CARPENTER TECHNOLOGY

DATASHEET

CP TI, GRADE 4

Applicable specifications: AMS 4901 (Sheet, Strip, Plate), AMS 4921 (Bar, Wire, Forgings, Billet), ASTM B265 (Sheet, Strip, Plate), ASTM B348 (Bar, Billet) , ASTM B367 (Castings),ASTM B381 (Forgings), ASTM F67 (Sheet, Strip, Bar), ASTM F1341 (Wire), ISO 5832-2, MIL-T-9047 (Bars, Billets)

Associated designations: UNS R50700

Type analysis

Single figures are nominal except where noted.

Titanium	Balance	**Iron**	Max 0.50 %	**Oxygen**	Max 0.40 %
Carbon	Max 0.08 %	**Nitrogen**	Max 0.05 %	**Hydrogen**	Max 0.015 %
Other, Total	Max 0.40 %				

ASTM B348-99, "Other, Total" = 0.40% maximum and AMS 4921 rev. G = 0.3% maximum.

Forms manufactured

Bar-Rounds	**Bar-Shapes**	**Dynalube Coil**	**Ingot**	**Plate**
SMART Coil® Titanium Coil*	**ULTRABAR® Precision Bar**	**Weld Wire**	**Wire**	**Wire-Shapes**

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

Description

Pure titanium undergoes an allotropic transformation from the hexagonal close-packed (hcp) alpha phase to the body-centered cubic beta phase at a temperature of 882.5°C (1620.5°F). Commercially pure (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, 2, 3, or 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. With strain hardening (cold work), the strength can be dramatically increased.** Grade 4 combines excellent corrosion resistance, corrosion fatigue performance, and high strength, making it a candidate for many chemical and marine applications.

Key Properties:

- Strongest grade of commercially pure titanium
- Excellent corrosion and corrosion fatigue resistance
- Good ductility and moderate formability
- Applicable service temperatures up to 204°C (400°F)
- Can be cold worked to attain strengths of >950 MPa

Markets:

- Aerospace
- Consumer
- Defense
- Industrial
- Medical
- Transportation

Applications:

- Dental, medical, and orthopedic implants
- Airframe and aircraft engine components
- Chemical processing machinery and reaction vessels

> CP TI, GRADE 4

Corrosion resistance

The corrosion resistance of CP Ti Grade 4 is based on the presence of a stable, continuous, tightly adherent oxide layer that forms spontaneously upon exposure to oxygen. If damaged, it reforms 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 315°C (600°F). 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 (>1000 ppm at 75°C 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 Ti Grade 4 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.

> CP TI, GRADE 4

Corrosion resistance

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	**Humidity**	Excellent

GENERAL CORROSION RATES IN VARIOUS MEDIA

MEDIUM	CONCENTRATION	TEMPERATURE		CORROSION RATE	
	%	°F	°C	mm/yr	mils/yr
Nitric acid	35	Boiling	Boiling	0.127–0.508	5–20
Atric acid + 0.01% $K_2Cr_2O_7$	40	Boiling	Boiling	0.01	0.39
Ammonium hydroxide	28	212	100	—	—
Stearic acid	100	355	180	0.003	0.12
Adipic acid	67	464	240	—	—
Bismuth/lead	Molten	570	300	Good resistance	Good resistance
Bromine, moist	Vapor	86	30	<0.003	0.12
Hydrogen peroxide pH 4.3	5	150	66	0.061	2.4
H_2O_2 + 20 g/l NaOH	10 g/l	140	60	55.9	2200

