Technical Datasheet CARPENTER TECHNOLOGY

Ti-3Al-8V-6Cr-4Mo-4Zr (Beta C™)

Type Analysis

Single figures are nominal except where noted.

Carbon (Maximum)	0.05 %	**Chromium**	5.50 to 6.50 %
Molybdenum	3.50 to 4.50 %	**Titanium**	Balance
Aluminum	3.00 to 4.00 %	**Vanadium**	7.50 to 8.50 %
Zirconium	3.50 to 4.50 %	**Nitrogen (Maximum)**	0.03 %
Iron (Maximum)	0.30 %	**Oxygen (Maximum)**	0.120 %
Hydrogen (Maximum)	0.030 %	**Yttrium (Maximum)**	0.005 %
Other, Total (Maximum)	0.40 %		

* Other, Each (Maximum) = 0.150%

General Information

Description

Pure titanium undergoes an allotropic transformation from the hexagonal close-packed alpha phase to the body-centered cubic beta phase at a temperature of 882.5ºC (1620.5ºF). Alloying elements can act to stabilize either the alpha or beta phase. Through the use of alloying additions, the beta phase can be sufficiently stabilized to coexist with alpha at room temperature. This fact forms the basis for the creation of titanium alloys that can be strengthened by heat treating.

Titanium alloys are generally classified into three main categories: alpha alloys, which contain neutral alloying elements (such as Sn) and/or alpha stabilizers (such as Al, O) only and are not heat treatable; alpha + beta alloys, which generally contain a combination of alpha and beta stabilizers and are heat treatable to various degrees; and beta alloys, which are metastable and contain sufficient beta stabilizers (such as Mo , V) to completely retain the beta phase upon quenching, and can be solution treated and aged to achieve significant increases in strength.

Ti-3Al-8V-6Cr-4Mo-4Zr (Ti-3-8-6-4-4, commonly known as Beta-C TM) is a metastable beta alloy developed in the 1960s. Like other beta alloys, it is used when particularly high strengths are needed along with the light weight and corrosion resistance offered by titanium. Ti-3-8-6-4-4 has gained in popularity among beta alloys because it is one of the easier beta alloys to melt, exhibiting low segregation, and to process, exhibiting good working and heat treating properties. Depending on the application, Ti-3-8-6-4-4 can be used in either the solution annealed (ST) or the solution treated plus aged (STA) conditions. Increases in strength on the order of 40% are obtained by solution treating and aging.

Applications

Ti-3-8-6-4-4 is appropriate for applications where very high strength, light weight and corrosion resistance are important. It has become a standard material for a particular niche of specialized applications which have included aircraft springs and underground tubes and casing equipment for gas and oil well operations. It has also been used in fasteners and high-performance auto racing applications.

Corrosion Resistance

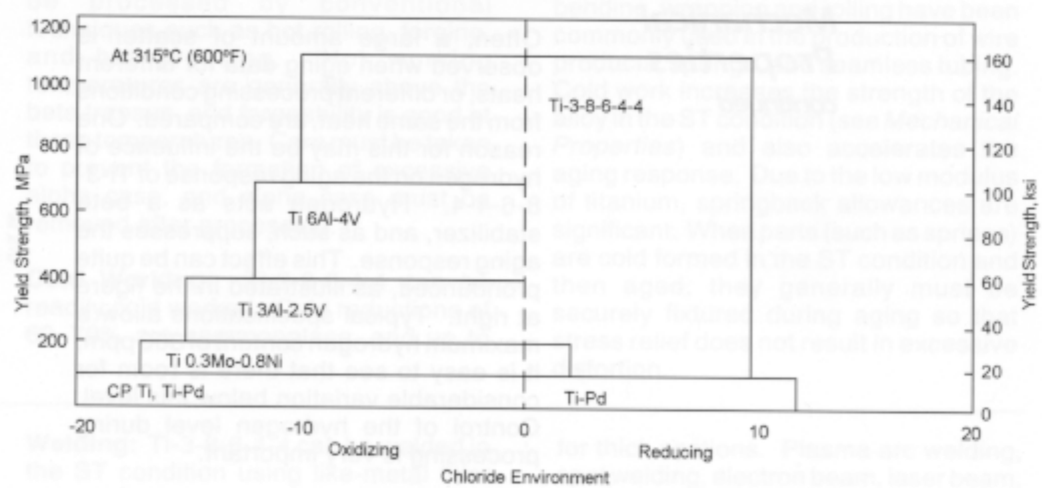
Like other Ti alloys, the corrosion resistance of Ti-3-8-6-4-4 is based on the presence of a stable, continuous, tightly adherent oxide layer. This layer forms spontaneously upon exposure to oxygen (air or moisture) in the environment. Compared to CP Ti, Ti-3- 8-6-4-4 has better resistance to reducing environments (hydrochloric, sulfuric acid) and less resistance to oxidizing environments (nitric acid, chloride salts). These differences are due mainly to the influence of molybdenum in the alloy.

