A Developmental Precipitation-Hardenable Ni-Cr-Co Superalloy for High Temperature Service in the Automotive and Power Industries

INCONEL® alloy 740 is a nickel-chromium-cobalt alloy developed by Special Metals Corporation. The alloy is age hardenable by the precipitation of a gamma prime second phase. Potential applications include advanced power production boiler tubes and diesel engine exhaust valves.

The chemical composition of alloy 740 is shown in Table 1. It is nickel-base and solid solution strengthened by its content of cobalt. It exhibits excellent resistance to high temperature corrosion due to the effects of chromium. During heat treatment, niobium, aluminum, and titanium form the gamma prime precipitates required for strengthening.

The effect of aging time and temperature upon the room-temperature hardness and tensile properties of hot-rolled and solution-annealed plate is shown in Table 2.

Some physical constants for INCONEL alloy 740 are listed in Table 3. Values for modulus of elasticity for annealed and aged material at various temperatures are shown in Table 4. Thermal properties of annealed material are given for a range of temperatures in Table 5.

INCONEL alloy 740 exhibits high strength at elevated temperatures. Tensile properties of aged specimens at temperatures up to 1500°F (816°C) are shown in Table 6. Creep rupture curves for alloy 740 between 1290°F (700°C) and 1470°F (800°C) are seen in Figure 1. Dotted lines indicate extrapolation beyond existing data. Long-term creep testing is ongoing within the European Thermie AD 700 project.

Alloy 740 offers excellent resistance to corrosive attack at elevated temperature. By virtue of its high content of chromium, the alloy resists oxidation, carburization, and sulfidation. Evidence of the alloy's resistance to oxidation is seen in Table 7. With its high content of nickel and low level of iron, alloy 740 resists high temperature attack by halides as well.

Resistance to coal ash corrosion is a requirement of service in high temperature coal-fired boilers. Table 8 and Figure 2 show the resistance of alloy 740 in simulated corrosive boiler conditions (controlled laboratory environment).

Alloy 740 is readily fabricated in the annealed condition. Joining is accomplished with the gas tungsten-arc welding (GTAW) process using NIMONIC® Filler Metal 263. If a high joint strength is required , the deposited weldment may be precipitation hardened. Table 9 shows room-temperature tensile data for transverse butt welds joining 0.625 in. (16 mm) plate deposited with NIMONIC Filler Metal 263 using the GTAW process.

INCONEL alloy 740 is still under development. While the composition is defined, work is continuing on processing the alloy. For the current status of the alloy or to discuss a potential application, please contact us via the website **www.specialmetals.com.**

Table 1 - Nominal Composition of INCONEL alloy 740

C	Ni	Cr	Mo	Co	Al	Ti	Nb	Mn	Fe	Si
0.03	Bal	25.0	0.5	20.0	0.9	1.8	2.0	0.30	0.7	0.5

Table 2 - Aging Response of INCONEL alloy 740 Plate at 1400°F (760°C) and 1470°F (800°C). (Hot-rolled and solution-annealed plate 6-mm thick was used as starting stock)

Rockwell C Hardness	0.2% YS, ksi	UTS, ksi	Elong., %	R of A, %	Aging
33.6	118.7	175.3	36.4	47.6	760°C/4hr/AC
34.4	120.9	178.2	37.4	43.0	760°C/8hr/AC
35.5	123.2	180.1	33.4	43.0	760°C/16hr/AC
35.6	114.8	173.4	37.0	45.8	800°C/4hr/AC
33.8	116.6	175.7	35.2	44.8	800°C/8hr/AC
33.8	114.2	176.3	33.6	42.8	800°C/16hr/AC

Table 3 - Physical Constants

Density, g/cm^3	8.05
lb/in^3	0.291
Melting Range, °C	1288-1362
°F	2350-2484
Electrical Resistivity, Ω-circ mil/ft	702.7
μΩ-m	1.168

INCONEL® alloy 740

Table 4 - Modulus of Elasticity

Temperature, °F	Modulus of Elasticity, Tension, 10^3 ksi
72	32.0
200	31.6
400	31.9
600	29.8
800	28.7
1000	27.7
1200	26.4
1400	25.1
1600	23.4
°C	GPa
22	221
100	218
200	212
300	206
400	200
500	193
600	186
700	178
800	169
900	158*

*Extrapolated value.

Table 5 - Thermal Properties

Temperature	Thermal Conductivity	Coefficient of Expansion[a]	Specific Heat
°F	Btu-in./ft^2-h-°F	10^{-6} in./in./°F	Btu/ln-°F
73	72.9	-	0.108
200	79.9	6.84	0.112
400	90.9	7.25	0.117
600	102.0	7.53	0.119
800	113.3	7.80	0.120
1000	124.9	7.96	0.121
1200	136.9	8.24	0.126
1400	149.3	8.61	0.133
1600	162.1	8.88	0.143
1800	175.6	-	0.152
2000	189.6	-	0.155
2100	196.9	-	0.152
°C	W/m-°C	µm/m°C	J/kg-°C
23	10.2	-	449
100	11.7	12.38	476
200	13.0	13.04	489
300	14.5	13.50	496
400	15.7	1393	503
500	17.1	14.27	513
600	18.4	14.57	519
700	20.2	15.03	542
800	22.1	15.72	573
900	23.8	15.81*	635
1000	25.4	-	656
1100	27.3	-	669
1150	27.9	-	669

[a]Mean coefficient of linear expansion between 73°F (23°C) and temperature shown.
*Extrapolated value.

