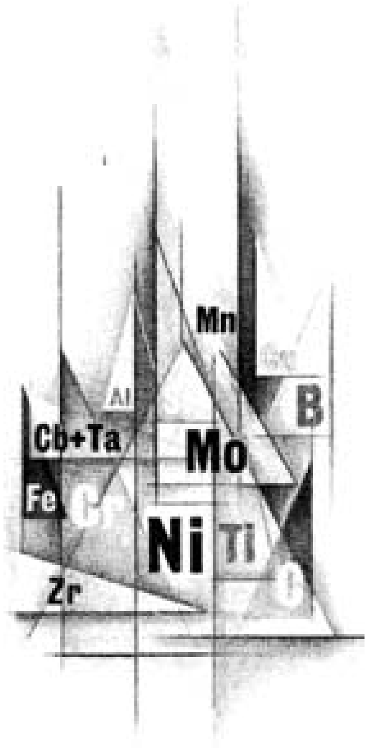


Engineering Properties of ALLOY 713C

CONTENTS

Engineering Properties
of ALLOY 713C

Alloy 713C* is a precipitation hardenable, nickel-chromium base cast alloy, which possesses excellent strength properties up to 1800 ºF. The alloy has good castability, remarkable resistance to oxidation and thermal fatigue, and outstanding structural stability. It was originally intended to air melt the master alloy and recast the product under argon (air melted, argon cast). With the advent of improved vacuum technology it was found that an increased level of high temperature properties can be consistently attained by vacuum melting the master material and remelting and casting it under vacuum (vacuum melted, vacuum cast).

COMPOSITION–Weight Per Cent

Element	Nominal	Range (AMS 5391)
Chromium	12.50	12.00 -14.00
Molybdenum	4.20	3.80 - 5.20
Columbium + Tantalum	2.20	1.80 - 2.80
Aluminum	6.10	5.50 - 6.50
Titanium	0.80	0.50 - 1.00
Carbon	0.12	0.08 - 0.20
Boron	0.012	0.005- 0.015
Zirconium	0.10	0.05 - 0.15
Silicon	lap†	0.50 max
Manganese	lap†	0.25 max
Iron	lap†	2.50 max
Copper	lap†	0.50 max
Nickel	bal	bal

SPECIFICATIONS

The AMS 5391 specification for alloy 713C requires the following mechanical properties in the as cast condition.

Stress-Rupture Properties

Test Temp, ºF	Stress, psi	Life, hr	Elong, % in 4D
1800	22,000	30 min	5 min

Tensile Properties

Test Temp, ºF	0.2% Yield Strength, psi	Tensile Strength, psi	Elong, % in 4D
70	100.000 min	110.000 min	3 min

Hardness

Rockwell C 30-42

There are many alternate specifications in existence and individual companies should be contracted as to their requirements.

* U.S. Patent #2,570,193, produced under license from The International Nickel Company, Inc.
† Low as possible.

PHYSICAL PROPERTIES

Density

0.286 lb/cu in. (7.913 g/cu cm)

Melting Range

2300-2350 °F (1260-1288 °C)

Thermal Expansion (See Figure 1)

Test Temp, °F	Mean Coefficient, per °F	Test Temp, °F	Mean Coefficient. per °F
70- 200	5.92×10^{-6}	70-1200	7.81×10^{-6}
70- 400	6.61	70-1400	8.17
70- 600	7.00	70-1600	8.63
70- 800	7.26	70-1800	9.13
70-1000	7.52	70-2000	9.48

Thermal Conductivity[1] (See Figure 2)

Test Temp, °F	Thermal Conductivity, BTU-in/hr/sq ft/°F	Test Temp, °F	Thermal Conductivity, BTU-in/hr/sq ft/°F
200	146	1200	166
400	154	1400	179
600	160	1600	218
800	162	1800	334
1000	164		

Electrical Resistivity[2] (See Figure 3)

Test Temp, °F	Electrical Resistivity, microhm-cm	Test Temp, °F	Electrical Resistivity, microhm-cm
70	144	1000	157
200	148	1200	157
400	152	1400	158
600	155	1600	158
800	156	1800	159

Oxidation Resistance[3] (See Figure 4)

Oxidation tests were performed in a tube furnace with a continuous flow of air.

	Penetration Rate, Inches per Year	
Test Temp, °F	Continuous Exposure	Intermittent Exposure
1700	.0033	.0050
1800	.0067	.0064
1900	.0088	.0092
2000	.0181	.0190

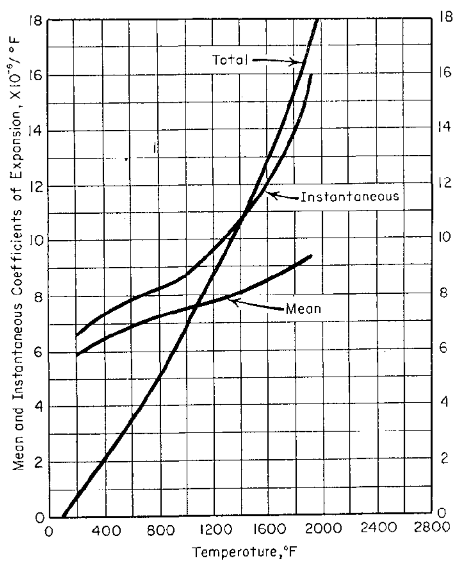


Figure 1. Thermal-Expansion Characteristics of As Cast, Air Melted, Argon Cast Alloy 713C.

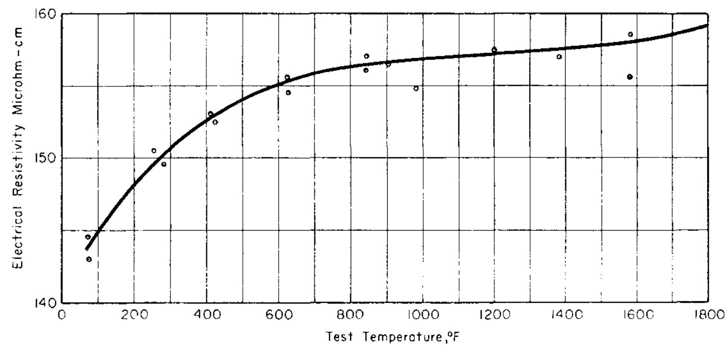


Figure 3. Electrical Resistivity of As Cast, Vacuum Melted, Vacuum Cast Alloy 713C[2].

