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TITAN GRADE 5 AERO

Distinctive feature and main attributes

Pure titanium undergoes an allotropic transformation from the hexagonal close-packed alpha phase to the body-centered cubic beta phase at a temperature of 882.5°C (1'620.5°F). 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 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.

TITAN GRADE 5 Aero, as an α+β titanium alloy, is among the most widely used titanium materials and accounts for more than 50% of total titanium consumption. The alloy is heat treatable and allows moderate increases in strength.

TITAN GRADE 5 Aero is recommended for use at service temperatures up to approximately 350°C (660°F).

TITAN GRADE 5 Aero offers a combination of high strength, light weight, formability and corrosion resistance which have made it a world standard in aerospace applications.

Use and application range

TITAN GRADE 5 Aero may be considered in any application where a combination of high strength at low to moderate temperatures, light weight and excellent corrosion resistance are required.

Some of the many applications where this alloy has been used include aircraft turbine engine components, aircraft structural components, aerospace fasteners, high-performance automotive parts, marine applications, medical devices, and sports equipment.

Chemical composition (% wt)

C	Al	N	O	Ti
max. 0.10	5.50 – 6.75	0.05	max. 0.020	balance

V	Fe	H	Others
3.50 – 4.50	max. 0.40	max. 0.015	max. 0.40

Single figures are nominal except where noted.

*Other, Each (Maximum) = 0.1 %

**For AMS 4928 (Bar, Billet, Forgings) Hydrogen = 0.0125 % and Iron = 0.3 %

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TITAN GRADE 5 AERO

Corrosion resistance

TITAN GRADE 5 Aero immediately and spontaneously forms a stable, continuous, tightly adherent oxide film upon exposure to oxygen in air or water. This accounts for its excellent corrosion resistance in a variety of media. TITAN GRADE 5 Aero is highly resistant to general corrosion in aqueous solutions including seawater, as well as in oxidizing acids, chlorides (in the presence of water), rocket propellants and alkalis. Conditions under which TITAN GRADE 5 Aero is susceptible to general corrosion are in the presence of reducing acids or dry chlorine gas.

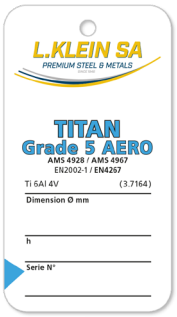
Stresscorrosion cracking (SCC) and crevice corrosion have been shown to occur in environments containing chlorides or other halide ions. For this reason, it is general practice to avoid the use of chlorinated solvents, cutting fluids, etc. in processing titanium.

Titanium and its alloys, including TITAN GRADE 5 Aero, are susceptible to hydrogen embrittlement. Gaseous or cathodic hydrogen can diffuse into the metal, forming brittle hydrides. Thus, it is important to minimize hydrogen pickup during processing, particularly heat treating and acid pickling. Specifications for TITAN GRADE 5 Aero mill products typically specify a maximum hydrogen limit of about 150 ppm.

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.

Type of corrosion	*Corrosion resistance*
Sulfuric Acid	Moderate
Sodium Hydroxide	Moderate
Seawater	Excellent
Acetic Acid	Excellent
Salt Spray (NaCl)	Excellent
Humidity	Excellent

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TITAN GRADE 5 AERO

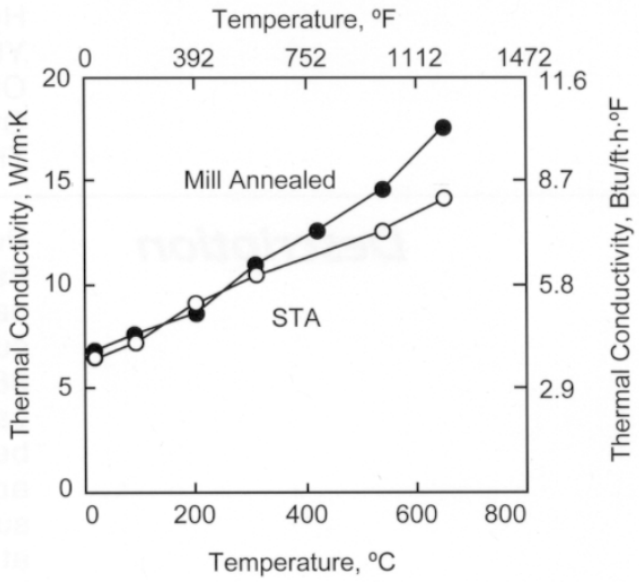
General Corrosion Rates in Various Media

Medium	Concentration %	Temperature		Corrosion Rate	
		°C	°F	mm/yr	mils/yr
Seawater	n/a	room	room	nil	nil
Hydrochloric Acid	2	37.8	100	nil – 0.030	nil – 1.2
Hydrochloric Acid	10	37.8	100	0.508 – 1.02	20.0 – 40.0
Hydrochloric Acid + 5% CrO_3	10	65.6	150	nil – 0.005	nil – 0.2
Hydrochloric Acid vapors	vapors	37.8	100	8.33 – 1.04	328 – 408
Nitric Acid	65	boiling	boiling	0.076 – 0.13	3.0 – 5.0
Sulfuric Acid	2	37.8	100	0.396 – 0.549	15.6 – 21.6
Sodium Hydroxide	25	boiling	boiling	0.046 – 0.051	1.8 – 2.0

Physical Properties

Specific Gravity: 0.160

Thermal Conductivity



Modulus of Elasticity (E)	15.2 × 10^3 ksi
Beta Transus	1'800 – 1'850 °F
Liquidus Temperature	2'976 – 3'046 °F
Solidus Temperature	2'900 – 2'940 °F

