ALLOY Data

CP Titanium Grade 4

Type Analysis

Carbon (Maximum)	0.08 %	**Titanium**	Balance
Nitrogen (Maximum)	0.05 %	**Iron (Maximum)**	0.50 %
Oxygen (Maximum)	0.400 %	**Hydrogen (Maximum)**	0.015 %
Other, Total (Maximum)	0.40 %		

ASTM B 348-99, "Other, Total" = 0.40% maximum and AMS 4921 rev. G = 0.3% maximum.

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).

Commercially pure, or CP, titanium is unalloyed. At service temperatures it consists of 100% hcp alpha phase. As a single-phase material, its properties are controlled by chemistry (iron and interstitial impurity elements) and grain size. CP Titanium is classified into Grades 1 through 4 depending on strength and allowable levels of the elements iron, carbon, nitrogen, and oxygen. CP Ti Grade 4 is the strongest of these grades, with a minimum yield strength of 480 MPa (70 ksi), and has the highest allowable oxygen and iron content of the grades.

Grade 4 combines the excellent resistance to corrosion and corrosion fatigue of titanium with high strength that makes it a candidate to compete with steels and nickel alloys for many chemical and marine applications.

Applications

CP Titanium Grade 4 could be considered in any application where strength and corrosion resistance are important. Grade 4 also has good ductility, is moderately formable, and has superior corrosion fatigue resistance in seawater. Applicable service temperatures for CP Ti Grade 4 are up to 204ºC (400ºF).

Some applications have included airframe and aircraft engine components, marine and chemical processing machinery, heat exchangers, reaction vessels for chemical processing and desalinization plants, corrosive waste disposal wells, and pulp and paper production.

Corrosion Resistance

The corrosion resistance of CP Ti Grade 4 is based on the presence of a stable, continuous, tightly adherent oxide layer which forms spontaneously upon exposure to oxygen. If damaged, it re-forms readily as long as there is some source of oxygen (air or moisture) in the environment. CP Ti Grade 4 has outstanding resistance to corrosion fatigue in marine environments. In seawater, it is fully resistant to corrosion at temperatures up to 315ºC (600ºF). The possibility of crevice corrosion must be considered, however, and components appropriately designed to avoid tight crevices.

CP Ti Grade 4 is highly resistant to many chemical environments including oxidizing media, alkaline media, organic compounds and acids, aqueous salt solutions, and wet or dry hot gases. It also has sufficient corrosion resistance in liquid metals, nitric acid, mildly reducing acids, and wet chlorine or bromine gas (as long as a minimal amount of oxygen or water is present).

Conditions under which CP Ti Grade 4 is susceptible to corrosion are strongly reducing acids, alkaline peroxide solutions, and molten chloride salts. Crevice corrosion can occur in hot halide or sulfate solutions (>1000ppm at 75ºC or higher), which is a consideration in marine applications.

CP Ti Grade 4 is resistant to stress-corrosion cracking (SCC) in aqueous solutions, and is largely resistant to SCC in general. Conditions under which CP Ti Grade 4 is susceptible to SCC include anhydrous methanol, methanol/halide solutions, nitrogen tetroxide, and in contact with liquid or solid cadmium or liquid mercury.

CP Grade 4 titanium is susceptible to hydrogen embrittlement due to the formation of hydrides. Specifications for CP Ti Grade 4 mill products typically specify a maximum hydrogen limit of 150 ppm, but it is possible for degradation to occur at lower levels, especially in the presence of a notch. The presence of a notch or other stress raiser increases the detrimental effect, as hydrogen migrates to the notch area, raising the local concentration of hydrides. It is important to minimize hydrogen pickup during processing, particularly heat treating and acid pickling.