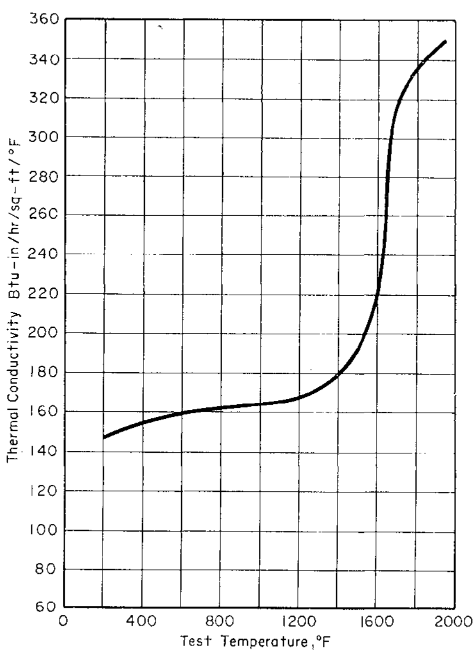


Figure 2. Thermal Conductivity of As Cast, Vacuum Melted, Vacuum Cast Alloy[1].

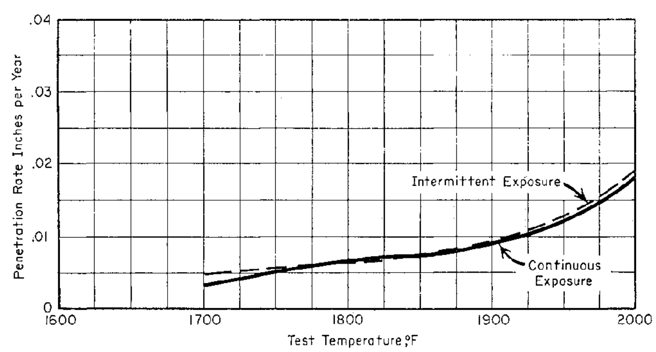


Figure 4. Oxidation Rate of As Cast, Vacuum Melted, Vacuum Cast Alloy 713C[3].

HEAT TREATMENT

Alloy 713C is normally used in the as cast condition. An improvement in the 1700-1900 °F stress-rupture life is often obtained by solution treating for 2 hours at 2150 °F, under vacuum or in an argon atmosphere, followed by air cooling; however, material in this condition tested under high stress at 1350 ºF shows a marked decrease in rupture life and ductility. A stabilizing treatment of 16 hours at 1700 ºF, applied to the solution treated material, followed by air cooling, restores the 1350 ºF properties as well as maintaining the high temperature properties. (See Table I)

Table I

The Effect of Heat Treatment on Typical Stress-Rupture Properties of Alloy 713C

(vacuum melted, vacuum cast)

Condition	Temp, ºF	Stress, psi	Life, hr	Elong,%
As cast	1700	30,000	76	7
2150 ºF–2 hr–AC	1700	30,000	121	4
2150 ºF–2 hr–AC + 1700 ºF–16 hr–AC	1700	30,000	131	5
As cast	1350	90,000	232	5
2150 ºF–2 hr–AC	1350	90,000	28	2
2150 ºF–2 hr–AC + 1700 ºF–16 hr–AC	1350	90,000	274	5

MECHANICAL PROPERTIES

Tensile Properties (See Figure 5)

Test Temp, ºF	0.2% Yield Strength, psi	Tensile Strength, psi	Elong, %	Red. Area,%
70	106,600	123,000	7.9	11.6
1000	102,200	125,600	9.7	17.0
1200	104,200	125,700	6.7	10.5
1400	108,000	136,000	5.9	10.5
1500	95,100	120,500	6.0	11.5
1600	72,100	105,400	13.9	20.0
1700	55,800	85,300	11.8	17.7
1800	44,200	68,400	19.7	25.0

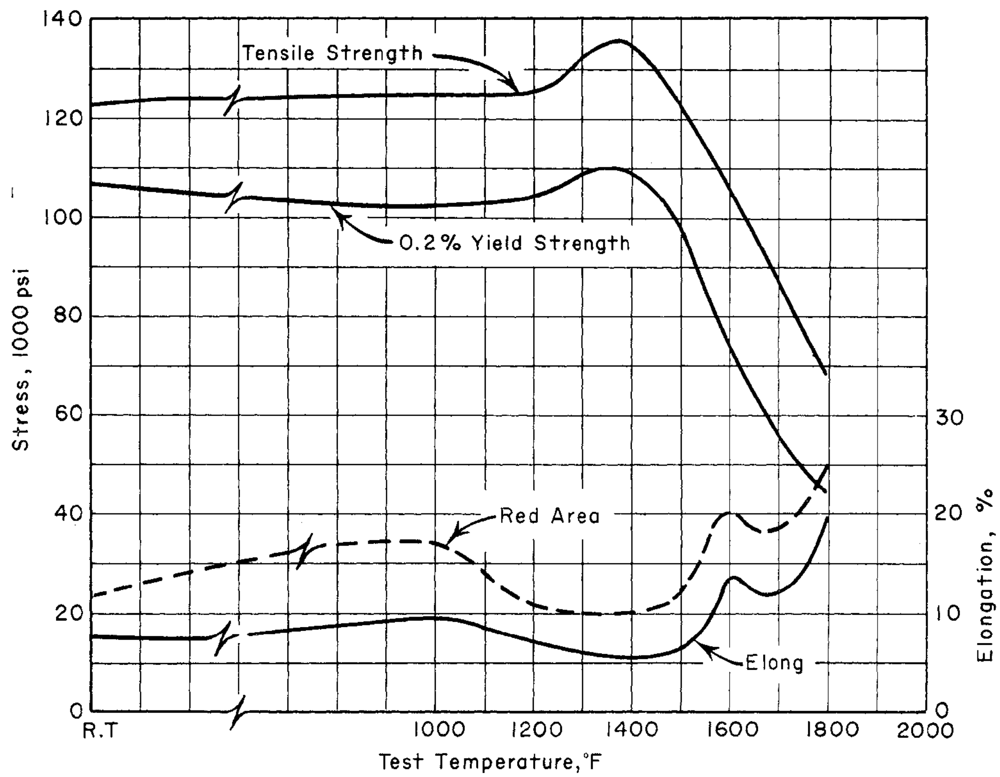


Figure 5. Typical Tensile Properties of As Cast, Vacuum Melted, Vacuum Cast Alloy 713C.

Stress-Rupture Properties (See Figure 6 and Table II)

Test Temp, ºF	Stress, psi, for Rupture in . . . 10 hr	100 hr	1000 hr	10,000 hr
1350	–	(97,000)*	76,000	56,000
1500	(86,000)*	60,000	44,000	30,000
1700	(42,000)*	30,000	18,000	12,000
1800	29,000	21,000	13,000	–
2000	9,500	6,400	–	–

*** ( ) Denotes extrapolated values.**

Stress-Rupture Parameter (See Figure 7)

Effect of Overheat (See Figure 8)

The effect of one-half hour overheats at temperatures 100 and 200 ºF above base temperatures of 1500, 1700 and 1800 ºF was evaluated with the overheats being applied 48 hours after the start of nominal 200-hour tests. In Figure 8, the effect of overheating is indicated by the difference in height between the bars representing the predicted and actual values of rupture life. This chart should only be used to appraise general trends since the average values shown make no allowance for normal scatter in test results or limited test data. The fact that for each test condition the actual rupture life was greater than the predicted life indicates that alloy 713C was not only immune to damage from the overheats but that it was actually strengthened by them.

