Technical Datasheet CARPENTER TECHNOLOGY

CarTech® Waspaloy

Identification

UNS Number
- N07001

AISI Number
- No. 685

Type Analysis

Single figures are nominal except where noted.

Carbon	0.02 to 0.10 %	**Manganese (Maximum)**	0.50 %
Sulfur (Maximum)	0.020 %	**Silicon (Maximum)**	0.75 %
Chromium	18.00 to 21.00 %	**Nickel**	Balance
Molybdenum	3.50 to 5.00 %	**Copper (Maximum)**	0.10 %
Cobalt	12.00 to 15.00 %	**Titanium**	2.75 to 3.25 %
Aluminum	1.20 to 1.50 %	**Boron**	0.003 to 0.008 %
Zirconium	0.02 to 0.12 %	**Iron (Maximum)**	2.00 %

General Information

Description

CarTech Waspaloy is a precipitation hardening, nickel-based alloy which has been used in elevated temperature applications. The alloy has been used for gas turbine engine parts which require considerable strength and corrosion resistance at temperatures up to 1600°F (871°C). CarTech Waspaloy is usually vacuum-induction plus consumable electrode remelted.

Corrosion Resistance

Waspaloy displays excellent resistance to corrosion by combustion products encountered in gas turbines and aircraft jet engines at temperatures up to 1600°F (871°C). Intergranular oxidation occurs at temperatures above 1600°F (871°C).

Properties

Physical Properties

Specific Gravity	8.25	
Density	0.2940	lb/in³
Mean Specific Heat		
200°F	0.1250	Btu/lb/°F
1000°F	0.1300	Btu/lb/°F
1200°F	0.1310	Btu/lb/°F
1500°F	0.1330	Btu/lb/°F
1600°F	0.1380	Btu/lb/°F
1800°F	0.1700	Btu/lb/°F

Specific heat

Temperature		Specific Heat	
°F	°C	Btu/lb • °F	kJ/kg • K
200	93	0.125	0.52
1000	538	0.130	0.54
1200	649	0.131	0.55
1400	760	0.133	0.56
1600	871	0.138	0.58
1800	982	0.170	0.71

Mean CTE		
77 to 200°F	6.80	$\times 10^{-6}$ in/in/°F
77 to 600°F	7.30	$\times 10^{-6}$ in/in/°F
77 to 1000°F	7.70	$\times 10^{-6}$ in/in/°F
77 to 1500°F	8.70	$\times 10^{-6}$ in/in/°F
77 to 2000°F	10.4	$\times 10^{-6}$ in/in/°F

Coefficient of thermal expansion

Temperature		Coefficient	
°F	°C	10^{-6}/°F	10^{-6}/°C
200	93	6.8	12.2
600	316	7.3	13.1
1000	538	7.7	13.9
1500	816	8.7	15.7
2000	1093	10.4	18.7

Thermal Conductivity		
70°F	79.00	BTU-in/hr/ft²/°F
800°F	113.0	BTU-in/hr/ft²/°F
1200°F	138.0	BTU-in/hr/ft²/°F
1500°F	160.0	BTU-in/hr/ft²/°F
1800°F	182.0	BTU-in/hr/ft²/°F

Thermal conductivity

Temperature		Btu-in/ft²•hr•°F	W/m • K
°F	°C		
70	21.1	79	11
800	427	113	16
1200	649	138	20
1500	816	160	23
1800	982	182	26

Modulus of Elasticity (E)		
77°F	30.6	$\times 10^{3}$ ksi
500°F	29.1	$\times 10^{3}$ ksi
1000°F	26.7	$\times 10^{3}$ ksi
1300°F	24.9	$\times 10^{3}$ ksi
1600°F	22.7	$\times 10^{3}$ ksi

Modulus of elasticity

Temperature		psi x 10^{6}	MPa x 10^{3}
°F	°C		
77	25	30.6	211.0
500	260	29.1	200.6
1000	538	26.7	184.1
1300	704	24.9	171.7
1600	871	22.7	156.5

Electrical Resistivity		
70°F, Precipitation Aged	721.0	ohm-cir-mil/ft
70°F, Solution Treated	747.0	ohm-cir-mil/ft
70°F, Stabilization Aged	733.0	ohm-cir-mil/ft