Ti-3-8-6-4-4 is also somewhat more resistant to crevice corrosion than CP Ti in media such as salt water. Like other Ti alloys, it is largely resistant to stress-corrosion cracking (SCC), with the exception of a few specific environments. These include methanol/halide solutions and chloride brines above 180ºC (355ºF). Palladium additions of <0.1% have been shown to increase resistance to SCC in brines. A Ti-3-8-6-4-4 + Pd grade is available and has been used in some deep gas well applications.

Important Note: *The following 4-level rating scale is intended for comparative purposes only. Corrosion testing is recommended; factors which affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish and dissimilar metal contact.*

Sulfuric Acid	Moderate	Acetic Acid	Excellent
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Excellent
Sea Water	Excellent	Sour Oil/Gas	Good
Humidity	Excellent		

Comparison of Corrosion Resistance vs. Yield Strength [1]



Ti-3-8-6-4-4: General Corrosion Rates in Various Media

Medium	Concentration %	Temperature	Corrosion Rate mm/yr	Corrosion Rate mils/yr
Hydrochloric Acid	1.0	boiling	0.058	2.3
Ferric Chloride	10	boiling	nil	nil
Sulfuric Acid, aerated	5	boiling	1.85	73
Sulfuric Acid + 50 g/l $FeCl_3$	10	boiling	0.05	2.0

Properties

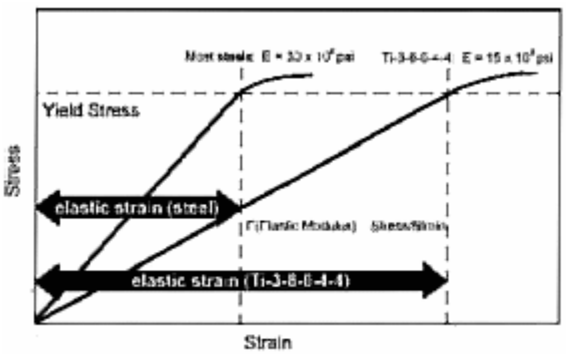
Physical Properties

Specific Gravity	4.83	
Density		
Solution Annealed	0.1740	lb/in³
Solution Treated & Aged	0.1740	lb/in³
Mean Specific Heat (73°F)	0.1230	Btu/lb/°F
Mean CTE (73 to 212°F)	4.60	x 10^{-6} in/in/°F
Thermal Conductivity (73°F)	43.02	BTU-in/hr/ft²/°F
Modulus of Elasticity (E)		
Overaged	13.2	x 10^{3} ksi
Solution Annealed	11.4	x 10^{3} ksi
Solution Treated & Aged	14.4	x 10^{3} ksi
Modulus of Rigidity (G) (Solution Treated and Aged)	5.60	x 10^{3} ksi
Beta Transus	1325 to 1375	°F
Liquidus Temperature	3000	°F

