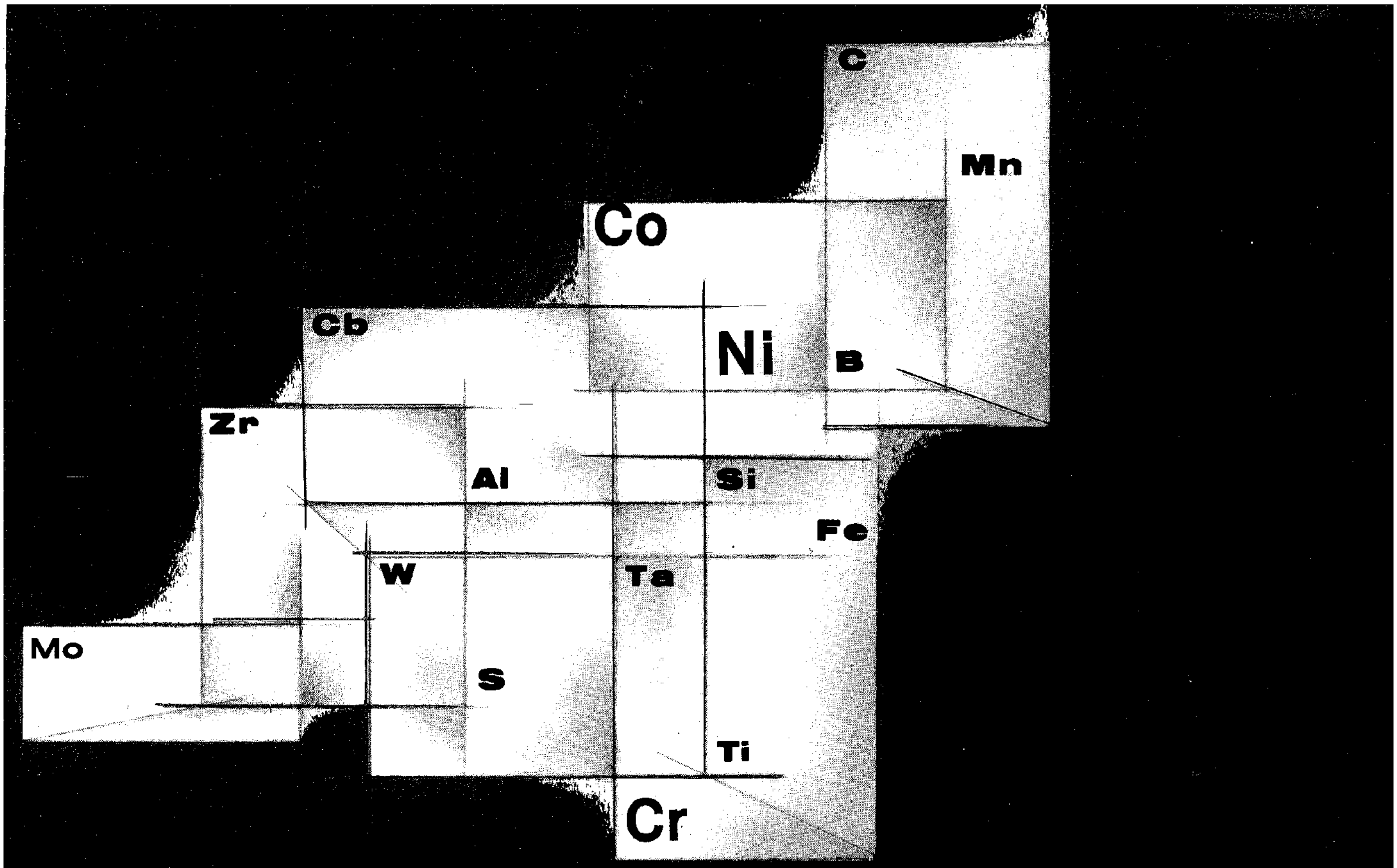

Alloy IN-738

Technical Data

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ALLOY IN-738 TECHNICAL DATA

INTRODUCTION

Alloy IN-738* is a vacuum melted, vacuum cast, precipitation hardenable nickel-base alloy possessing excellent high temperature creep-rupture strength combined with hot corrosion resistance superior to that of many high-strength superalloys of lower chromium content. It is designed to provide the gas turbine industry with an alloy which will have good creep strength up to 1800*F combined with the ability to withstand long-time exposure to the hot corrosive environments associated with the engine.

