR SEVERAL OTHER ALLOYS  
 (45, pp. 2, 3, 13, 14)

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## NONFERROUS ALLOYS

|               |                                    |
|---------------|------------------------------------|
| Alloy         | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V |
| Source        | Haynes (10) p. 5                   |
| Condition     | As Cast, Corrosion Tested (a)      |
|               | Wt. Change (a)                     |
|               | Mg per Cm <sup>2</sup> (Loss)      |
| Bare          | 71.3                               |
| Coating C - 3 | 9.5                                |
| Coating C - 9 | 9.4                                |

(a) Exposed 1 hr in Na<sub>2</sub>SO<sub>4</sub> + 0.5 percent NaCl at 1652F.

TABLE 2.03131 EFFECT OF CORROSIVE ENVIRONMENT ON WEIGHT CHANGE IN BARE AND COATED CONDITION

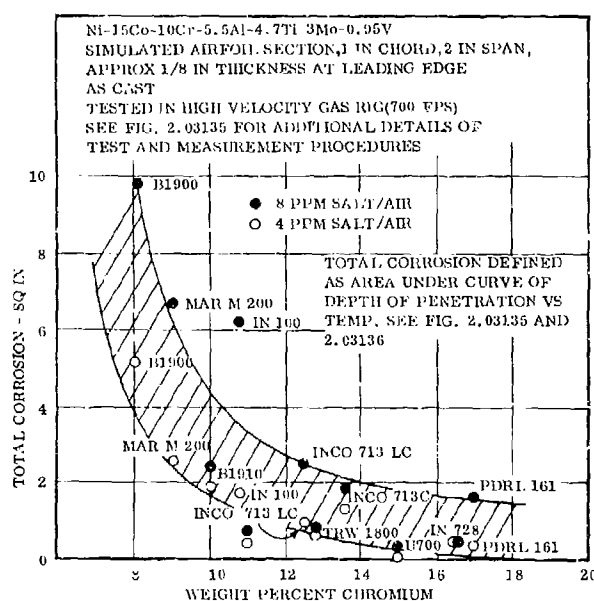


FIG. 2.03133 CORRELATION SHOWING THAT LOW CORROSION RESISTANCE OF ALLOY IS RELATED TO ITS LOW CHROMIUM CONTENT (27, p. 132)

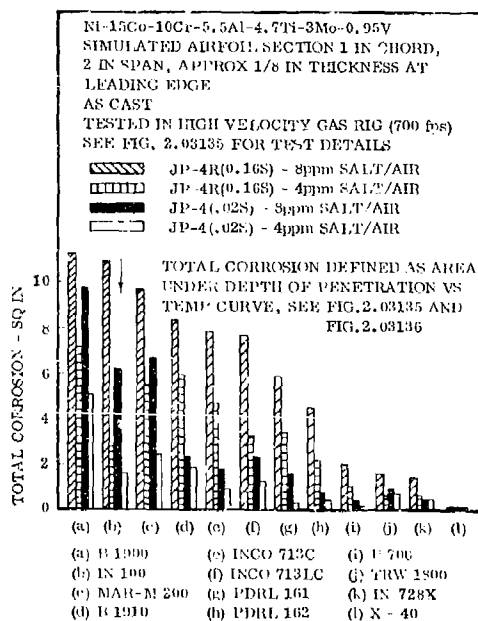


FIG. 2.03132 RELATIVE CORROSION OF VARIOUS SUPERALLOYS FOR TWO FUELS OF DIFFERENT SULFUR CONTENT AND TWO SALT/AIR RATIO CONTENTS (27, p. 131)

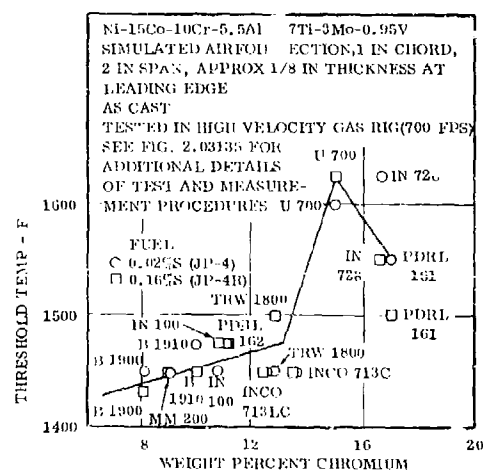


FIG. 2.03134 CORRELATION SHOWING THAT THE LOW THRESHOLD TEMPERATURE FOR CORROSION IS PRINCIPALLY RELATED TO ITS LOW CHROMIUM CONTENT (27, p. 33)

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

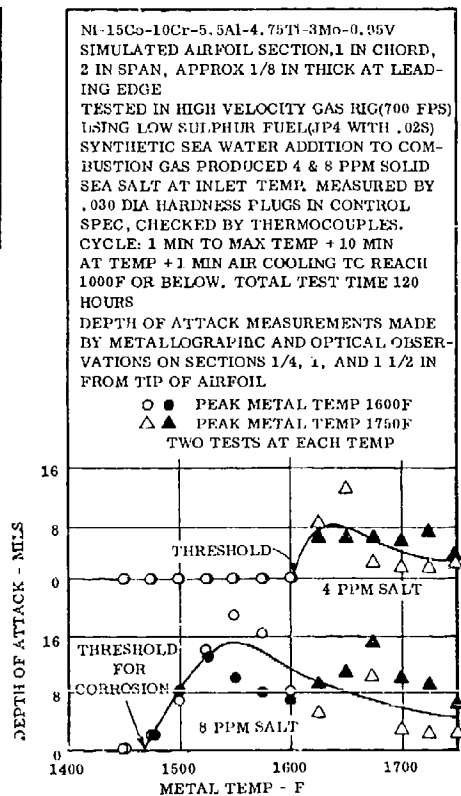


FIG. 2.03135 CORROSION (AS MEASURED BY DEPTH OF  
 ATTACK) FOR ALLOY IN 700 FPS VELOCITY  
 GAS JET USING LOW SULPHUR FUEL (JP4)  
 WITH 4 PPM AND 8 PPM SEA SALT IN INLET AIR  
 (27, pp. 1-6, 76, 88)

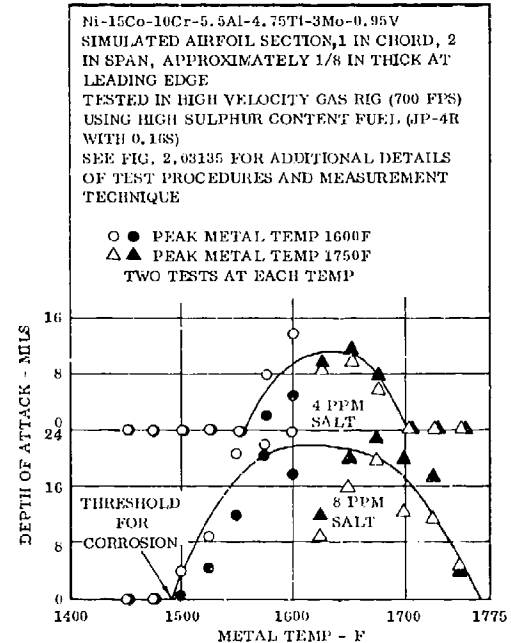


FIG. 2.03136 CORROSION (AS MEASURED BY DEPTH OF  
 ATTACK) FOR ALLOY IN 700 FPS VELOCITY  
 GAS JET USING HIGH SULPHUR FUEL (JP-4R)  
 WITH 4 PPM AND 8 PPM SEA SALT IN INLET  
 AIR (27, pp. 1-6, 100, 112)

|           |                                                                                                                                                                     |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Source    | (46) pp 2, 3, 7, 16, 18                                                                                                                                             |
| Alloy     | Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V                                                                                                                                 |
| Coating   | Coating Al-Cr-Mn: 1900F, 1.5 hr + 3 hr cool from pack + 1600F, 50 hr.                                                                                               |
| Coating   | Coating AEP No.32: RT application + 2000F, 2 hr + 1600F, 50 hr.                                                                                                     |
| Specimen  | Standard T56-A-9 solid turbine blades                                                                                                                               |
| Test      | Heat blades rotating at 1800 rpm in city gas-fired furnace to 1900F. Spray with aspirated 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 .01 IN <sup>2</sup> (0.1 IN on each side)                               |
|           | Av. No. cycles to hot corrosion failure (6 specimens)                                                                                                               |
|           | Coated with Al-Cr-Mn - 713                                                                                                                                          |
|           | Coated with AEP No.32 - 541                                                                                                                                         |

TABLE 2.03137 HOT CORROSION RESISTANCE OF THINWALL ALLOY  
 WITH TWO PROPRIETARY COATINGS IN 1900F CYCLIC  
 TEMPERATURE TEST

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

IN-100

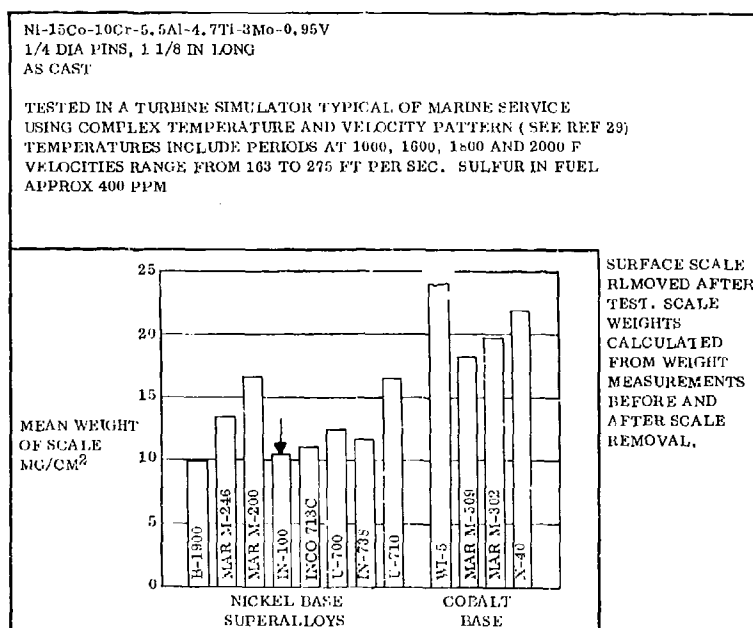


FIG. 2.03138 COMPARISON OF HOT-CORROSION BEHAVIOR IN A MARINE TURBINE  
SIMULATOR WITH OTHER NICKEL-AND COBALT-BASE ALLOYS (29, pp. 1-17)

|                                                                          |                                                     |                        |                      |               |
|--------------------------------------------------------------------------|-----------------------------------------------------|------------------------|----------------------|---------------|
| Source                                                                   | (23) p 9                                            |                        |                      |               |
|                                                                          | Nominal: Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V         |                        |                      |               |
| Alloy                                                                    | For actual compositions see Fig. 3.024 (1)          |                        |                      |               |
| Condition                                                                | As Cast, Various Compositions and Grain Sizes Noted |                        |                      |               |
| Test specimen & test condition                                           | 1/2 in. dia x 1 1/4 in.                             | C.L. tested at RT (2)  |                      |               |
| Level of electron vacancy concentration, N <sub>v</sub> , and grain size | F <sub>tu</sub><br>ksi                              | F <sub>ty</sub><br>ksi | e(1% in.)<br>Percent | RA<br>Percent |
| Low N <sub>v</sub> , Fine Grain Size                                     | 141.0                                               | 101.9                  | 12                   | 11            |
| Medium N <sub>v</sub> , Fine Grain Size                                  | 153.2                                               | 112.5                  | 9.5                  | 8.5           |
| High N <sub>v</sub> , Fine Grain Size                                    | 142.6                                               | (3) 96.7               | 9.0                  | 9.0           |
| Low N <sub>v</sub> , Coarse Grain Size                                   | 142.2                                               | 102.6                  | 9.0                  | 9.0           |
| Medium N <sub>v</sub> , Coarse Grain Size                                | 128.7                                               | 99.9                   | 7.0                  | 9.0           |
| High N <sub>v</sub> , Coarse Grain Size                                  | 128.3                                               | 106.2                  | 3.5                  | 6.0           |
| Min. required by AMS 5397                                                | 115.0                                               | 95.0                   | 5.0                  | -             |

(1) Three alloys with minor variations in composition, achieved by additions of Al & Ti to same master heat. Several levels of electron vacancy concentration, N<sub>v</sub>, 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 3.021 ROOM TEMPERATURE TENSILE PROPERTIES OF AS  
CAST ALLOY IN THREE LEVELS OF ELECTRON  
VACANCY CONCENTRATION, AND AT TWO LEVELS  
OF GRAIN SIZE

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

IN-100

|                         |                                                                    |       |      |                     |       |       |                    |       |       |
|-------------------------|--------------------------------------------------------------------|-------|------|---------------------|-------|-------|--------------------|-------|-------|
| Source                  | (24) pp 3, 4, 6, 8                                                 |       |      |                     |       |       |                    |       |       |
| Alloy                   | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V (nominal), <sup>(3)</sup>       |       |      |                     |       |       |                    |       |       |
| Condition               | Forged <sup>(1)</sup> and Heat Treated <sup>(2)</sup> as Indicated |       |      |                     |       |       |                    |       |       |
|                         | Heat Treated                                                       |       |      | HT + 1350F, 1000 hr |       |       | HT + 1550F, 250 hr |       |       |
|                         | Ti + Al Content (3)                                                |       |      |                     |       |       |                    |       |       |
|                         | Low                                                                | Med   | High | Low                 | Med   | High  | Low                | Med   | High  |
| F <sub>tu</sub> - (ksi) | 185.5                                                              | 183.5 | 175  | 179                 | 187   | 164   | 179.5              | 176.5 | 151.5 |
| F <sub>ty</sub> - (ksi) | 139.5                                                              | 140.5 | 141  | 144                 | 142.. | 140.5 | 124                | 123   | 120.5 |
| e (1.25 IN) - percent   | 19                                                                 | 17.5  | 12.5 | 12.5                | 18    | 5     | 22.5               | 20.5  | 3.5   |
| RA - percent            | 15                                                                 | 14.5  | 11.0 | 12.5                | 17.5  | 8     | 21                 | 18.5  | 4.5   |

(1) 5 in dia casting extruded to 3.15dia @ 2050F. Flattened at 2050F to 1 3/4 thick pancake, then to 1 in thick pancake, then to 5/8 in thick pancake. Machined to 1/4 in dia specimens x 1.25 in gage length specimens.

(2) 2215F, 4 hrs + 2000F, 4 hrs + 1550F, 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,  $\bar{N}_v$ :

Low  $\bar{N}_v = 2.25$  : Ni-13.73Co-10.26Cr-4.95Al-4.08Ti-3.66Mo-.96V

Med  $\bar{N}_v = 2.40$  : Ni-13.41Co-10.15Cr-5.36Al-4.09Ti-3.58Mo-.96V

High  $\bar{N}_v = 2.59$  : Ni-13.42Co-10.13Cr-5.46Al-4.63Ti-3.58Mo-1.01V

TABLE 3.022 MECHANICAL PROPERTIES AT ROOM TEMPERATURE OF FORGED ALLOY IN THREE CONDITIONS OF PRONENESS TO SIGMA PHASE PRECIPITATION. PROPERTIES SHOWN AFTER NORMAL HEAT TREATMENT AND AFTER HEAT TREATMENT FOLLOWED BY EXPOSURE TO ELEVATED TEMPERATURE.

|                         |                                                                                                   |                                      |                                      |                          |                     |
|-------------------------|---------------------------------------------------------------------------------------------------|--------------------------------------|--------------------------------------|--------------------------|---------------------|
| Alloy                   | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                                                |                                      |                                      |                          |                     |
| Source                  | (24) p 8                                                                                          |                                      |                                      |                          |                     |
| Condition               | Forged + HT (2215F, 4 hrs + 2000F, 4 hrs + 1550F, 16 hrs + 1400F, 24 hrs + Exposure as indicated) |                                      |                                      |                          |                     |
| Thermal Exposure        | Al + Ti Content                                                                                   | F <sub>tu</sub> (ksi) <sup>(4)</sup> | F <sub>ty</sub> (ksi) <sup>(4)</sup> | e(1.25in) <sup>(4)</sup> | RA % <sup>(4)</sup> |
| As Heat Treated         | Low <sup>(1)</sup>                                                                                | 185.5                                | 139.5                                | 19                       | 15                  |
|                         | Medium <sup>(2)</sup>                                                                             | 183.5                                | 140.5                                | 17.5                     | 14.5                |
|                         | High <sup>(3)</sup>                                                                               | 175                                  | 141                                  | 12.5                     | 11                  |
| Exposed 1000 hr @ 1350F | Low <sup>(1)</sup>                                                                                | 179                                  | 144                                  | 12.5                     | 12.5                |
|                         | Medium <sup>(2)</sup>                                                                             | 187                                  | 142.5                                | 18                       | 17.5                |
|                         | High <sup>(3)</sup>                                                                               | 164                                  | 140.5                                | 5                        | 8                   |
| Exposed 250 hrs @ 1550F | Low <sup>(1)</sup>                                                                                | 179.5                                | 124                                  | 22.5                     | 21                  |
|                         | Medium <sup>(2)</sup>                                                                             | 176.5                                | 123                                  | 20.5                     | 18.5                |
|                         | High <sup>(3)</sup>                                                                               | 151.5                                | 120.5                                | 3.5                      | 4.5                 |

(1) Sigma free

(2) Moderately sigma prone

(3) Very sigma prone, see Table 3.022 for actual compositions

(4) Average of 2 tests

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,  $\bar{N}_v$ , RELATING TO PROPENSITY TOWARD SIGMA FORMATION)

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## NONFERROUS ALLOYS

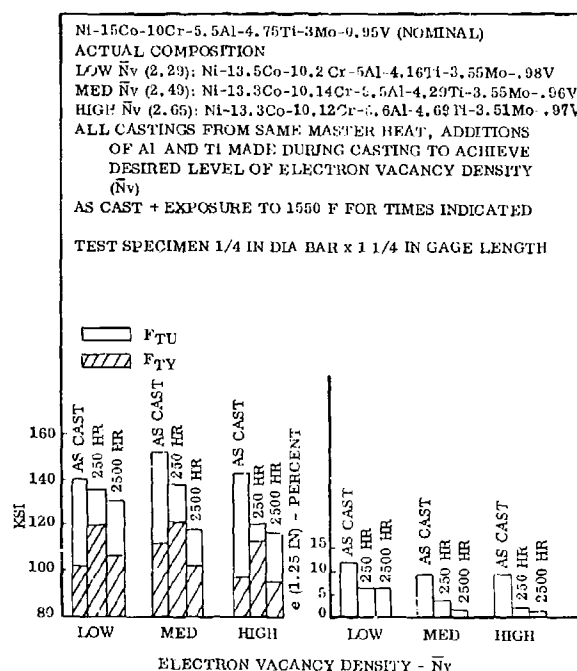


FIG. 3.024 EFFECT OF EXPOSURE AT 1550 F FOR 250 HR AND FOR  
 2500 HR ON ROOM TEMPERATURE TENSILE PROPERTIES  
 OF ALLOY WITH Al-Ti COMPOSITION VARIED TO ACHIEVE  
 THREE LEVELS OF ELECTRON VACANCY CONCENTRATION,  
 $\bar{N}_v$  (22, pp. 1-3, 10)

|                      |                                                                                                                                                                                                                                                                                                               |                            |              |               |               |                                |
|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|--------------|---------------|---------------|--------------------------------|
| Source               | (28) pp. 4, 5, 7                                                                                                                                                                                                                                                                                              |                            |              |               |               |                                |
| Alloy                | Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V (Nominal, see actual below)                                                                                                                                                                                                                                               |                            |              |               |               |                                |
| Composition          | As Cast: Ni-15.4Co-10.5Cr-5.55Al-4.72Ti-3.02Mo-1.05V<br>FM Powder: Ni-13.97Co-9.54Cr-5.65Al-4.82Ti-3.70Mo-1.58 ppm O <sub>2</sub><br>HM Powder: Ni-15.4Co-10.5Cr-5.55Al-4.72Ti-3.02Mo-1.05V-53 ppm O <sub>2</sub><br>NM Powder: Ni-15.18Co-9.4Cr-5.81Al-4.82Ti-3.08Mo-.99V-79 ppm O <sub>2</sub>              |                            |              |               |               |                                |
| Powder Size          | FM Powder - 250 to 44 microns<br>HM Powder - 707 to 74 microns<br>NM Powder - 500 to 44 microns                                                                                                                                                                                                               |                            |              |               |               |                                |
| Powder Consolidation | HHP FM Powder: Pressed at 2320F, 25,000 psi for 1 hr to strip 1 x 1.5 x 20 IN<br>HHP HM Powder: Extruded to 3/4 IN Dia Rod, Pressed at 2300F, 15,000 psi 1 hr,<br>Extruded at 2000F with 12:1 Reduction<br>Direct Extruded FM & NM Powders; Extruded at 2150F with 20:1 Reduction to<br>1/2 IN Dia Bar x 7 Ft |                            |              |               |               |                                |
| Specimen Size        | 3/8 IN Dia Threaded Tensile Bar                                                                                                                                                                                                                                                                               |                            |              |               |               |                                |
|                      | As Cast                                                                                                                                                                                                                                                                                                       | HM Powder<br>As HHP + Extr | FM<br>As HHP | FM<br>As Extr | NM<br>As Extr | NM(1)<br>As Grain<br>Coarsened |
| $F_{tu}$ ksi         | 143                                                                                                                                                                                                                                                                                                           | -                          | 143          | 244           | 238           | 186                            |
| $F_{ty}$ ksi         | 136                                                                                                                                                                                                                                                                                                           | -                          | 137          | 175           | 171           | 137                            |
| $e$ (1 IN)           | 4                                                                                                                                                                                                                                                                                                             | -                          | 8            | 20            | 21            | 14                             |
| RA, PERCENT          | 8                                                                                                                                                                                                                                                                                                             | -                          | 10           | 16            | 17            | 7                              |
| Hardness RC          | 32                                                                                                                                                                                                                                                                                                            | 41                         | 49           | 43            | 43            | 33                             |

(1) Exposed 2270F, 24 hours. Average grain size 100  $\mu$  m, some grains as large as 200  $\mu$  m

TABLE 3.025 ROOM TEMPERATURE TENSILE PROPERTIES AND HARDNESS OF POWDER  
 METALLURGY PRODUCT PREPARED FROM POWDERS OF VARIOUS COMPOSITIONS  
 AND GRAIN SIZE AND CONSOLIDATED BY SEVERAL PROCESSES