Solidus Temperature	2830	°F
Electrical Resistivity (73°F)	962.7	ohm-cir-mil/ft

Elastic and Shear Moduli for Ti-3-8-6-4-4 and Other Materials

Material		Elastic Modulus		Shear Modulus	
		GPa	psi x 10^6	GPa	psi x 10^6
Ti-3-8-6-4-4	Solution Annealed	78-91	11.4-13.2	-	-
	Solution Treated + Aged	99-124	14.4-18.0	39-43	5.6-6.3
	Overaged	91-96	13.2-14.0	-	-
CP Titanium		103-107	15.0-15.5	45	6.5
Ti 6Al-4V		105-116	15.2-16.8	41-45	5.9-6.5
Most Steels		190-215	27.6-31.2	74-83	10.7-12.0
Nickel Alloys		200-222	29.0-32.2	76-85	11.0-12.3



For two samples with identical yield strength, the lower-modulus material will have the greater elastic strain.

Magnetic Properties

Magnetic Attraction

- None

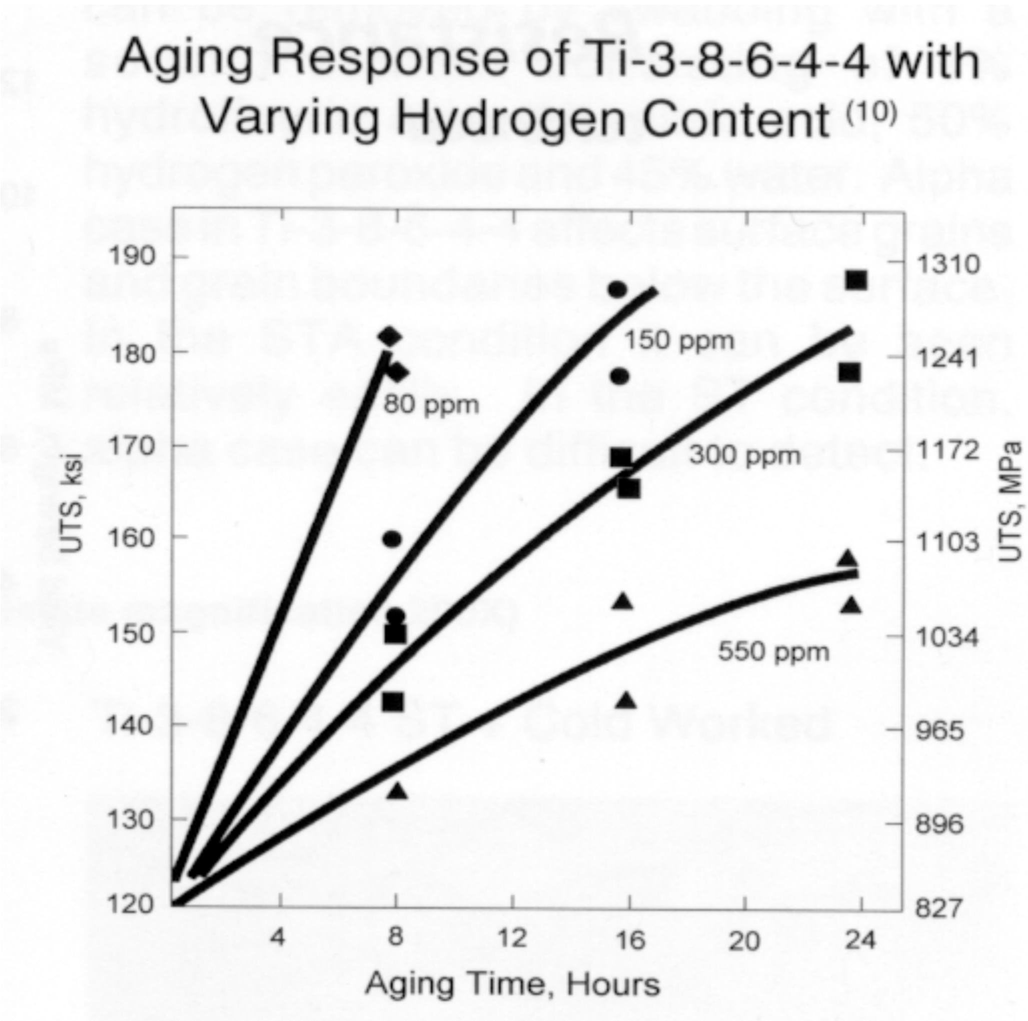
Typical Mechanical Properties

Specific Strength:
Ti-3-8-6-4-4 has one of the lowest densities for a beta titanium alloy. Combined with the high strengths attainable by heat treating, this makes it an ideal material for applications such as aircraft and race car springs, where weight can be a critical consideration. Specific strength (strength/density) provides a means to compare materials based on a combination of strength and weight.