Alloy IN-738 exhibits tensile properties superior to and elevated temperature stress-rupture properties comparable to those of the widely used Alloy 713C along with substantially better sulfidation resistance.

Two versions of Alloy IN-738 are produced: a high carbon version designated IN-738C and a low carbon version designated IN-738LC. The data reported in this bulletin were obtained primarily on high carbon (C) material. Where data are reported for the low carbon (LC) modification, they will be so indicated.

COMPOSITION

The nominal composition and recommended range to which Alloy IN-738 is produced are shown in Table I. Two versions are shown: high carbon IN-738C and low carbon IN-738LC. The low carbon version also has lower zirconium content.

TABLE I
Composition of Alloy IN-738

	Composition, weight percent			
	High Carbon IN–738C		Low Carbon, Low Zirconium IN–738LC	
Element	Range	Nominal	Range	Nominal
Carbon	0.15-0.20	0.17	0.09-0.13	0.11
Cobalt	8.00-9.00	8.50	3.00-9.00	8.50
Chromium	15.70-16.30	16.00	15.70-16.30	16.00
Molybdenum	1.50-2.00	1.75	1.50-2.00	1.75
Tungsten	2.40-2.80	2.60	2.40-2.80	2.60
Tantalum	1.50-2.00	1.75	1.50-2.00	1.75
Columbium (Niobium)	0.60-1.10	0.90	0.60-1.10	0.90
Aluminum	3.20-3.70	3.40	3.20-3.70	3.40
Titanium	3.20-3.70	3.40	3.20-3.70	3.40
Aluminum + Titanium	6.50-7.20	6.80	6.50-7.20	6.80
Boron	0.005-0.015	0.010	0.007-0.012	0.010
Zirconium	0.05-0.15	0.10	0.03-0.08	0.05
Iron	0.05 max	LAP†	0.05 max	LAP†
Manganese	0.02 max	LAP	0.02 max	LAP
Silicon	0.30 max	LAP	0.30 max	LAP
Sulfur	0.015 max	LAP	0.015 max	LAP
Nickel	Balance	Balance (61)	Balance	Balance (61)

† Low as possible

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* U.S. Patent #3,459,545, produced under license from The International Nickel Company, Inc.

Effect of Carbon Content

Low carbon is needed in Alloy IN-738 for improved castability in large section sizes. Tensile and stress-rupture properties are not appreciably affected by the lower carbon content.

Effect of Zirconium Content

Zirconium levels are lower in Alloy IN-738LC for improved castability.

HEAT TREATMENT

Alloy IN-738 achieves the best combination of mechanical properties after the following heat treatment: 2050°F/2 hr/air cool + 1550°F/24 hr/air cool. All properties in this bulletin are reported on material given this treatment unless otherwise indicated.

MINIMUM MECHANICAL PROPERTIES

No property specification has yet been written for Alloy IN-738. However, the alloy appears capable of at least meeting the stress-rupture properties specified for Alloy 713C in AMS 5391, whereas its tensile properties offer a significant advantage over Alloy 713C.

PHYSICAL PROPERTIES

Density

0.293 Ib/cu in. (8.11 g/cu cm)

Melting Range

2250-2400°F (1230-1315°C)

Stability

The gas turbine industry is deeply concerned with the susceptibility of superalloys to sigma formation. Electron vacancy calculations are commonly used to predict the sigma forming tendency in superalloys. A method for the calculation of the electron vacancy number, Nv, is shown in Appendix I. The electron vacancy number for low carbon Alloy IN-738LC is 2.31. To ensure microstructural stability in Alloy IN-738C, the Nv value should not exceed 2.36. No sigma phase was found in heat treated Alloy IN-738C of optimum composition after more than 5,000 hours stress-rupture testing at 1500°F under a stress of 40,000 psi.