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

|                       |                                                                                                  |       |                    |       |
|-----------------------|--------------------------------------------------------------------------------------------------|-------|--------------------|-------|
| Alloy                 | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V <sup>(1)</sup>                                                |       |                    |       |
| Source                | (19) pp 6, 7, 10                                                                                 |       |                    |       |
| Condition             | Superplastically Forged <sup>(2)</sup> , ASTM Grain Size 12-14                                   |       |                    |       |
| Heat Treatment        | Solutionized at 2050F, Stabilized at 1600F and 1800F + Precipitation Hardened at 1200F and 1400F |       |                    |       |
|                       | Disk 1 (499 - A2A)                                                                               |       | Disk 2 (499 - A2B) |       |
|                       | RT                                                                                               | 1300F | RT                 | 1300F |
| F <sub>tu</sub> (ksi) | 232.4                                                                                            | 177.0 | 232.0              | 179.1 |
| F <sub>ty</sub> (ksi) | 164.5                                                                                            | 152.7 | 164.9              | 156.0 |
| e percent             | 22.0                                                                                             | 14.0  | 22.0               | 14.7  |
| RA percent            | 22.2                                                                                             | 22.3  | 21.5               | 16.4  |

(1) Typical composition: Ni-18, 5Co-12, 4Cr-4.98Al-4, 32Ti-3.2Mo-0.78V-.07C-.06Zr-.02B

(2) By patented Gatorizing™ Process

TABLE 3.026 TENSILE PROPERTIES OF SUPERPLASTICALLY FORMED PANCAKE FORGING USED IN FATIGUE CRACK GROWTH STUDIES

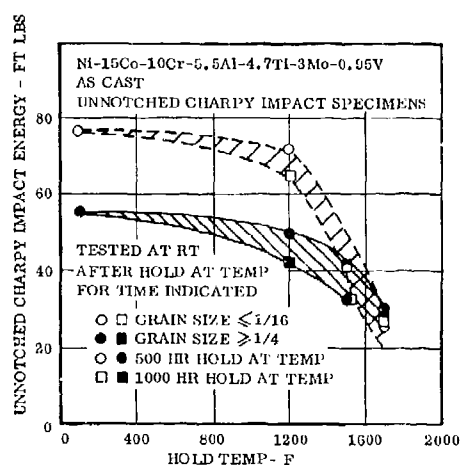


FIG. 3.0291 UNNOTCHED CHARPY IMPACT STRENGTH AT ROOM TEMPERATURE AFTER HOLD FOR 500 OR 1000 HR AT ELEVATED TEMPERATURE (4, p.11)

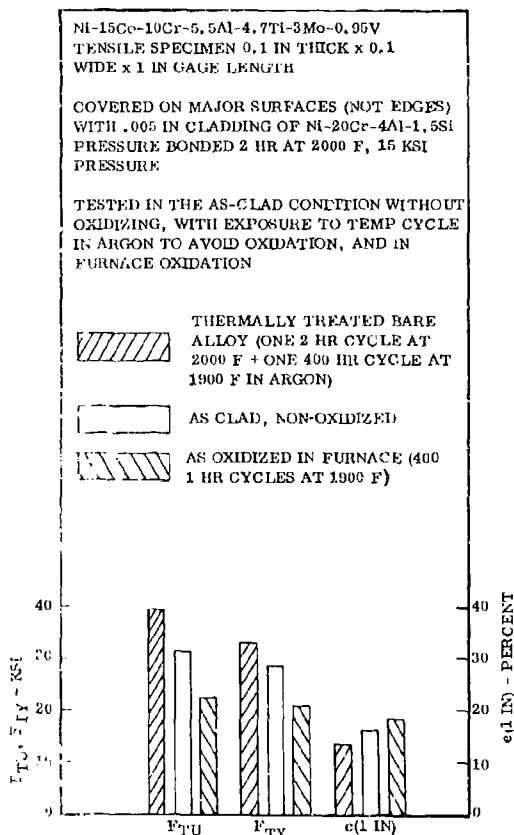


FIG. 3.027 COMPARISON OF TENSILE PROPERTIES OF ALLOY WITH Ni-20Cr-4Al-1.2Si CLADDING ALLOY BEFORE AND AFTER OXIDATION (42, pp. 2, 3, 20, 29)

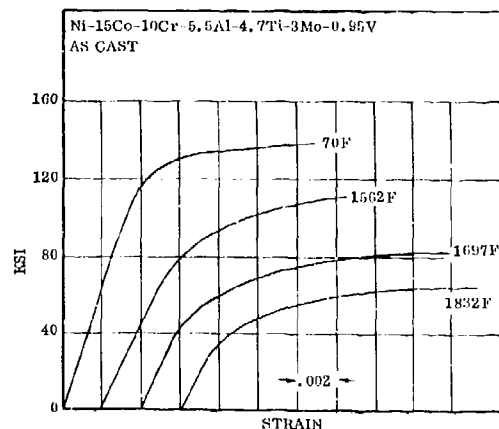


FIG. 3.0311 STRESS-STRAIN CURVES FOR AS-CAST ALLOY AT ROOM AND ELEVATED TEMPERATURES (16 pp. 7, 10, 115 REVISED BY PERSONAL COMMUNICATION, METCUT TO MPDC 6-13-78)

REVISED: DECEMBER 1978

## NONFERROUS ALLOYS

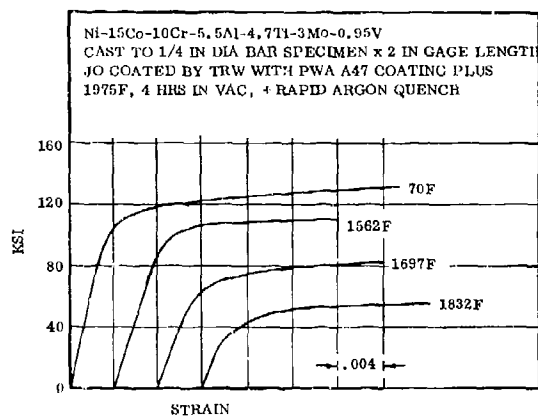


FIG. 3.03112 STRESS-STRAIN CURVES FOR JO COATED ALLOY  
AT ROOM AND ELEVATED TEMPERATURES  
(16, pp. 7, 10, 123)

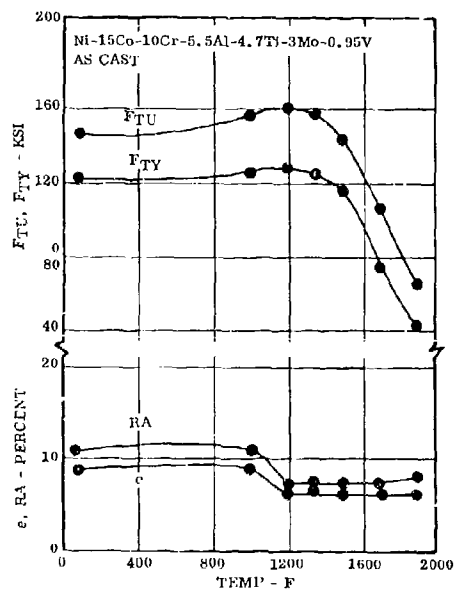


FIG. 3.03121 EFFECT OF TEST TEMPERATURE ON  
MECHANICAL PROPERTIES AS CITED  
BY ALLOY DEVELOPER (4, p. 5)

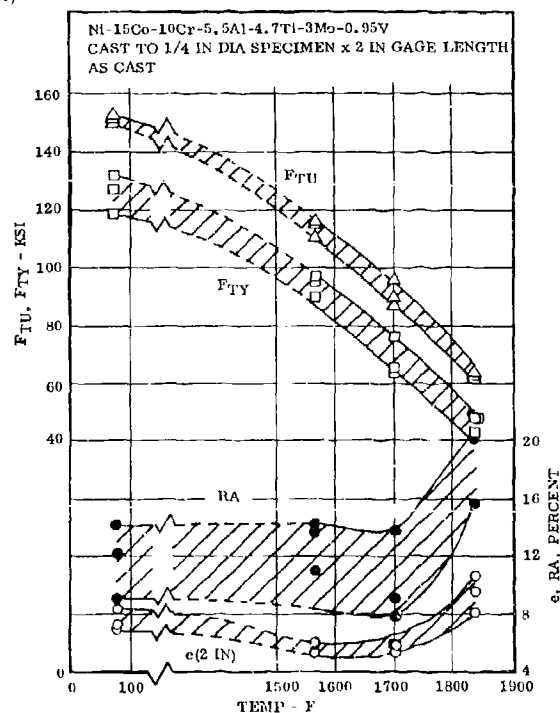


FIG. 3.03122 TENSILE PROPERTIES OF AS CAST BAR AT ROOM  
AND ELEVATED TEMPERATURES (16, pp. 13, 112, 114)

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

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

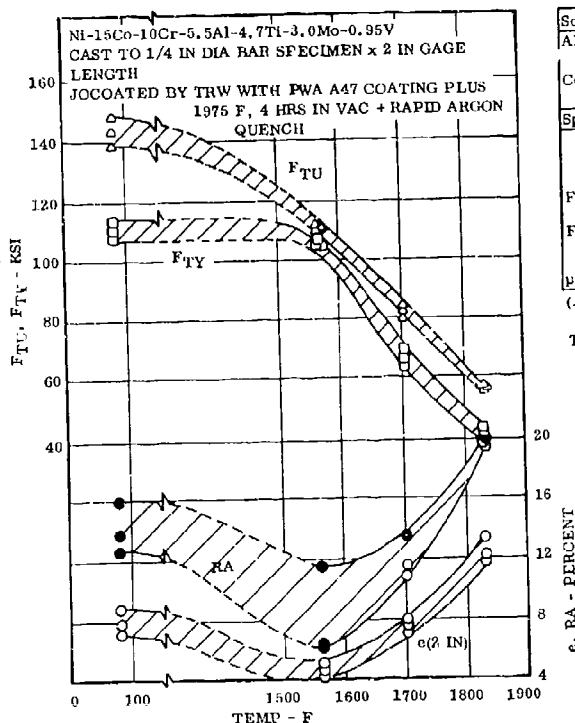


FIG. 3.03123 TENSILE PROPERTIES OF JOCOATED BAR AT ROOM AND ELEVATED TEMPERATURES (16 pp.13,121,122)

|                                          |         |                              |                               |                               |
|------------------------------------------|---------|------------------------------|-------------------------------|-------------------------------|
| Source (38) p 95                         |         |                              |                               |                               |
| Alloy Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V |         |                              |                               |                               |
| Condition                                | As Cast | 2150F 2 hr<br>Rapid Air Cool | 2050F 24 hr<br>Rapid Air Cool | 1900F 24 hr<br>Rapid Air Cool |
| (1)                                      |         |                              |                               |                               |
| Tested at 1300F                          |         |                              |                               |                               |
| $F_{tu}$ (ksi)                           | 156     | 138                          | 129.3                         | 135.7                         |
| $F_{ty}$ (ksi)                           | 124.3   | 119                          | 114.7                         | 119.3                         |
| e percent                                | 8.8     | 6.0                          | 4.5                           | 3.7                           |
| RA percent                               | 14.3    | 7.0                          | 8.1                           | 5.8                           |

(1) All values average of 3 tests.

TABLE 3.03131 EFFECT OF SEVERAL SOLUTION HEAT TREATMENTS ON THE TENSILE PROPERTIES AT 1300F

|                                                                                  |                    |                  |       |      |             |
|----------------------------------------------------------------------------------|--------------------|------------------|-------|------|-------------|
| Source (46) pp 2, 3, 7, 68, 69                                                   |                    |                  |       |      |             |
| Alloy Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                         |                    |                  |       |      |             |
| Condition As Cast + Coated with Two Proprietary Coatings: Al-Cr-Mn or AEP No. 32 |                    |                  |       |      |             |
| See Fig. 3.0515 for Coating Conditions                                           |                    |                  |       |      |             |
| Specimen Type Simulated Airfoil, See Fig. 3.0515                                 |                    |                  |       |      |             |
|                                                                                  | AEP No. 32 Coating | Al-Cr-Mn Coating |       |      |             |
|                                                                                  | RT                 | 1400F            | 1300F | RT   | 1400F 1800F |
| $F_{tu}$ (ksi)                                                                   | (1)                | 125.8            | 67.8  | (1)  | 110.3 68.4  |
| $F_{ty}$ (ksi)                                                                   | 108.9              | 101.9            | 55.3  | 96.7 | 108.4 49.9  |
| e (in)                                                                           | 3.7                | 3.7              | 3.2   | 1.7  | - 5.3       |
| percent                                                                          |                    |                  |       |      |             |

(1) Average of two tests

TABLE 3.03141 TENSILE PROPERTIES AT ROOM AND ELEVATED TEMPERATURES OF THINWALL ALLOY COATED WITH TWO PROPRIETARY COATINGS

Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V  
2 x 1/4 x .040 IN SHEET  
AS CAST + CODEP C-2 COATING (APPROX. 2 MILS) PARTIAL STRIP BY LOCALIZED GRIT BLAST; COMPLETE STRIP BY IMMERSION IN SOLUTION OF 30 V/O HNO<sub>3</sub> + 1 V/O TURCO 4104 FOR 1 HR.  
RECOATING WITH VACUUM FIRED SLURRY SLIP PACK OF 56 Cr-44 Al  
OXIDIZED 150 HRS, 1750F  
TESTED AT 1800F

$F_{tu}$  OF UNCOATED ALLOY AT 1800F - 56.3 KSI  
 $F_{ty}$  OF UNCOATED ALLOY AT 1800F - 41.2 KSI

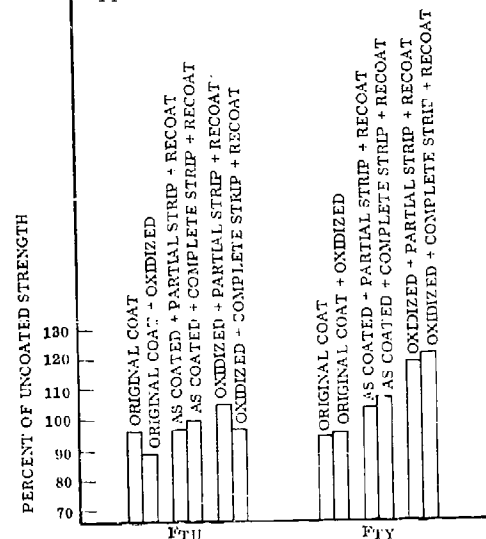


FIG. 3.03142 EFFECT OF COATING, HIGH TEMPERATURE EXPOSURE, AND SEVERAL REPAIR PROCESSES ON TENSILE AND YIELD STRENGTH AT 1800F COMPARED TO AS CAST UNCOATED BASE MATERIAL (25, pp.36,115,116)

REVISED: DECEMBER 1978

## NONFERROUS ALLOYS

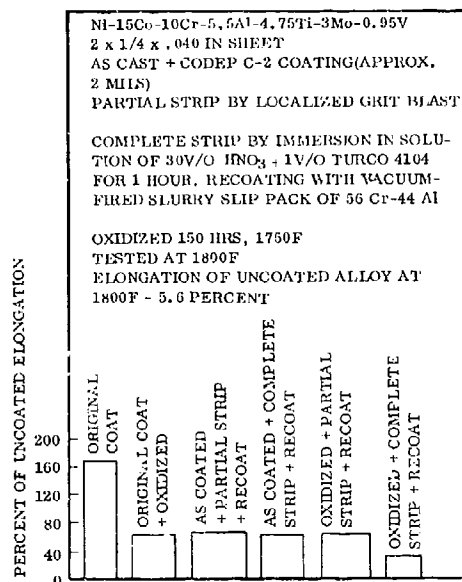


FIG. 3.03143 EFFECT OF COATING, HIGH TEMPERATURE  
 EXPOSURE, AND SEVERAL REPAIR PROCESSES  
 ON ELONGATION AT 1800F COMPARED TO AS  
 CAST UNCOATED BASE MATERIAL (25, pp.36,115,118)

| Source (39) p 339                                                       |                                                        |                                                                                                                                           |                                                                                                                   |
|-------------------------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| Alloy Ni 15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                |                                                        |                                                                                                                                           |                                                                                                                   |
| Condition Powder Metallurgy product, deformed and heat treated as shown |                                                        |                                                                                                                                           |                                                                                                                   |
|                                                                         | Extruded 10.6 to 1 at 2000F,<br>Rolled 3 to 1 at 2000F | Extruded 10.6 to 1 at 2000F,<br>Rolled 3 to 1 at 2000F +<br>2150F, 4 hr, oil quench +<br>1200F, 22 hr, air cool +<br>1400F, 8 hr air cool | Extruded 10.6 to 1 at 2000F,<br>Superplastically deformed<br>100% in tension at 2000F<br>+ 2275F, 56 hr, air cool |
| RT                                                                      |                                                        |                                                                                                                                           |                                                                                                                   |
| F <sub>tu</sub> (ksi)                                                   | 310                                                    | 254.6                                                                                                                                     | 170.7                                                                                                             |
| F <sub>ty</sub> (ksi)                                                   | 295.8                                                  | 177.8                                                                                                                                     | 129.4                                                                                                             |
| e percent                                                               | 12                                                     | 27                                                                                                                                        | 10                                                                                                                |
| RA percent                                                              | 8                                                      | 25                                                                                                                                        | 15                                                                                                                |
| 1200F                                                                   |                                                        |                                                                                                                                           |                                                                                                                   |
| F <sub>tu</sub> (ksi)                                                   | 257.4                                                  | 204.8                                                                                                                                     | 163.6                                                                                                             |
| F <sub>ty</sub> (ksi)                                                   | 241.8                                                  | 180.6                                                                                                                                     | 125.2                                                                                                             |
| e percent                                                               | 10                                                     | 15                                                                                                                                        | 8                                                                                                                 |
| RA percent                                                              | 16                                                     | 12                                                                                                                                        | 10                                                                                                                |

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

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

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

IN-100

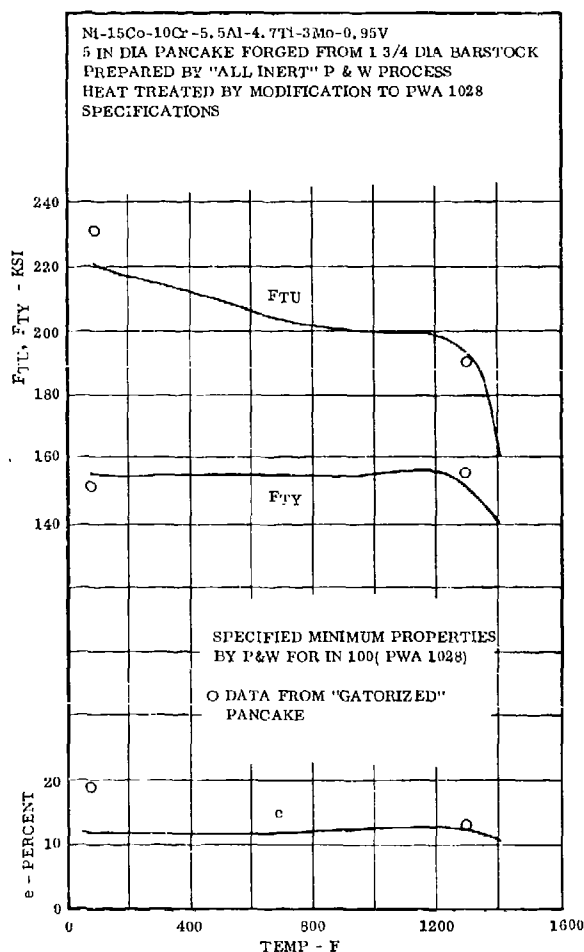


FIG. 3.03152 TENSILE PROPERTIES OF SPECIMEN FROM POWDER  
ALLOY PANCAKE AT RT AND 1300F, WITH COMPARISON  
TO PRATT & WHITNEY SPECIFICATIONS FOR ALLOY  
(35, FIGS. 1,2)

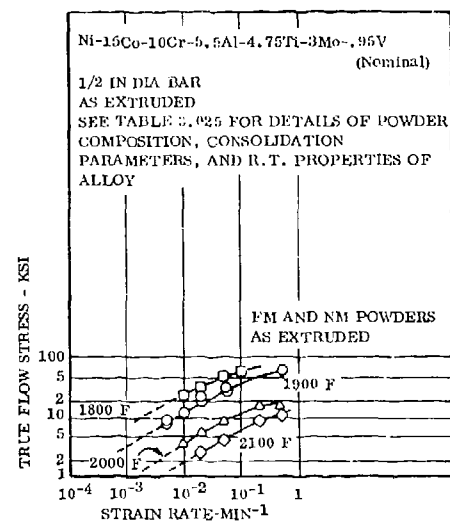


FIG. 3.03153 FLOW CHARACTERISTICS IN THE RANGE  
AT LOW STRAIN RATES AND TEMPERA-  
TURES WHERE SUPERPLASTICITY CAN  
BE ACHIEVED (28 p.Z-24)

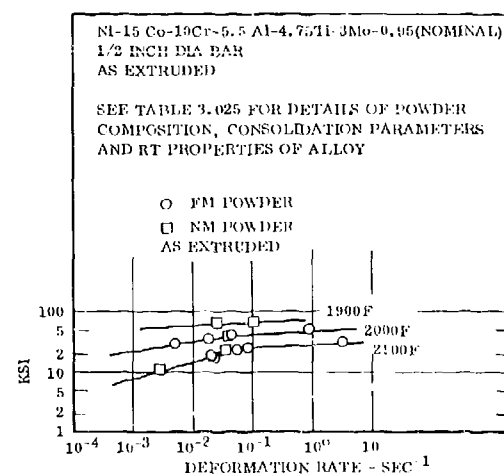


FIG. 3.03154 RELATION BETWEEN STRESS AND HIGH  
DEFORMATION RATE AT 1900 TO 2100F  
FOR ALLOY EXTRUDED DIRECTLY FROM  
POWDER, (28, p.Z-22)

