

WASPALOY

Applicable designations: 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

Associated specifications: AISI 685, UNS N07001

Type analysis

Single figures are nominal except where noted.

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

Forms manufactured

Bar-Rounds	Billet	Strip	Wire	Wire-Rod
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Description

Waspaloy is a precipitation hardening, nickel-base alloy used in elevated temperature applications and those that require considerable strength and corrosion resistance at temperatures up to 1600°F (871°C). Waspaloy is usually vacuum-induction plus consumable electrode remelted.

Key Properties:

- High-temperature performance
- High strength
- Corrosion resistance

Markets:

- Aerospace
- Defense
- Energy
- Industrial
- Medical
- Transportation

Applications:

- Gas turbine engine parts
- Fasteners
- Internal combustion engine components
- Medical devices
- Well drilling equipment

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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).

Physical properties

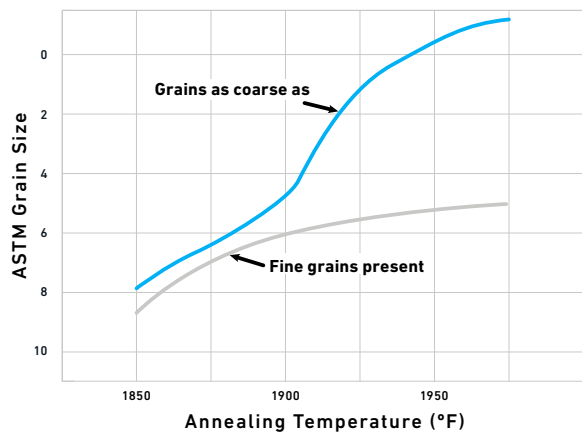
PROPERTY	At or From	English Units	Metric Units
SPECIFIC GRAVITY	—	8.25	8.25
DENSITY	—	0.297 lb/in ³	—
MEAN SPECIFIC HEAT	200°F (93°C)	0.125 Btu/lb/°F	0.52 kJ/kg·K
	1000°F (538°C)	0.130 Btu/lb/°F	0.54 kJ/kg·K
	1200°F (649°C)	0.131 Btu/lb/°F	0.55 kJ/kg·K
	1400°F (760°C)	0.133 Btu/lb/°F	0.56 kJ/kg·K
	1600°F (871°C)	0.138 Btu/lb/°F	0.58 kJ/kg·K
	1800°F (982°C)	0.170 Btu/lb/°F	0.71 kJ/kg·K
MEAN COEFFICIENT OF THERMAL EXPANSION (CTE)	77 to 200°F (25 to 93°C)	6.8×10^{-6} in/in/°F	12.2×10^{-6} length/length/°C
	77 to 600°F (25 to 316°C)	7.3×10^{-6} in/in/°F	13.1×10^{-6} length/length/°C
	77 to 1000°F (25 to 538°C)	7.7×10^{-6} in/in/°F	13.9×10^{-6} length/length/°C
	77 to 1500°F (25 to 816°C)	8.7×10^{-6} in/in/°F	15.7×10^{-6} length/length/°C
	77 to 2000°F (25 to 1093°C)	10.4×10^{-6} in/in/°F	18.7×10^{-6} length/length/°C
THERMAL CONDUCTIVITY	70°F (21.1°C)	79 Btu·in/ft ² ·hr·°F	11 W/m·K
	800°F (427°C)	113 Btu·in/ft ² ·hr·°F	16 W/m·K
	1200°F (649°C)	138 Btu·in/ft ² ·hr·°F	20 W/m·K
	1500°F (816°C)	160 Btu·in/ft ² ·hr·°F	23 W/m·K
	1800°F (982°C)	182 Btu·in/ft ² ·hr·°F	26 W/m·K
ELASTIC MODULUS (E)	77°F (25°C)	30.6×10^3 ksi	$211.0 \text{ MPa} \times 10^3$
	500°F (260°C)	29.1×10^3 ksi	$200.6 \text{ MPa} \times 10^3$
	1000°F (538°C)	26.7×10^3 ksi	$184.1 \text{ MPa} \times 10^3$
	1300°F (704°C)	24.9×10^3 ksi	$171.7 \text{ MPa} \times 10^3$
	1600°F (871°C)	22.7×10^3 ksi	$156.5 \text{ MPa} \times 10^3$
ELECTRICAL RESISTIVITY	Precipitation aged 1400°F (760°C) 16 hrs, AC	721 ohm-cir-mil/ft	1200 microohm-mm
	Solution treated 1975°F (1080°C) 4 hrs, AC	747 ohm-cir-mil/ft	1240 microohm-mm
	Stabilization aged 1550°F (843°C) 24 hrs, AC	733 ohm-cir-mil/ft	1220 microohm-mm