Specific Heat

The specific heat of Alloy IN-738 is given in Table II.

Thermal Conductivity

The thermal conductivity of Alloy IN-738 is given in Table III.

TABLE II
Specific Heat of Alloy IN-738

Temperature °F	Specific Heat Btu/Ib/°F
70	0.10
200	0.11
400	0.12
600	0.125
800	0.13
1000	0.135
1200	0.14
1400	0.15
1600	0.16
1800	0.17
2000	0.17

TABLE III
Thermal Conductivity of Alloy IN-738

Temperature °F	Thermal Conductivity Btu/ft^2/in./hr/°F
400	82
600	95
800	108
1000	123
1200	137
1400	149
1600	162
1800	176
2000	189

Thermal Expansion

Thermal expansion coefficients for Alloy IN-738 are given in Table IV. Mean and instantaneous coefficients of thermal expansion are shown in Figure 1.

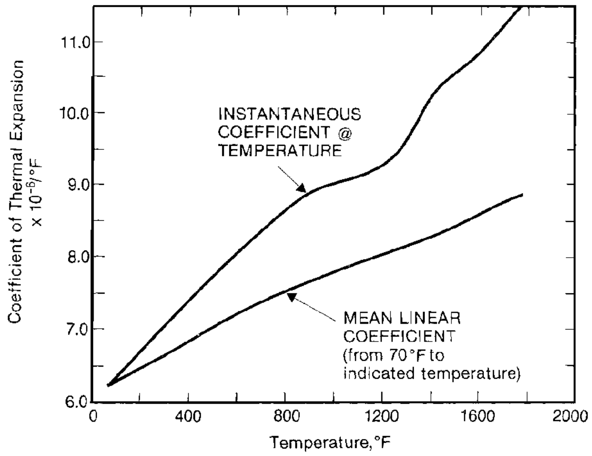

Figure 1 – Thermal Expansivity of Alloy IN-738

TABLE IV
Mean Coefficient of Thermal Expansion
of Alloy IN-738

Temperature Interval °F	Mean Coefficient of Thermal Expansion per °F
70 to 200	6.45×10^{-6}
70 to 400	6.75
70 to 600	7.15
70 to 800	7.55
70 to 1000	7.75
70 to 1200	8.05
70 to 1400	8.25
70 to 1600	8.55
70 to 1800	8.85

Modulus of Elasticity

The dynamic moduli of elasticity and Poisson's Ratio of Alloy IN-738 are given in Table V.

TABLE V
Dynamic Moduli of Elasticity and Poisson's Ratio of Alloy IN-738

	Dynamic Moduli of Elasticity		
Temperature °F	Tension (E) psi	Torsion (G) psi	Poisson's Ratio ν
75	29.1×10^{6}	11.3×10^{6}	0.28
200	28.3	11.1	0.27
400	27.6	10.8	0.27
600	26.8	10.5	0.28
800	26.0	10.1	0.28
1000	25.4	9.8	0.30
1200	24.3	9.4	0.30
1400	23.2	9.0	0.30
1600	21.9	8.5	0.29
1800	20.3	7.8	0.30

Note: Poisson's ratio computed from the expression $\nu = \frac{E}{2G} - 1$

CHEMICAL PROPERTIES

Oxidation

Static and cyclic oxidation tests were performed on Alloy IN-738 and a number of other high-strength nickel-base superalloys. The test results are shown below:

1. Static Tests - 1000 hr in still air at 1800ºF and 2000ºF.

	Weight Change, mg/cm^2	
Alloy	1800°F	2000°F
713C	+0.6	+29
IN-738	–16	–102
UDIMET* 500 (cast)	–22	–328
UDIMET 700	–8	-

2. Cyclic Test - Samples were given a cyclic exposure by heating in air at 1800°F for 22 hr, then cooling to room temperature and holding for 2 hr. The cycle is then repeated.