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## NONFERROUS ALLOYS

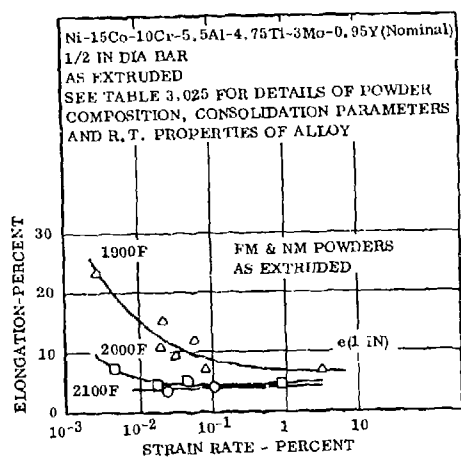


FIG. 3.3155 HIGH STRAIN RATE EFFECT ON ELONGATION AT FRACTURE AT 1900 TO 2100F FOR ALLOY DIRECTLY EXTRUDED FROM POWDER (28,p.2-22)

|                             |                                     |       |             |             |
|-----------------------------|-------------------------------------|-------|-------------|-------------|
| Source                      | (26) p. VII - 10                    |       |             |             |
| Alloy                       | Ni-15Co-10Cr-5.5Al-4.75Ti-3Mo-0.95V |       |             |             |
| Condition                   | As Cast + 1600F, 4 hrs, AC          |       |             |             |
| Test Condition              | 5000 psig                           |       |             |             |
|                             | Helium                              |       | Hydrogen    |             |
|                             | RT                                  | 1250F | RT          | 1250F       |
| $F_{tu}$ (ksi)              | 118.5                               | 103.2 | 107.5, 87.5 | 99.0, 114.0 |
| $F_{ty}$ (ksi)              | 99.8                                | 101.8 | 106.5, 87.5 | 99.0, 106.1 |
| $e(l \text{ in})$ , percent | 9.5                                 | 2.0   | 3.0, 2.5    | 1.5, 2.0    |
| RA percent                  | 14.7                                | 6.7   | 3.3, 5.5    | 2.0, 7.1    |

TABLE 3.03171 TENSILE PROPERTIES AT RT AND 1250F IN 5000 psig HELIUM AND HYDROGEN

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

IN-100

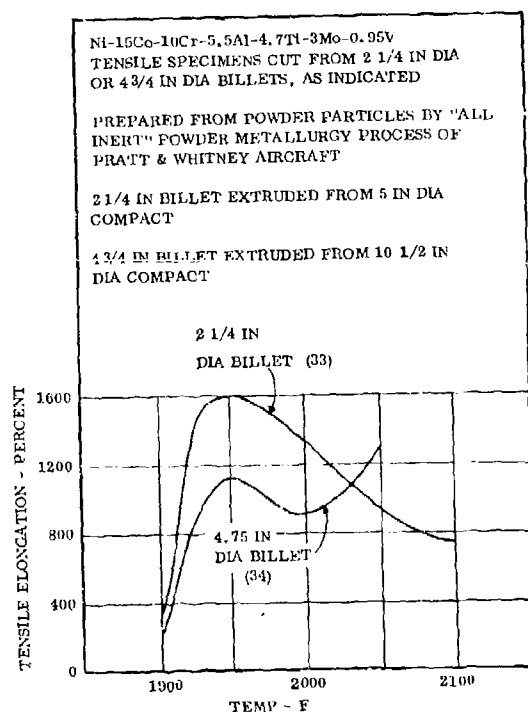


FIG. 3.03156 SUPERPLASTICITY EXHIBITED BY POWDER METALLURGY ALLOY (33, FIG. 3), (34, FIG. 3)

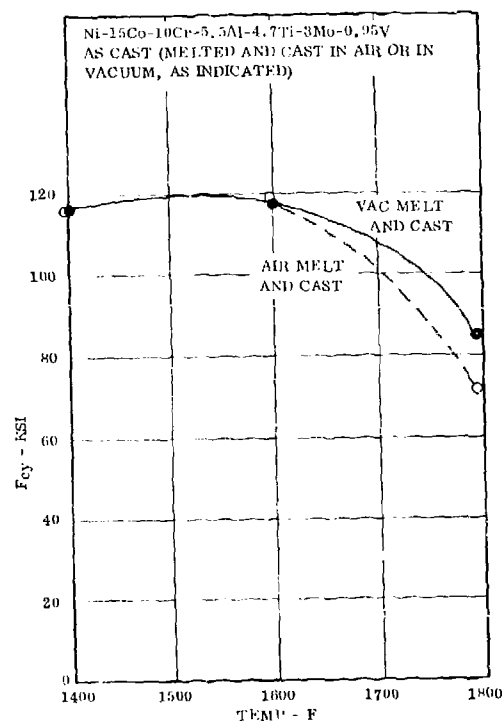


FIG. 3.0321 EFFECT OF TEST TEMPERATURE ON COMPRESSION YIELD STRENGTH FOR AIR MELTED AND CAST ALLOY AND FOR VACUUM MELTED AND CAST ALLOY (32, FIG 4, 5)

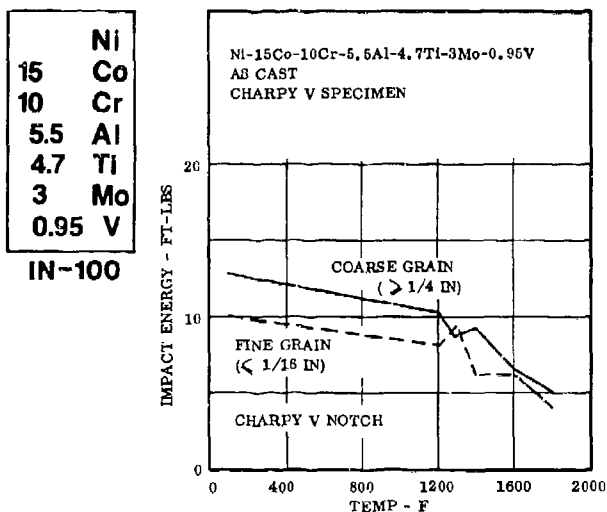


FIG. 3.0331 EFFECT OF TEMPERATURE ON CHARPY V IMPACT ENERGY (4, p.12)

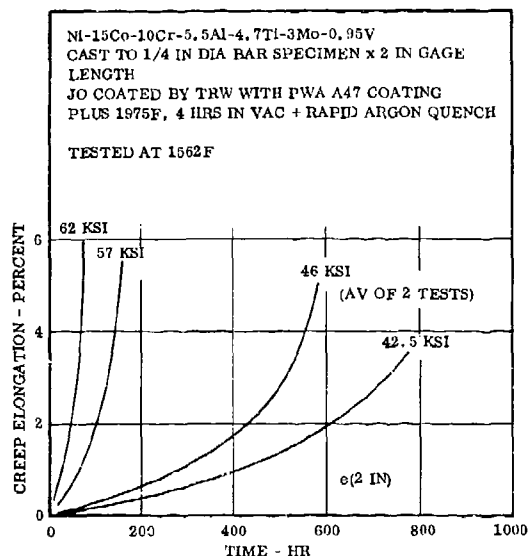


FIG. 3.0412 CREEP CURVES FOR JO COATED ALLOY AT 1562F.  
(16, pp. 13,121,124,125,)

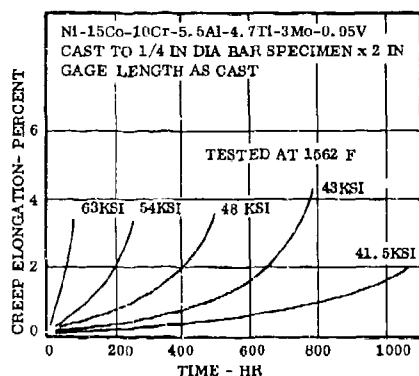


FIG. 3.0411 CREEP CURVES OF AS CAST ALLOY AT 1562F (16, pp.13,112,114,117)

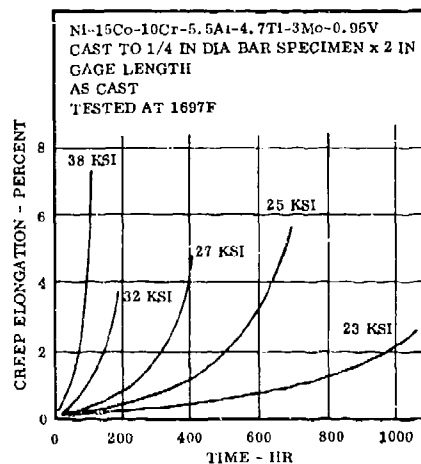


FIG. 3.0413 CREEP CURVES OF AS CAST ALLOY AT 1697F (16, pp. 13,112,114,116)

REVISED: DECEMBER 1978

## NONFERROUS ALLOYS

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

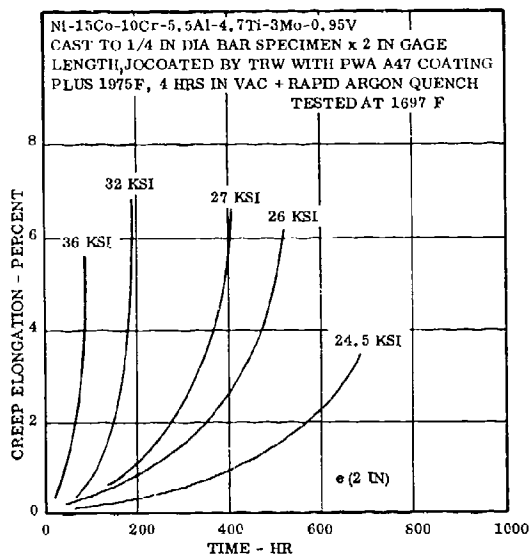


FIG. 3.0414 CREEP CURVES FOR JO COATED ALLOY AT 1697F  
(16 pp. 13, 121, 124, 126)

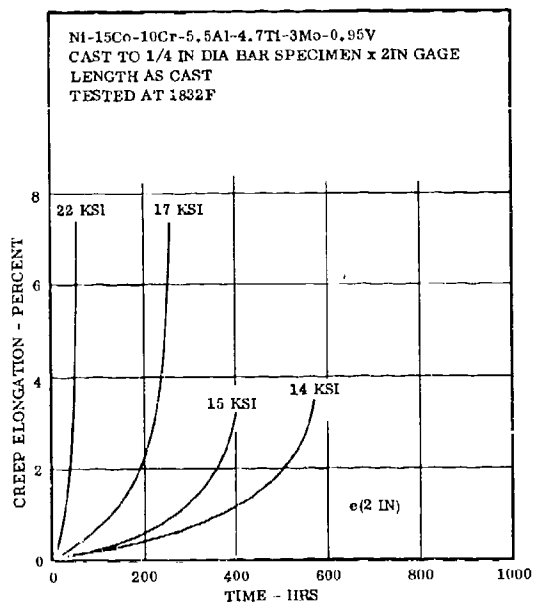


FIG. 3.0415 CREEP CURVES OF AS CAST ALLOY AT 1832F.  
(16 pp. 13, 112, 114, 119)

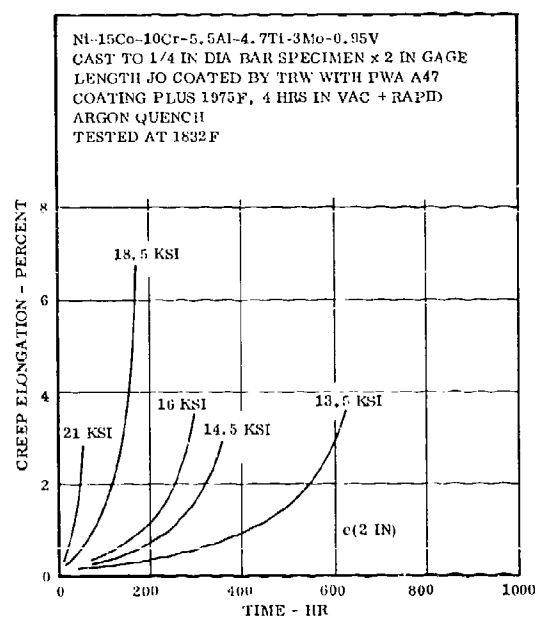


FIG. 3.0416 CREEP CURVES FOR JO COATED ALLOY AT 1832F  
(16 pp. 13, 121, 124, 127)

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

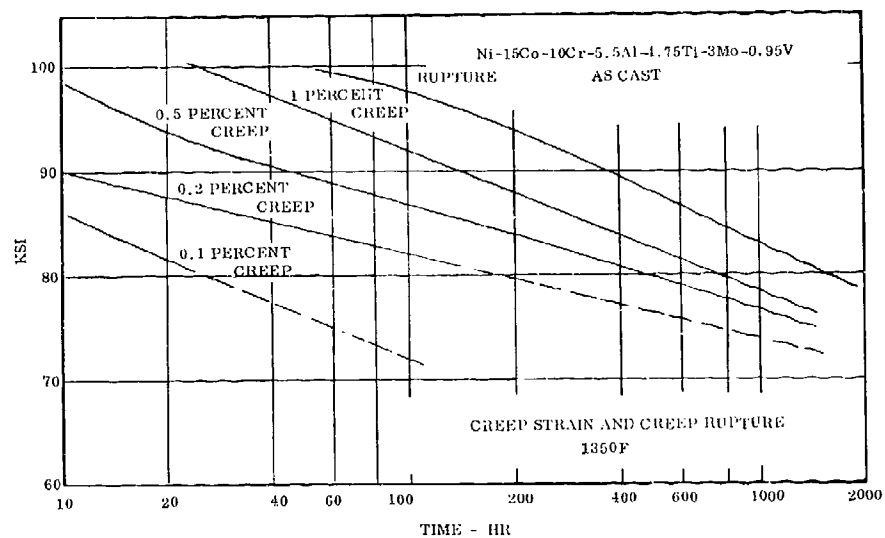


FIG. 3.0417 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1350F (4)

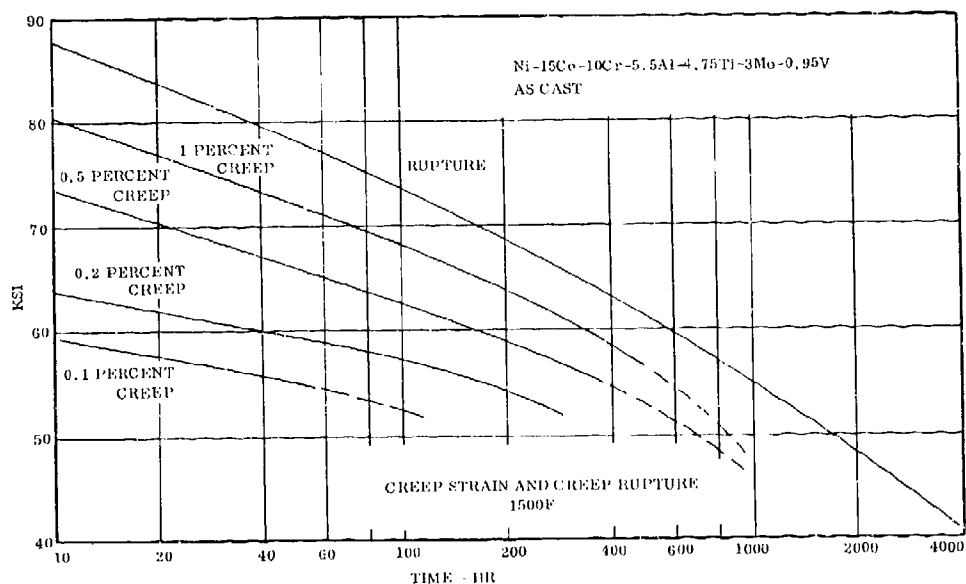
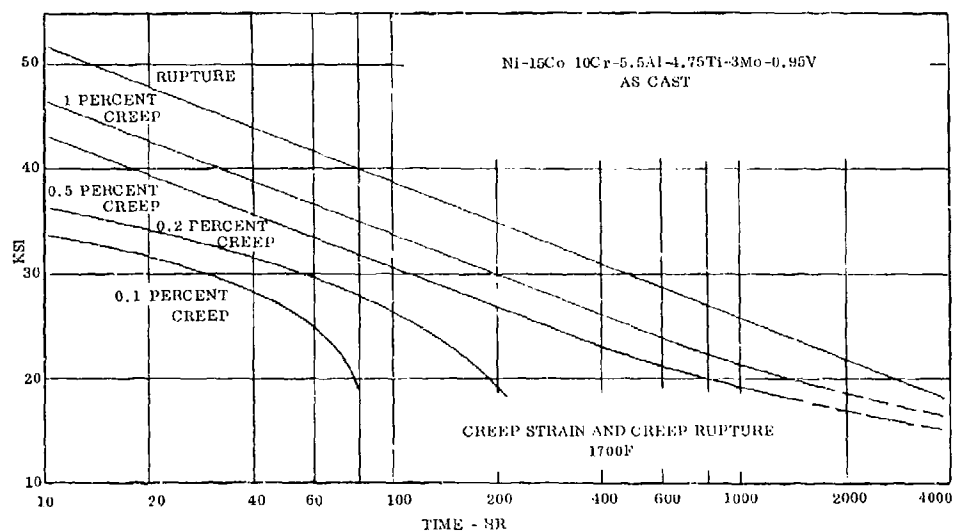


FIG. 3.0418 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1500F (4)

REVISED: DECEMBER 1978

# NONFERROUS ALLOYS



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

IN-100

FIG. 3.0419 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1700F (4)

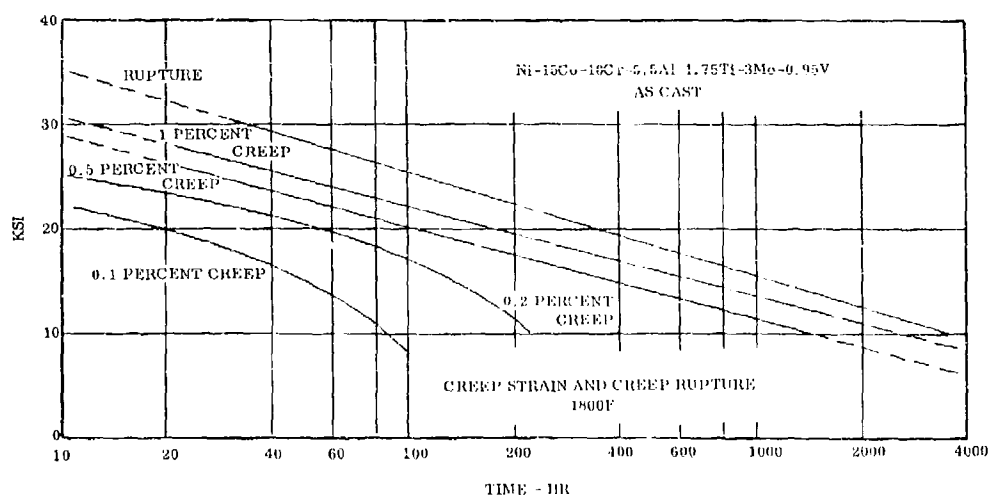


FIG. 3.04110 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1800F (4)

NiCo

# NONFERROUS ALLOYS

REVISED: DECEMBER 1978

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

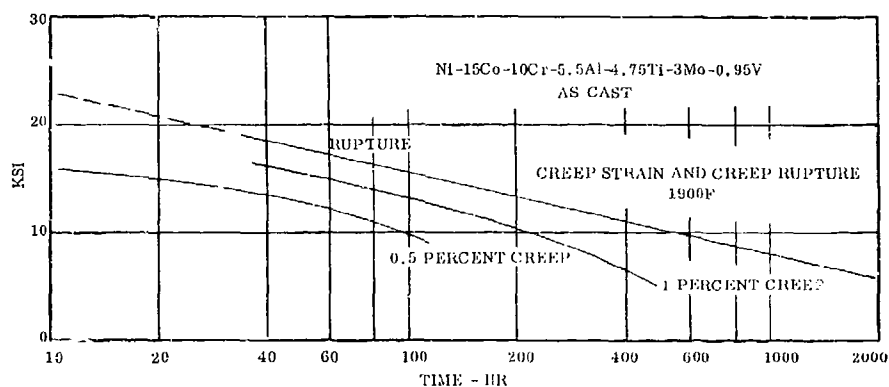


FIG. 3.04111 ALLOY DEVELOPER'S SUGGESTED DESIGN CURVES FOR CREEP STRAIN AND CREEP RUPTURE AT 1800F (4)

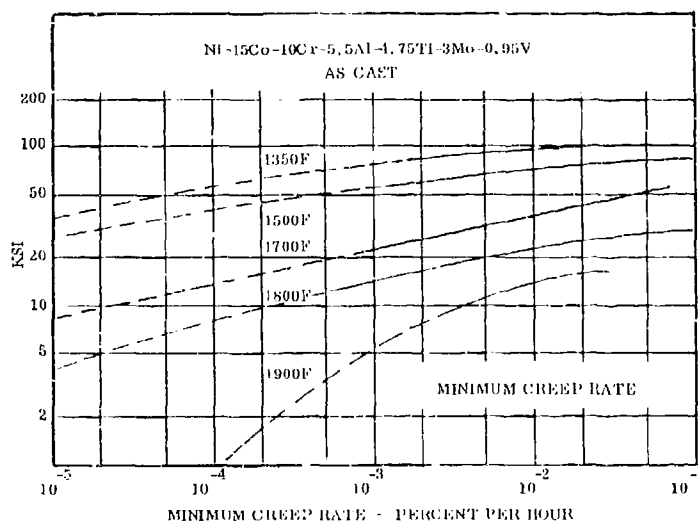


FIG. 3.04112 MINIMUM CREEP RATE CURVES FOR TEMPERATURES FROM 1350 TO 1900F (5)

REVISED: DECEMBER 1978

## NONFERROUS ALLOYS

|                               |                                                                                                   |                 |                  |                 |
|-------------------------------|---------------------------------------------------------------------------------------------------|-----------------|------------------|-----------------|
| Alloy                         | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V <sup>(a)</sup>                                                 |                 |                  |                 |
| Source                        | (19) pp 6, 7, 10                                                                                  |                 |                  |                 |
| Condition                     | Superplastically Forged <sup>(b)</sup><br>ASTM Grain Size 12-14                                   |                 |                  |                 |
| Heat Treatment:               | Solutionized at 2050F, Stabilized at 1600F and 1800F, + Precipitation Hardened at 1200F and 1400F |                 |                  |                 |
|                               | Disk 1 (499-A2A)                                                                                  |                 | Disk 2 (499-A2B) |                 |
|                               | 1300F<br>80 ksi                                                                                   | 1350F<br>95 ksi | 1300F<br>80 ksi  | 1350F<br>95 ksi |
| Time to 0.1 Percent Creep, hr | -                                                                                                 | -               | 114.5            | -               |
| Time to 0.2 Percent Creep, hr | 175.5                                                                                             | -               | 142.5            | -               |
| Time to Rupture, hr           | >233.2                                                                                            | 28.0            | >143.2           | 18.9            |
| e at Fracture, Percent        | -                                                                                                 | 10.6            | -                | 7.6             |
| RA at Fracture, Percent       | -                                                                                                 | 15.9            | -                | 12.2            |

(a) Typical composition: Ni-18.5Co-12.4Cr-4.98Al-4.32Ti-3.2Mo-0.78V-.07C-.06Zr-.02B

(b) By patented GATORIZING PROCESS

TABLE 3.0421 CREEP AND CREEP RUPTURE PROPERTIES OF SUPERPLASTICALLY FORMED PANCAKE FORGING USED IN FATIGUE CRACK GROWTH STUDIES