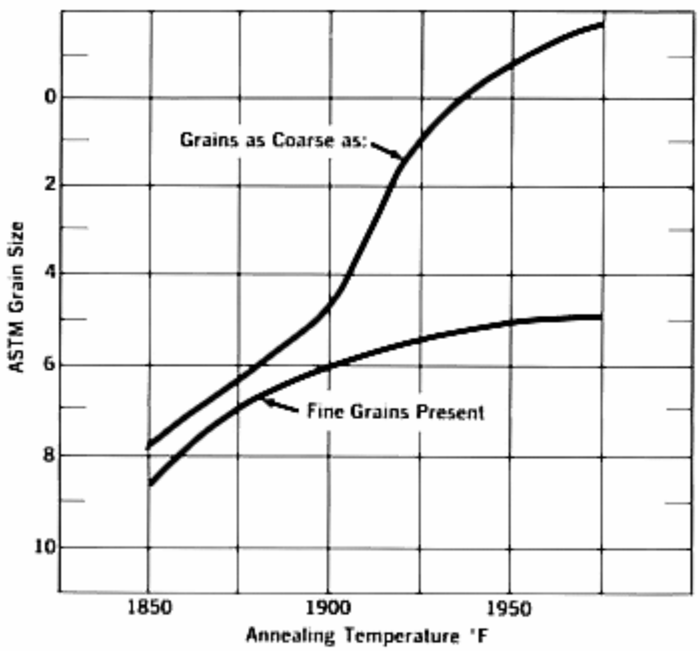
Electrical resistivity

Heat Treatment		ohm-cir mil/ft	microhm-mm
Solution treated	4 hrs. 1975°F (1080°C), AC	747	1240
Stabilization aged	24 hrs. 1550°F (843°C), AC	733	1220
Precipitation aged	16 hrs. 1400°F (760°C), AC	721	1200

Typical Mechanical Properties

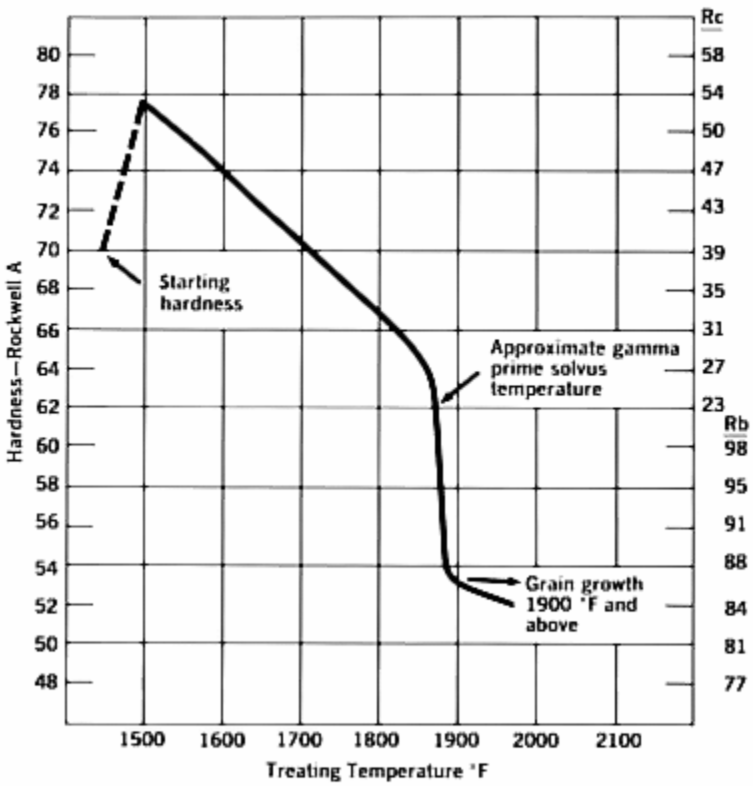
Grain Size—Carpenter Waspaloy

Estimated ASTM grain sizes which can be expected for four-hour solution or annealing treatments, assuming a fine-grain hot- or cold-worked starting structure. Grain size "scatter" must be expected when treating above 1900°F (1038°C).