Alloy	Weight Loss in 1000 hr, mg/cm^2
713C	0.7
IN-738	14

Sulfidation

Alloy IN-738 has been evaluated in crucible, rig and engine tests in comparison with a number of other alloys. The crucible tests generally consisted of immersion of ¼ in. x ¼ in. x 1 in. rectangular samples in a molten mixture of salts followed by descaling operations to determine weight loss. The rig tests were performed generally by rotating samples of pin shapes or airfoil shapes in a combustion stream of fuel containing sulfur. Intermittent cooling cycles were employed to simulate engine operation. During the heating portion of the cycle, salts and/or alkaline metal were injected into the stream as detailed in the following tabulations. The test results are shown below:

1. Crucible Test - 10% NaCl/90% Na_2SO_4 at 1700°F

Alloy	Time, hr	Observations
713C	2-4	Destroyed
UDIMET 500 (cast)	40-100	Gross Attack
IN-738	250-300	Slight Attack

2. Crucible Test (controlled replacement of salt) - 300 hr at 1650°F

	Weight Loss, mg/cm^2	
Alloy	10% NaCl/90% Na_2SO_4	25% NaCl/75% Na_2SO_4
UDIMET 500 (cast)	6	16
IN-738	7	14

3. Cyclic Rig Test - 1000 hr at 1600°F Diesel Fuel (1% Sulfur) Air/Fuel Ratio: 30/1, 5 ppm sea salt.

Alloy	Surface Loss, mg	Max Penetration, mil
IN-738	3.3	19
713C	38-130 + †	60-130 + †
UDIMET 500 (wrought)	1.7-3.8	12-13

†Specimen consumed

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*Trademark of Special Metals Corporation

4. Cyclic Rig Test - 1000 hr at 1800°F Diesel Fuel (1% Sulfur) Air/Fuel Ratio: 30/1, 5 ppm sea salt.

Alloy	Surface Loss, mg	Max Penetration, mil
IN-738	3.1	15
713C	130 + *	130 + *
UDIMET 500 (wrought)	3.5	21
UDIMET 500 (cast)	8.8	36

*Specimen consumed

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5. Sulfidation Cyclic Rig Test - 150 hr at 1550°F and 1750°F, JP-5R Fuel, Air/Fuel Ratio: about 17/1, 3.5 ppm salt.

	Weight Loss, g, at Peak Temperature	
Alloy	1550°F	1750°F
IN-738	2.1	4.0
713C	5.5	7.1
UDIMET 700	4.0	7.9

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6. Sulfidation Cyclic Rig Test - 173 hr JP-5R Fuel, Air/Fuel Ratio: about 17/1, 3.5 ppm salt. Cycle of 1550°F/3 min, 1850°F/2 min, cooled 2 min.

Alloy	Weight Loss, g
B-1900	6.8
IN-738	2.5
MDL 20	3.0
MAR-M* 421	4.2

*Trademark of Martin Marietta Corporation

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7. Combustion Chamber Test - Fuel Oil doped with 5 ppm Na, 0.5 ppm Mg, 1% S at 1450°F.

Alloy	Weight Loss, % in 50 hr
IN-738	0.183
X-45	0.206
UDIMET 500 (wrought)	0.143

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8. Crucible Test - Na_2SO_4 $MgSO_4$ under a gas of 0.15% SO_2, 2.25% CO, balance N_2 at 1450°F.

	Weight Loss, mg/cm^2, after				
Alloy	32 hr	64 hr	136 hr	250 hr	500 hr
IN-738	0.32	0.56	0.97	1.4	-
UDIMET 500 (cast)	0.35	0.51	0.71	-	3.3
713C	8.3	23	90	-	-

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9. Gas Test - 100 hr at 1800°F, Flowing H_2S and SO_2-rich gas to accelerate corrosion.

Alloy	Weight Loss, mg/cm^2
IN-738	310
713C	770
UDIMET 700	1440

10. Engine Test - 45 hr at 1780°F, 0.75 ppm sea salt. 40 min cycle of 30 min at 1780°F, 10 min ram cool air.

Alloy	Rating*
713C	1
MAR-M 246	1.1
TRW-NASA VI A	1.4
GMR 235D	1.9
IN-738	6.2
UDIMET 710	5.8

*Higher number indicates increasing resistance.
Corrosion resistance of Alloy 713C used as base.