Important Note: *The following 5-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.*

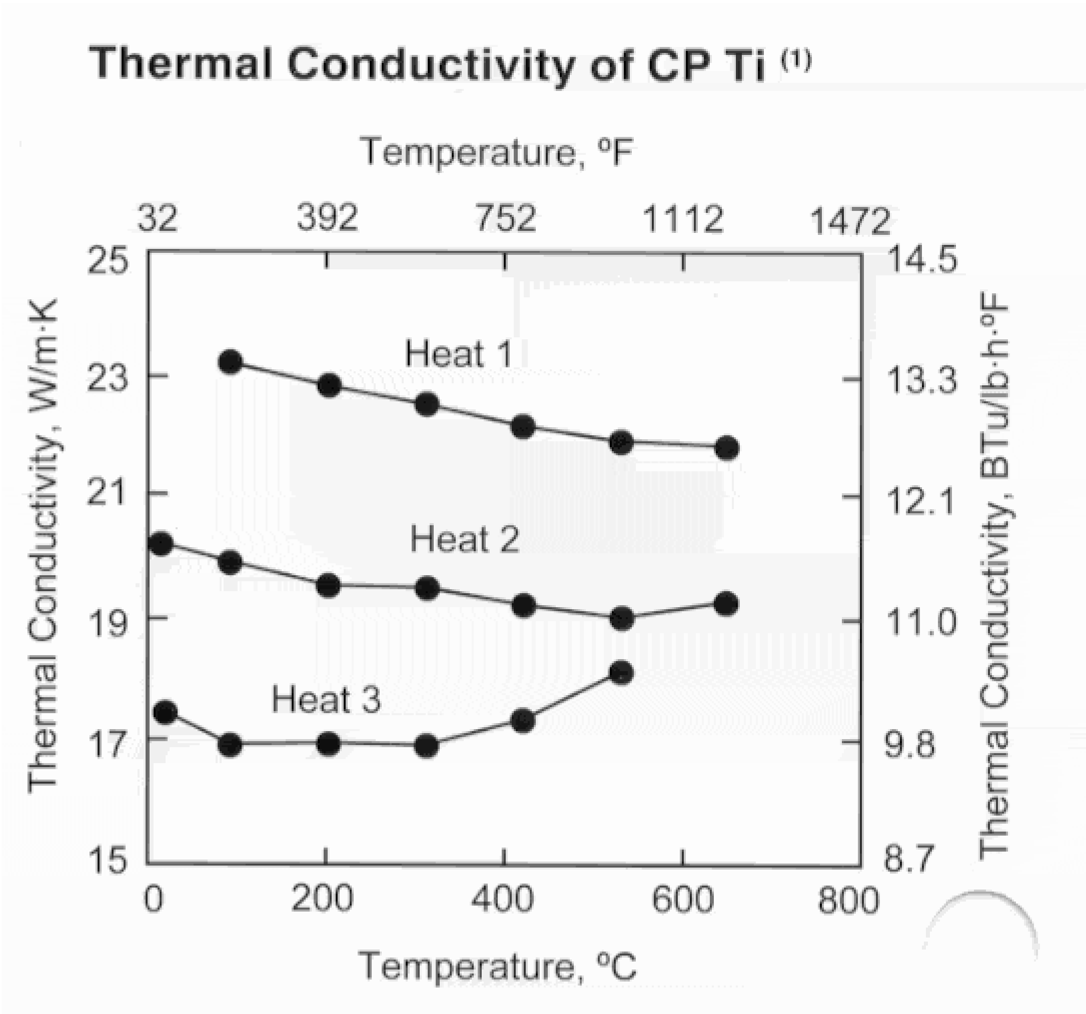
Sulfuric Acid	Moderate	Acetic Acid	Excellent
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Excellent
Sea Water	Excellent	Humidity	Excellent