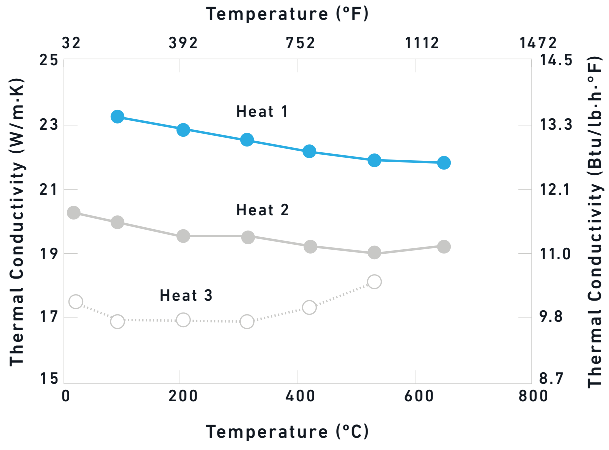
info@cartech.com | 610 208 2000

> CP TI, GRADE 4

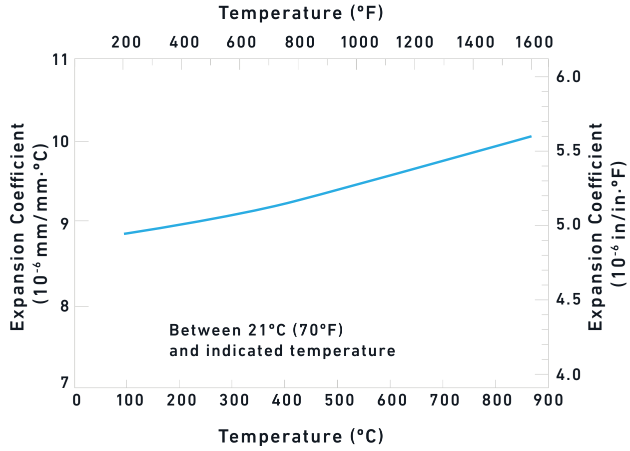
Physical properties

PROPERTY	Condition / At or From	English Units	Metric Units
DENSITY	—	0.1630 lb/in^3	kg/m^3
MEAN SPECIFIC HEAT (73°F)	—	0.1250 Btu/lb/°F	J/kg·K
MODULUS OF ELASTICITY (E)	—	15.0 x 10^3 ksi	—
BETA TRANSUS	1715 to 1765°F	—	°C
ALPHA TRANSUS	1635 to 1685°F	—	°C
LIQUIDUS TEMPERATURE	3000 to 3040°F	—	°C
ELECTRICAL RESISTIVITY (73°F)	—	60.00 ohm-cir-mil/ft	microohm·cm

THERMAL CONDUCTIVITY OF CP TI



THERMAL EXPANSION OF CP TI



> CP TI, GRADE 4

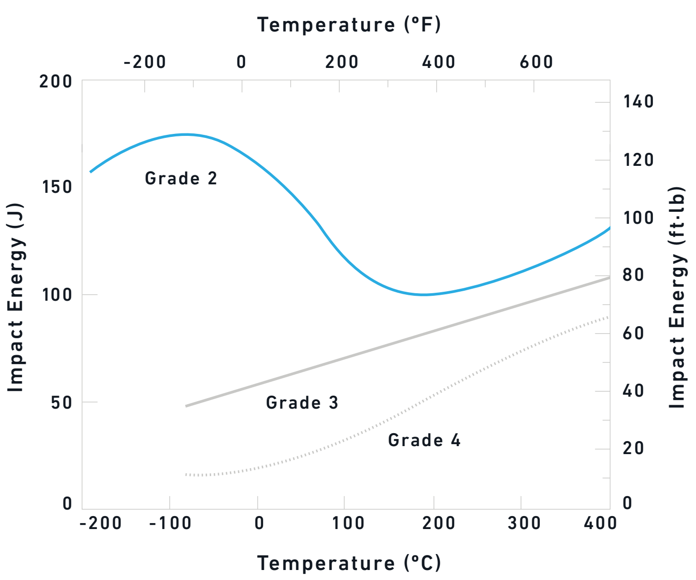
Magnetic properties

CP Ti, Grade 4 exhibits no magnetic attraction.