Hardness Properties—Carpenter Waspaloy

Hardnesses which can be expected for oil- or water-quenched bars 1" (25.4 mm) round or smaller. Two to four hours treating time.



Stress Rupture Properties—Carpenter Waspaloy

Solution Treatment (+ Aged*)	Stress Rupture					
	1350°F (732°C)/75 ksi (517 MPa)			1500°F (816°C)/47.5 ksi (327.5 MPa)		
	Life (Hrs)	% Elongation	% Reduction of Area	Life (Hrs)	% Elongation	% Reduction of Area
1850°F (1010°C)/ 4 hrs/O.Q.	35.3	32.8	42.2	5.6	39.4	62.6
1875°F (1024°C)/ 4 hrs/O.Q.	56.1	11.0	17.2	8.2	36.1	54.6
1900°F (1038°C)/ 4 hrs/O.Q.	131.7	13.2	13.2	46.5	30.0	30.9
1925°F (1051°C)/ 4 hrs/O.Q.	125.6	8.7	17.4	38.9	19.2	26.6
1950°F (1066°C)/ 4 hrs/O.Q.	92.7	10.3	13.2	43.6	22.7	26.1
1975°F (1079°C)/ 3 hrs/O.Q.	91.3	5.3	12.0	52.4	19.4	23.3

*Aging: 1550°F (843°C)/4 hrs/A.C. + 1400°F (760°C)/16 hrs/A.C.

Tensile Properties—Carpenter Waspaloy
Bar stock

Solution Treatment (+ Aged*)	Tensile Test Results								
	Test Temperature		0.2% Yield Strength		Ultimate Tensile Strength		% Elongation	% Reduction of Area	Rockwell C Hardness
	°F	°C	ksi	MPa	ksi	MPa			
1850°F (1010°C)/ 4 hrs/O.Q.	70	21	156	1076	209	1441	27	47	42
	1000	538	142	980	197	1358	22	30	—
1875°F (1024°C)/ 4 hrs/O.Q.	70	21	151	1041	207	1427	28	49	41/42
	1000	538	133	917	187	1289	23	29	
1900°F (1038°C)/ 4 hrs/O.Q.	70	21	123	848	193	1331	33	38	37/38
	1000	538	108	745	168	1158	31	32	—
1925°F (1051°C)/ 4 hrs/O.Q.	70	21	122	841	190	1310	32	37	36/37
	1000	538	106	731	163	1124	31	35	—
1950°F (1066°C)/ 4 hrs/O.Q.	70	21	118	814	188	1296	32	36	35/36
	1000	538	102	703	161	1110	32	35	—
1975°F (1079°C)/ 3 hrs/O.Q.	70	21	116	800	185	1276	31	29	35
	1000	538	100	690	159	1096	31	35	—

*Aging: 1550°F (843°C)/4 hours/A.C. + 1400°F (760°C)/16 hrs/A.C.

Heat Treatment

Annealing

Hardening and strength properties are developed by precipitation of gamma prime (Ni_3TiAl). The solution temperature for gamma prime in Waspaloy is normally 1890/1910°F (1032/1043°C). This is also the temperature range at which grain growth begins. Annealed, or low hardness can be obtained only by cooling very rapidly from temperatures above the gamma prime solvus. Water quenching will result in hardnesses as low as Rockwell B 90, while air cooling will result in Rockwell C 28/30. Uniform low hardness cannot be obtained on sections having considerable mass. Air cooling is desirable for large sections.

Solution Treatment

Best stress rupture and creep properties are generally obtained by high temperature solution treatments, 1900/1975°F (1038/1079°C). The 1975°F (1079°C) temperature will result in coarse grain size and lower tensile yield strength. If the alloy is treated below solvus temperature at, for example, a temperature of 1850°F (1010°C), the as-hot-worked grain size will be retained and high tensile yield strength will result, with some loss in stress-rupture properties.

A practical compromise for adequate rupture properties, acceptable tensile properties and moderate grain growth is: solution treat just above the gamma prime solvus temperature, 1875/1900°F (1024/1038°C). Rotating parts are generally treated toward the low side, 1865/1875°F (1018/1024°C). For rupture-oriented applications, treating toward the high side, 1900/1925°F (1038/1051°C), is suggested.