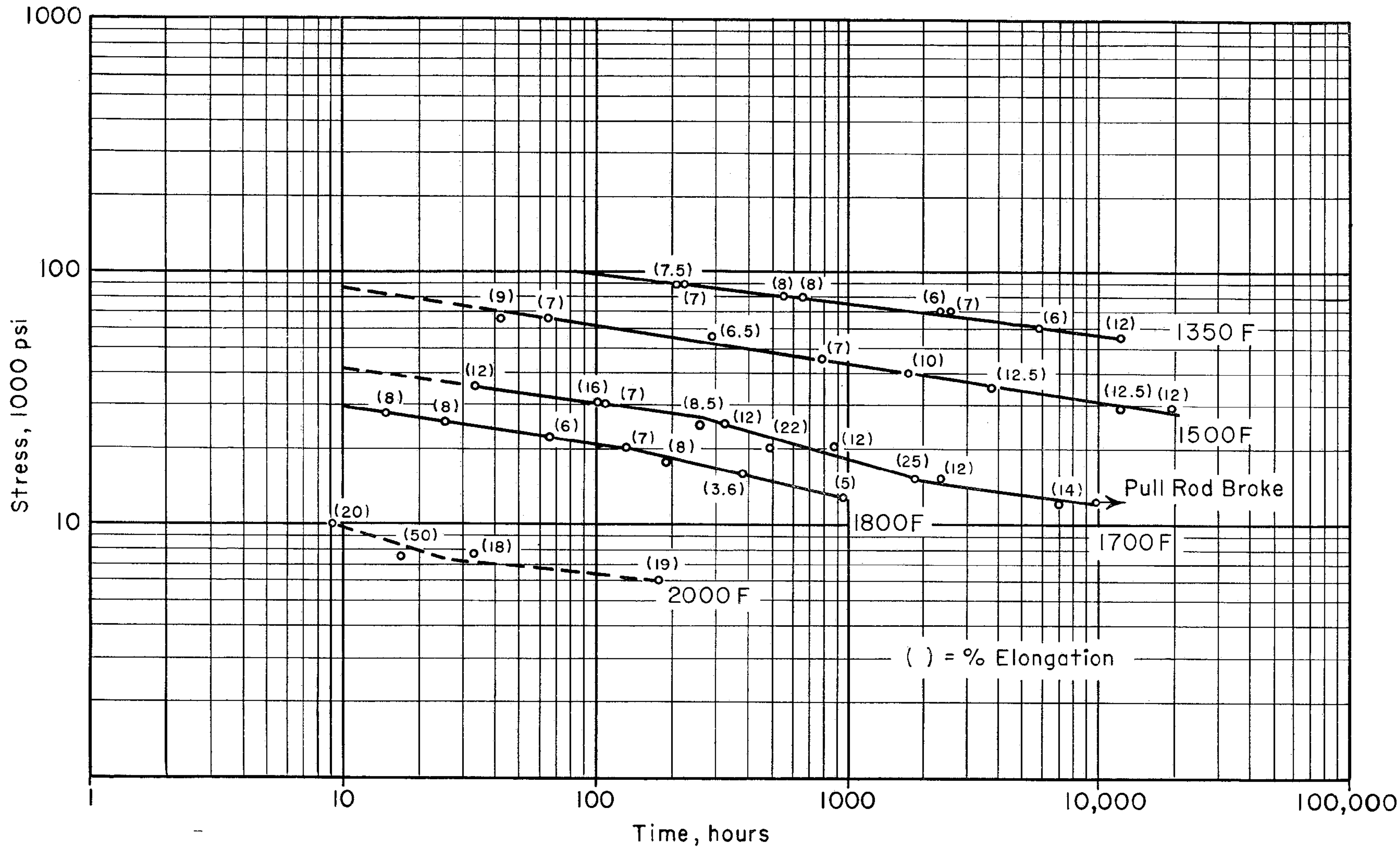


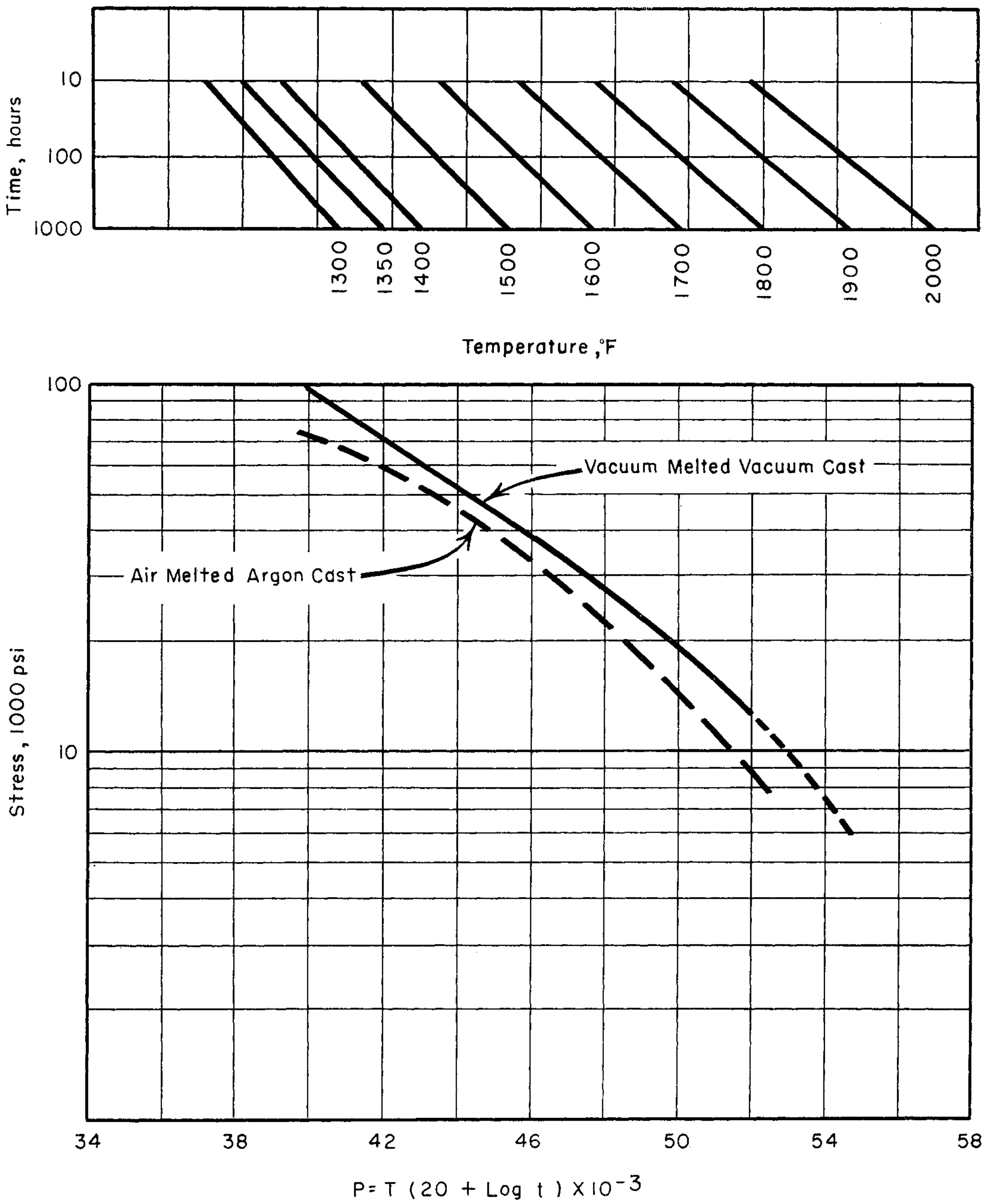
Figure 6. Stress Rupture Data on As Cast, Vacuum Melted, Vacuum Cast Alloy 713C.