Table 6 - Tensile Properties of Aged INCONEL alloy 740 at Elevated Temperatures

Test Temperature		Yield Strength		Tensile Strength		Elongation, %	Reduction of Area, %	Material Condition
°F	°C	ksi	MPa	ksi	MPa			
74	23	45.5	313.7	115.5	796.4	57.5	67.5	Annealed[a]
74	23	104.5	720.5	169.5	1168.7	51.34	49.4	Annealed and Aged[b]
1000	538	89.4	616.4	142.1	979.8	31.3	39	Annealed and Aged[b]
1100	593	88.1	607.4	143.9	992.2	31.4	32.8	Annealed and Aged[b]
1200	649	90.1	621.2	148.4	1023.2	38.4	39.8	Annealed and Aged[b]
1300	704	94	648.1	132.5	913.6	37.9	43.7	Annealed and Aged[b]
1400	760	88.2	608.1	111.1	766.0	32.5	43.9	Annealed and Aged[b]
1472	800	80.7	556.4	94.5	651.6	34.8	46.2	Annealed and Aged[b]
1500	816	74.6	514.4	88.2	608.1	37.7	47.8	Annealed and Aged[b]
1600	871	44.1	304.1	53	365.4	55.2	67.8	Annealed and Aged[b]
1700	927	21.5	148.2	29	200.0	63.5	79.4	Annealed and Aged[b]
1800	982	8.7	60.0	15.2	104.8	112.5	93.1	Annealed and Aged[b]

[a]Annealed 2100°F/30 minutes/Water Quench.
[b]Annealed 2100°F/30 minutes/Water Quench/Aged 1470°F/16 hours/Air Cool.

Table 7 - Oxidation Resistance of INCONEL alloy 740 (4,032 Hours in Air Plus 5% Water Vapor at 1290°F (700°C)

Mass Change (mg/cm^2)	Metal Loss (microns)	Depth of Attack (microns)
0.472	2.5	14.0

Table 8 - Penetration Results for INCONEL alloy 740 in Coal Ash Corrosion Test* at 1290°F (700°C)

Time (Hours)	Metal Loss (microns)	Depth of Attack (microns)
116	0	4
500	4	14
1000	5	19
1984	16	33
5008	39	60

* 15 Vol.% CO_2 + 10 Vol.%H_2O + 2 Vol.% O_2 + 1 Vol.% SO_2 + Bal. N_2 and coated with synthetic coal ash consisting Of 2.5 Wt.% Na_2SO_4 + 2.5 Wt.% K_2SO_4 + (Fe_2O_3/Al_2O_3/SiO_2) in the ratio 1:1:1

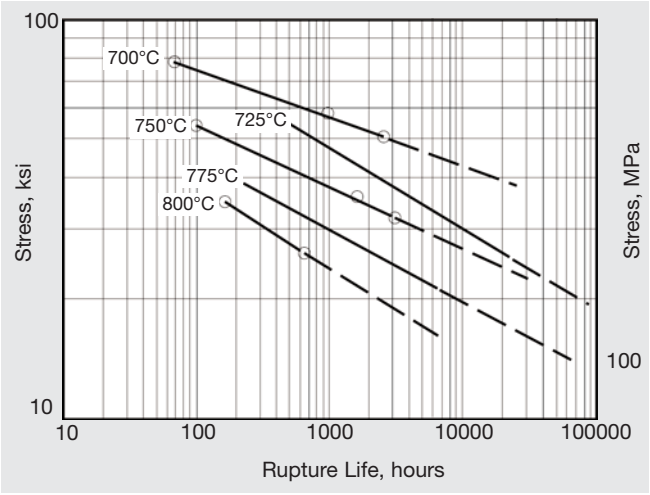

Figure 1 - Creep Rupture : INCONEL alloy 740 hot-rolled, solution-annealed and aged (800°C/16h/AC) bar.

Table 9 - Room Temperature Tensile Properties of Transverse Sections from Butt Weldments Joining 0.625 in. (16 mm) Thick INCONEL alloy 740 Plate Made using GTAW with NIMONIC Filler Metal 263

Condition	0.2% Yield Strength, ksi (MPa)	Ultimate Tensile Strength, ksi (MPa)	Elongation, %	Failure Location
As Welded	68.0 (467)	117.8 (812)	39.4	Base Metal
As Welded	67.4 (465)	118.3 (816)	38.5	Base Metal
Aged*	111.0 (765)	152.6 (1052)	14.4	Weld
Aged*	108.2 (746)	151.6 (1045)	12.9	Weld

*1470°F (800°C)/4 hours/AC.