11. The behavior of Alloy IN-738, UDIMET 500 and X-45 in a eutectic mixture of Na_2SO_4–$MgSO_4$ and 0.15% SO_2 at 1450°F is shown in Figure 2.

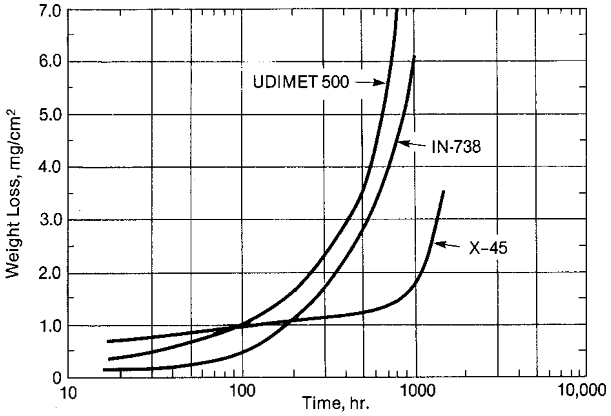

Figure 2 – Time vs. Weight Loss Plots for Alloy IN-738 and Several Other Alloys in Eutectic Na_2SO_4–$MgSO_4$ and 0.15% $S0_2$ at 1450°F

MECHANICAL PROPERTIES

Tensile Properties

Typical room temperature tensile properties of low carbon (LC) and high carbon (C) Alloy IN-738 are compared in Table VI. The properties are essentially the same, with the low carbon version having lower strength and higher ductility.

Typical short-time elevated temperature properties of Alloy IN-738 are shown in Table VII. Figure 3 compares typical tensile properties of Alloy IN-738 and Alloy 713C.

Typical stress-rupture properties of Alloy IN-738C are given in Table VIII. Stress-rupture curves (least square) are shown in Figure 4 which includes both fine and coarse grain material. A comparison of the stress-rupture data with that of Alloy 713C is shown in Figure 5 by means of a Larson-Miller stress-rupture parameter plot. Table IX shows additional stress-rupture data of Alloy IN-738 in terms of stress for rupture in 100, 1000 and 10,000 hours.

Some long-time creep-rupture test results of Alloy IN-738 are shown in Table X. The time to produce specific amounts of creep strain are given in this table along with rupture life.

Impact Properties

The room-temperature impact properties of Alloy IN-738 are shown in Table XI. Test results are shown on unnotched Charpy impact samples exposed for various periods at temperatures from 1200 to 1700°F.

TABLE VI
Room Temperature Tensile Properties
of Alloy IN-738*

	Low Carbon IN-738LC	High Carbon IN-738C
0.2% Yield Strength, psi	130,000	138,000
Tensile Strength, psi	150,000	159,000
Elongation, %	7	5.5
Reduction of Area, %	9	5

* Determined on cast-to-size test bars.

TABLE VII
Short-Time Elevated Temperature Tensile Properties of Alloy IN-738

Temperature °F	Yield Strength (0.2% Offset) psi	Tensile Strength psi	Elongation (2 in.) %	Reduction of Area %
70	138,000	159,000	5.5	5
1200	132,000	153,000	7	7
1400	115,000	140,000	6.5	9
1600	80,000	112,000	11	13
1800	50,000	66,000	13	15

TABLE VIII
Stress-Rupture Properties of Alloy IN-738C

Temperature °F	Stress psi	Life hr	Elongation %	Reduction of Area %
1350	90,000	212	6	8
1500	40,000	3314	5	5
1700	33,000	95	8	14
1800	22,000	66	12	18

TABLE IX
Stress-Rupture Properties of Alloy IN-738

	Low Carbon IN-738LC		High Carbon IN-738C	
	Stress, psi, for Rupture in		Stress, psi, for Rupture in	
Temperature °F	1000 hr	10,000 hr	100 hr	1000 hr
1350	80,000	62,000	96,000	78,000
1500	46,000	33,000	66,000	48,000
1700	19,000	12,000	31,000	20,000
1800	12,000	7,000	19,000	12,000