Typical mechanical properties

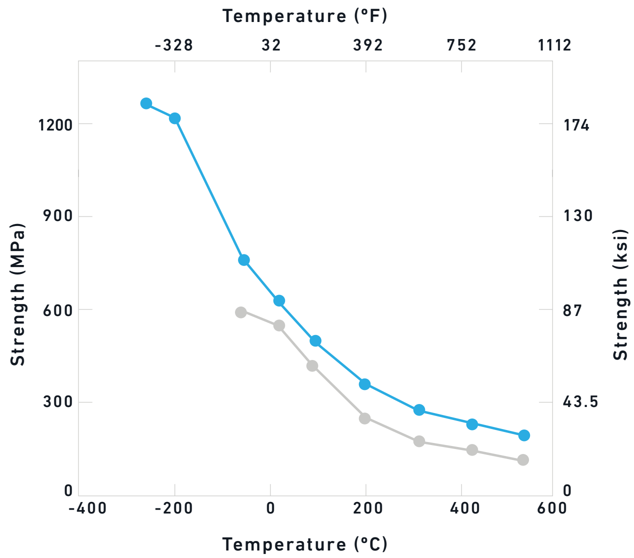
CP Ti, Grade 4 has the highest strength of the CP grades, making it competitive with stainless steels for many corrosion-resistant applications. Its strength is on a par with annealed stainless steels, and, in addition, it offers lighter weight and superior corrosion resistance. CP Grade 4 titanium is 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.

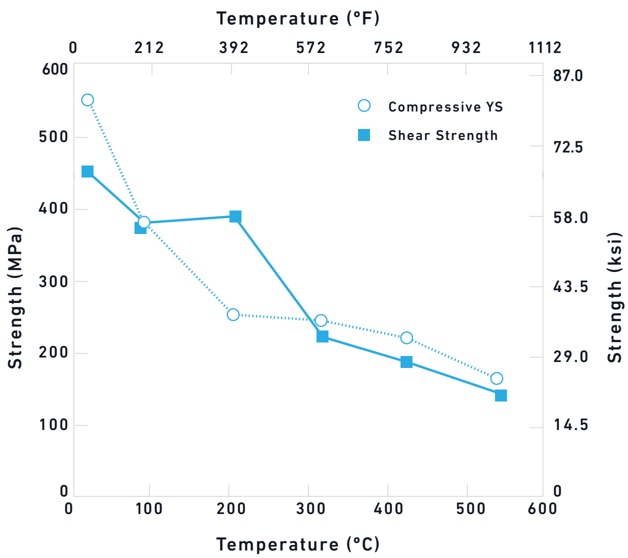
CHARPY V-NOTCH IMPACT TOUGHNESS VS. TEMPERATURE



> CP TI, GRADE 4

ELEVATED TEMPERATURE MECHANICAL PROPERTIES—TENSILE STRENGTH VS. TEMPERATURE





APPROXIMATE FATIGUE LIMIT RANGES (ROTATING-BEAM FATIGUE)	ksi	MPa
Smooth	50–60	340–420
Notched (K=2.7)	35	250

ROOM TEMPERATURE MECHANICAL PROPERTIES	YIELD STRENGTH (MIN)		ULTIMATE TENSILE STRENGTH (MIN)		ELONGATION	REDUCTION OF AREA
	ksi	MPa	ksi	MPa	%	%
Specified properties	70	480	80	550	15	30
Typical properties	70–92	480–635	95–100	655–690	20–25	38–51
High strength, custom	—	—	>137	>950	>15	—

> CP TI, GRADE 4

ROOM TEMPERATURE MECHANICAL PROPERTIES										
MATERIAL	**YIELD STRENGTH (MIN)**		**ULTIMATE TENSILE STRENGTH (MIN)**		**ELONGATION**	**SPECIFIC STRENGTH**		**SPECIFIC YIELD STRENGTH**	
	ksi	**MPa**	**ksi**	**MPa**	**%**	**in x 10²**	**m x 10³**	**in x 10²**	**m x 10³**
CP Ti 4 min.	70	480	80	550	15	491	125	429	109
CP Ti 4 typ.	80	550	97	670	22	595	152	491	125
316 min.	35	240	80	550	30	276	70	121	31
430 min.	30	205	65	450	22	232	59	107	27
403 min.	30	205	70	485	25	250	64	107	27

TYPICAL ROOM-TEMPERATURE STRENGTHS, ANNEALED CONDITION		
	ksi	**MPa**
Ultimate bearing strength	120	825
Compressive yield strength	70	480
Ultimate shear strength	42	290

TOUGHNESS

CP Ti is very ductile and tough. Because of its high toughness and low strength, standard plane-strain fracture toughness testing (K1c) is impractical for CP Ti. Notched impact (Charpy) testing is generally used to evaluate toughness.