Age

The normal aging treatment for Waspaloy is: stabilize 1550°F (843°C) 4 hours, air cool, followed by precipitation aging 1400°F (760°C) 16 hours, air cool.

Workability

Hot Working

Hot working is usually conducted in the temperature range 1800/2150°F (982/1177°C). The recommended furnace temperature is 2000/2100°F (1093/1149°C). Finishing should be discontinued at a temperature not lower than 1850°F (1010°C) (optical). Wherever possible, the hot working should proceed at a rate designed to maintain the proper hot-working temperature through internal "frictional heat." If deformation is too rapid, the temperature of the workpiece can "build up" and exceed the recommended 2150°F (1177°C) temperature and "hot short" tears will result. The alloy is normally air cooled from the hot-work operation. Hot workability of Carpenter Waspaloy is enhanced through proprietary melting techniques.

Cold Working

Waspaloy has reasonably good cold ductility when annealed either above or below the gamma prime solvus temperature. Since the alloy work hardens very rapidly, frequent anneals will be required. Minor reductions, of less than 5%, or sizing operations, should be avoided; otherwise critical strain can cause severe grain growth during subsequent solution treatments.

Cold-worked areas will age more rapidly than unworked sections. Contraction during aging of worked areas will result in severe and complex stresses during heating through the aging temperature range to a solution or annealing temperature. If shallow or nonuniform cold working is unavoidable, strainage cracking can develop unless the part can be heated extremely rapidly through the aging temperature. Thus, cold-worked parts should not be aged. A nonuniformly cold-worked part should not be put into service where the operating temperature will reach the aging temperature range, probably 1000/1600°F (538/871 °C).

Machinability

Waspaloy is difficult to machine in any condition of heat treatment. The air-cooled solution-treated condition is best for most operations (this is Rockwell C 30 partially aged). Rigid, well-powered machines are required for best results. Cemented carbide tools are preferred for most operations and care must be exercised to obtain positive cuts at all times, otherwise "glazing over" and work hardening of the surface will occur.

The following tool geometry, feeds, and speeds have been found satisfactory for lathe turning:

0° back rake
6- 8° side rake
5- 8° clearance (end and side)
15-20° lead angles may be used to reduce feed pressure on roughing cuts.

Additional Machinability Notes

Speeds of 35/50 sfm (0.18/0.25 m/s) with feeds of 0.0015/0.005" (0.038/0.13 mm) per revolution are recommended.

Slower speeds and greater feeds should be used for roughing cuts and faster speeds and lighter feeds for finishing cuts. Better tool life will be obtained by machining in the solution-treated condition; however, a smoother finish can be obtained by machining in the fully aged condition.

Weldability

Waspaloy should always be in the annealed or solution-treated condition before attempting welding. Good fitup and careful control of arc length and current input will minimize weld restraint. Clean surfaces are important chemical descaling, cleaning solvents, vapor blasting (not sand blasting), and emery cleaning are recommended.

Any molten weld metal must be protected from atmospheric contamination. Argon is recommended for both sides of butt joints. Rapid cooling of the weld area is best practice. Copper back-up bars and/or water-cooled fixtures or sprays are recommended.

All welded parts should be re-solution treated. "Strain-age" cracking can be minimized by heating welded parts through the aging temperature to the solution-treating temperature as rapidly as possible.

Other Information

Applicable Specifications

- AMS 5706
- AMS 5707
- AMS 5708
- AMS 5709
- AMS 7471
- EMS 52517
- EMS 55388
- EMS 55424
- LHM 2417
- PWA 1007
- PWA 1016
- PWA 1027
- PWA 1057

Forms Manufactured

- Bar-Rounds
- Billet
- Strip
- Wire
- Wire-Rod

Technical Articles

- A Designer's Manual On Specialty Alloys For Critical Automotive Components
- A Guide to Etching Specialty Alloys for Microstructural Evaluation
- Alloy Selection for Cold Forming (Part I)
- Alloy Selection for Cold Forming (Part II)
- Forging Difficult Alloys: How to Get Better Results, Consistently
- How to Select the Right Stainless Steel or High Temperature Alloy for Heading
- New Stainless for Fasteners Combines Corrosion Resistance, High Hardness and Cold Formability
- Selection of Age-Hardenable Superalloys
- Trends in High Temperature Alloys

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