Table II

Long-Time Stress-Rupture Data on Alloy 713C
(as cast, vacuum melted, vacuum cast)

Temp, ºF	Stress, psi	Life, hr	Elong, %	R.A., %
2000	10,000	9	20	26
	7,500	17	50	73
	7,500	33	18	56
	6,000	176	19	65
1800*	27,500	15	8	21
	25,000	25	8	22
	22,000	65	6	13
	20,000	132	7	21
	18,000	191	8	–
	16,000	381	3.5	12
	13,000	943	5	11.5
1700	35,000	33	12	23
	30,000	103	16	15
	30,000	109	7	14
	25,000	266	8.5	25
	25,000	327	12	19
	20,000	496	22	34
	20,000	867	12	31
	15,000	1896	25	40
	15,000	2376	12	27
	12,500	6905	14	25
	12,500	9602	(pull rod broke)	
1500	65,000	42	9	11
	65,000	66	7	9
	55,000	292	6.5	9
	45,000	795	7	14
	40,000	1738	10	12.5
	35,000	3765	12.5	19
	29,000	12182	12.5	17
	29,000	19862	11	12
1350	90,000	221	7	10
	80,000	656	8	9
	70,000	2380	6	10
	60,000	5832	6	10
1350†	90,000	210	7.5	7.5
	80,000	562	8	8.5
	70,000	2594	7	6.5
	55,000	12033	12	12

* This data obtained on a different heat.
† Test bars in as cast plus 1700 ºF–16 hrs–AC condition.



P = Parameter
T = Degrees Rankin (Add 460 Degrees Fahrenheit)
t = Time to Rupture in Hours

Figure 7. Larson-Miller Stress Rupture Parameter Curve.

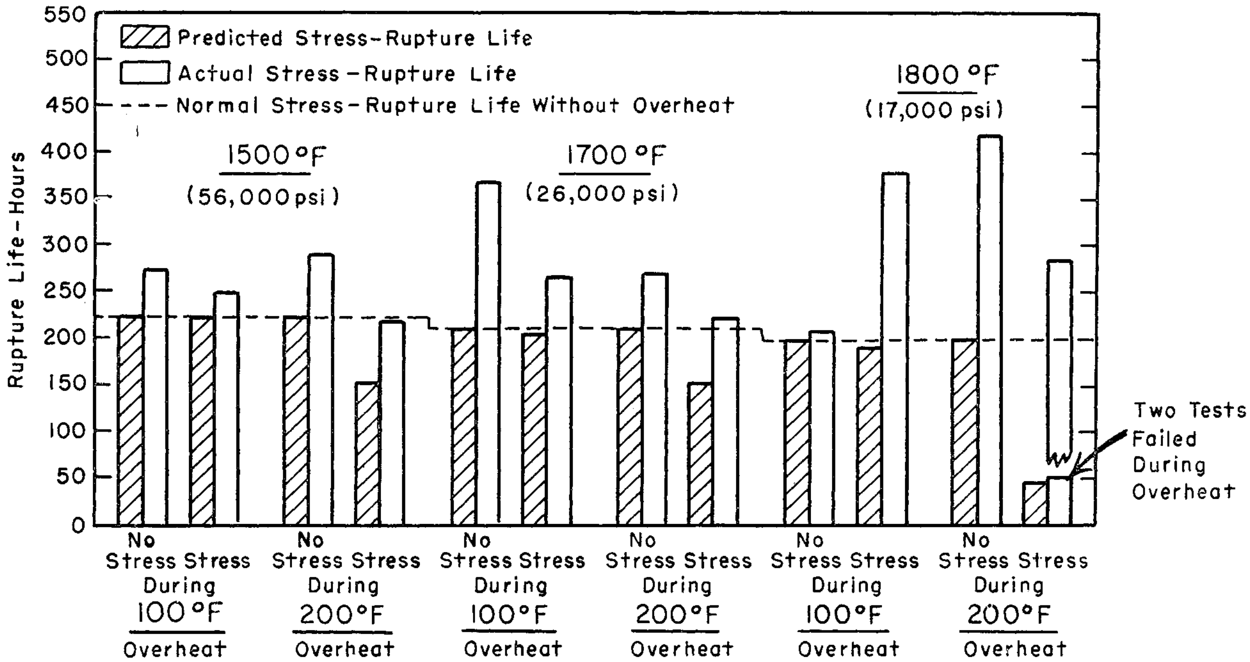


Figure 8. Effect of Overheat on As Cast, Vacuum Melted, Vacuum Cast Alloy 713C.

Creep Rate (See Figures 9-11 and Table III)

Test Temp, ºF	Stress, psi, for Designated Creep Rate 0.0001%/hr	0.001%/hr	0.01%/hr
1350	(47,000)*	68,000	83,000
1500	(24,000)*	39,000	56,000
1700	(11,500)*	15,500	26,000

*( ) Denotes extrapolated values.

Minimum Creep Rate (See Figures 9-11 and Table III)

Stress, psi	Minimum Creep Rate for Designated Temperature, %/hr 1350 ºF	1500 ºF	1700 ºF
20,000	–	–	.0032
30,000	–	.00030	.0240
40,000	–	.00120	–
50,000	.00014	.00460	–
60,000	.00041	(.01800)*	–

*( ) Denotes extrapolated values.