Fatigue Limits:
Some generalized fatigue limits for STA Ti-3-8-6-4-4 are provided below.
Smooth (Axial Fatigue, R = 0.1) ~600 MPa (87 ksi)
Notched (KT = 3) ~275 MPa (40 ksi)

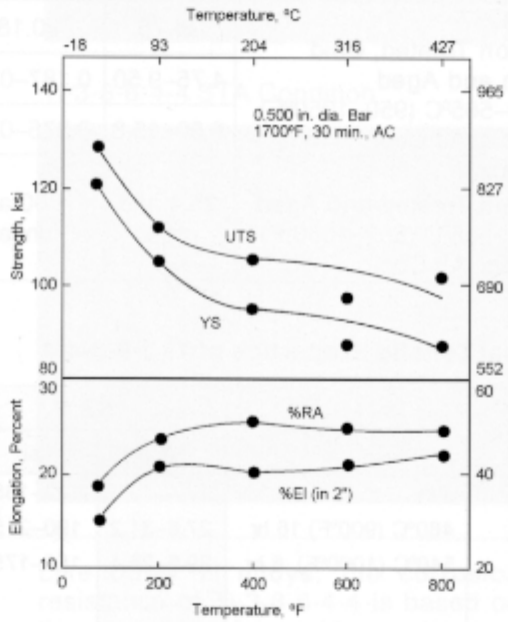
Fracture Toughness:
Reported fracture toughness (KIc) values for STA Ti-3-8-6-4-4 vary from 53-90 MPa*m (48-82 ksi*in) depending on sample orientation and material condition.

Typical Room-Temperature Strengths for Ti-3-8-6-4-4:
Compressive Yield Strength STA 1235 MPa (180 ksi)
Compressive Yield Strength ST+CW+A 1250 MPa (181 ksi)
Double Shear Strength ST 643 MPa (93 ksi)
Double Shear Strength STA 643 MPa (93 ksi)

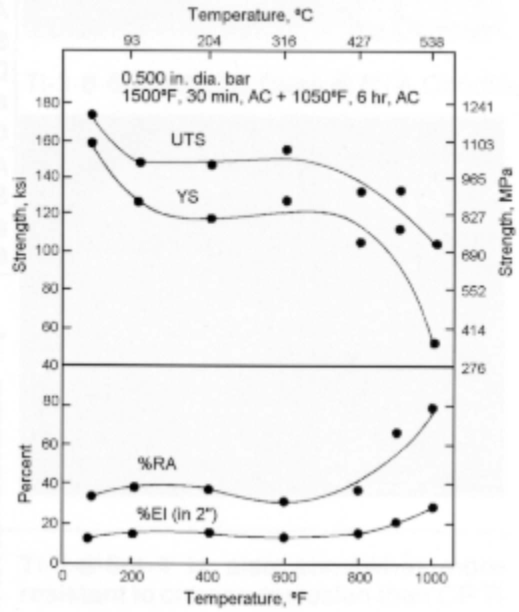

Aging Response of Ti-3-8-6-4-4 with Varying Hydrogen Content (10)
UTS, ksi
190
180
170
160
150
140
130
120
UTS, MPa
1310
1241
1172
1103
1034
965
896
827
80 ppm
150 ppm
300 ppm
550 ppm
4
8
12
16
20
24
Aging Time, Hours

Elevated Temperature Mechanical Properties for Ti-3-8-6-4-4

Tensile Properties vs. Temperature ST Condition (2)