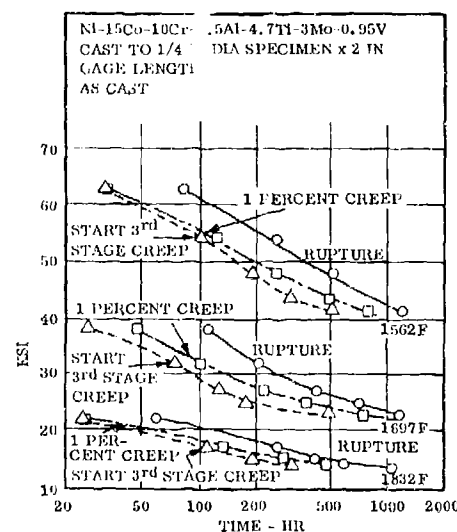


FIG. 3.0431 RELATION AMONG START OF THIRD STAGE CREEP, TIME TO 1 PERCENT CREEP, AND RUPTURE TIME FOR AS CAST ALLOY (16,p.116)

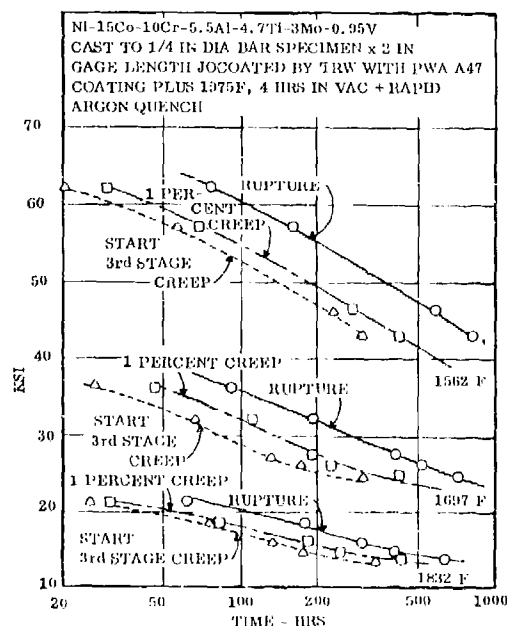


FIG. 3.0432 RELATION AMONG TIME OF THIRD STAGE CREEP, TIME TO 1 PERCENT CREEP AND RUPTURE TIME FOR JOCOATED ALLOY (16,p.124)

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

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

IN-100

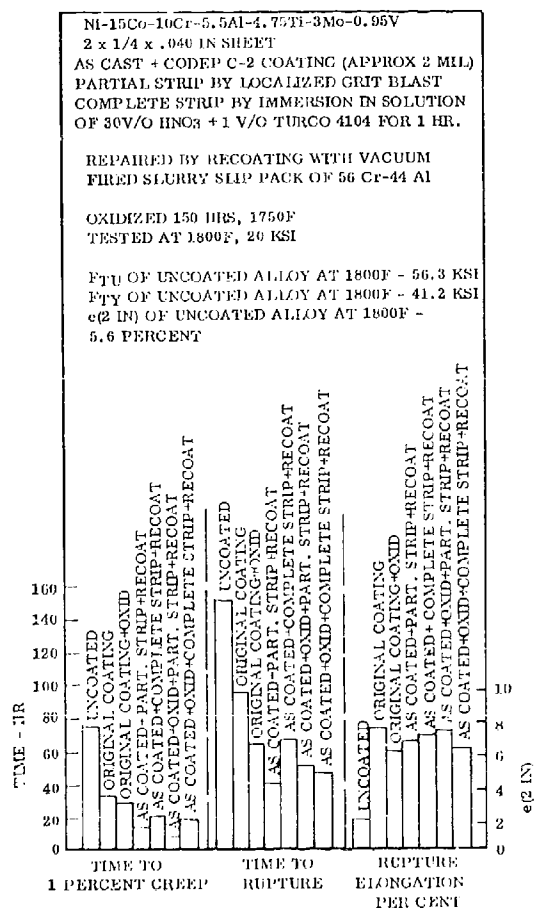


FIG. 3.0441 CREEP AND RUPTURE PROPERTIES OF ALLOY AFTER REPAIR OF OXIDATION DAMAGE AND MECHANICAL DAMAGE EFFECTS (25, pp. 36, 130)

REVISED: DECEMBER 1978

## NONFERROUS ALLOYS

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

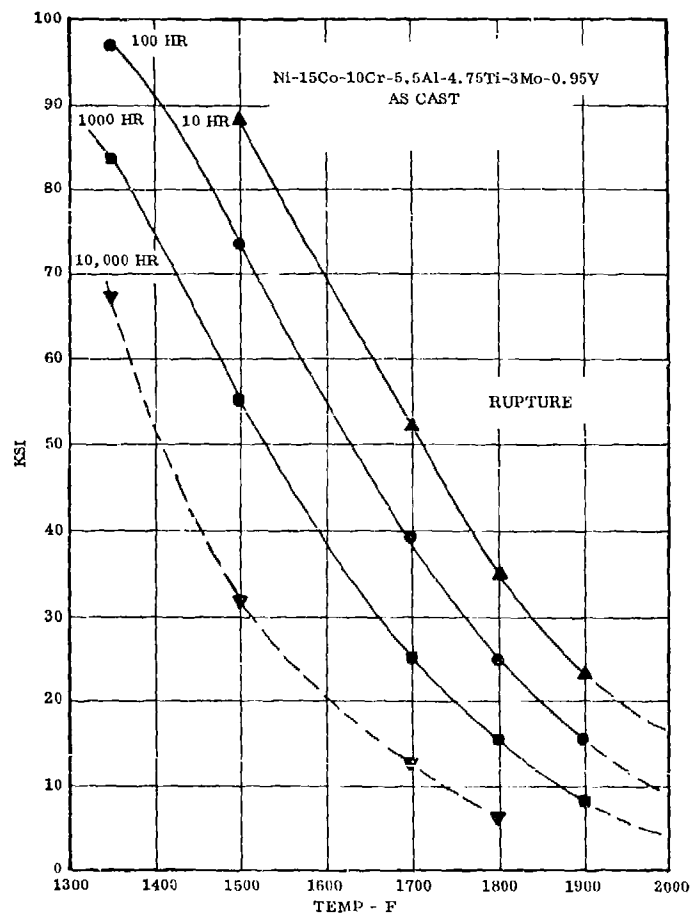


FIG. 3.0451 TYPICAL CREEP RUPTURE PROPERTIES IN LIFE RANGE FROM 10 TO 10,000 HRS AT TEMPERATURES FROM 1300 TO 2000 F (4)

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

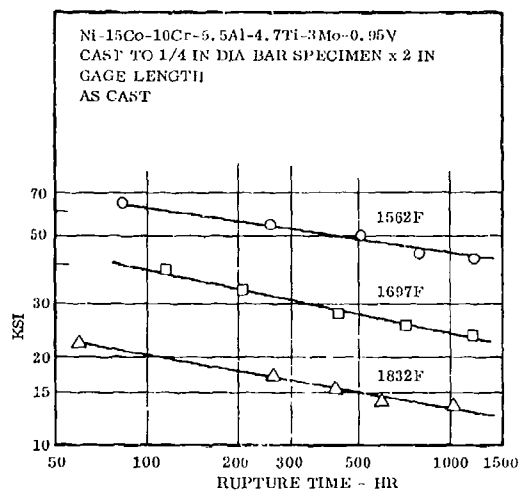


FIG. 3.0452 CREEP RUPTURE CURVES FOR AS CAST ALLOY AT 1562F, 1697F, AND 1832F (16, pp.13, 116 120)

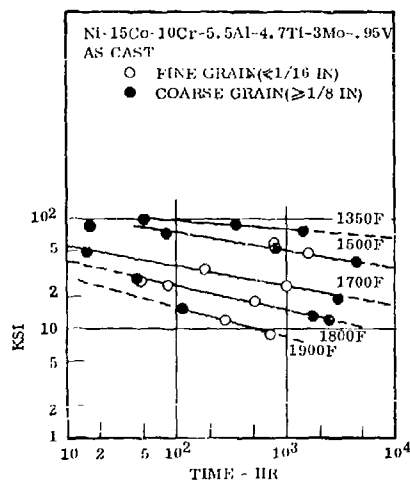


FIG. 3.0453 CREEP RUPTURE DATA FOR AS CAST ALLOY AS DETERMINED BY DEVELOPER (4, p.6)

| Source (38) p.95                         |         |                |                |                |
|------------------------------------------|---------|----------------|----------------|----------------|
| Alloy Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V |         |                |                |                |
| Condition                                | As Cast | 2150F, 2 Hr    | 1900F, 24 Hr   | 2050F, 24 Hr   |
|                                          |         | Rapid Air Cool | Rapid Air Cool | Rapid Air Cool |
| Tested at <sup>(1)</sup>                 |         |                |                |                |
| 1800F, 29 ksi                            |         |                |                |                |
| Life, hrs                                | 31.8    | 32             | 28.3           | 25.9           |
| c, percent                               | 6.9     | 6.8            | 8.5            | 7.13           |
| RA, percent                              | 8.8     | 10.7           | 11.5           | 9.3            |

(1) All values average of 3 tests

TABLE 3.0461 EFFECT OF SEVERAL SOLUTION HEAT TREATMENTS ON THE CREEP-RUPTURE LIFE AT 1800F, 29 KSI

REVISED: DECEMBER 1978

## NONFERROUS ALLOYS

| Alloy                        | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V    |            |                 |            |                 |            |                 |            |
|------------------------------|---------------------------------------|------------|-----------------|------------|-----------------|------------|-----------------|------------|
| Source                       | Haynes (10 p 13)                      |            |                 |            |                 |            |                 |            |
| Condition                    | As Cast (Bare or Coated As Indicated) |            |                 |            |                 |            |                 |            |
|                              | 34 ksi<br>1700F                       |            | 22 ksi<br>1800F |            | 17 ksi<br>1850F |            | 13 ksi<br>1900F |            |
|                              | Bare                                  | (a) Coated | Bare            | Coated (a) | Bare            | Coated (a) | Bare            | Coated (a) |
| Creep Rupture<br>Life, Hours | 68.4                                  | 53.7       | 122             | 129        | 224             | 170        | 180             | 210        |
| $e(2in)$ ,<br>percent        | 5.2                                   | 5.8        | 8.4             | 6.2        | 6.5             | 10         | 5.1             | 9.0        |

(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

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

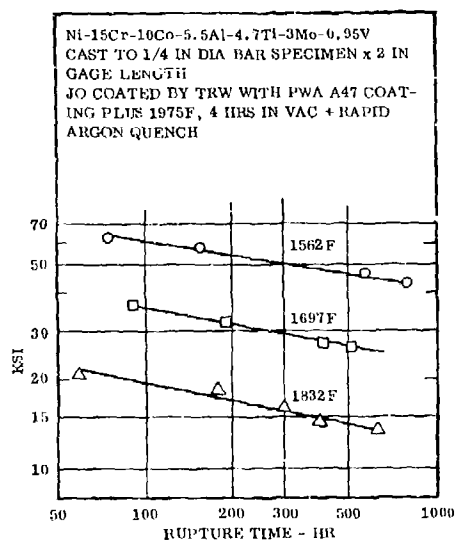


FIG. 3.0472 CREEP RUPTURE CURVES FOR JO COATED ALLOY AT 1562F, 1697F, AND 1832F (16, pp. 13, 121, 128)

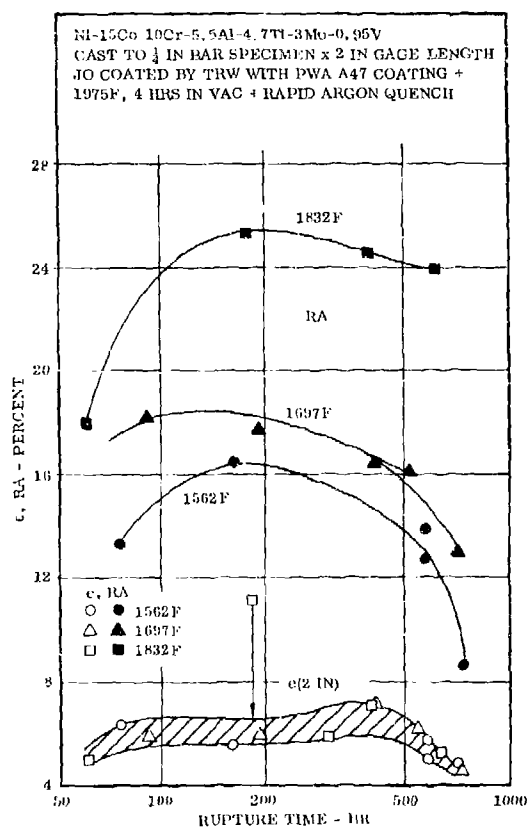


FIG. 3.0473 CORRELATION BETWEEN DUCTILITY AND RUPTURE TIME AT 1562F, 1697F, AND 1832F FOR JO COATED ALLOY (16, pp. 13, 124)

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

|                                   |                                                |               |                  |               |               |
|-----------------------------------|------------------------------------------------|---------------|------------------|---------------|---------------|
| Source                            | (46) pp 2, 3, 7, 64                            |               |                  |               |               |
| Alloy                             | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V             |               |                  |               |               |
| Condition                         | As Cast + Coated With Two Proprietary Coatings |               |                  |               |               |
| Specimen Type                     | Simulated Airfoil, (see Fig. 3.0515)           |               |                  |               |               |
|                                   | AEP No. 32 Coating                             |               | Al-Cr-Mn Coating |               |               |
|                                   | 1800F, 20 ksi                                  | 1450F, 65 ksi | 1800F, 20 ksi    | 1450F, 65 ksi | 1450F, 50 ksi |
| Creep Rupture Life, hrs. Spec No. |                                                |               |                  |               |               |
| 1                                 | 61.6                                           | 166.9         | 27.9             | 27.9          | 401.7         |
| 2                                 | 53.4                                           | 141.3         | 19.8             |               | 401.6         |
| 3                                 | 21.0                                           | 31.6          | 7.1              |               |               |
| 4                                 | 17.9                                           |               |                  |               |               |
| 5                                 | 13.7                                           |               |                  |               |               |
| 6                                 | 10.0                                           |               |                  |               |               |
| Average (1)                       | 23.5                                           | 90.6          | 15.8             | 27.9          | 401.7         |
| e(lin) Percent Spec No.           |                                                |               |                  |               |               |
| 1                                 | 3.8                                            | 5.2           | 3.6              | 5.9           | 3.0           |
| 2                                 | 3.2                                            | 3.3           | 4.2              |               | 3.7           |
| 3                                 | 1.2                                            | 1.3           | 7.1              |               |               |
| 4                                 | 3.3                                            |               |                  |               |               |
| 5                                 | 3.2                                            |               |                  |               |               |
| 6                                 | 3.0                                            |               |                  |               |               |
| Average                           | 3.0                                            | 3.3           | 5.0              | 5.9           | 3.4           |

(1) Based on Log<sub>10</sub> of Life (Averages of Log Life)

TABLE 3.0474 CREEP RUPTURE LIVES AND ELONGATIONS AT 1450F AND 1800F FOR THIN WALL ALLOY COATED WITH TWO PROPRIETARY COATINGS

|                                          |                                    |        |
|------------------------------------------|------------------------------------|--------|
| Alloy                                    | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V |        |
| Source                                   | General Electric, (12)             |        |
| Condition                                | As Cast                            |        |
|                                          | 1500F                              |        |
|                                          | 40 ksi                             | 50 ksi |
| Life with sigma formation, hrs.          | 967                                | 469    |
| Estimated life, no sigma formation, hrs. | 8000                               | 2000   |

TABLE 3.0481 BENEFICIAL EFFECTS ON CREEP RUPTURE BEHAVIOR ACHIEVED BY AVOIDING SIGMA PHASE PRECIPITATION

|                        |                                                             |                   |            |                     |                   |            |                     |                   |            |
|------------------------|-------------------------------------------------------------|-------------------|------------|---------------------|-------------------|------------|---------------------|-------------------|------------|
| Source                 | (24) pp 3, 4, 6, 14                                         |                   |            |                     |                   |            |                     |                   |            |
| Alloy                  | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V (Nominal) <sup>(1)</sup> |                   |            |                     |                   |            |                     |                   |            |
| Condition              | Forged and Heat Treated (1)                                 |                   |            |                     |                   |            |                     |                   |            |
|                        | Low Nv - 2.29                                               |                   |            | Medium Nv - 2.40    |                   |            | High Nv - 2.59      |                   |            |
| Test Temp & Stress (2) | Time to Rupture Hrs                                         | e(1.25IN) Percent | RA Percent | Time to Rupture Hrs | e(1.25IN) Percent | RA Percent | Time to Rupture Hrs | e(1.25IN) Percent | RA Percent |
| 1200F, 150 ksi         | 27                                                          | 15                | 13         | -                   | -                 | -          | -                   | -                 | -          |
| 1200F, 95 ksi          | 14,005                                                      | 2                 | 2.5        | 12,027              | 3                 | 2.5        | 3,309               | 1                 | 0          |
| 1300F, 95 ksi          | 705                                                         | 2.5               | 1.5        | 877.5               | 5                 | 5          | 639                 | 5.5               | 7          |
| 1425F, 95 ksi          | 19.1                                                        | 3.5               | 2.5        | 39.1                | 7                 | 6          | 19.4                | 9.5               | 11         |
| 1550F, 40 ksi          | 1,337                                                       | 5                 | 4          | 1,307               | 5.5               | 5          | 310.6               | 11                | 12.5       |
| 1625F, 40 ksi          | 203                                                         | -                 | 4          | 234                 | 6                 | 4.5        | 145                 | 8                 | 6.5        |
| 1800F, 20 ksi          | 129                                                         | -                 | 10.5       | 122                 | 5                 | 5          | 9                   | 9                 | 9.5        |

(1) See Table 3.022 for actual compositions, forging parameters and heat treatment

(2) Average of 2 tests in most cases

TABLE 3.0482 CREEP RUPTURE PROPERTIES OF FORGED ALLOY IN THREE CONDITIONS OF PRONENESS TO SIGMA PHASE PRECIPITATION

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## NONFERROUS ALLOYS

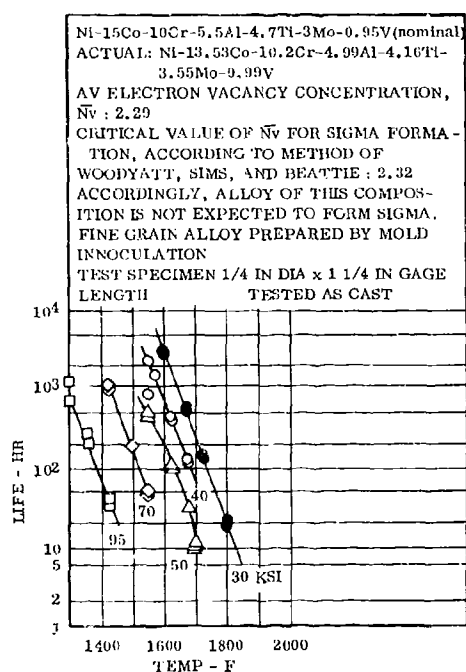


FIG. 3.0483 CREEP RUPTURE CURVES FOR FINE GRAIN ALLOY OF COMPOSITION SUFFICIENTLY LOW IN AL AND TI TO AVOID SIGMA PRECIPITATION (23, pp.3,5,12)

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

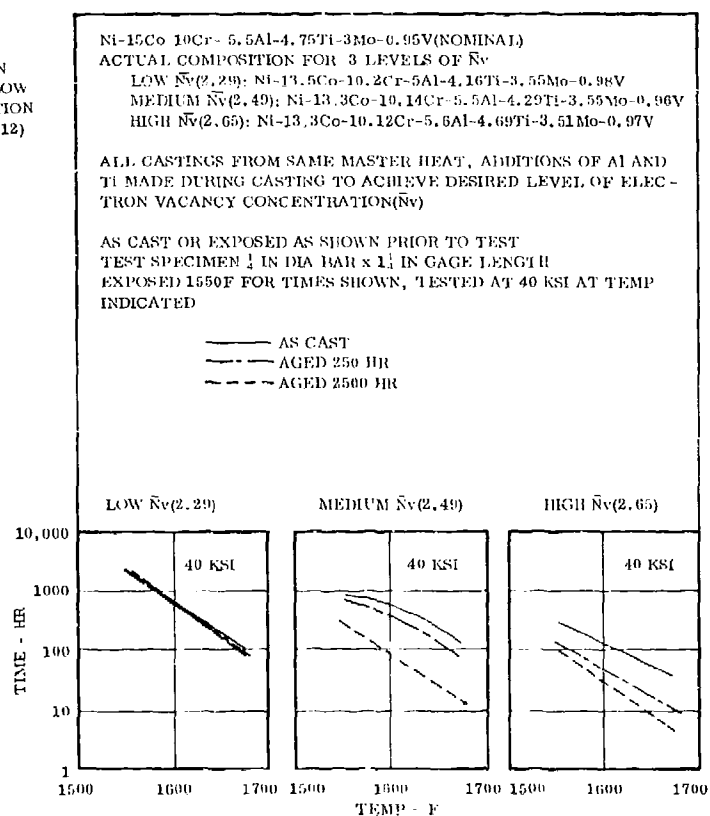


FIG. 3.0484 CREEP RUPTURE CURVES AT 40 KSI FOR ALLOY IN THREE LEVELS OF ELECTRON VACANCY CONCENTRATION ACHIEVED BY ADDITIONS OF AL-TI TO A SINGLE HEAT. TESTED IN AS CAST CONDITION OR AFTER EXPOSURE AT 1550F FOR 250 AND 2500 HRS. (22, pp.1-3,15)

|      |    |
|------|----|
|      | 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 3.0484 FOR ACTUAL COMPOSITIONS OF ALLOYS OF LOW, MEDIUM, AND HIGH ELECTRON VACANCY CONCENTRATION, ACHIEVED BY VARIATIONS OF AL AND TI.