Table III
Long-Time Creep Data on Alloy 713C
(as cast, vacuum melted, vacuum cast)

Temp, ºF	Stress, psi	Time, hours, for Total Creep Strain† of . . . 0.1%	0.2%	0.5%	1.0%	Minimum Creep Rate, %/hr
1350	90,000	–	5	10	30	.02190
	80,000	5	12	38	108	.00694
	70,000	25	55	230	650	.00117
	60,000	–	120	740	2040	.00036
	55,000*	235	470	1580	3380	.00028
1500	65,000	–	–	2.5	6	–
	65,000	–	–	3	11	–
	55,000	5	12	40	100	.00870
	45,000	7	15	105	275	.00270
	40,000	43	125	378	690	.00130
	35,000	135	305	870	1590	.00055
	29,000	–	–	1040	2960	.00027
1700	35,000	1.5	2	5	11	.09460
	30,000	3	8	24	42	.02360
	25,000	15	30	80	155	.00540
	25,000	13	25	82	180	.00533
	20,000	22	40	98	185	.00544
	20,000	30	80	165	390	.00220
	15,000	30	130	220	540	.00150
	15,000	45	105	400	1030	.00062
	12,500	200	435	1675	3315	.00023
	12,500	80	360	1620	3750	.00023

* Test bars in as cast plus 1700 ºF – 16 hr – AC condition.
† Strain rates measured after extension on loading.