Tensile Properties vs. Temperature STA Condition (2)



Minimum Specified Tensile Properties of Age Hardened Ti-3-8-6-4-4

Condition	Diameter		Tensile Properties after Aging			
			UTS		%El	%RA
	mm	in.	MPa	ksi		
AMS 4957 **Solution Treated, Cold Drawn and Aged** at 510-565ºC (950-1050ºF), 6-10 hrs, Air Cool	≤4.75	≤0.187	1310-1445	190-210	10	20
	4.75-9.50	0.187-0.375	1275-1415	185-205	10	20
	9.50-15.8	0.375-0.625	1240-1380	180-200	8	20
AMS 4958 **Solution Treated and Aged** at 454-565ºC (850-1050ºF) 6-20 hrs, Air Cool	25.4 and under	1.00 and under	1240	180	8	20

Material	Minimum UTS		Density (ρ)		Specific Strength	
	MPa	ksi	g/cm³	lb/in³	m x 10³	in x 10⁶
Ti-3-8-6-4-4 Solution Annealed (AMS 4958)	827	120	4.82	0.174	17.5	690
Ti-3-8-6-4-4 STA (AMS 4957)	1241	180	4.82	0.174	26.3	1034
Spring Steels						
17-7 PH (AMS 5637)	1650	240	7.81	0.282	21.6	851
Music Wire (ASTM A-228)	1620	235	8.05	0.290	20.6	810
High-Temperature Alloys						
A286 (AMS 5737)	978	140	7.94	0.286	12.4	490
IN718 (AMS 5662)	1310	190	8.51	0.307	15.8	619
Other Titanium and Ti Alloys						
CP Ti Grade 4	552	80	4.51	0.163	12.5	491
Ti 6Al-4V	924	134	4.43	0.160	21.3	838

Typical Tensile Properties of Ti-3-8-6-4-4

Cold Work %	Aging Treatment	UTS		0.2%YS		%El	%RA
		MPa	ksi	MPa	ksi		
0	none	830–930	120–135	760-860	110–125	15–30	50–65
0	480ºC (900ºF) 16 hr	1310–1480	190–215	1210-1340	175–195	7–15	15–35
0	540ºC (1000ºF) 6 hr	1070–1210	155–175	970-1070	140–155	15–20	30–45
25	none	1030–1140	150–165	930-1070	135–155	15–20	50–60
25	480ºC (900ºF) 12 h	1450–1520	210–220	1340-1410	195–205	10–15	20–30
25	540ºC (1000ºF) 6 hr	1240–1380	180–200	1140-1280	165–185	15–25	25–50
30	none	1070–1170	155–170	970-1070	140–155	13–18	45–55
30	510ºC (950ºF) 6 hr	1410–1520	205–220	1240-1380	180–200	12–16	12–25
30	540ºC (1000ºF) 6 hr	1240–1380	180–200	1170-1280	170–185	12–20	25–50
50	none	1170–1340	170–195	1070-1170	155–170	12–15	40–50
50	480ºC (900ºF) 8 h	1450–1590	210–230	1380-1480	200–215	6–15	10–25
50	540ºC (1000ºF) 4 hr	1380–1480	200–215	1280-1340	185–195	10–15	25–40

Heat Treatment

Ti-3-8-6-4-4 is a heat treatable alloy. Maximum strengths are obtained by solution treating plus aging. Solution treatment is typically done at 55-85ºC (100-150ºF) above the beta transus. Upon reasonably fast cooling (air cooling or equivalent is sufficient), the bcc beta phase is retained. This structure imparts excellent formability; cold reductions of 70-80% can be achieved in ST material.

Aging at intermediate temperatures results in the precipitation of finely dispersed alpha phase, with attendant strengthening. Cold working prior to aging shortens aging times and results in even higher strengths. By varying the cold work, solution treating cycles and aging treatments, a variety of mechanical property combinations can be obtained, allowing properties to be tailored to suit a particular application.