SEE ALSO TABLE 3.021 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  $N_v$  ALLOY WHEREIN NO SIGMA FORMS IN THE TIMES SHOWN. ACTUAL DATA ARE SHOWN IN FIGURE 3.0483

CURVES FOR ONSET OF SIGMA PRECIPITATION ARE BASED ON FIG. 2.0123 BUT CORRECTED BY ESTIMATION TO ACCOUNT FOR EFFECT OF STRESS

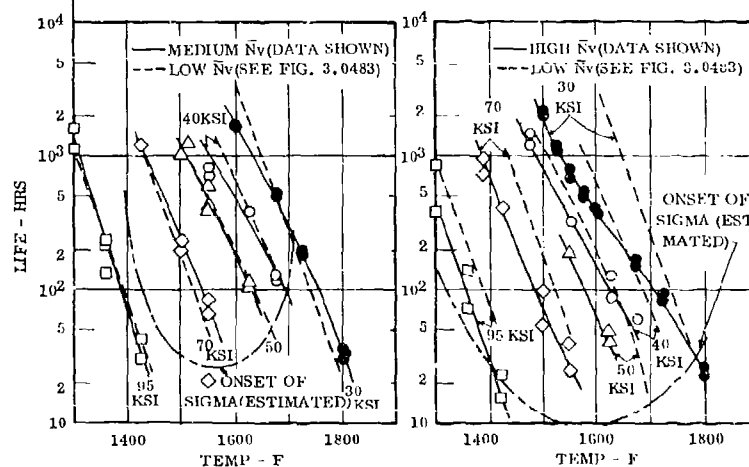


FIG. 3.0485 CREEP RUPTURE CURVES FOR FINE GRAIN ALLOYS OF LOW, MEDIUM, AND HIGH ELECTRON VACANCY CONCENTRATION ( $N_v$ ), REPRESENTING PROGRESSIVELY INCREASING TENDENCY TOWARD SIGMA PHASE PRECIPITATION. CURVES SHOW THAT STRONG TENDENCY FOR SIGMA PRECIPITATION RESULTS IN REDUCTION OF CREEP RUPTURE STRENGTHS. (23, pp. 3, 7, 8, 12, 13)

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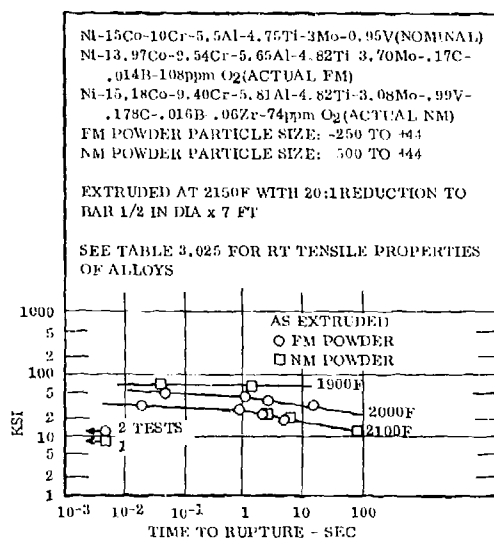


FIG. 3.0491 CREEP RUPTURE PROPERTIES IN VERY SHORT TIME RANGE AT 1900 TO 2100F FOR EXTRUDED ALLOY PREPARED FROM TWO LOTS OF POWDER (28, pp. Z-4 TO Z-7, Z-21)

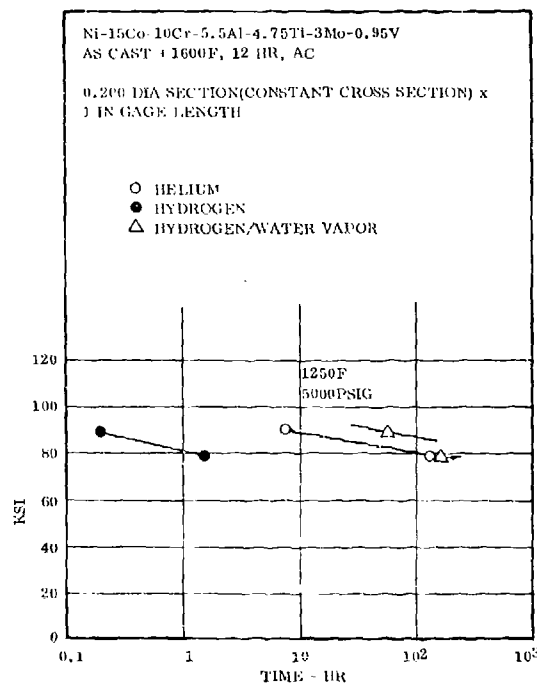


FIG. 3.04101 CREEP RUPTURE OF ALLOY IN HELIUM, HYDROGEN, AND HYDROGEN/WATER VAPOR AT 1250F AND 5000 PSIG PRESSURE (26, pp. III-13, VII-13)

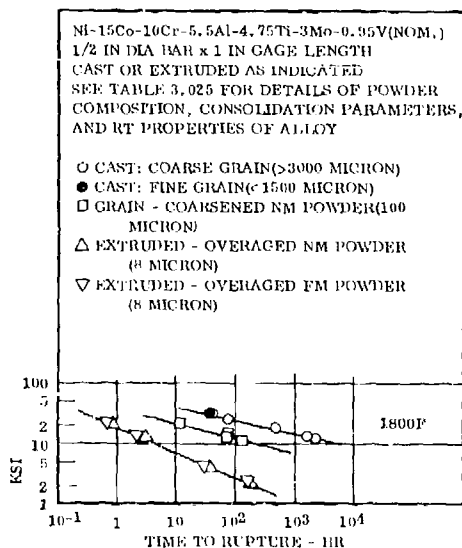


FIG. 3.0492 CREEP RUPTURE CURVES AT 1800F FOR CAST ALLOY OF VARIOUS GRAIN SIZE, AND FOR ALLOY EXTRUDED FROM POWDERS(28, p. Z-25)

|               |                                                     |
|---------------|-----------------------------------------------------|
| Alloy         | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                  |
| Source        | Haynes                                              |
| Condition     | As Cast, Tested at RT, R.R. Moore*                  |
|               | Number of Cycles To Failure<br>at $\pm 25$ ksi, 70F |
| Bare          | $19.2 \times 10^6$                                  |
| C - 9 Coating | $31.8 \times 10^6$ (av of 5 tests)                  |
| * Bending, R  | 1                                                   |

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

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

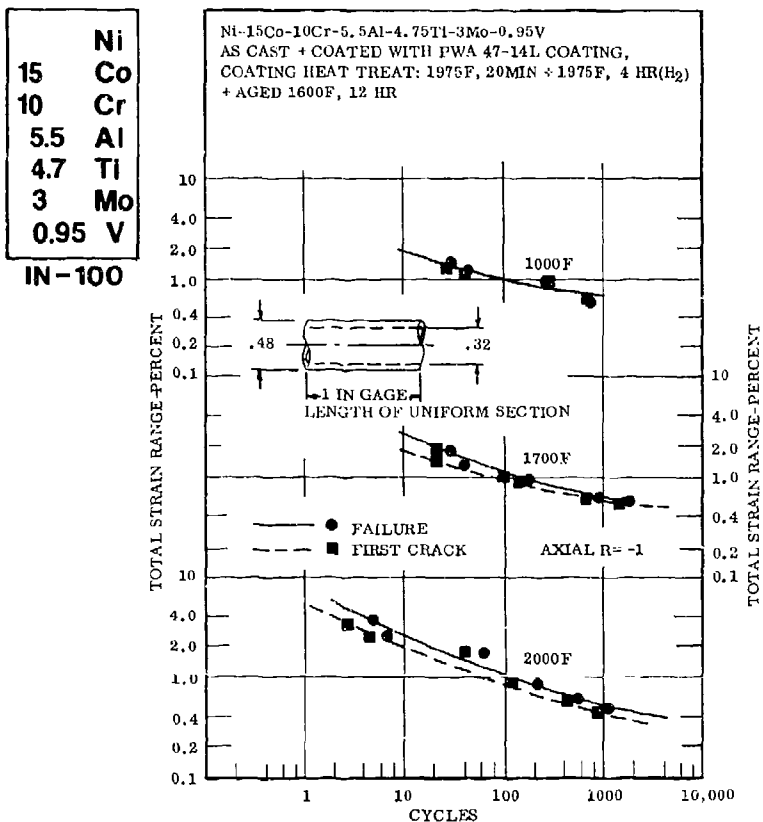


FIG. 3.0512 LOW CYCLE FATIGUE CHARACTERISTICS OF SMOOTH HOLLOW SPECIMEN WITH ONE INCH GAGE LENGTH OF UNIFORM CROSS SECTION AT TEMPERATURES FROM 1000 TO 2000F IN STRAIN-CONTROLLED CYCLING (1, p. C-8, C-12)

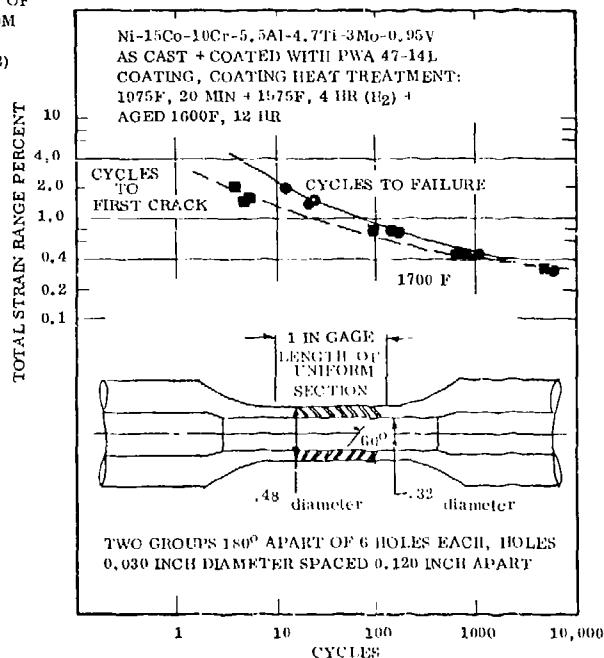


FIG. 3.0513 LOW CYCLE FATIGUE CHARACTERISTICS AT 1700F OF HOLLOW SPECIMEN WITH TWO SETS OF DIAGONAL HOLES (1, p. C8, C12)

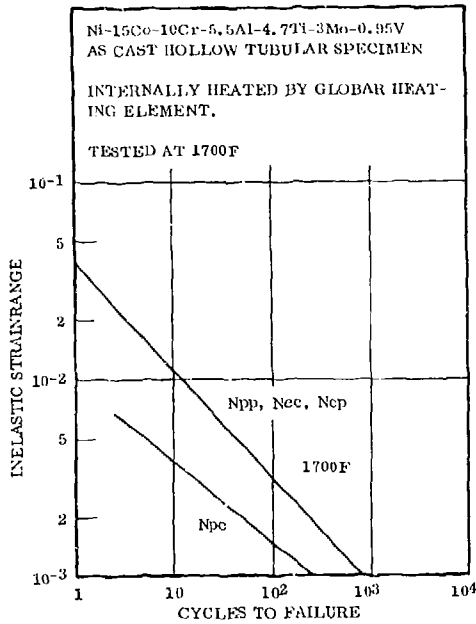


FIG. 3.0514 STRAINRANGE PARTITIONING LIFE RELATIONSHIPS FOR CAST ALLOY AT 1700F (49, p.23)

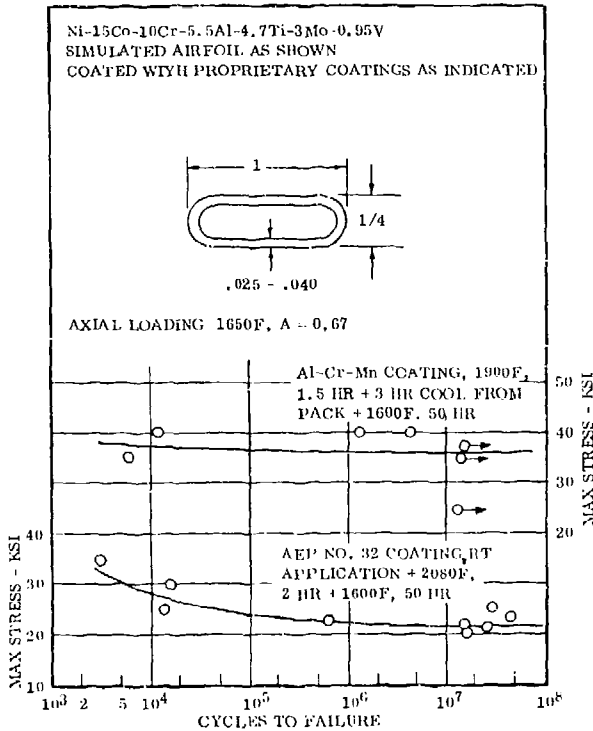


FIG. 3.0515 AXIAL FATIGUE AT 1650F OF SIMULATED HOLLOW AIRFOILS COATED WITH PROPRIETARY COATINGS (46, pp. 7, 83, 84)

|             |                                      |       |
|-------------|--------------------------------------|-------|
| Alloy       | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V   |       |
| Source      | Haynes (10) p. 10                    |       |
| Condition   | As Cast, Tested in Thermal Shock (b) |       |
|             | Number of Cycles to Cracking         |       |
|             | 1850F                                | 2100F |
| Bare        | 500                                  | 400   |
| Coating C-9 | > 500 (a)                            | 200   |
| Coating C-3 | -                                    | 200   |

(a) Two tests, stopped at 500 cycles, no cracking  
(b) Airfoil shape alternated for 60 seconds in furnace at test temperature, then 90 seconds in water spray

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

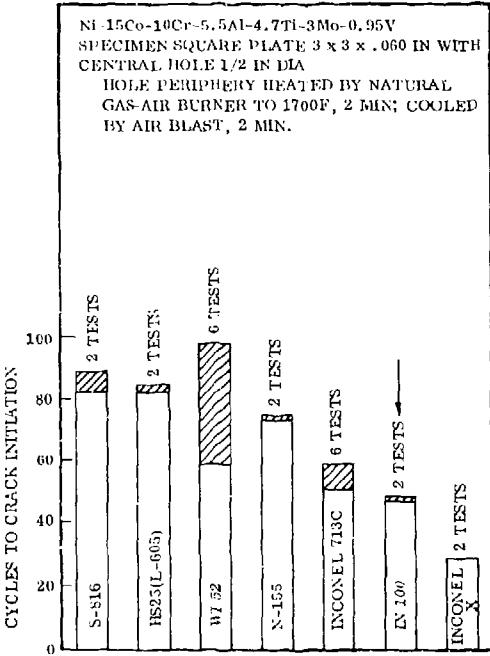


FIG. 3.0522 THERMAL FATIGUE RESISTANCE OF SQUARE PLATE RAPIDLY HEATED AND COOLED AT PERIPHERY OF CENTRAL HOLE, AND COMPARISON WITH THERMAL FATIGUE RESISTANCE OF OTHER COMMONLY USED CAST ALLOYS (30, p. 15)

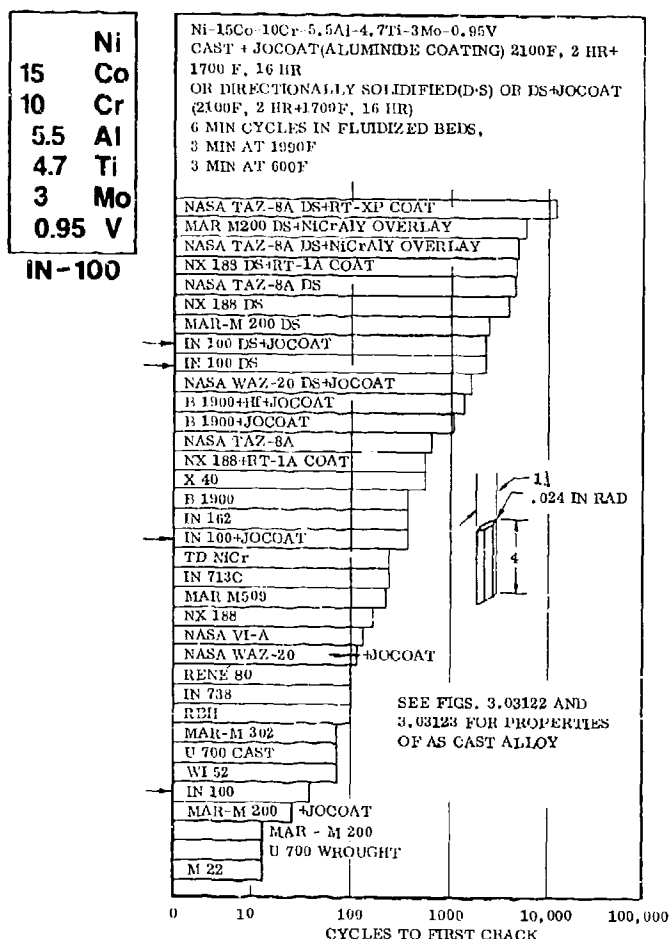


FIG. 3.0523 THERMAL FATIGUE CRACK INITIATION OF AS CAST OR DIRECTIONALLY SOLIDIFIED ALLOY WITH AND WITHOUT JOCOAT TESTED IN ALTERNATE FLUIDIZED BEDS AT 1990 AND 600F. (31, pp. 17,19,24)

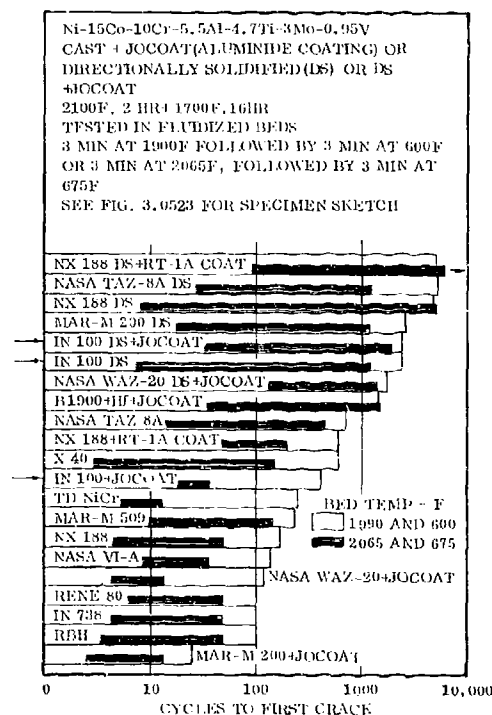


FIG. 3.0524 THERMAL FATIGUE CRACK INITIATION OF AS CAST OR DIRECTIONALLY SOLIDIFIED ALLOY WITH AND WITHOUT JOCOAT TESTED IN ALTERNATE FLUIDIZED BEDS AT TWO SETS OF TEMPERATURES (31, pp. 17-19,25)

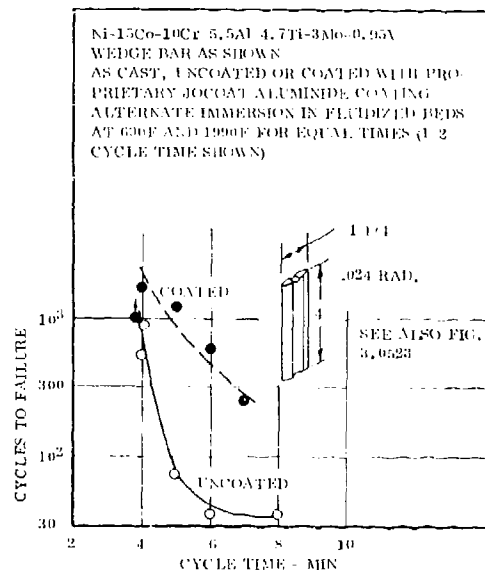


FIG. 3.0525 EFFECT OF CYCLE TIME ON THERMAL FATIGUE CRACKING OF COATED AND UNCOATED WEDGES ALTERNATELY IMMERSSED IN FLUIDIZED BEDS AT 600F AND 1990F (38, p. 654)

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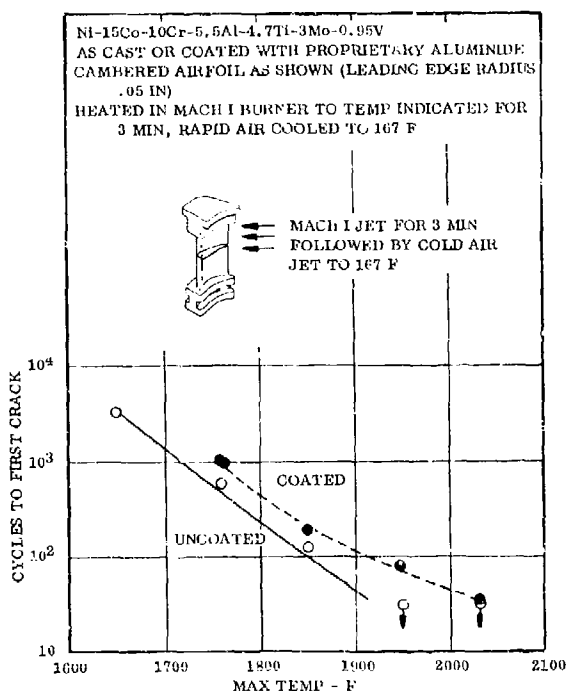


FIG. 3.0526 EFFECT OF MAXIMUM CYCLE TEMPERATURE ON THERMAL FATIGUE CRACKING OF COATED AND UNCOATED AIRFOILS SIMULATING TURBINE BLADES SUBJECTED TO MACH I GAS FLOW FOLLOWED BY RAPID AIR JET COOLING (48, p. 665)

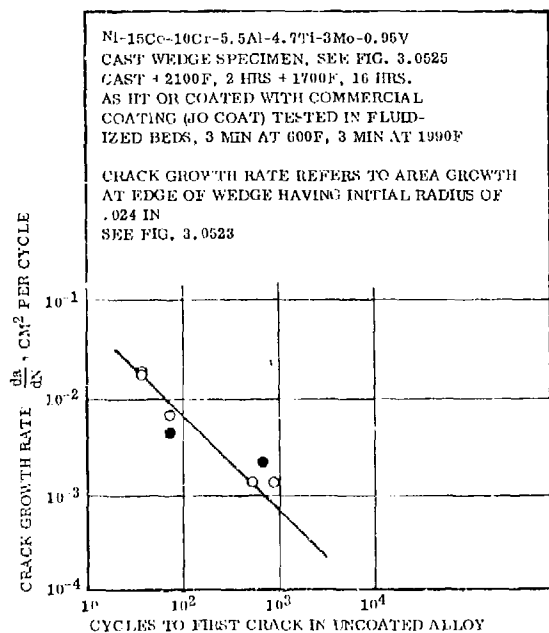


FIG. 3.0527 RELATION BETWEEN CRACK GROWTH RATE AND RESISTANCE TO INITIAL CRACKING IN THERMAL CYCLING (50, TABLE II, FIG. 9)

|                                     |                                                                                                                                                       |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Source                              | (16) pp 2, 3, 42, 43                                                                                                                                  |
| Alloy                               | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                                                                                                    |
| Condition                           | Coated with Al-Cr-Mn or AEP No. 32, see Fig. 3.0515 for Coating Treatment                                                                             |
| Specimen Type                       | Cast simulated hollow airfoil, see Fig. 3.0515                                                                                                        |
| Test Conditions                     | Mean tensile stress of 10.5 ksi, 40 sec. at 2050F + 40 sec. cooling with RT air, Specimen inspected with Fluorescent Penetrant after every 100 cycles |
| Specimen                            | Cycles to Fatigue Crack                                                                                                                               |
|                                     | Coating                                                                                                                                               |
|                                     | Comparison with best and worst alloys to be tested                                                                                                    |
|                                     | Best Worst                                                                                                                                            |
| Number                              | Al-Cr-Mn AEP No. 32 NASA VI-A AEP No. 32 on U-700                                                                                                     |
| 1                                   | 4808 4090 9556 628                                                                                                                                    |
| 2                                   | 3080 3545 8130 440                                                                                                                                    |
| 3                                   | 1920 1979 8130 340                                                                                                                                    |
| 4                                   | 1640 1977 7918 260                                                                                                                                    |
| 5                                   | 1547 1360 7049 230                                                                                                                                    |
| 6                                   | 1405 983 6250 210                                                                                                                                     |
| 7                                   | 685 831 2010 170                                                                                                                                      |
| Av. based on Log. cycles to failure | 1834 1807 6406 296                                                                                                                                    |

TABLE 3.0528 THERMAL FATIGUE OF THINWALL ALLOY WITH TWO PROPRIETARY COATINGS SUBJECTED TO 10.5 KSI TENSILE MEAN STRESS AND 70 TEMPERATURE CYCLING FROM 2050F.