CP Ti Grade 4: General Corrosion Rates in Various Media

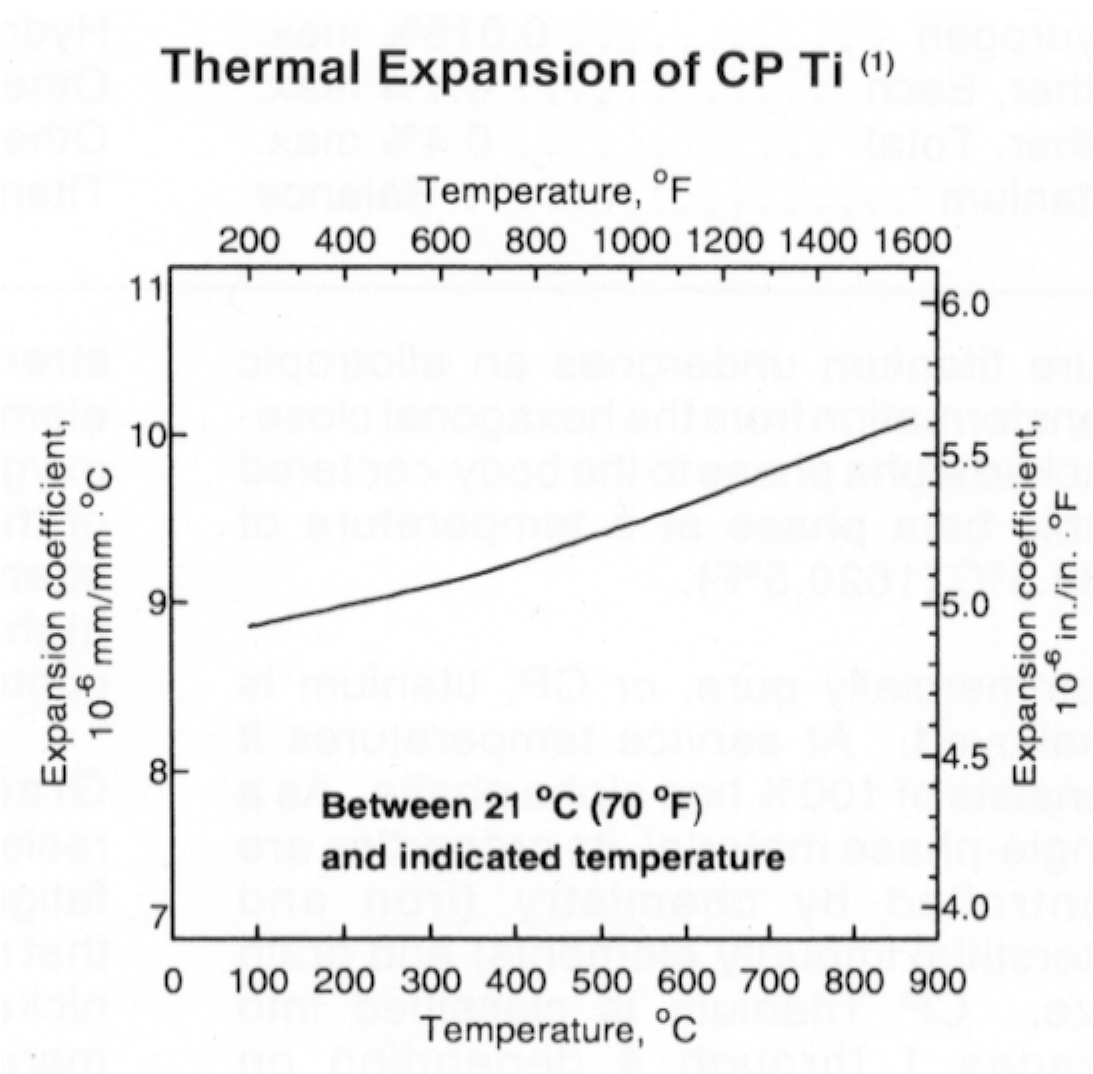
Medium	Concentration %	Temperature		Corrosion Rate	
		ºC	ºF	mm/yr	mils/yr
Nitric Acid	35	boiling		0.127-0.508	5-20
Nitric Acid + 0.01% $K_2Cr_2O_7$	40	boiling		0.01	0.39
Ammonium Hydroxide	28	100	212	nil	
Stearic Acid	100	180	355	0.003	0.12
Adipic Acid	67	240	464	nil	
Bismuth/lead	molten	300	570	good resistance	
Bromine, moist	vapor	30	86	<0.003	0.12
Hydrogen Peroxide pH 4.3	5	66	150	0.061	2.4
H_2O_2 + 20 g/l NaOH	10g/l	60	140	55.9	2200