Titanium and its alloys have a high affinity for gases including oxygen, nitrogen and hydrogen. When Ti-3-8-6-4-4 is heated in air, oxygen absorption results in the formation of a hard, brittle oxygen-stablized alpha layer known as alpha case, which must be removed before further processing.

Heat treating of Ti-3-8-6-4-4 is often performed in a vacuum or inert gas atmosphere to avoid alpha case formation and the associated material loss. Vacuum annealing can also be used to remove excess hydrogen, a process known as vacuum degassing. Parts to be vacuum heat treated must be thoroughly cleaned (see Descaling (Cleaning) Notes).

Heat Treatments for Ti-3-8-6-4-4

Solution Treatment	788-927ºC (1450-1700ºF) 10-60 min.—air cool (or equivalent) or faster
Aging	455-593ºC (850-1100ºF) 6-14 hr.—air cool (or equivalent)

Workability

Hot Working

Ti-3-8-6-4-4 can be processed by conventional techniques such as hot rolling, forging, and hot pressing. Hot working temperatures are generally above the beta transus, and forgeability is good at these temperatures. Care must be taken to prevent the formation of excessive alpha case, and alpha case must be removed after processing.

Cold Working

Ti-3-8-6-4-4 can be readily cold worked. Cold reductions of 60-70% are commonplace, and up to 80-90% can be achieved. Cold drawing, bending, wrapping and rolling have been commonly used in the production of wire products, springs, and seamless tubing. Cold work increases the strength of the alloy in the ST condition (see Mechanical Properties) and also accelerates the aging response. Due to the low modulus of titanium, springback allowances are significant. When parts (such as springs) are cold formed in the ST condition and then aged, they generally must be securely fixtured during aging so that stress relief does not result in excessive distortion.

Machinability

The machining characteristics of Ti-3-8- 6-4-4 are similar to other titanium alloys; however, slower speeds are generally advised. Recommended speeds for Ti-3- 8-6-4-4 in the ST condition are approximately 50-70% as fast as Ti 6Al-4V, and 20-30% as fast as CP Grade 1. For the STA condition, speeds drop to 55-65% of Ti 6Al-4V and 15-25% of CP Grade 1. In general, low cutting speeds, heavy feed rates, and copious amounts of cutting fluid are recommended for machining Ti-3-8-6-4-4. Sharp tools and rigid setups are also important. Because of the strong tendency of titanium to gall and smear, feeding should never be stopped while the tool and work are in moving contact. Non-chlorinated cutting fluids are generally used to eliminate any possibility of chloride-induced stress-corrosion cracking. It should be noted that titanium chips are highly combustible, and appropriate safety precautions are necessary.

Following are typical feeds and speeds for Ti-3-8- 6-4-4.

Typical Machining Speeds and Feeds – Titanium Alloy Ti-3Al-8V-6Cr-4Mo-4Zr (Beta C™)

The speeds and feeds in the following charts are conservative recommendations for initial setup. Higher speeds and feeds may be attainable depending on machining environment.

Turning—Single-point and Box Tools

Depth of Cut (Inches)	High Speed Tools			Carbide Tools (Inserts)				
	Tool Material	Speed (fpm)	Feed (ipr)	Tool Material	Speed (fpm)			Feed (ipr)
					Brazed	Throw Away	Coated	
Annealed								
.150	T15, M42	30	.010	C2	105	135	-	.008
.025		40	.005	C3	125	160	-	.005
Aged								
.150	T15, M42	25	.010	C2	90	105	-	.008
.025		35	.005	C3	110	125	-	.005

Turning—Cut-Off and Form Tools

Tool Material		Speed (fpm)	Feed (ipr)						
			Cut-Off Tool Width (Inches)				Form Tool Width (Inches)		
High Speed Tools	Car-bide Tools		1/16	1/8	1/4	1/2	1	1 ½	2
Annealed									
T15, M42		35	.001	.0015	.002	.002	.0015	.001	.001
	C2	75							
Aged									
T15, M42		30	.001	.001	.0015	.0015	.001	.0008	.012
	C2	60							