TABLE X
Long-Time Creep-Rupture Test Results on Alloy IN-738

Temperature °F	Stress psi	Time, hr, for Creep Strain* of				Rupture Life hr	Minimum Creep Rate %/hr
		0.1%	0.2%	0.5%	1.0%		
1350	75,000	10	20	75	235	1464	0.003
1350	75,000	10	30	120	320	1550	0.002
1350	65,000	60	250	810	1720	4666	0.0005
1350	65,000	90	250	740	1900	5219	0.0004
1500	40,000	12	24	110	315	1014	0.002
1500	35,000	60	160	580	1140	4704	0.0004
1500	35,000	130	290	680	1200	3348	0.0006
1700	17,000	38	80	200	375	1263	0.003
1700	13,000	400	760	2160	3100	5571	0.0002
1700	13,000	140	360	1080	2080	4815	0.0004
1800	10,000	30	100	200	500	1262	0.0012

*Creep strain measured after extension on loading.

TABLE XI
Room Temperature Impact Properties of Alloy IN-738C

	Charpy Impact, Unnotched, ft-Ib						
		After Exposure at					
		1200°F		1500°F		1700°F	
Grain Size	Before Exposure	500 hr	1000 hr	500 hr	1000 hr	500 hr	1000 hr
Fine (1/8 in. or smaller)	56	44	30	20	13	14	10
Coarse (1/4 in. or larger)	37	54	38	20	16	17	14

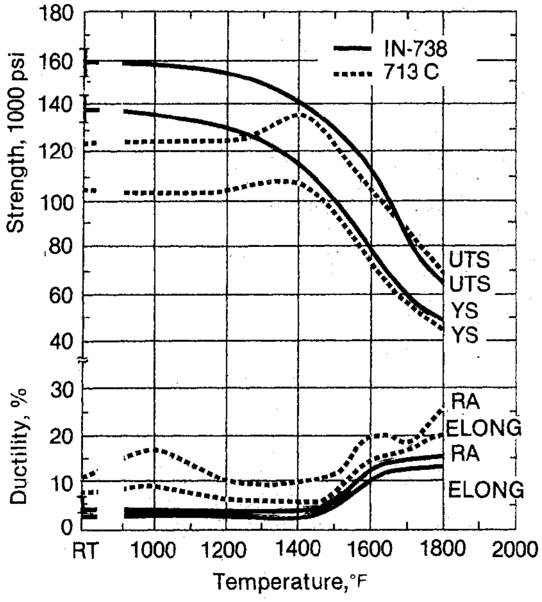

Figure 3 – Typical Tensile Properties of Alloy IN-738 Compared to Alloy 713C

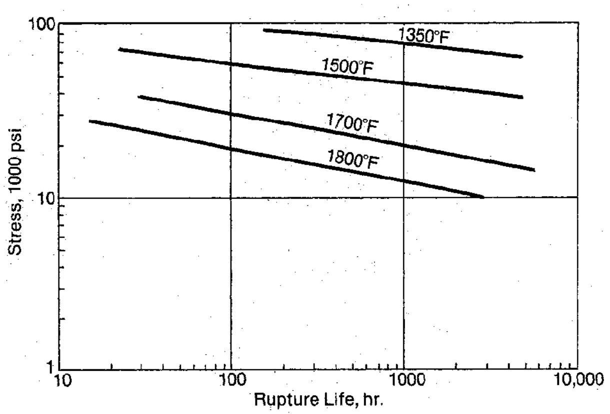

Figure 4 – Stress-Rupture Properties of Heat Treated Alloy IN-738

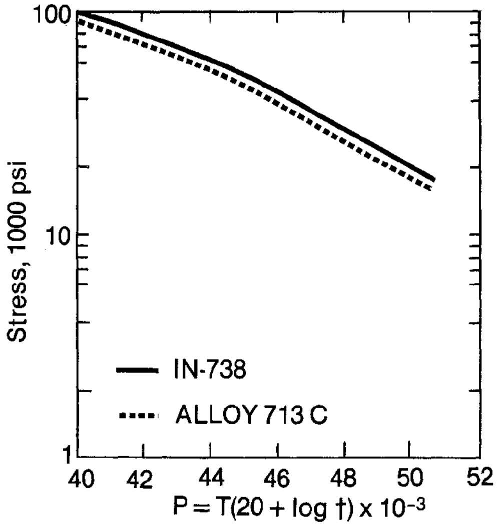

Figure 5 – Larson-M filler Stress-Rupture Parameter Plot
Comparing Alloy IN-738 and Alloy 713C