Properties

Physical Properties	
Density	
--	0.1630 lb/in³
Mean Specific Heat	
73 °F	0.1250 Btu/lb/°F



Modulus of Elasticity (E)	
--	15.0 x 10^3 ksi
Beta Transus	
--	1715 to 1765 °F
Alpha Transus	
--	1635 to 1685 °F
Liquidus Temperature	
--	3000 to 3040 °F
Electrical Resistivity	
73.4 °F	60.00 ohm-cir-mil/ft



Magnetic Properties

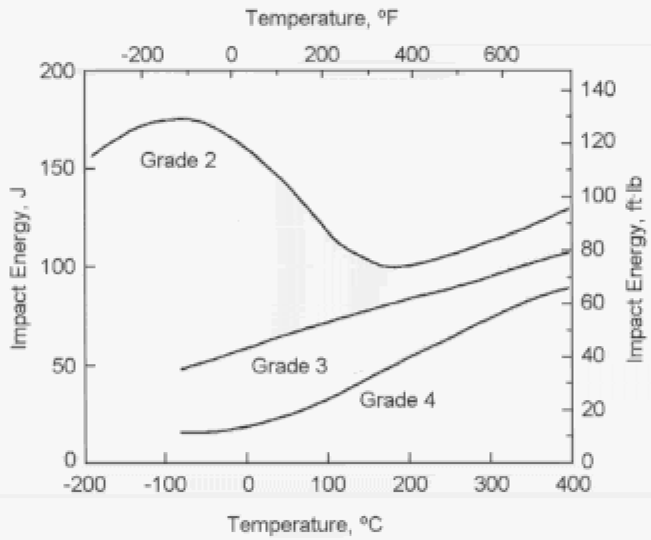
Magnetic Attraction

- None

Typical Mechanical Properties

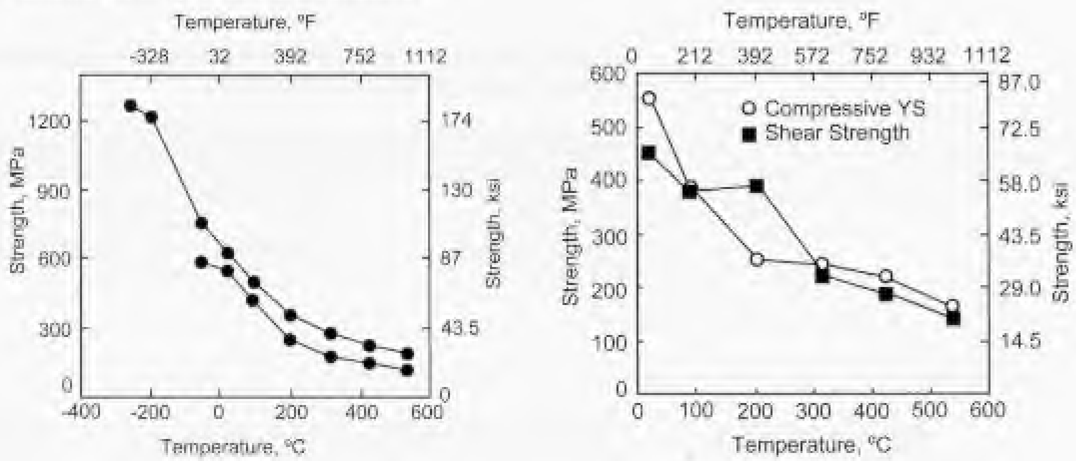
CP Ti Grade 4 has the highest strength of the CP grades, making it competitive with stainless steels for many corrosion resistant applications. Its strength is on a par with annealed stainless steels, and, in addition, it offers lighter weight and superior corrosion resistance. CP Grade 4 titanium is not subject to grain boundary embrittlement or sensitization at elevated temperatures. Specific strength (strength/density) provides a way to compare materials based on a combination of strength and weight.