> CP TI, GRADE 4

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-stabilized 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	
Anneal	1100–1400°F (595–760°C) 2 hours, air cool (or equivalent).
Stress relief	1000–1100°F (540–595°C) 15-30 minutes, air cool (or equivalent).

> CP TI, GRADE 4

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 30–50°C (50–100°F) above the beta transus, and temperatures for finish processing are typically in the alpha/beta phase field, ranging from about 815°C (1500°F) to about 900°C (1650°F). 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 480–540°C (900–1000°F) and milder forming from 200–315°C (400–600°F). 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.
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.

> CP TI, GRADE 4

Typical machining speeds and feeds

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, IN	HIGH-SPEED TOOLS			CARBIDE TOOLS			
	SPEED, FPM	FEED, IPR	TOOL MATERIAL	SPEED, FPM		FEED, IPR	TOOL MATERIAL
				UNCOATED	COATED		
.150	105	.010	M-42, T-15	250	320	.008	C-2
.025	115	.005	—	290	370	.005	C-3

TURNING — CUT-OFF AND FORM TOOLS

SPEED, FPM	FEED, IPR							TOOL MATERIAL	
	CUT-OFF TOOL WIDTH, IN			FORM TOOL WIDTH, IN				HIGH-SPEED TOOLS	CARBIDE TOOLS
	1/16	*1/8*	*1/4*	*1/2*	*1*	*1-1/2*	*2*		
80	.001	.0015	.002	.0025	.0015	.001	.001	M-42, T-15	—
185	.001	.0015	.002	.0025	.0015	.001	.001	—	C-2

ROUGH REAMING

HIGH-SPEED TOOLS		CARBIDE TOOLS		FEED, IPR, REAMER DIAMETER, IN					
SPEED, FPM	TOOL MATERIAL	SPEED, FPM	TOOL MATERIAL	*1/8*	*1/4*	*1/2*	*1*	*1-1/2*	*2*
120	M-1, M-2, M-7	300	C-2	.004	.008	.012	.018	.022	.025

DRILLING — HIGH-SPEED TOOLS

SPEED, FPM	FEED, IPR								TOOL MATERIAL
	NOMINAL HOLE DIAMETER, IN								
	1/16	*1/8*	*1/4*	*1/2*	*3/4*	*1*	*1-1/2*	*2*	
40–55	.001	.002	.005	.008	.010	.012	.025	.017	M-1, M-7, M-10

DIE THREADING

SPEED, FPM				TOOL MATERIAL
7 OR LESS	8 TO 15	16 TO 24	25 AND UP, TPI	
5–20	9–25	10–30	15–40	M-1, M-2, M-7, M-10

> CP TI, GRADE 4

MILLING — END PERIPHERAL

DEPTH OF CUT, IN	HIGH-SPEED TOOLS						CARBIDE TOOLS					
	SPEED, FPM	FEED, IN PER TOOTH – CUTTER DIAMETER, IN				TOOL MATERIAL	SPEED, FPM	FEED, IN PER TOOTH – CUTTER DIAMETER, IN				TOOL MATERIAL
		1/4	1/2	3/4	1-2			1/4	1/2	3/4	1-2	
.050	130	.002	.003	.005	.006	M-2, M-3, M-7	323	.002	.003	.006	.008	C-2

TAPPING

SPEED, FPM	TOOL MATERIAL
12–40	M-1, M-7, M-10 Nitrated

BROACHING — HIGH-SPEED TOOLS

SPEED, FPM	CHIP LOAD, IPT	TOOL MATERIAL
25	.003	M-2, M-7

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 FOR TI AND TI ALLOYS (AFTER THERMAL EXPOSURE IN AIR)

HEAT TREATMENT	THERMAL CYCLE		REMOVAL REQUIRED	
	°F	°C	IN	MM
Anneal	1300	705	.0008	.020
Stress relief	1000–1100	540–595	.0002	.005

info@cartech.com | 610 208 2000

> CP TI, GRADE 4

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.

For additional information, please contact your nearest sales office:
info@cartech.com | 610 208 2000