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

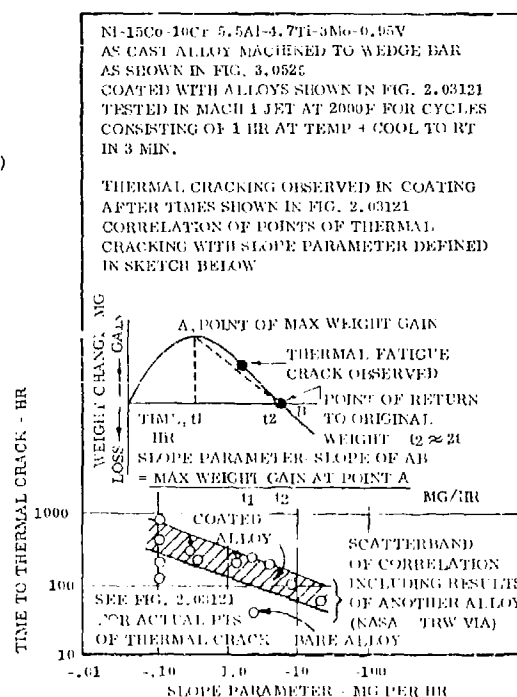


FIG. 3.0529 CORRELATION OF TIME TO INITIATE THERMAL CRACKING WITH WEIGHT GAIN SLOPE PARAMETER FOR ALLOY COATED IN VARIOUS WAYS (50, pp. 14, 15)

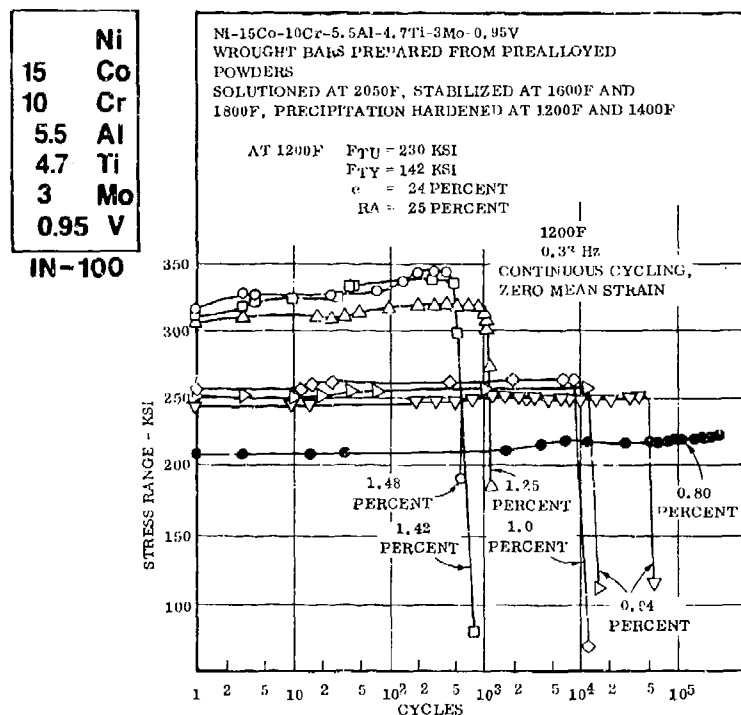


FIG. 3.0531 STRESS RANGE VARIATION DURING LOW CYCLE FATIGUE TESTS AT 1200F OF POWDER METALLURGY BARS PREPARED BY PRATT AND WHITNEY GATORIZING PROCESS (37, FIG. 6)

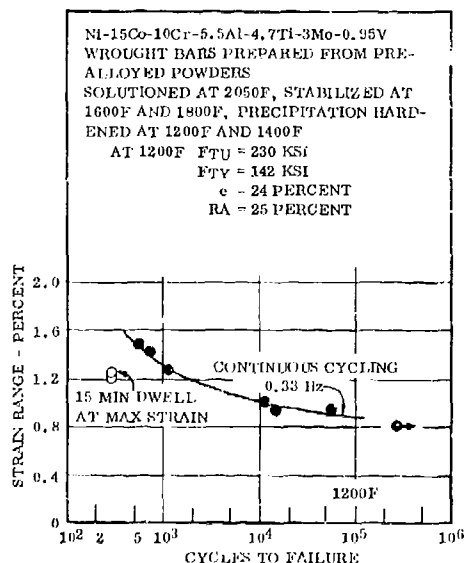


FIG. 3.0532 LOW CYCLE FATIGUE AT 1200F OF POWDER METALLURGY BARS PREPARED BY PRATT AND WHITNEY GATORIZING PROCESS, DATA POINTS REPRESENT CYCLES TO COMPLETE FRACTURE (37, FIG. 15)

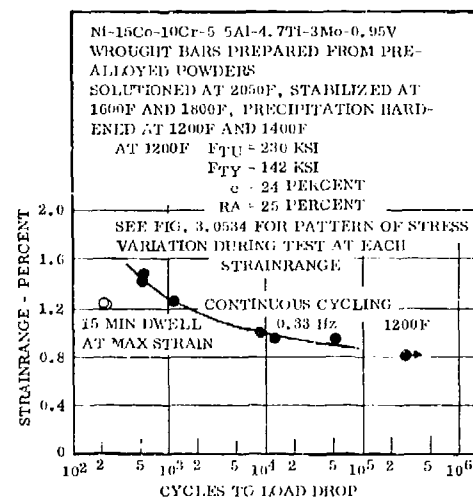


FIG. 3.0533 LOW CYCLE FATIGUE AT 1200F OF POWDER METALLURGY BARS PREPARED BY PRATT AND WHITNEY AIRCRAFT GATORIZING PROCESS, DATA POINTS REPRESENT CYCLES TO 5 PERCENT LOAD DROP (37, FIG. 14)

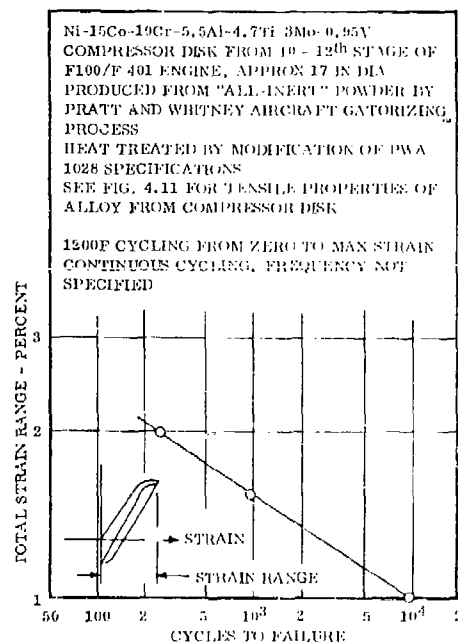


FIG. 3.0534 LOW CYCLE FATIGUE AT 1200F OF SPECIMEN FROM POWDER METALLURGY COMPRESSOR DISK (36, FIG. 3)

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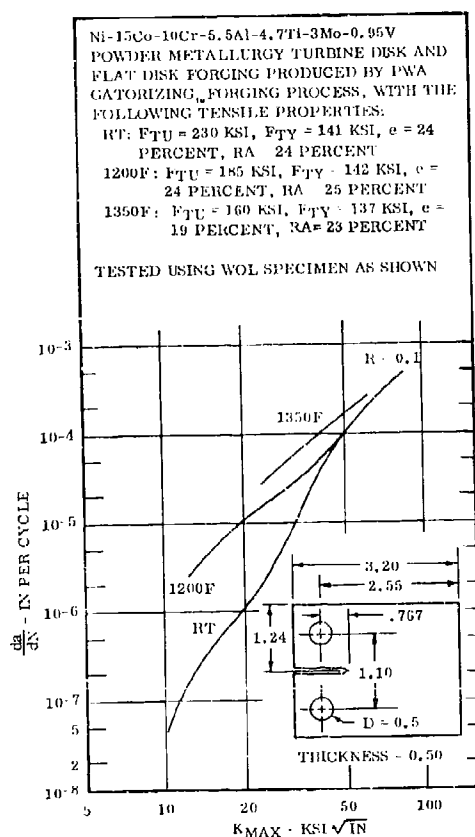


FIG. 3.0541 BASIC CRACK GROWTH CURVES AT RT, 1200F, 1350F, FOR CONSTANT AMPLITUDE LOADING OF WOL SPECIMEN (40, TABLE 1, FIGS. 1, 3)

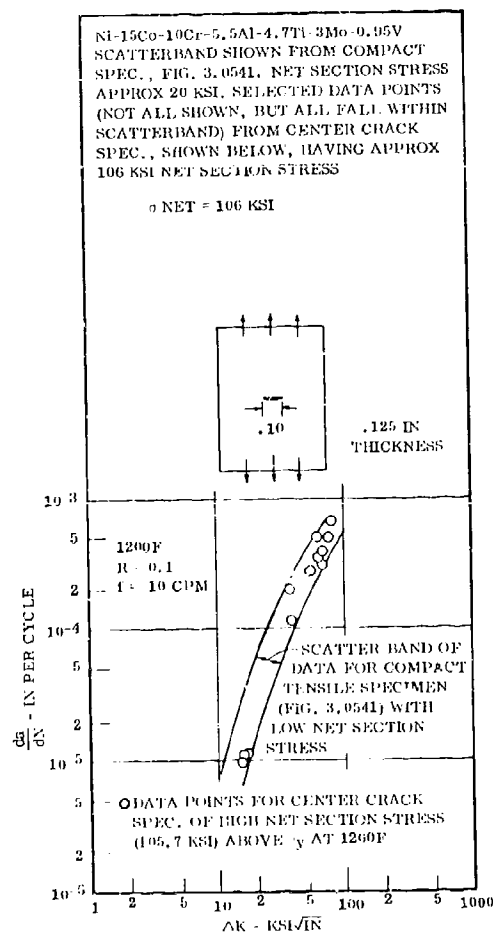


FIG. 3.0542 EFFECT OF NET SECTION STRESS ON CRACK GROWTH RATE AT 1200F (20, pp. 4, 5, 6, 8, 17)

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

IN-100

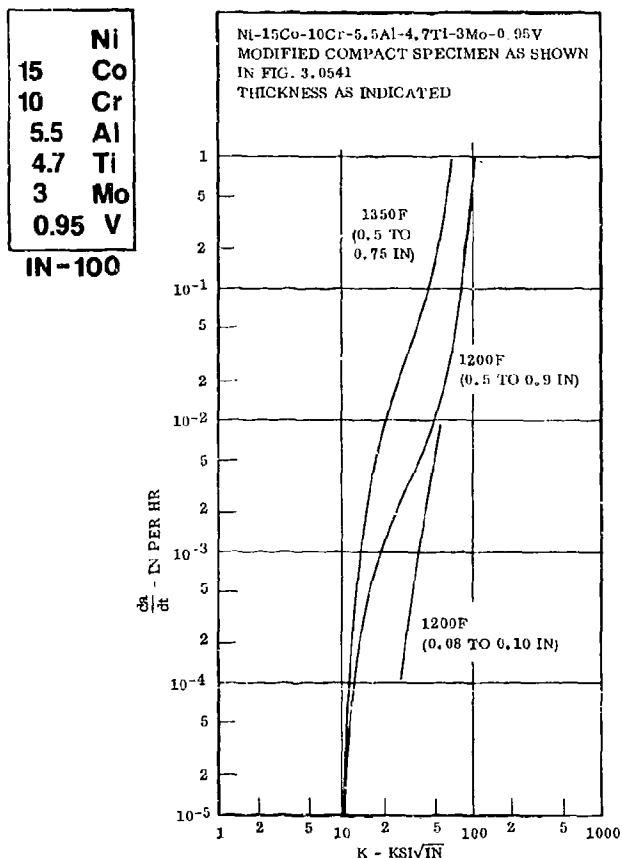


FIG. 3.0543 EFFECT OF TEMPERATURE AND SPECIMEN THICKNESS ON SUSTAINED LOAD CRACK PROPAGATION RATE. (20, pp. 4, 8, 13)

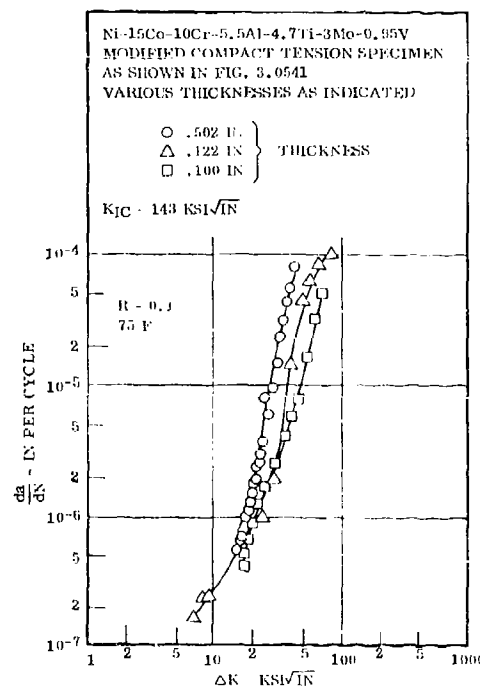


FIG. 3.0544 EFFECT OF SPECIMEN THICKNESS ON CRACK GROWTH RATE AT RT. (20, pp. 4, 8, 9)

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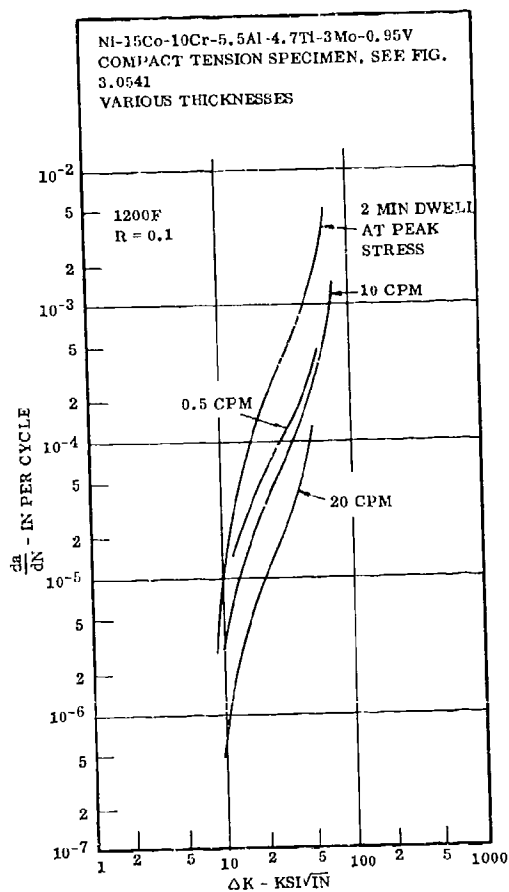


FIG. 3.0545 EFFECT OF FREQUENCY ON CRACK GROWTH RATE IN CONTINUOUS CYCLING AT 1200F  
(20, pp. 4, 5, 6, 8, 25)

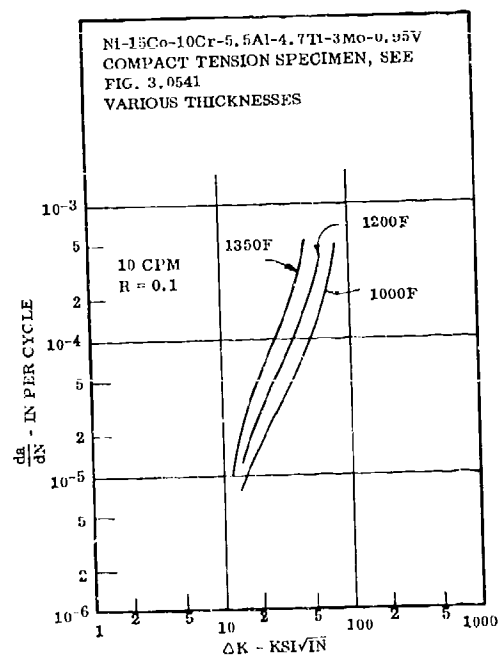


FIG. 3.0546 EFFECT OF TEMPERATURE ON CRACK GROWTH RATE AT 10 CPM, R = 0.1  
(20, pp. 4, 5, 6, 8, 28)

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

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

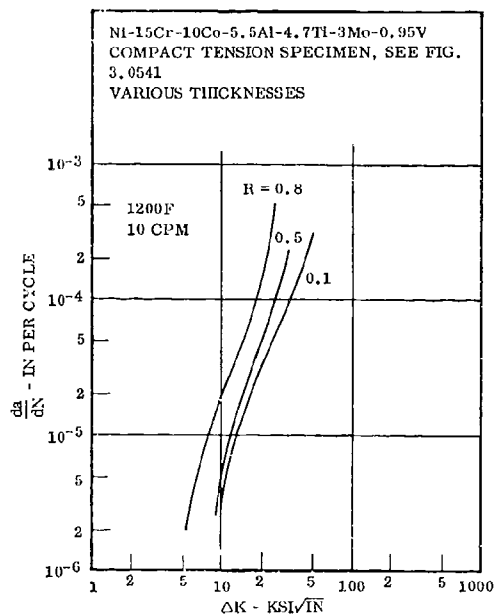


FIG. 3.0547 EFFECT OF STRESS RATIO ON CRACK GROWTH RATE AT 1200F, 10 CPM  
(20, pp. 4, 5, 6, 8, 26)

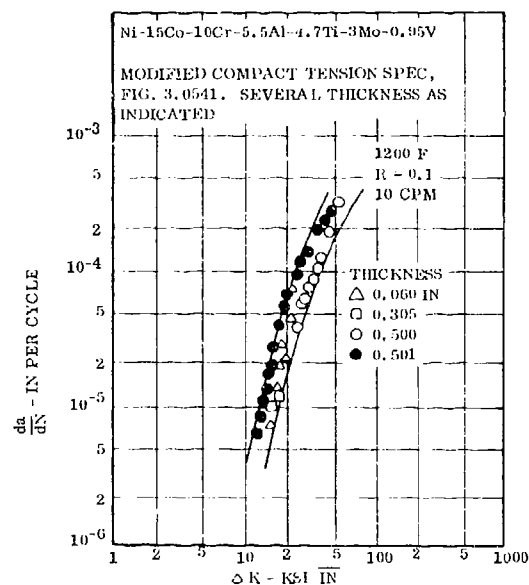


FIG. 3.0549 EFFECT OF SPECIMEN THICKNESS ON CRACK GROWTH RATE AT 1200 F CONTINUOUS CYCLING AT 10 CPM  
(20, pp. 4, 8, 11)

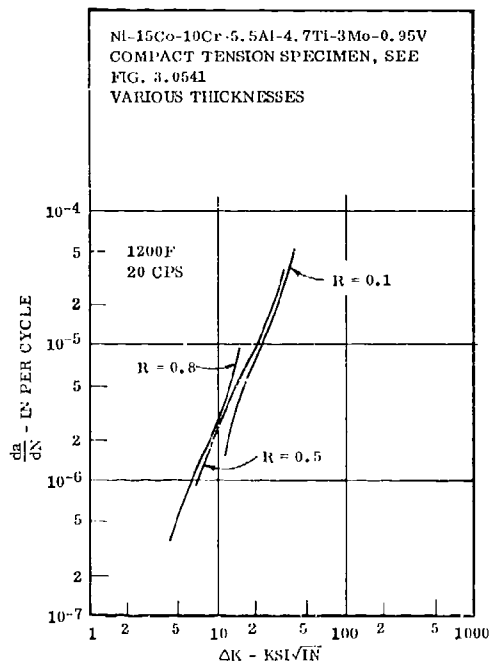


FIG. 3.0548 EFFECT OF STRESS RATIO ON CRACK GROWTH RATE AT 1200F, 20 CPS.  
(20, pp. 4, 5, 6, 8, 27)

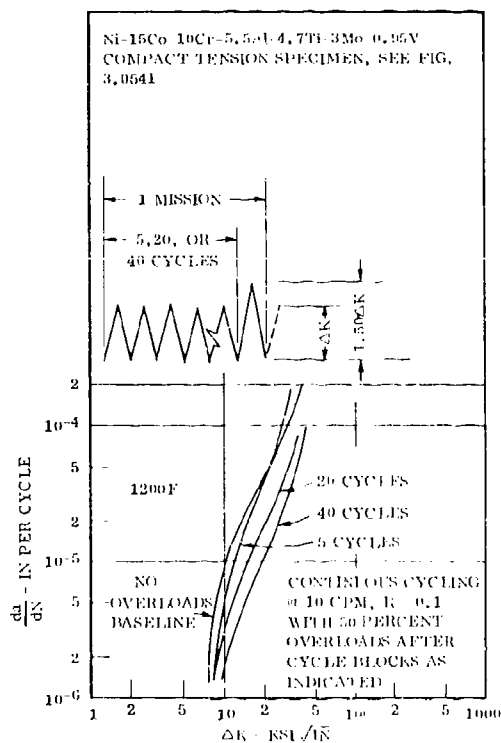


FIG. 3.0551 CRACK GROWTH AT 1200F UNDER CONTINUOUS CYCLING AND WITH 50 PERCENT OVERLOAD EVERY 5, 20, OR 40 CYCLES  
(20, pp. 4, 5, 48)