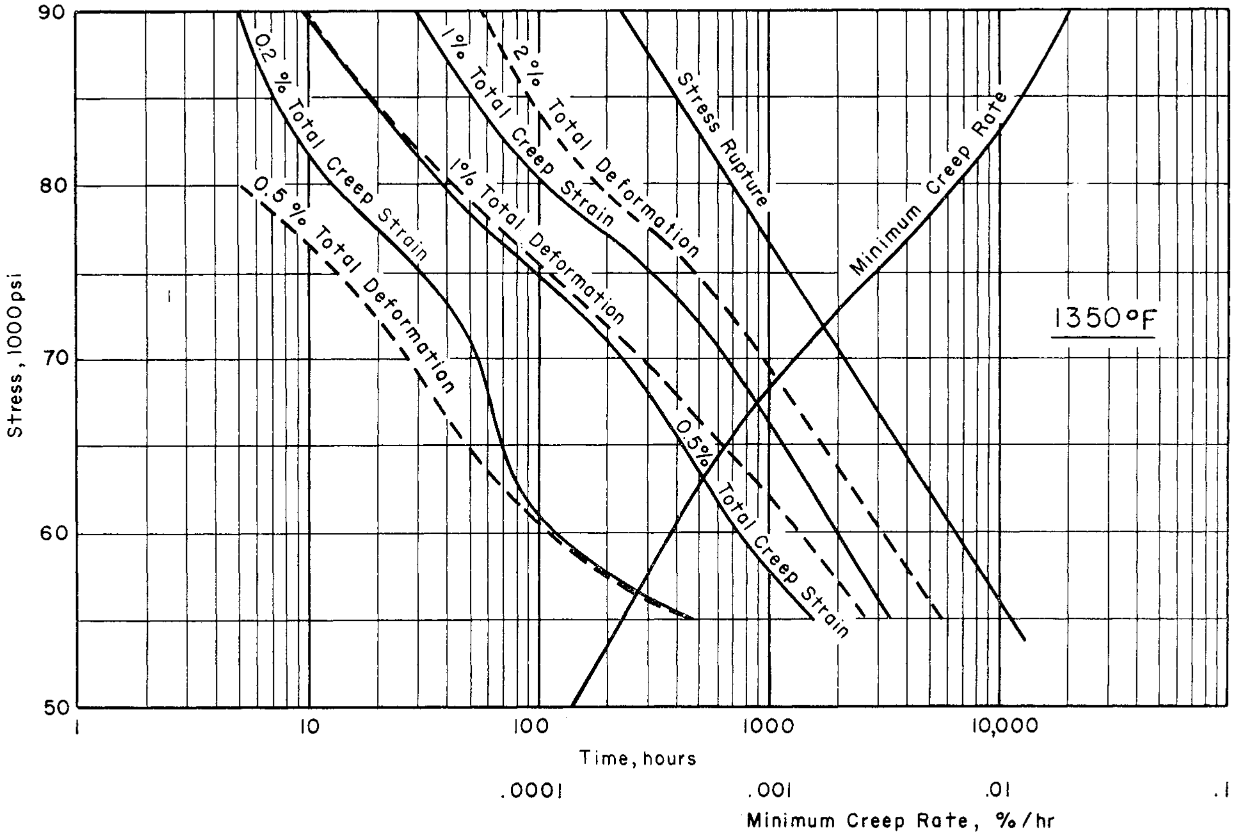


Figure 9. Design Curve for Alloy 713C at 1350 °F

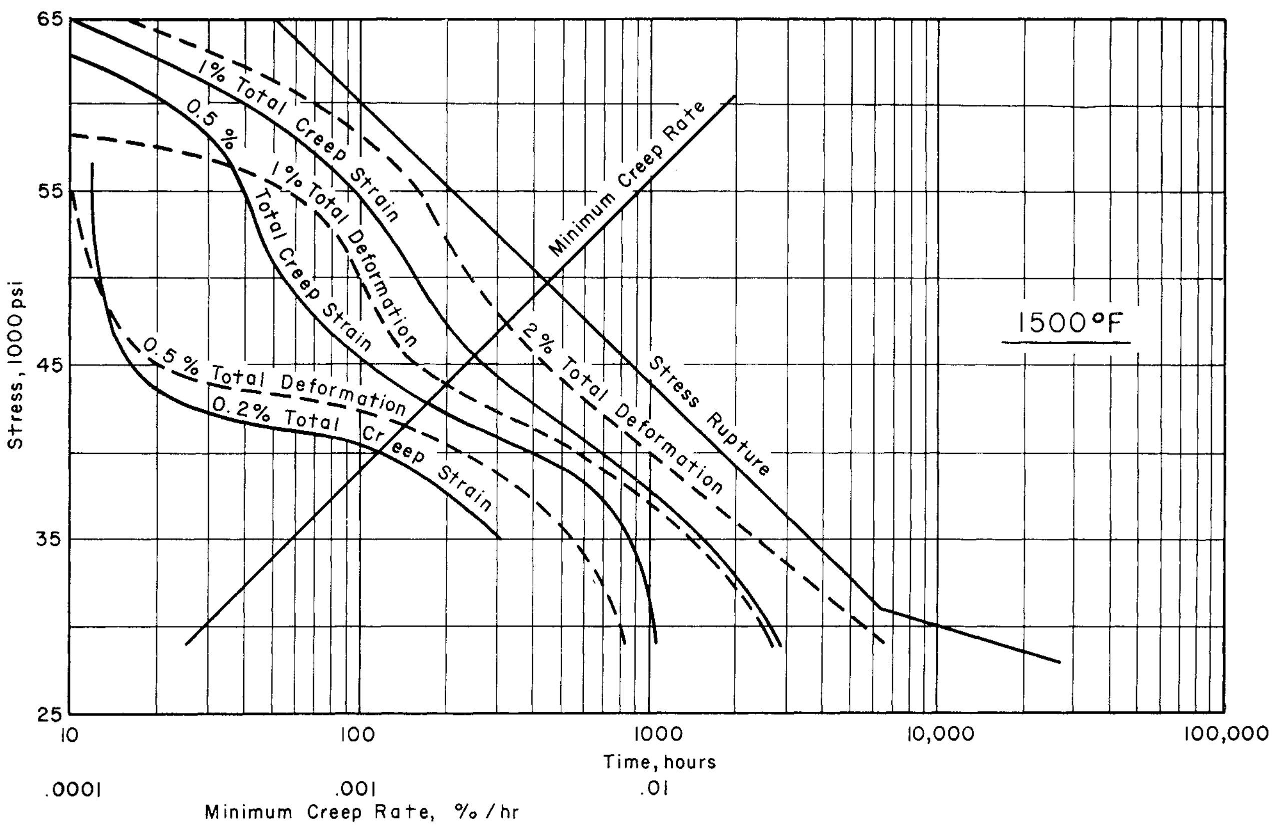


Figure 10. Design Curve for Alloy 713C at 1500 °F.

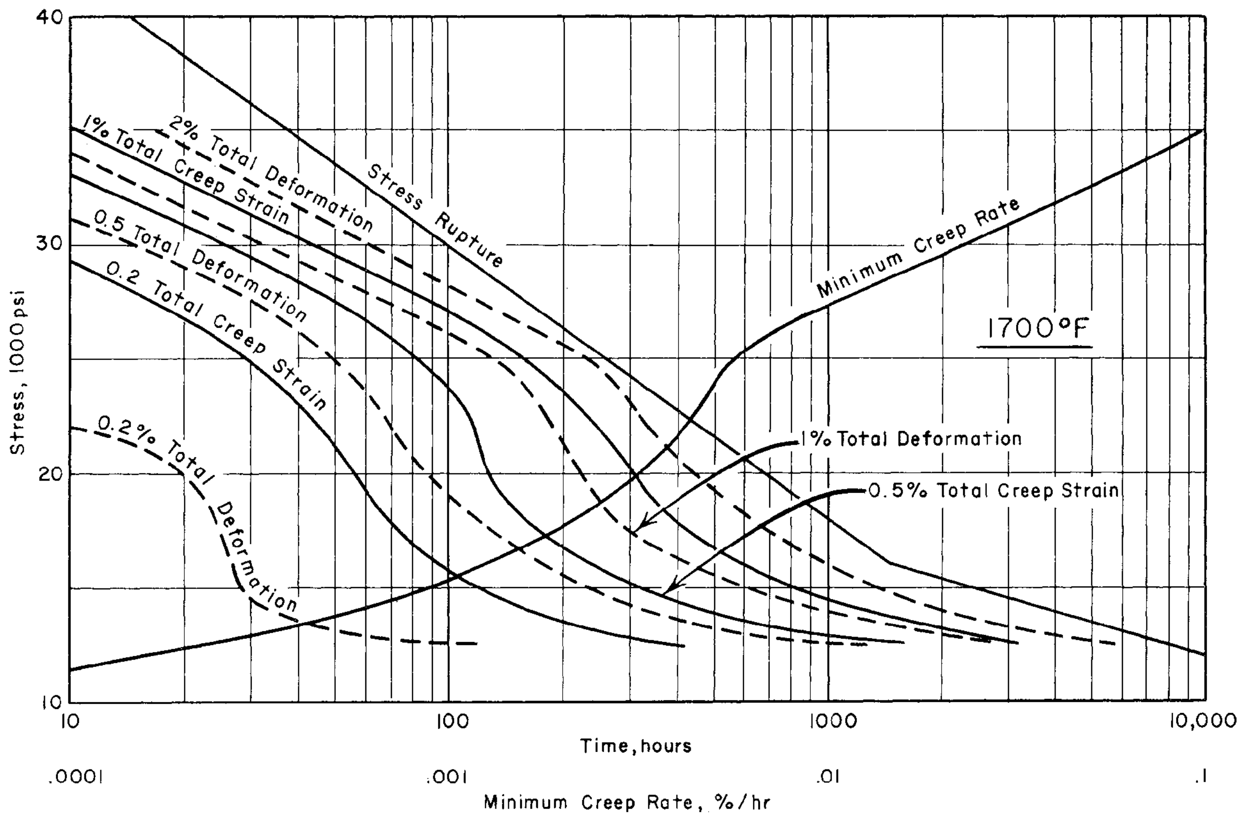


Figure 11. Design Curve for Alloy 713C at 1700 °F.

Dynamic Modulus of Elasticity (See Figure 12)

Test Temp, °F	Dynamic Modulus, psi	Test Temp, °F	Dynamic Modulus, psi
78	29.94 x 10^6	1000	26.16 x 10^6
200	29.48	1200	25.14
400	28.72	1400	24.20
600	27.97	1600	22.64
800	27.17	1800	21.37

Impact Properties (See Figures 13-14 and Table IV)

In general cast alloys do not attain the high level of impact properties associated with wrought material. A solution heat treatment of alloy 713C appears to offer a slight improvement up to 1300 °F. Depending upon the grain size, condition and prior holding time at temperature, the impact values of alloy 713C decrease from 9 ft-lb at room temperature to 5 ft-lb at 1800 °F.

Hot Hardness (See Figure 15)

Test Temp, °F	Hardness, R_c
70	38
1400	36
1600	18.5
1800	–8

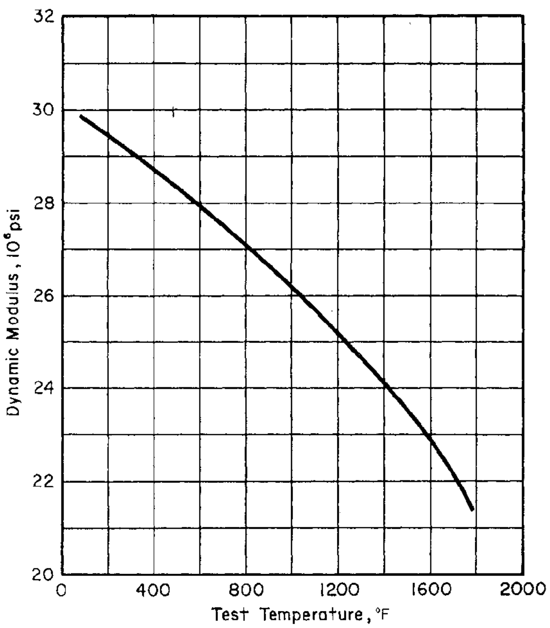


Figure 12. Dynamic Modulus of Elasticity of As Cast, Vacuum Melted, Vacuum Cast Alloy 713C.