Table 10 - Room Temperature Tensile Properties of Transverse Sections from Butt Weldments Joining 0.750 in. (19 mm) Thick INCONEL alloy 740 Plate Made using GTAW with INCONEL Filler Metal 740

Condition	0.2% Yield Strength, ksi (MPa)	Ultimate Tensile Strength, ksi (MPa)	Elongation, %	Failure Location
As Welded	70.2 (484)	118.1 (814)	37.1	Base Plate
As Welded	63.3 (436)	118.3 (816)	37.1	Base Plate
Aged*	125.4 (865)	157.8 (1088)	11.0	Weld
Aged*	120.9 (834)	161.2 (1111)	13.4	Weld

*1470°F (800°C)/4 hours/AC.

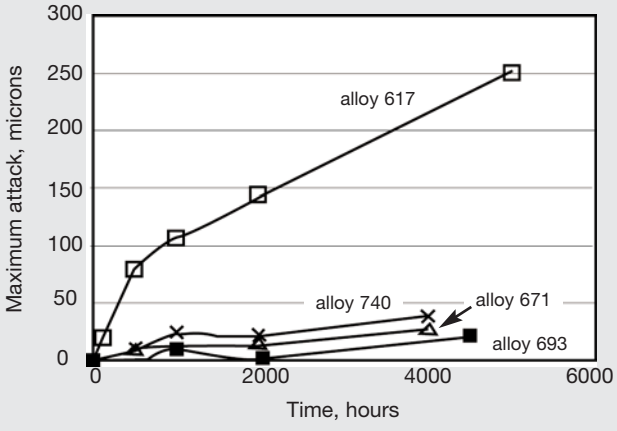

Figure 2 - Effects of exposure in a simulated coal ash corrosion test.
Exposure conditions:
Flue gas: N_2-15%CO_2-3.5%O_2-0.25%SO_2 at 700°C
Salt coating: 5% $NaSO_4$-5% K_2SO_4-90% (Fe_2O_3-Al_2O_3-SiO_2 in 1:1:1 ratio)
Samples were cycled to room temperature at the times indicated and re-coated.

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Fabrication

Figure 3 shows the cold working curve for INCONEL alloy 740. More information on fabricating is available in the Special Metals publication "Fabricating" on the website, www.specialmetals.com.

Joining and Machining

Information on joining and fabricating INCONEL alloy 740 is available in Special Metals publications "Joining" and "Machining" on the website, www.specialmetals.com.

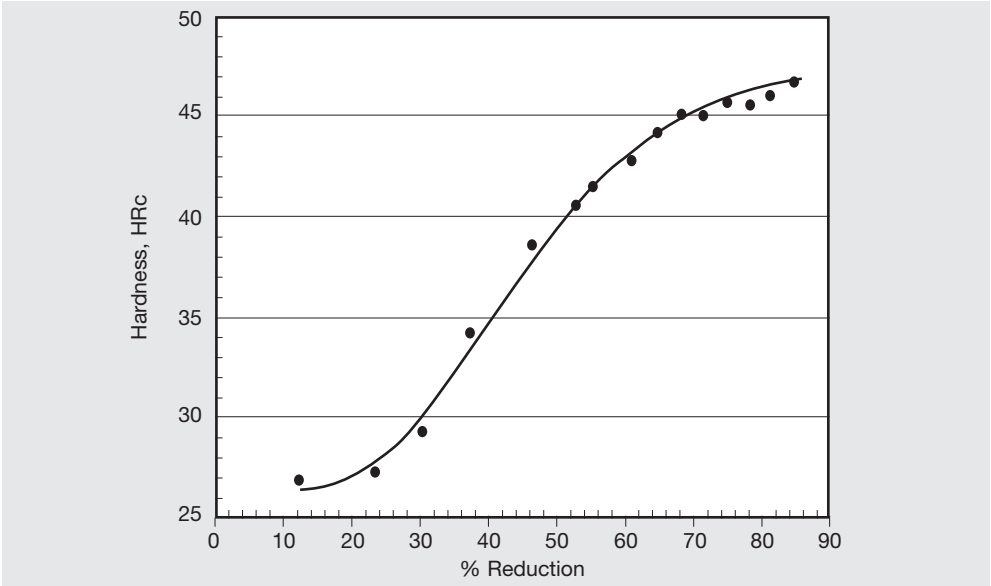

Figure 3. Rockwell 'C' hardness as a function of percent cold work for alloy 740 hot-rolled and annealed rod.

Table 11 - Machining Parameters for Turning

High Speed Steel				Coated Carbide			
Speed		Feed		Speed		Feed	
Surface ft/min.	m/min	in/rev	mm/rev	Surface ft/min	m/min	in/rev	mm/rev
10-18	3.0-6.3	0.005-0.015	0.127-0.381	30-81	9.1-24.7	0.005-0.015	0.127-0.381

Specifications

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