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Typical mechanical properties

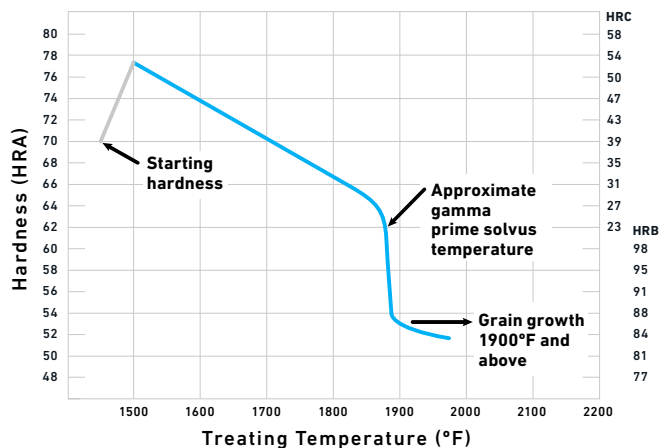
GRAIN SIZE

Estimated ASTM grain sizes that can be expected for 4-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

Hardnesses that can be expected for oil- or water-quenched bars 1 in. (25.4 mm) round or smaller. 2 to 4 hours treating time.



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STRESS RUPTURE PROPERTIES

SOLUTION TREATMENT (+ AGED*)	1350°F (732°C) / 75 ksi (517 MPa)			1500°F (816°C) / 47.5 ksi (327.5 MPa)		
	LIFE	ELONGATION	REDUCTION OF AREA	LIFE	ELONGATION	REDUCTION OF AREA
	hrs	%	%	hrs	%	%
1850°F (1010°C) 4 hrs, OQ	35.3	32.8	42.2	5.6	39.4	62.6
1875°F (1024°C) 4 hrs, OQ	56.1	11.0	17.2	8.2	36.1	54.6
1900°F (1038°C) 4 hrs, OQ	131.7	13.2	13.2	46.5	30.0	30.9
1925°F (1051°C) 4 hrs, OQ	125.6	8.7	17.4	38.9	19.2	26.6
1950°F (1066°C) 4 hrs, OQ	92.7	10.3	13.2	43.6	22.7	26.1
1975°F (1079°C) 3 hrs, OQ	91.3	5.3	12.0	52.4	19.4	23.3

*Aging: 1550°F (843°C) 4 hrs, AC + 1400°F (760°C) 16 hrs, AC

TENSILE PROPERTIES — BAR STOCK

SOLUTION TREATMENT (+AGED*)	TEST TEMPERATURE		0.2% YIELD STRENGTH		ULTIMATE TENSILE STRENGTH		ELONGATION	REDUCTION IN AREA	HARDNESS
	°F	°C	ksi	MPa	ksi	MPa	%	%	HRC
1850°F (1010°C) 4 hrs, OQ	70	21	156	1076	209	1441	27	47	42
	1000	538	142	980	197	1358	22	30	—
1875°F (1024°C) 4 hrs, OQ	70	21	151	1041	207	1427	28	49	41/42
	1000	538	133	917	187	1289	23	29	—
1900°F (1038°C) 4 hrs, OQ	70	21	123	848	193	1331	33	38	37/38
	1000	538	108	745	168	1158	31	32	—
1925°F (1051°C) 4 hrs, OQ	70	21	122	841	190	1310	32	37	36/37
	1000	538	106	731	163	1124	31	35	—
1950°F (1066°C) 4 hrs, OQ	70	21	118	814	188	1296	32	36	35/36
	1000	538	102	703	161	1110	32	35	—
1975°F (1079°C) 3 hrs, OQ	70	21	116	800	185	1276	31	29	35
	1000	538	100	690	159	1096	31	35	—

*Aging: 1550°F (843°C) 4 hrs, AC + 1400°F (760°C) 16 hrs, AC

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Heat treatment

Annealing

Hardening and strength properties are developed by precipitation of gamma prime (Ni₃TiAl). 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.

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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 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 in. (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.

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contact your nearest sales office:**

info@cartech.com | 610 208 2000

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