Rough Reaming

High Speed		Carbide Tools		Feed (ipr) Reamer Diameter (inches)					
Tool Material	Speed (fpm)	Tool Material	Speed (fpm)	1/8	1/4	1/2	1	1 ½	2
Annealed									
T15, M42	30	C2	75	.002	.005	.007	.010	.012	.014
Aged									
T15, M42	20	C2	50	.002	.004	.006	.008	.010	.012

Drilling

Tool Material	Speed (fpm)	High Speed Tools: Feed (inches per revolution) Nominal Hole Diameter (inches)							
		1/16	1/8	1/4	1/2	3/4	1	1 ½	2
Annealed									
T15, M42	25	-	.001	.003	.004	.005	.006	.007	.008
Aged									
T15, M42	20	-	.001	.002	.003	.004	.004	.005	.005

Die Threading

Tool Material	FPM for High Speed Tools: 7 or less, tpi	8 to 15, tpi	16 to 24, tpi	25 and up, tpi
Annealed				
M1, M2, M7, M10	5 – 20	9 – 25	10 – 30	15 – 40
Aged				
M1, M2, M7, M10	5 – 20	9 – 25	10 – 30	15 – 40

Milling, End-Peripheral

Depth of Cut (inches)	High Speed Tools						Carbide Tools					
	Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in)				Tool Material	Speed (fpm)	Feed (ipt) Cutter Diameter (in)			
			1/4	1/2	3/4	1-2			1/4	1/2	3/4	1-2
Annealed												
.050	T15	45	.0015	.003	.005	.006	C2	130	.0015	.003	.006	.008
Aged												
.050	T15	35	.001	.002	.003	.005	C2	110	.001	.002	.004	.006

Tapping

Tool Material	High Speed Tools: Speed (fpm)
Annealed	
M1, M7, M10 Nitrided	5-15
Aged	
M1, M7, M10 Nitrided	2-15

Broaching

Tool Material	High Speed Tools: Speed (fpm)	Chip Load (ipt)
Annealed		
T15, M42	5	.002
Aged		
T15, M42	5	.002

When using carbide tools, surface speed feet/minute (SFPM) can be increased between 2 and 3 times over the high-speed suggestions. Feeds can be increased between 50 and 100%.

Figures used for all metal removal operations covered are average. On certain work, the nature of the part may require adjustment of speeds and feeds. Each job has to be developed for best production results with optimum tool life. Speeds or feeds should be increased or decreased in small steps.

Weldability

Ti-3-8-6-4-4 can be welded in the ST condition using like-metal filler material. Inert gas shielding techniques must be employed to prevent oxygen pickup and embrittlement in the weld area. Gas tungsten arc welding is the most common welding process for Ti-3-8-6-4-4. Gas metal arc welding is used for thick sections. Plasma arc welding, spot welding, electron beam, laser beam, resistance welding, and diffusion welding are also applicable to Ti-3-8-6-4-4. Welding is not recommended for STA material because of the likelihood of a localized difference in mechanical properties.

Other Information

Wear Resistance

Ti-3-8-6-4-4 and its alloys have a tendency to gall and are not recommended for wear applications.

Descaling (Cleaning)

Following solution treatment in air, it is very important to completely remove not only the surface scale, but the underlying layer of brittle alpha case as well. Incomplete removal can result in failures in later stages of processing. Surface removal can be accomplished by mechanical methods such as grinding or machining, or by descaling (using molten salt or abrasive) followed by pickling in a nitric/hydroflouric acid mixture.

In beta alloys, alpha case tends to penetrate the grain boundaries beneath the surface. Thus, the actual depth may be greater than is readily apparent, and the effective thickness may not be uniform. In general, surface removal requirements for Ti-3-8-6-4-4 and other beta alloys are greater than for other Ti alloys.