Fatigue Properties

Axial Properties

Axial push-pull fatigue tests were performed on low carbon Alloy IN-738LC. Stress for a fatigue life of 10^8 cycles data are shown in Table XII.

Thermal Fatigue Resistance

The thermal fatigue resistance of Alloy IN-738 and of several other alloys was determined using a fluidized bed for heat transfer. Test results for Alloy IN-738, Alloy IN-100 and Alloy 713C are shown in Table XIII.

FABRICATION

Machining and Grinding

Generally speaking, the machinability of Alloy IN-738 is comparable to that of other high-temperature, high-strength nickel-base alloys. Further, information on machining and grinding of Alloy IN-738 is contained in Inco publication A-609 “Machining and Grinding IN-738 Alloy.”

Castability

Alloy IN-738 is normally vacuum melted and vacuum investment cast using procedures like those used for other high-strength, high-temperature nickel-base alloys. Typical casting conditions are 200-400°F metal superheat above the liquidus temperature with a 1500-1800°F mold preheat temperature. Conditions will vary depending on size and geometry of the parts.

Alloy IN-738LC was developed for improved castability in large section sizes.

Welding

Alloy IN-738, like other nickel-base superalloys, is not ordinarily considered weldable in the normal sense. If welding is required, the user should contact his supplier for suggested procedures.

Applications

The greatest use for Alloy IN-738 is in the industrial gas turbine industry for engine parts required to withstand high temperature and stress combined with hot corrosion and sulfidation resistance. Applications of the alloy primarily are for gas turbine and jet engine components, such as blades, vanes and integral-wheels.

TABLE XII
Fatigue Properties of Alloy IN-738LC*

Temperature °F	Stress, psi, for Fatigue Life of 10^8 cycles
Room	18,000
932	17,000
1472	18,000
1652	17,000

*Axial push-pull fatigue tests.

TABLE XIII
Thermal Fatigue Resistance of Alloys*

	Thermal Fatigue Cycles to First Crack Peak Temperature of		
Alloy	1472°F	1652°F	1832°F
IN-738	1790	150	13
IN-100	>1372	107	29
IN-713C	>1462	107	27

*Fluidized bed used for heat transfer. Alternate 2-minute immersion of 1-5/8 in. diameter tapered disc specimens, with 0.010 in. edge radius, in hot and cold beds.

APPENDIX I

Method for Calculation of Electron Vacancy Number

1. Convert the composition from weight percent to atomic percent.
2. After long-time exposure in the sigma forming temperature range, the MC carbides tend to transform to $M_{23}C_6$.
   a. Assume one-half of the carbon forms MC in the following preferential order: TaC, CbC, TiC.
   b. Assume the remaining carbon forms $M_{23}C_6$ with the M comprising 23 atoms of Cr.
3. Assume the boron is combined as Mo_3B_6.
4. Assume the gamma prime to be Ni (Al, Ti, Ta, Cb).
5. Assume the residual matrix will consist of the atomic percent minus those atoms contained in the carbides, the boride and the gamma prime reactions. The total of these remaining atomic percentages gives the atomic concentration in the matrix. Conversion of this on a 100 percent basis gives the atomic percent of each element remaining in the matrix. It is this percentage that is used in order to calculate the electron vacancy number.
6. The formula for calculation of the electron vacancy number, Nv, is as follows:
   $Nv = 0.66Ni + 1.71Co + 2.66Fe + 4.66(Cr + Mo + W) + 6.66Zr$.

INCO

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