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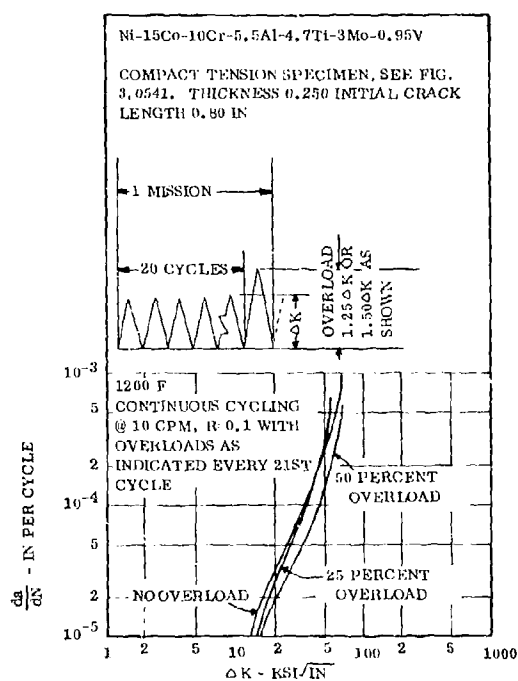


FIG. 3.0552 CRACK GROWTH AT 1200F UNDER CONTINUOUS CYCLING AND WITH 25 PERCENT OR 50 PERCENT OVERLOADS EVERY 21 CYCLES (20, pp. 4, 5, 6, 47)

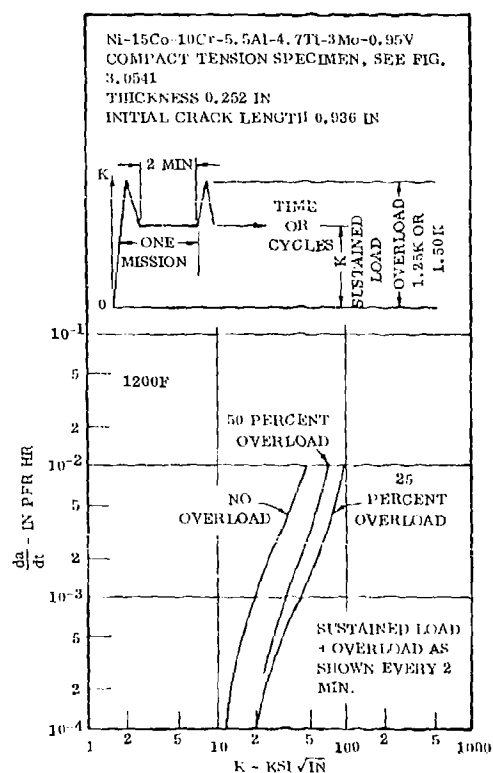


FIG. 3.0553 CRACK GROWTH AT 1200F UNDER SUSTAINED LOAD AND WITH 25 PERCENT OR 50 PERCENT OVERLOADS EVERY 2 MINUTES (20, pp. 4, 5, 41, 43)

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

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

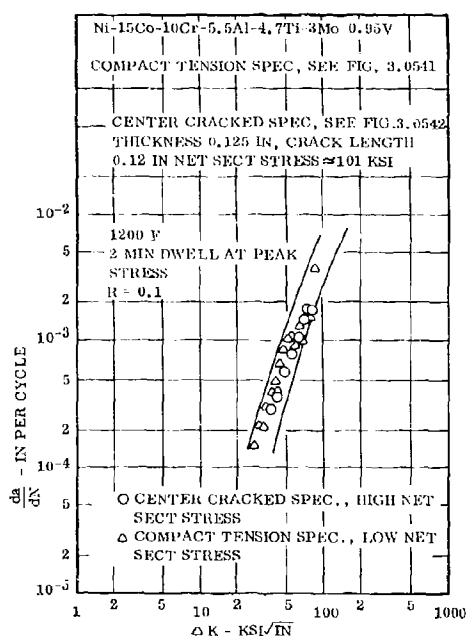


FIG. 3.0561 EFFECT OF NET SECTION STRESS ON CRACK GROWTH RATE FOR 2 MINUTE DWELL AT PEAK STRESS AT 1200 F (20, pp. 4, 5, 6, 8, 18)

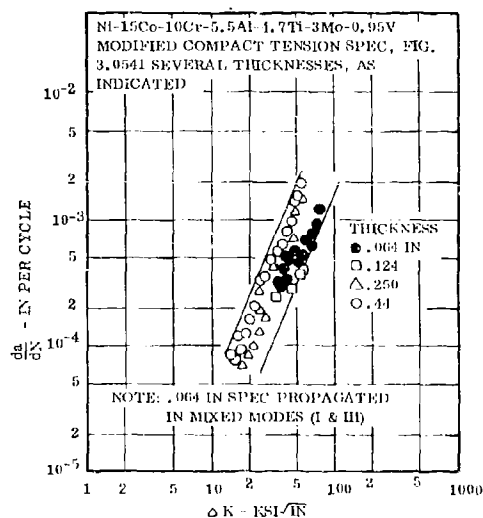


FIG. 3.0562 EFFECT OF SPECIMEN THICKNESS ON CRACK GROWTH RATE AT 1200 F, 2 MIN DWELL AT MAX LOAD, 10 CPM DURING VARIABLE STRESS PERIOD (20, pp. 4, 8, 12)

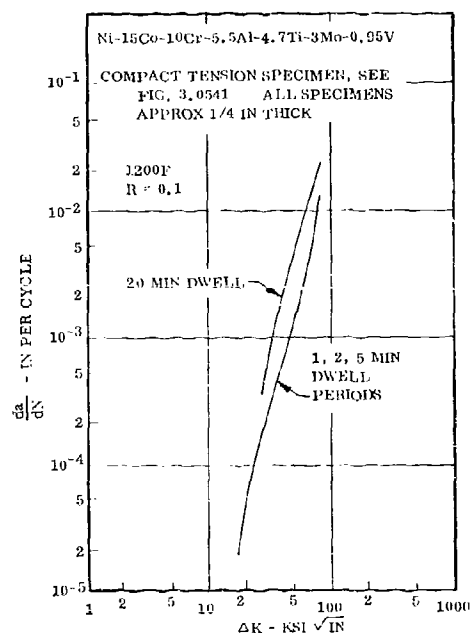


FIG. 3.0563 EFFECT OF DWELL TIME AT PEAK STRESS ON CRACK GROWTH RATE AT 1200 F, R = 0.1. (20, pp. 4, 5, 6, 8, 32)

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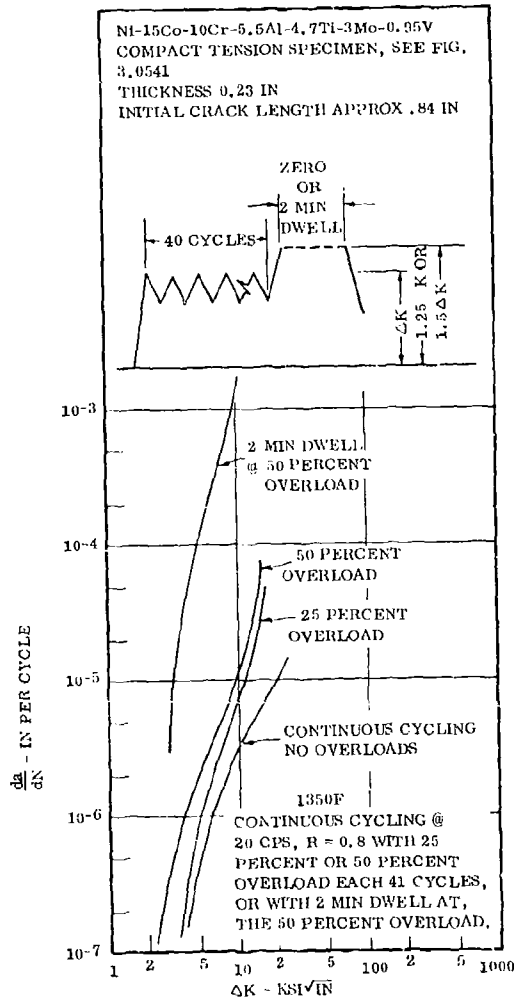


FIG. 3.0564 CRACK GROWTH AT 1350F AT CONTINUOUS CYCLING, OR WITH 25 AND 50 PERCENT OVERLOAD, OR WITH 2 MIN DWELL AT THE 50 PERCENT OVERLOAD CONDITION  
(20, pp. 4, 5, 54, 55)

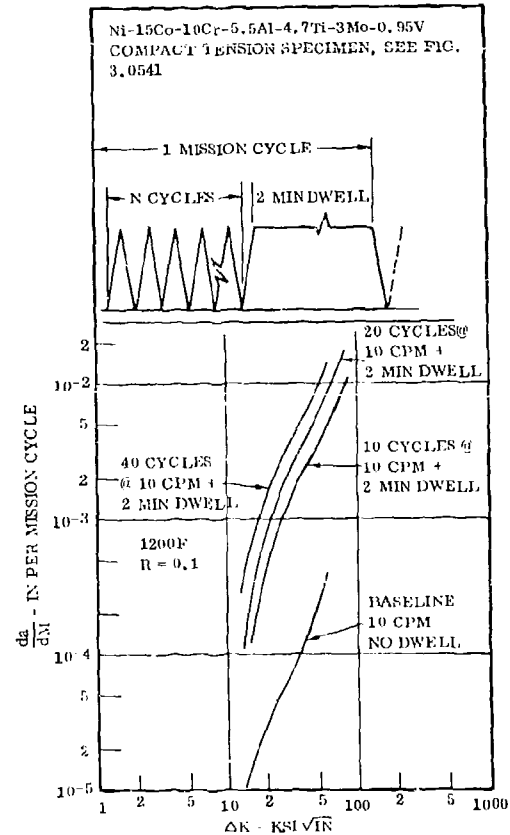


FIG. 3.0565 INTERACTION OF LOW CYCLE FATIGUE WITH DWELL PERIODS AT MAX LOAD FOR TESTS AT 1200F, R = 0.1 (20, pp. 4, 6, 7, 33, 34)

Ni  
Co  
Cr  
Al  
Ti  
Mo  
V  
IN-100

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

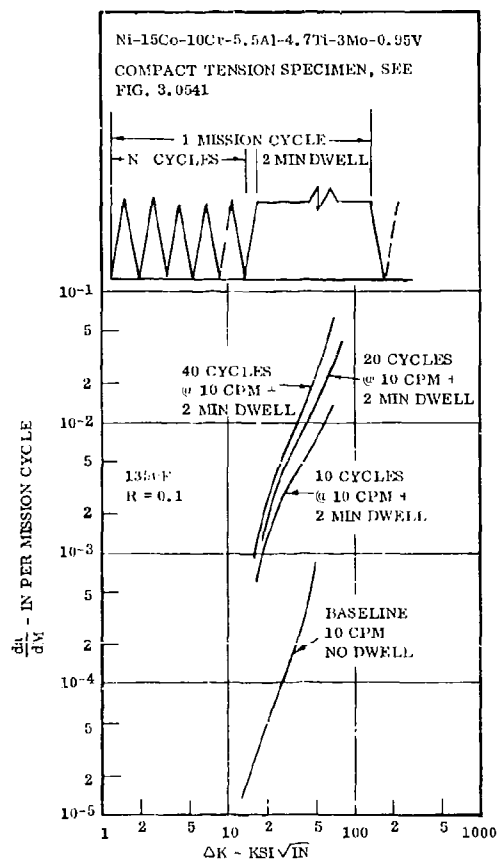


FIG. 3.0566 INTERACTION OF LOW CYCLE FATIGUE WITH DWELL PERIODS AT MAX LOAD FOR TESTS AT 1350F,  $R = 0.1$  (20, pp. 4, 6, 7, 33, 35)

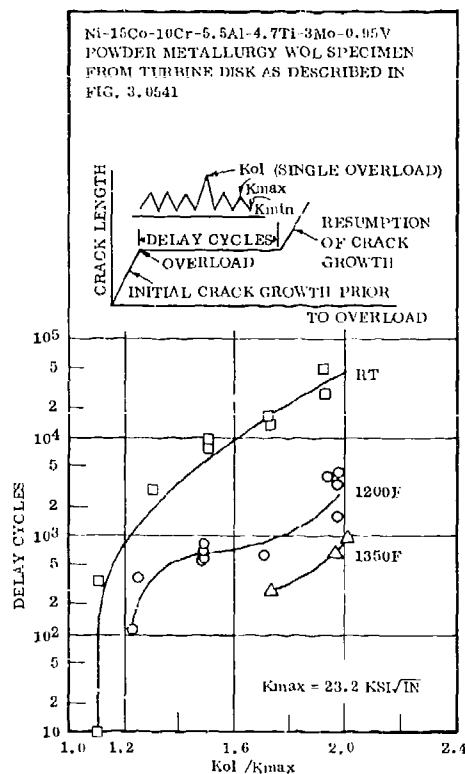


FIG. 3.0571 DELAY CYCLES PRIOR TO RESUMPTION OF BASIC CRACK GROWTH AFTER SINGLE CYCLE OF OVERLOAD, BASELINE  $K_{max} = 23.2 \text{ KSI}\sqrt{\text{IN}}$  (40, FIGS. 2, 4)

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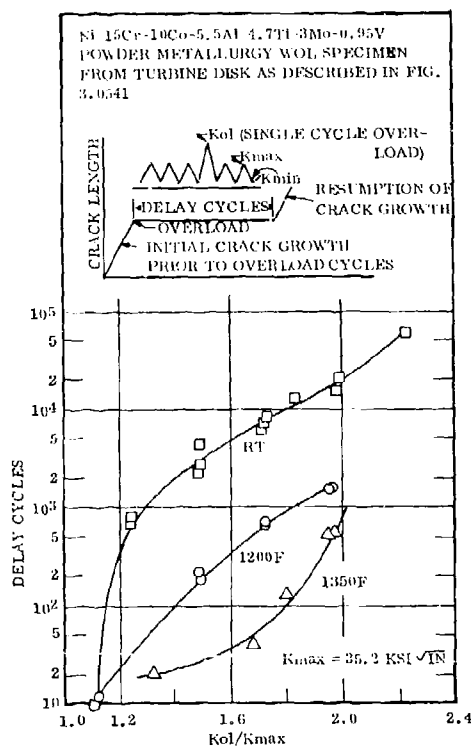


FIG. 3.0572 DELAY CYCLES PRIOR TO RESUMPTION OF BASIC CRACK GROWTH AFTER SINGLE CYCLE OVERLOAD, BASELINE  $K_{max} = 35.2 \text{ KSI}\sqrt{\text{IN}}$  (40, FIGS. 2,3)

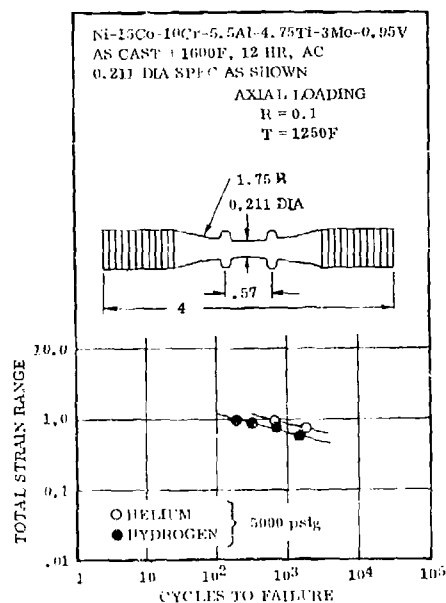


FIG. 3.0581 LOW CYCLE FATIGUE AT 1250F IN HIGH PRESSURE HYDROGEN AND HELIUM (26, pp. III-9, V-9, 17)

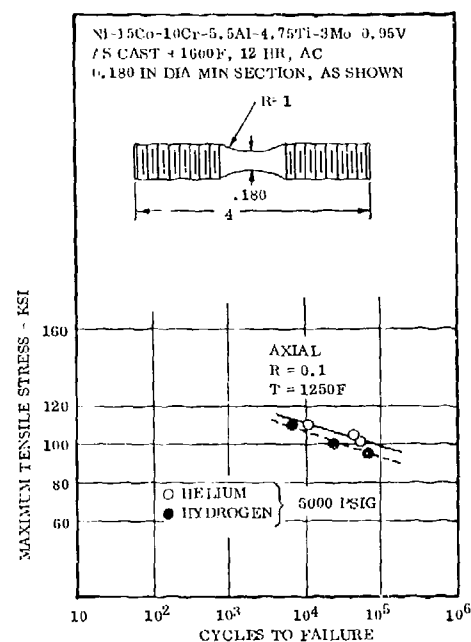


FIG. 3.0582 HIGH CYCLE AXIAL FATIGUE IN HIGH PRESSURE HYDROGEN AND HELIUM AT 1250F (26, pp. III-10, IV-4, 9)

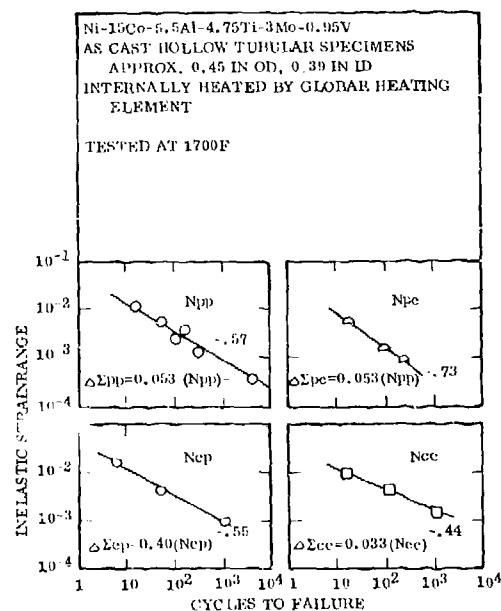


FIG. 3.0541 INELASTIC STRAIN RANGE VS. LOW-CYCLE FATIGUE LIFE FOR EACH PARTITIONED STRAIN RANGE COMPONENT FOR AS-CAST THINWALL TUBING AT 1700F (49, p. 23), (53, p. 4 & FIG. 6)

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

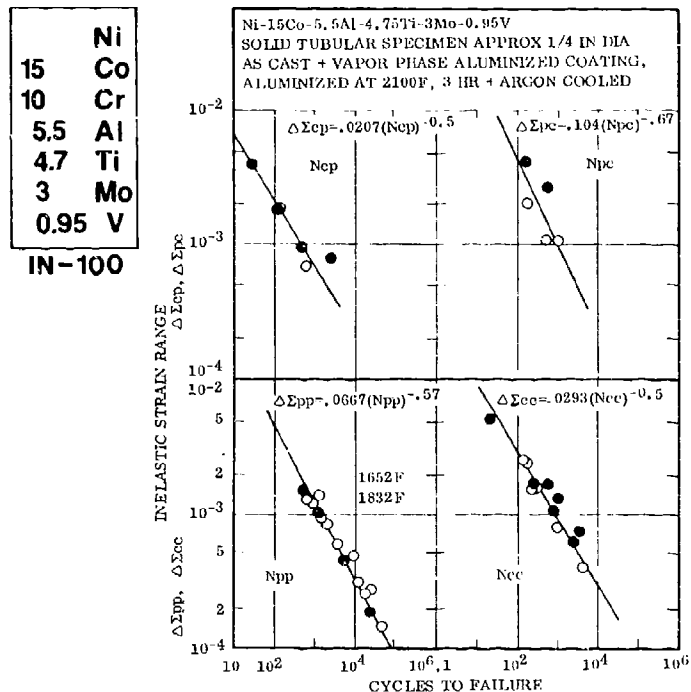


FIG. 3.05142 STRAINRANGE PARTITIONING LIFE RELATIONSHIPS AT 1652F AND 1832F FOR AS-CAST ALUMINUM-COATED ALLOY (54, pp. 4-10)

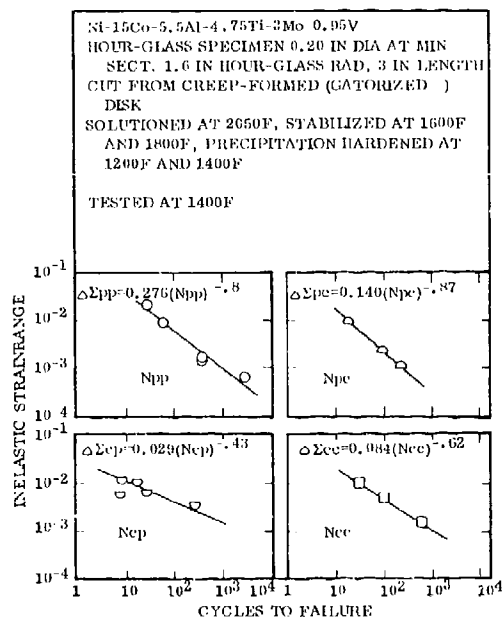


FIG. 3.05143 INELASTIC STRAINRANGE VS LOW-CYCLE FATIGUE LIFE FOR EACH PARTITIONED STRAINRANGE COMPONENT AT 1400F. SPECIMENS FROM CREEP-FORMED (GATORIZED) TURBINE DISK (53, p. 4 & FIG. 5)

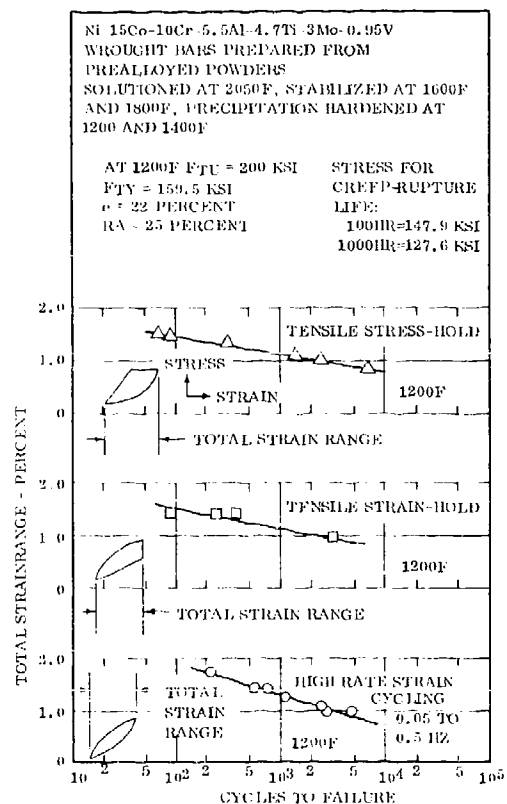


FIG. 3.05144 TOTAL STRAIN RANGE VS LOW-CYCLE FATIGUE LIFE AT 1200F OF POWDER METALLURGY BARS PREPARED BY PRATT & WHITNEY GATORIZING PROCESS AND TESTED UNDER RAPID STRAIN CYCLING, TENSILE STRESS-HOLD, AND TENSILE STRAIN-HOLD, (52)