Titanium and its alloys are also susceptible to hydrogen embrittlement. Ti-3-8-6-4-4, like beta alloys in general, is more prone to hydrogen pickup, but also more tolerant of higher hydrogen levels than alpha or alpha/beta alloys. Although allowable levels of hydrogen are higher than for other Ti alloys, hydrogen content should be minimized and care must be taken to prevent excessive hydrogen pickup during heat treating and pickling. Hydrogen content can also have a dramatic effect on the aging response of Ti-3-8-6-4-4 (see Mechanical Properties).

Aging treatments on finished parts can be safely performed in air without necessitating significant surface removal, as long as parts are thoroughly cleaned before heat treating. However, final solution treatments must be performed in a vacuum if machining or pickling is to be avoided.

The cleanliness of parts to be vacuum heat treated is of prime importance. Oils, fingerprints, or residues remaining on the surface can result in alpha case formation even in the vacuum atmosphere. In addition, chlorides found in some cleaning agents have been associated with elevated-temperature stress-corrosion cracking of some Ti alloys.

Parts to be vacuum heat treated should be processed as follows: thorough cleaning using a non-chlorinated solvent or aqueous cleaning solution, followed by rinsing with copious quantities of deionized or distilled (not regular tap) water to remove all traces of cleaning agent, and finally, drying. Following cleaning, parts must be handled with clean gloves to prevent recontamination of the surface.

Applicable Specifications

- AMS 4957 (Bar, Wire, Cold Drawn)
- AMS 4958 (Bar, Rod, STA)
- MIL-T 9046 (Sheet, Strip, Plate)
- MIL-T 9047 (Bars, Billets)

Forms Manufactured

*SMART Coil is a registered trademark of Dynamet Holdings, Inc. licensed to Dynamet Incorporated.

- Bar-Rounds
- Bar-Shapes
- Dynalube Coil
- Ingot
- Plate
- Sheet
- SMART Coil® Titanium Coil
- Weld Wire
- Wire
- Wire-Shapes

References

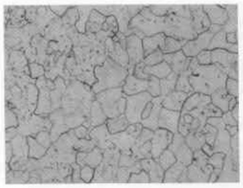
The information in this publication was compiled from a variety of sources, including the following:

Materials Properties Handbook: Titanium Alloys, ASM International, 1994
Aerospace Structural Metals Handbook, Volume 4, CINDAS/Purdue University, 1998
Titanium: a Technical Guide, ASM International, 1988
Metals Handbook, Desk Edition, ASM International, 1984
Specifications Book, International Titanium Association, 1999
Beta-C TM is a registered trademark of RMI Corporation, Niles, OH
Metcut Research Associates Inc. data
Handbook of Spring Design, Spring Manufacturers Institute, 1981
Beta Titanium Alloys in the 1980's, TMS/AIME, 1984
Boeing Company Design Manual BDM-1566
Dynamet technical publications and unpublished data

Ti-3-8-6-4-4 specimens can be prepared for metallographic examination by standard methods. Abrasive cutting, especially of small samples, is not recommended due to the tendency to "burn" the surface and produce alpha case. Kroll's reagent (1–3% hydroflouric acid plus 2–6% nitric acid in water) is commonly used for determination of general microstructure in ST and STA conditions. Etching the STA condition results in a dark stained surface, which can be removed by swabbing with a second etchant consisting of 1% hydroflouric acid, 4% nitric acid, 50% hydrogen peroxide and 45% water. Alpha case in Ti-3-8-6-4-4 affects surface grains and grain boundaries below the surface. In the STA condition it can be seen relatively easily. In the ST condition, alpha case can be difficult to detect.

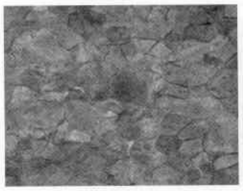
Microstructures of Ti-3-8-6-4-4 (approximate magnification 200X)

Ti-3-8-6-4-4 ST Condition

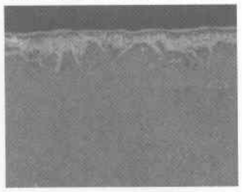


Ti-3-8-6-4-4 ST + Cold Worked

Ti-3-8-6-4-4 STA Condition



Ti-3-8-6-4-4 Alpha Case in STA Condition



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