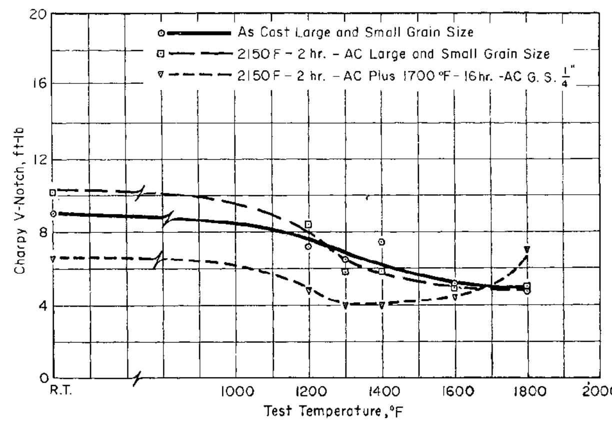


Figure 14. Impact Properties of As Cast, Vacuum Melted, Vacuum Cast, Alloy 713C After Holding 24 Hours at Temperature.

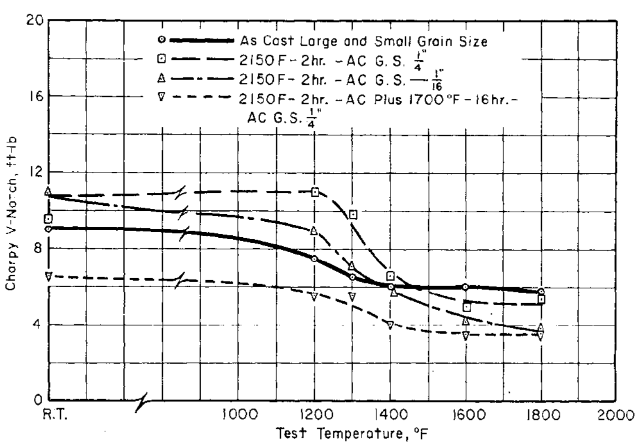


Figure 13. Impact Properties of As Cast, Vacuum Melted, Vacuum Cast Alloy 713C After Holding 30 Minutes at Temperature.

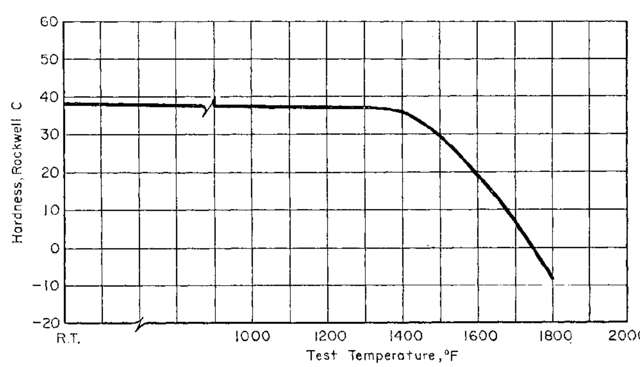


Figure 15. Hot Hardness of As Cast, Air Melted, Argon Cast Alloy 713C.

Table IV

Impact Properties of Alloy 713C

Charpy V-Notch, ft-lb

(vacuum melted, vacuum cast)

Test Temp, ºF	As Cast Grain Size, 1/8 - 1/4"		As Cast Grain Size, 1/32 - 1/8"		2150 ºF–2 hr–AC Grain Size, 1/8 - 1/4"		2150 ºF–2 hr–AC Grain Size, 1/32 - 1/8"		2150 ºF–2 hr–AC + 1700 ºF–16 hr–AC Grain Size, 1/8 - 1/4"	
30-MINUTE HOLDING TIME AT TEMPERATURE										
70	9	7.5	9	11	8	8	8.5	13.5	8	5.5
	10.5	9	8	8	11	10.5	11.5	10.5	7.5	5
1200	7	8	7	7	11	11	8	10	4	7
1300	7	6	6.5	6	10	9.5	7	7	5	6
1400	6	6	6	7	7	6	6	6	4	4
1600	6	6	6.5	6	4.5	5.5	4	4.5	4	3
1800	6	5.5	6	5.5	5.5	5.5	3.5	4	4.5	3.5
24-HOUR HOLDING TIME AT TEMPERATURE										
1200	7	7	7.5	7	10.5	7	8	8	4.5	5
1300	7	6	7.5	6	4	7.5	6.5	5.5	3	5
1400	6	8.5	7	8	6	7	4.5	6	4	–
1600	5	4.5	5	6	4	6.5	5.5	4	4.5	4.5
1800	5	5.5	3.5	5	6.5	4.5	5	4	9	5

Fatigue

STRESS-RUPTURE AND S-N FATIGUE CURVE[(4)] (See Figure 16)

Basic fatigue and stress-rupture data at 1700 ºF was determined for both the smooth and notched material. Using a stress concentration factor of K_t = 2.9 the fatigue strength is reduced and the creep strength enhanced.

FATIGUE DATA (See Table V)

Reversed stress axial fatigue tests at various temperatures on both coarse and fine grained material indicate the following endurance limits at 10^8 cycles:

Test Temp, ºF	Coarse Grain Material Endurance Limit, psi	Fine Grain Material Endurance Limit, psi
70	32,500	33,500
1200	23,000	25,500
1350	27,500	26,000
1500	26,000	28,000
1700	22,500	23,000

Table V

Fatigue Properties of Alloy 713C

(as cast, vacuum melted, vacuum cast)

Grain Size (1)	Stress Application	Temp, ºF	Speed, cpm	Endurance Limit, psi (10^8 Cycles, A= ∞ K_t=1.0)
Coarse	Axial	70	7,500	34,000
Coarse	Axial	70	14,500	32,500
Fine	Axial	70	14,500	33,500
Coarse	Rotary(2)	70	3,500	40,000
Fine	Rotary(2)	70	3,500	47,500
Coarse	Axial	1200	12,500	23,000
Fine	Axial	1200	12,500	25,500
Coarse	Axial	1200	12,500	22,000(3)
Coarse	Axial	1200	12,500	22,500(4)
Coarse	Axial	1350	12,000	27,500
Fine	Axial	1350	12,000	26,000
Coarse	Axial	1500	11,500	26,000
Fine	Axial	1500	11,500	28,000
Coarse	Axial	1700	9,500	22,500
Fine	Axial	1700	9,500	23,000

(1) Fine Grain Size- 1/16" average diameter
Coarse Grain Size = 3/16"-1/4" average diameter
(2) Rotating Beam values shown for comparative purposes
(3) 2150 ºF–2 hr–AC
(4) 2150 ºF–2 hr–AC + 1700 ºF–16 hr–AC