CP Ti: Charpy V-Notch Impact Toughness vs. Temperature [1]



Elevated Temperature Mechanical Properties for CP Ti Grade 4

Tensile Strength vs. Temperature [1]



Fatigue Limits

Approximate Fatigue Limit Ranges for CP Ti Grade 4 (Rotating-Beam Fatigue)
Smooth . . . . 340-420 MPa (50-60 ksi)
Notched (K = 2.7) . . . . 250 MPa (35 ksi)

Room Temperature Mechanical Properties of CP Ti Grade 4

	UTS min	*YS min*	*%El*	*%RA*
Specified Properties	*550 MPa (80 ksi)*	*480 MPa (70 ksi)*	*15*	*30*
Typical Properties	*655–690 MPa (95–100 ksi)*	*480–635 MPa (70–92 ksi)*	*20–25*	*38–51*

Material	UTS		YS		%El	Specific Strength		Specific Yield Str.	
	MPa	ksi	MPa	ksi		m x 10^2	in x 10^3	m x 10^2	in x 10^3
CP Ti 4 min.	550	80	480	70	15	125	491	109	429
Cp Ti 4 typ.	670	97	550	80	22	152	595	125	491
316 SS min.	550	80	240	35	30	70	276	31	121
430 SS min.	450	65	205	30	22	59	232	27	107
403 SS min.	485	70	205	30	25	64	250	27	107

Typical Room-Temperature Strengths for Annealed CP Ti Grade 4

Ultimate Bearing Strength .... 825 MPa (120 ksi)
Compressive Yield Strength .... 480 MPa (70 ksi)
Ultimate Shear Strength .... 290 MPa (42 ksi)

Toughness

CP Ti is very ductile and tough. Because of its high toughness and low strength, standard plane-strain fracture toughness testing (K 1c) is impractical for CP Ti. Notched impact (Charpy) testing is generally used to evaluate toughness.

Heat Treatment

Heat treatments used for CP Ti are annealing and stress relieving. Annealing is used to fully soften the material and remove all residual stresses. Annealing of wrought products at typical temperatures (below the beta transus) results in a fully recrystallized equiaxed alpha structure. Precise control of grain size (and mechanical properties) can be achieved by adjusting the anneal temperature.

Stress relieving is used to remove some or most of the residual stresses from forming, or to recover compressive yield strength after stretching.

Titanium and its alloys have a high affinity for gases including oxygen, nitrogen and hydrogen. When CP Ti is heated in air, oxygen absorption results in the formation of an extremely hard, brittle oxygen-stablized alpha phase layer known as alpha case.

Intermediate and final annealing of CP Ti 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 pickup, a process known as vacuum degassing. Parts to be vacuum heat treated must be thoroughly cleaned (see Cleaning Notes).

Typical Heat Treatments for CP Ti Grade 4

Anneal	595-760ºC (1100-1400ºF) 2 hrs—air cool (or equivalent)
Stress Relief	540-595ºC (1000-1100ºF) 15-30 min.—air cool (or equivalent)

Workability

Hot Working

CP Ti Grade 4 can be processed by conventional techniques such as hot rolling, forging, and hot pressing. Temperatures for initial roughing may be as high as 30-50ºC (50-100ºF) above the beta transus, and temperatures for finish processing are typically in the alpha/beta phase field, ranging from about 815ºC (1500ºF) to about 900ºC (1650ºF).

CP Ti Grade 4 can be formed into finished parts by standard methods such as forging, spin forming, hydroforming, and hot pressing. Typically, more severe forming is done in the temperature range of 480-540ºC (900-1000ºF) and milder forming from 200-315ºC (400-600ºF). Care must be taken to prevent the formation of excessive alpha case, and alpha case must be removed after processing.