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## NONFERROUS ALLOYS

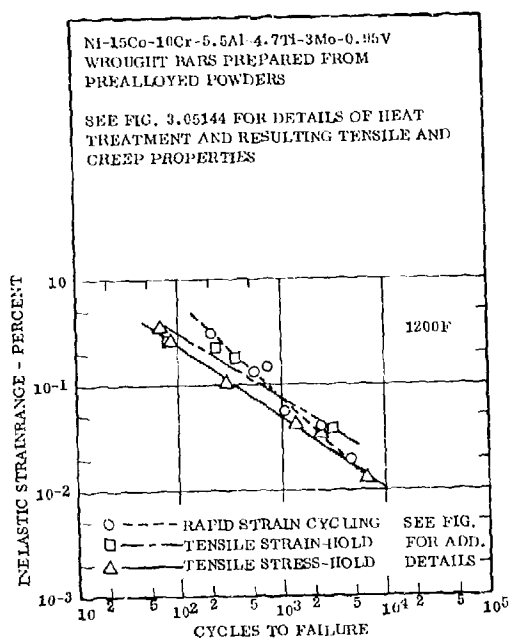


FIG. 3.05145 INELASTIC STRAINRANGE VS LOW CYCLE  
FATIGUE LIFE AT 1200F OF POWDER  
METALLURGY BARS PREPARED BY PRATT  
AND WHITNEY GATORIZING<sup>TM</sup> PROCESS AND  
TESTED UNDER RAPID STRAIN CYCLING,  
TENSILE STRESS-HOLD, AND TENSILE  
STRAIN-HOLD. (52)

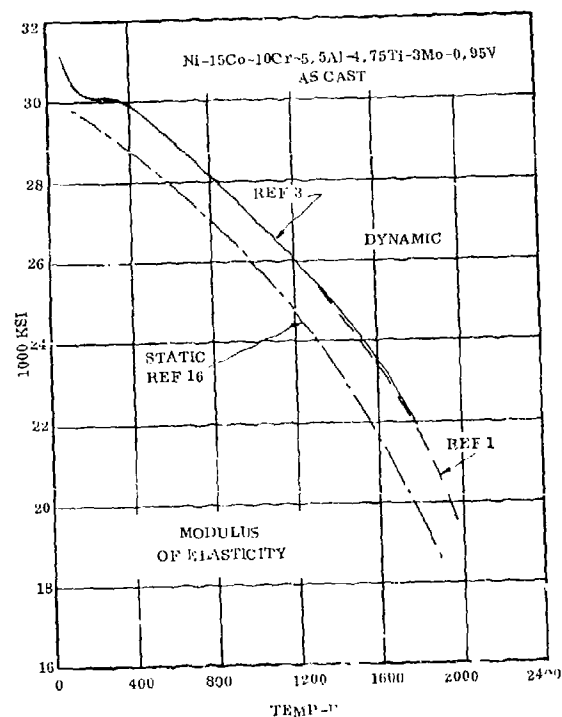


FIG. 3.052 DYNAMIC MODULUS OF ELASTICITY (3,p.8,1,p.C-7)  
(18,p.114)

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

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

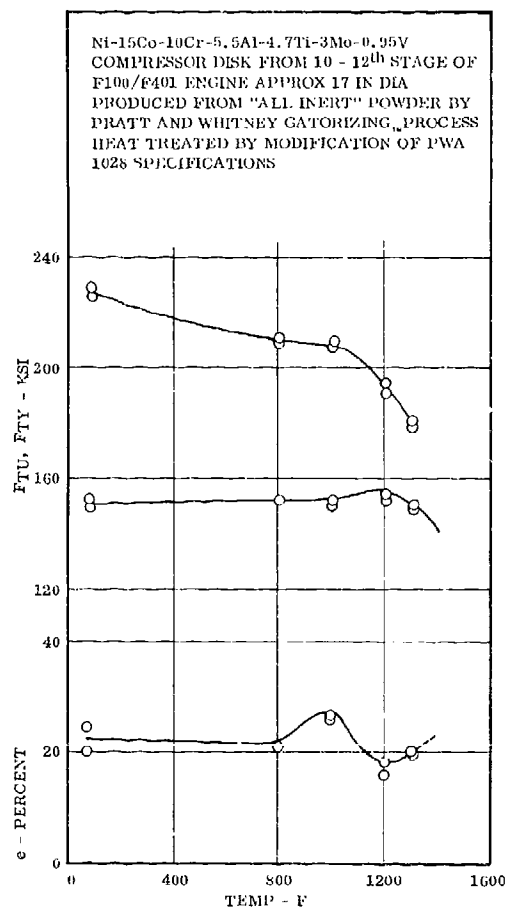


FIG. 4.11 MECHANICAL PROPERTIES FROM RT TO 1300F  
OF SPECIMENS FROM THE 10 - 12<sup>th</sup> STAGE  
COMPRESSOR OF F100/F401 ENGINE

(36, Fig. 2)

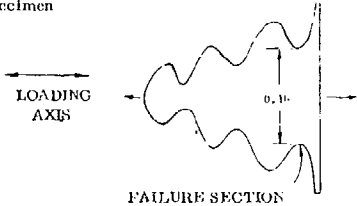
|                  |                                                                                                                                                                                                                                                                         |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Source           | (17) pp 30, 83                                                                                                                                                                                                                                                          |
| Alloy            | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                                                                                                                                                                                                                      |
| Condition        | As Cast and Machined To Fir Tree Specimen As Shown                                                                                                                                                                                                                      |
| Test Temperature | RT                                                                                                                                                                                                                                                                      |
| Specimen         |  <p>Fir Tree Attachment Loaded with Mating Waspalloy Female Fixture. Failure in IN 100 Across 0.16 IN Dimension As Shown. Depth 0.61 IN<br/><math>F_{tu}</math> of Alloy 115 KSI</p> |
| Specimen No.     | Nominal Stress At Failure, KSI                                                                                                                                                                                                                                          |
| 1                | 138.5                                                                                                                                                                                                                                                                   |
| 2                | 130.0                                                                                                                                                                                                                                                                   |

TABLE 4.12 ROOM TEMPERATURE TENSILE STRENGTH OF FIR 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 |    |

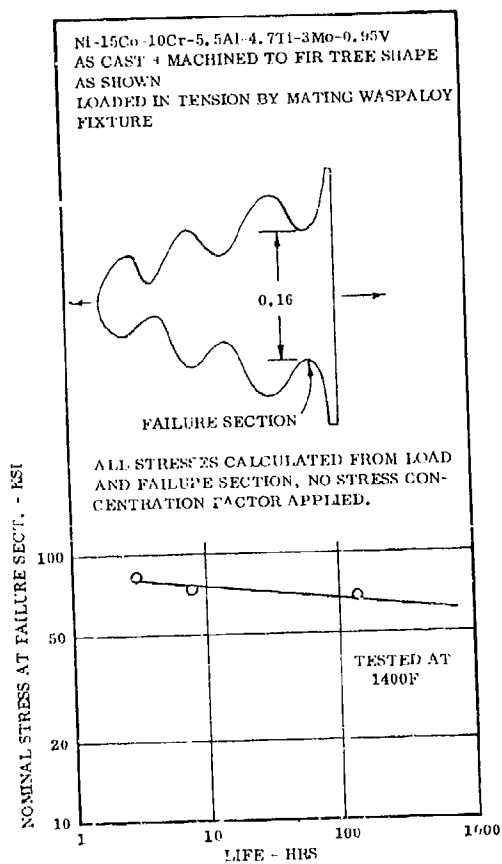
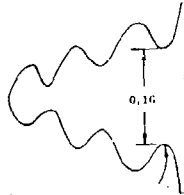


FIG. 4.13 CREEP RUPTURE AT 1400F OF FIR TREE  
SIMULATING TURBINE BLADE ATTACHMENT  
(47, pp. 31, 107)

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

| Source                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | (47) pp 32, 83                                             |                                  |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|----------------------------------|--------------------|-------------------------|----------------------------------|----|----|-------------------|----|----|-------------------|----|------------------------------------------------------------|-------------------|----|------------------------------------------------------------|--------------------|----|----|-------------------|
| Alloy                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                         |                                  |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| Condition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | As Cast and Machined To Fir Tree Specimen As Shown         |                                  |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| Test Temperature                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | RT                                                         |                                  |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| <div><div><p>0.16</p></div><div>FAILURE SECTION</div></div> <div><p>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.</p></div>                                                                                                                                                                                                                                                               |                                                            |                                  |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| <table><tr><th>Static Stress, ksi</th><th>Alternating Stress, ksi</th><th>Cycles to Failure<sup>(1)</sup></th></tr><tr><td>20</td><td>15</td><td><math>3.1 \times 10^6</math></td></tr><tr><td>20</td><td>30</td><td><math>8.7 \times 10^5</math></td></tr><tr><td>20</td><td>5 for <math>10^6</math> cycles + 10 for <math>10^6</math> cycles + 15 to failure</td><td><math>3.8 \times 10^6</math></td></tr><tr><td>25</td><td>5 for <math>10^6</math> cycles + 10 for <math>10^6</math> cycles + 15 to failure</td><td><math>2.04 \times 10^6</math></td></tr><tr><td>15</td><td>15</td><td><math>9.6 \times 10^6</math></td></tr></table> |                                                            |                                  | Static Stress, ksi | Alternating Stress, ksi | Cycles to Failure <sup>(1)</sup> | 20 | 15 | $3.1 \times 10^6$ | 20 | 30 | $8.7 \times 10^5$ | 20 | 5 for $10^6$ cycles + 10 for $10^6$ cycles + 15 to failure | $3.8 \times 10^6$ | 25 | 5 for $10^6$ cycles + 10 for $10^6$ cycles + 15 to failure | $2.04 \times 10^6$ | 15 | 15 | $9.6 \times 10^6$ |
| Static Stress, ksi                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Alternating Stress, ksi                                    | Cycles to Failure <sup>(1)</sup> |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| 20                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 15                                                         | $3.1 \times 10^6$                |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| 20                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 30                                                         | $8.7 \times 10^5$                |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| 20                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 5 for $10^6$ cycles + 10 for $10^6$ cycles + 15 to failure | $3.8 \times 10^6$                |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| 25                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 5 for $10^6$ cycles + 10 for $10^6$ cycles + 15 to failure | $2.04 \times 10^6$               |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |
| 15                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 15                                                         | $9.6 \times 10^6$                |                    |                         |                                  |    |    |                   |    |    |                   |    |                                                            |                   |    |                                                            |                    |    |    |                   |

(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  $10^6$ , alternating 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 FIR TREE FASTENING

|                                                                                                 |                                                                                                                                                                |                     |
|-------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| Source                                                                                          | (47) pp 25, 26, 33, 87, 94                                                                                                                                     |                     |
| Alloy                                                                                           | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                                                                                                             |                     |
| Test Specimen                                                                                   | 4 x 1.5 x 0.5 Bar Electron Beam Welded to Similar Waspaloy Bar. After Heat Treat, Machined to Specimen Described Below                                         |                     |
| Condition                                                                                       | As Cast + Welded + Heat Treat (to restrengthen Waspaloy): 1850F, 1 Hour + 1550F, 4 Hour + 1400F, 16 Hour + Machined to Approximately 0.3 x 0.3 At Test Section |                     |
| Test Temperature                                                                                | RT                                                                                                                                                             |                     |
| Basic Strength of Welded Alloys                                                                 | Min $F_{tu}$ , IN 100                                                                                                                                          | 115 KSI             |
|                                                                                                 | Min $F_{tu}$ , Waspaloy                                                                                                                                        | 180 KSI             |
| Condition Determined by X-Ray Prior to Test                                                     | Failure Strength KSI                                                                                                                                           | Location of Failure |
|                                                                                                 | Good                                                                                                                                                           | Weld                |
| Weld Cracks <sup>(1)</sup>                                                                      | 89.2                                                                                                                                                           | Weld                |
| (1) Caused by loss of ductility in IN 100 as result of change in microstructure during welding. |                                                                                                                                                                |                     |

TABLE 4.211 ROOM TEMPERATURE TENSILE STRENGTH OF WELDMENT TO WASPALOY

REVISED: DECEMBER 1978

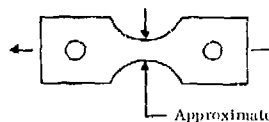
## NONFERROUS ALLOYS

|                                             |                                                                                                                                                         |                       |                     |
|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|---------------------|
| Source                                      | (47) pp 25, 26, 34, 87, 94                                                                                                                              |                       |                     |
| Alloy                                       | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                                                                                                      |                       |                     |
| Test Specimens                              | 4 x 1.5 x 0.5 Bar, Electron Beam Welded to Similar Waspaloy Bar. After Heat Treat, Machined to Specimens described below.                               |                       |                     |
| Condition                                   | As Cast + Welded + Heat Treat (to restrengthen Waspaloy): 1850F, 1 Hr + 1550F, 4 Hr + 1400F, 16 Hr + Machine To Approximately 0.3 x 0.3 at Test Section |                       |                     |
| Test Temperature                            | 1400F                                                                                                                                                   |                       |                     |
| Condition Determined by X-Ray Prior to Test | Stress at Failure Location (Ksi)                                                                                                                        | Life (Hr)             | Location of Failure |
| Weld Cracks <sup>(1)</sup>                  | 91                                                                                                                                                      | 0.1                   | Weld                |
| Weld Cracks <sup>(1)</sup>                  | 56.5                                                                                                                                                    | 31                    | Weld                |
| Good                                        | 54.6                                                                                                                                                    | >224.6 <sup>(2)</sup> | Waspaloy            |
| Weld Cracks                                 | 45.5                                                                                                                                                    | 76.5                  | Weld                |
| Weld Cracks                                 | 60.2                                                                                                                                                    | 1.8                   | Weld                |

(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 1400F OF ELECTRON BEAM WELDMENT TO WASPALOY

|                                                                                    |                                                                                                                                                                                 |                                                                                 |                                     |
|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-------------------------------------|
| Source                                                                             | (47) pp 25, 26, 35, 87                                                                                                                                                          |                                                                                 |                                     |
| Alloy                                                                              | Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                                                                                                                              |                                                                                 |                                     |
| Test Specimen                                                                      | 4 x 1.5 x 0.5 Bar Electron Beam Welded to Similar Waspaloy Bar + Heat Treatment as Shown Below + Machined to Specimen Shape Shown                                               |                                                                                 |                                     |
|  |                                                                                                                                                                                 | Steady Load Applied Axially, Vibratory Load Applied Normal To Plane of Specimen |                                     |
| Condition                                                                          | As Cast + Welded + Heat Treat (to restrengthen Waspaloy): 1850F, 1 Hr + 1550F, 4 Hr + 1400F, 16 Hr<br>Min $F_{tu}$ IN 100 - 115 KSI<br>Min $F_{tu}$ Waspaloy - 180 KSI<br>At RT |                                                                                 |                                     |
| Test Temperature                                                                   | RT                                                                                                                                                                              |                                                                                 |                                     |
| Condition as Determined by X-Ray Prior to Test                                     | Static Stress<br>KSI                                                                                                                                                            | Vibratory Stress<br>$\pm$ KSI                                                   | Cycles <sup>(1)</sup><br>To Failure |
| Weld Cracks <sup>(2)</sup>                                                         | 62.2                                                                                                                                                                            | 9.8                                                                             | $2.3 \times 10^6$                   |
| Weld Cracks <sup>(2)</sup>                                                         | 62.2                                                                                                                                                                            | 4.9                                                                             | $1.75 \times 10^6$                  |
| Good                                                                               | 62.2                                                                                                                                                                            | 4.9                                                                             | $>10^7$                             |
| Good                                                                               | 62.2                                                                                                                                                                            | 9.8                                                                             | $3.67 \times 10^6$                  |

(1) All failures in weld

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

(1) All failures in weld

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

TABLE 4.213 FATIGUE AT RT UNDER COMBINED STATIC AND VIBRATORY STRESS OF ELECTRON BEAM WELDMENT TO WASPALOY

Ni  
 Co  
 Cr  
 Al  
 Ti  
 Mo  
 V  
 IN-100

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

IN-100

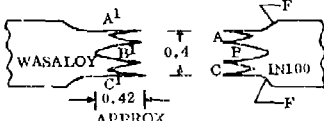
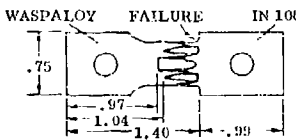
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |            |                                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|---------------------------------------------------|
| Source (47) pp 27, 28, 38, 91, 110                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |            |                                                   |
| Alloy Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |            |                                                   |
| <p>Test Specimen and Brazing</p>  <p>APPROX</p> <p>Faces A and A<sup>1</sup> and C and C<sup>1</sup> Mate. Double Fingers B Fit Into Hollow B<sup>1</sup>. Prior to Brazing .0005 Ni Plate Deposited on Times + 900F, 30 Min To Bond. For Brazing Clearances .002 to .004 In Maintained.</p> <p>Brazed In H<sub>2</sub> At 2000F, 20 Min. Diffusion of Braze 1800F, 8 Hr + 1900F, 8 Hr + 1950F, 56 Hr.</p> <p>Following Braze HT to Restrengthen Waspaloy: Fast Cool From 1950F to 1000F At 40F Per Min + 1550F, 4 Hr + Cool to 1000F + 1400F, 16 Hr</p> |            |                                                   |
| Test Temperature                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | RT         | Min F <sub>tu</sub> IN100 115 KSI                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |            | Min F <sub>tu</sub> Waspaloy 180 KSI              |
| Braze Area Percent                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Stress KSI | Location of Failure                               |
| 90                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 112        | Blade Radius<br>IN 100<br>Point F in Sketch Above |
| 90                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 100        |                                                   |

TABLE 4.221 ROOM TEMPERATURE TENSILE STRENGTH OF BRAZED ATTACHMENT TO WASPALOY

|                                                                                                                                                                                                                                                                                                     |                                                                                                                                                      |                                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| Source (47) pp 28, 28, 39, 91, 110                                                                                                                                                                                                                                                                  |                                                                                                                                                      |                                  |
| Alloy Ni-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                                                                                                                                                                                                                                                            |                                                                                                                                                      |                                  |
| Depth At Test Section Approximately 0.95 IN                                                                                                                                                                                                                                                         |                                                                                                                                                      |                                  |
| <p>Test Specimen</p>  <p>See Table 4.221 For Details of Geometry of Braze Surfaces and Brazing Procedure</p> <p>Axial Load Applied For Steady Stress</p> <p>Alternating Stress Applied By Resonant Vibration</p> |                                                                                                                                                      |                                  |
| Test Temperature                                                                                                                                                                                                                                                                                    | RT                                                                                                                                                   |                                  |
| Static Stress KSI                                                                                                                                                                                                                                                                                   | Alternating Stress KSI (2)                                                                                                                           | Cycles To Failure <sup>(1)</sup> |
| 29.8                                                                                                                                                                                                                                                                                                | 20.4                                                                                                                                                 | 5 x 10 <sup>5</sup>              |
| 14.9                                                                                                                                                                                                                                                                                                | 10.2 for 10 <sup>6</sup> cycles + 13.6 for 10 <sup>6</sup> cycles + 17 to failure                                                                    | 6.2 x 10 <sup>6</sup>            |
| 29.8                                                                                                                                                                                                                                                                                                | 6.9 for 10 <sup>6</sup> cycles + 10.2 for 10 <sup>6</sup> cycles + 13.6 for 10 <sup>6</sup> cycles + 17 for 10 <sup>6</sup> cycles + 20.4 to failure | 1.9 x 10 <sup>6</sup>            |
| 37.3                                                                                                                                                                                                                                                                                                | 6.9 for 10 <sup>6</sup> cycles + 10.2 for 10 <sup>6</sup> cycles + 13.6 to failure                                                                   | 9.2 x 10 <sup>6</sup>            |
| 22.4                                                                                                                                                                                                                                                                                                | 13.6                                                                                                                                                 | 10 <sup>7</sup>                  |

(1) All failures at base cross section of IN 100

(2) If failure did not occur in 10<sup>6</sup> cycles, alternating stress was increased for an additional 10<sup>6</sup> cycles if necessary at the next higher stress level shown. Failure cycles shown are for a 1 value of alternating stress listed.

TABLE 4.222 FATIGUE AT RT UNDER COMBINED STATIC AND VIBRATORY STRESS OF BRAZED JOINT SIMULATING TURBINE BLADE FASTENING TO WASPALOY

REVISED: DECEMBER 1978

## NONFERROUS ALLOYS

| Source (51) p 208                                           |                |                |         |        |                  |
|-------------------------------------------------------------|----------------|----------------|---------|--------|------------------|
| Alloy NI-15Co-10Cr-5.5Al-4.7Ti-3Mo-0.95V                    |                |                |         |        |                  |
| Condition Cast and Bonded To U700 by TLP Process (1)        |                |                |         |        |                  |
| Test Temperature 1400F                                      |                |                |         |        |                  |
| Base Metal IN 100, Min KSI $F_{tu}$ 115, $F_{ty}$ 95        |                |                |         |        |                  |
| Requirements at 1400F U-700 Min KSI $F_m$ 135, $F_{ty}$ 105 |                |                |         |        |                  |
| Bonding Condition                                           | $F_{tu}$ (KSI) | $F_{ty}$ (KSI) | $e$ (%) | RA (%) | Failure Location |
| 2000F, 4 Hrs                                                | 137.3          | 128.1          | 2.3     | 0.6    | IN 100           |
| 2000F, 4 Hrs                                                | 141.5          | 127            | 5.2     | 10.3   | IN 100           |
| 2000F, 4 Hrs                                                | 140.4          | 127            | 4.0     | 6.4    | Bond Region      |
| 2100F, 4 Hrs                                                | 136.1          | 124.4          | 4.2     | 10.3   | IN 100           |
| 2100F, 4 Hrs                                                | 134.2          | 128.1          | 1.7     | 2.3    | IN 100           |
| 2100F, 4 Hrs                                                | 142.0          | 129.4          | 8.6     | 9.5    | IN 100           |
| 2100F, 4 Hrs                                                | 134.8          | 121.8          | 3.8     | 10.3   | IN 100           |

(1) TLP is Pratt and Whitney Aircraft Trade Name for Transition-Liquid-Phase Bond by adding thin layer between surfaces to be bonded and exposing to temperature near melting point in vacuum. Melting temperature depressant (Boron) is added to bonding alloy. Some alloying elements of base composition (i.e. Al, Ti, C) are restricted to prevent formation of stable interface phases.

TABLE 4.231 TENSILE PROPERTIES AT 1400F FOR TLP BOND BETWEEN CAST ALLOY AND WROUGHT UDIMET 700

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Ni  
Co  
Cr  
Al  
Ti  
Mo  
V  
IN-100

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

IN-100

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