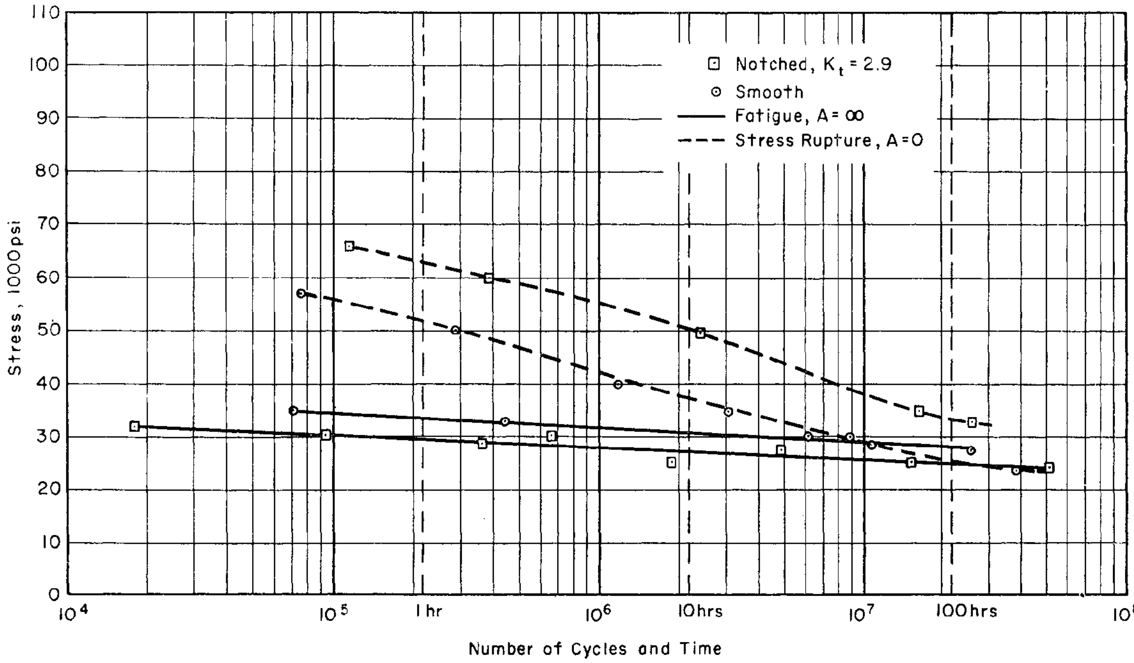


Figure 16. Stress Rupture and S-N Fatigue Curves for Notched and Unnotched Bars at 1700 ºF of As Cast, Air Melted, Argon Cast Alloy 713C[4].

THERMAL FATIGUE

Thermal fatigue data were obtained in a laboratory test rig in which a spot on the trailing edge of an investment cast stator blade section or a thermal fatigue specimen specially designed to simulate a stator blade was alternately heated by a gas-oxygen-air flame to the indicated temperature in one minute and then cooled by an air blast for one minute. As indicated by the following results, alloy 713C displays excellent thermal fatigue properties. Data for AMS 5382B alloy, widely used in applications requiring good resistance to thermal fatigue, are included for comparison.

Alloy	Temp, ºF	Average Cycles to Initiate Cracking	Average Cycles to 1/8" Long Crack
713C	1700	813	2493
713C	1800	854	2521
713C	2000	164	947
AMS 5382B	1700	426	928
	1800	196	529

FABRICATION

Machining and Grinding

Information on this subject is contained in Inco's brochure "MACHINING AND GRINDING INVESTMENT CASTING ALLOY 713C" which may be obtained on request.

JOINING

Welding

Although alloy 713C is not considered weldable, using the normal frame of reference, a considerable amount of fusion welding has nevertheless been done. In most instances, the welding operation has involved the joining of 713C to other more readily weldable metals, and this provides some latitude not present in matched welds. Matched welds have been made with some success in relatively light sections under conditions of low restraint. Welds are generally made using the gas tungsten arc process with either HASTELLOY* W Filler Wire or INCONEL† Filler Metal 92. Where permissible, repair welding of 713C castings can be done to a limited extent using the above filler metals. There has been encouraging progress made in producing crack-free welds by use of the electron beam process in welding 713C to dissimilar alloys. Mechanical testing has indicated that the welds retain excellent tensile properties.

Brazing

Alloy 713C can be satisfactorily brazed in dry hydrogen and inert gas atmospheres, and vacuum brazing can also be effectively used. In common with other age-hardened nickel-base alloys containing titanium and aluminum, this alloy is difficult to braze unless some method of fluxing–solid or gaseous–is used. Alternatively, the common practice is to pre-plate the areas to be furnace brazed with ½ to 1 mil of nickel, which prevents the formation of aluminum or titanium oxide films and permits ready wetting by the brazing alloy. Since 713C is generally employed because of its high temperature-strength characteristics, the higher melting point, stronger and more oxidation resistant brazing alloys are used in preference to the silver brazing alloys.

SURFACE TREATMENT

Cleaning

Depending upon surface condition and requirement, sand or grit blasting of finished parts is the general method of cleaning. Anodic etching in 85% H_3PO_4 at a current density of 60 amps per square foot removes surface material while preventing intergranular attack. A second dip in 70% HNO_3, 10% HF and 20% H_2O removes any adhering particles. A variety of molten caustic baths have also been used successfully.

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* Trademark of Cabot Corporation.
† Trademark of the Inco family of companies.

Etchants

Macro

1. Lepito's

   Part I - 30 g ammonium persulphate plus 150 cc water

   Part II - 500 g ferric chloride plus 200 cc concentrated hydrochloric acid

   Mix Part II into Part I and add 60 cc nitric acid. Immerse specimen.

2. Aqua Regia

   Concentrated nitric acid 25 cc

   Concentrated hydrochloric acid 75 cc

Micro

Modified Glyceregia

6 cc glycerine plus 5 cc concentrated hydrochloric acid plus 1 cc nitric acid. Swab specimen.

Electrolytic

3% sulfuric acid at 3 volts for 5-10 seconds.

Many etching reagents have been used satisfactorily on this alloy. The above list is intended only as a guide.

APPLICATION

Alloy 713C has found wide acceptance in the superalloy class due to its inherent castability, stability and high level of strength and ductility at elevated temperatures. Some commercial applications for the alloy include vane material and first stage blading in jet aircraft, guide vanes for industrial turbines, and diesel turbocharger wheels. The alloy is included in many experimental jet engines and small auxiliary gas turbines and is under evaluation for press forging die, extrusion die, and die-casting die applications.

REFERENCES

1. Pratt and Whitney Aircraft Company, Materials Engineering Section.
2. Union Carbide Stellite Company, "*Thermal and Electrical Conductivity of Haynes Alloy No. 713C*," Technical Services Report.
3. "*Haynes Alloy No. 713C,*" Data Sheet F-30; 154A, March 1960.
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