Cold Working

CP Ti Grade 4 has relatively good ductility and can be formed at room temperature, although cold forming deformation must be less severe than for the lower-strength grades. Standard methods, including bending, stretch forming, heading, stamping, and drawing, are applicable to CP Ti Grade 4. CP Ti work hardens fairly rapidly, which is a limitation in some operations, such as cold drawing. The Bauschinger effect results in a drop of up to 25% in compressive yield strength upon stretching at room temperature; this drop can be recovered by stress relieving. Due to the low modulus of titanium, springback allowances are significant. Hot sizing after cold forming is often used to correct for variations in springback.

Machinability

The machining characteristics of CP Ti Grade 4 are similar to those of austenitic stainless steels. In general, low cutting speeds, heavy feed rates, and copious amounts of cutting fluid are recommended. 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 workpiece 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 CP Ti Grade 4.

Typical Machining Speeds and Feeds – Titanium Alloy CP Titanium Grade 4
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) Uncoated	Speed (fpm) Coated	Feed (ipr)
.150 .025	T15, M42	105 115	.010 .005	C2 C3	250 290	320 370	.008 .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	Carbide Tools		1/16	1/8	1/4	1/2	1	1 ½	2
T15, M42		80	.001	.0015	.002	.0025	.0015	.001	.001
	C2	185	.001	.0015	.002	.0025	.0015	.001	.001

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
M1, M2, M7	120	C2	300	.004	.008	.012	.018	.022	.025

Drilling

High Speed Tools									
Tool Material	Speed (fpm)	Feed (inches per revolution) Nominal Hole Diameter (inches)							
		1/16	1/8	1/4	1/2	3/4	1	1 ½	2
M10, M7, M1	40-55	.001	.002	.005	.008	.010	.012	.025	.017

Die Threading

FPM for High Speed Tools				
Tool Material	7 or less, tpi	8 to 15, tpi	16 to 24, tpi	25 and up, tpi
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
.050	M2,M3 M7	130	.002	.003	.005	.006	C2	323	.002	.003	.006	.008

Tapping

High Speed Tools	
Tool Material	Speed (fpm)
M1, M7, M10 Nitrited	12-40

Broaching

High Speed Tools		
Tool Material	Speed (fpm)	Chip Load (ipt)
M2, M7	25	.003

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.

Typical Minimum Stock Removal Requirements for Ti and Ti Alloys (after Thermal Exposure in Air)

Heat Treatment	Thermal Cycle	Removal Required
Anneal	705ºC (1300ºF) 2 hrs.	0.020 mm (0.0008 in.)
Stress Relief	540-595ºC (1000-1100ºF) 30 min	0.005 mm (0.0002 in.)

Weldability

CP Ti Grade 4 can be welded using CP Ti filler metal. 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 CP Ti. Gas metal arc welding is used for thick sections. Plasma arc welding, spot welding, electron beam, laser beam, resistance welding and diffusion welding have all been used successfully in CP Ti welding applications.

Other Information

Wear Resistance

Commercially pure Ti and its alloys have a tendency to gall and are not recommended for wear applications.

Descaling (Cleaning)

Following heat treatment in air, it is extremely important to completely remove not only the surface scale, but the underlying layer of brittle alpha case as well. This 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.

Titanium is also susceptible to hydrogen embrittlement, and care must be taken to avoid excessive hydrogen pickup during heat treating and pickling/ chemical milling.

Final heat treatments on finished parts must be performed in 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 SCC of titanium 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 4901 (Sheet, Strip, Plate)
- AMS 4921 (Bar, Wire, Forgings, Billet)
- ASTM B 381 (Forgings)
- ASTM B265 (Sheet, Strip, Plate)
- ASTM B348 (Bar, Billet)
- ASTM B367 (Castings)
- ASTM F 1341 (Wire)
- ASTM F 67 (Sheet, Strip, Bar)
- ISO 5832-2
- 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
Metcut Research Associates Inc. data
Dynamet technical papers and unpublished data

CP Ti Grade 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. Alpha case in CP Ti cannot be reliably detected by metallography; its presence must be determined by microhardness testing. A typical microstructure is illustrated below.

Microstructure of CP Ti Grade 4, Annealed Condition
(approximate magnification 200X)

Disclaimer:
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