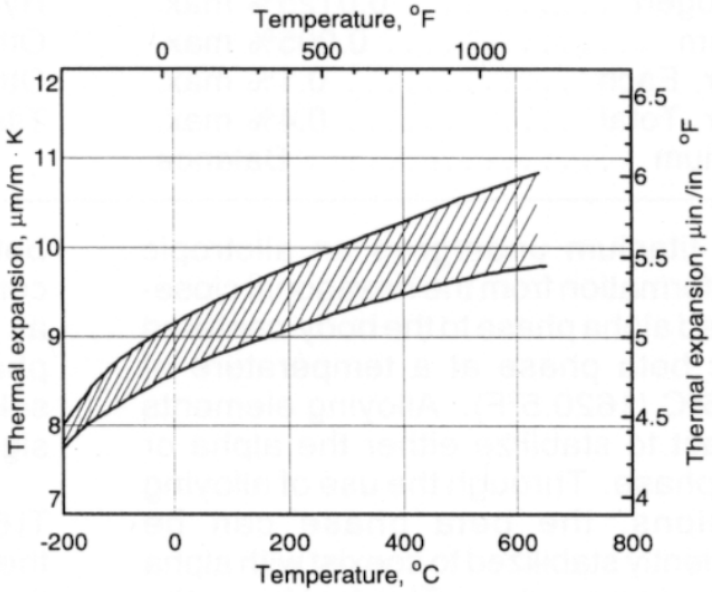
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TITAN GRADE 5 AERO

Electrical Resistivity	
–418°F	902.5 ohm-cir-mil/ft
73°F	1053 ohm-cir-mil/ft
986°F	1143 ohm-cir-mil/ft

Thermal Expansion



Magnetism Magnetic Attraction: None

Typical Mechanical Properties

Typical Room-Temperature Strengths for Annealed TITAN GRADE 5 Aero:

- Ultimate Bearing Strength: 1'380 – 2'070 MPa (200 – 300 ksi)
- Compressive Yield Strength: 825 – 895 MPa (120 – 130 ksi)
- Ultimate Shear Strength: 480 – 690 MPa (70 – 100 ksi)

Fatigue Limits:

High-cycle fatigue limits for TITAN GRADE 5 Aero are greatly influenced by both microstructure and surface conditions. Some generalize fatigue limits for annealed wrought material are provided below.

- Fatigue Limit Ranges for TITAN GRADE 5 Aero (Axial Fatigue, R = 0.06 – 0.1)
- Smooth 400 – 700 MPa (60 – 100 ksi)
- Notched (KT = 3) 140 – 270 MPa (20 – 40 ksi)

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TITAN GRADE 5 AERO

Fracture Toughness:
The fracture toughness (KIc) of TITAN GRADE 5 Aero lies between that of aluminum alloys and steels. Microstructures that tend to have higher toughness are those with greater amounts of lamellar alpha/beta and coarser structures in general. The ELI grade of TITAN GRADE 5 Aero exhibits toughness superior to the standard grade.

Room Temperature Mechanical Properties

Minimum Specified Tensile Properties

Condition	*UTS*	*YS*	*%El*	*%RA*
Annealed	896 MPa (130 ksi)	827 MPa (120 ksi)	10	25
STA (depending on diameter)	1'035 – 1'135 MPa (150 – 165 ksi)	965 – 070 MPa (140 – 155 ksi)	10	20

Typical Tensile Properties

Condition	*UTS*	*YS*	*%El*	*%RA*
Annealed	965 – 1'090 MPa (140 – 158 ksi)	875 – 995 MPa (127 – 144 ksi)	16	46
STA (depending on diameter)	1'100 – 1'220 MPa (160 – 177 ksi)	1'035 – 1'130 MPa (150 – 164 ksi)	15	52

One reason that TITAN GRADE 5 Aero has found such widespread use is its relatively high strength for a lightweight material.

Specific strength (strength/density) provides a means to compare materials on this basis.

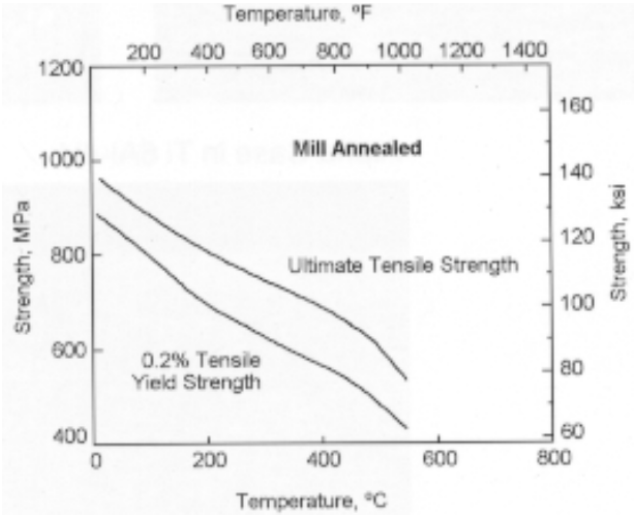
Material	*UTS (MPa)*	*UTS (ksi)*	*Specific Strength ($m \times 10^3$)*	*Specific Strength ($in \times 10^6$)*
TITAN GRADE 5 Aero STA	1'172	170	27.0	1'063
TITAN GRADE 5 Aero Annealed	924	134	21.3	838
4130 Steel	1'379	200	17.9	707
7075-T6 Aluminum	538	78	19.6	772
2024 T3 Aluminum	441	64	16.1	634
Inconel 718	1'276	185	15.3	603

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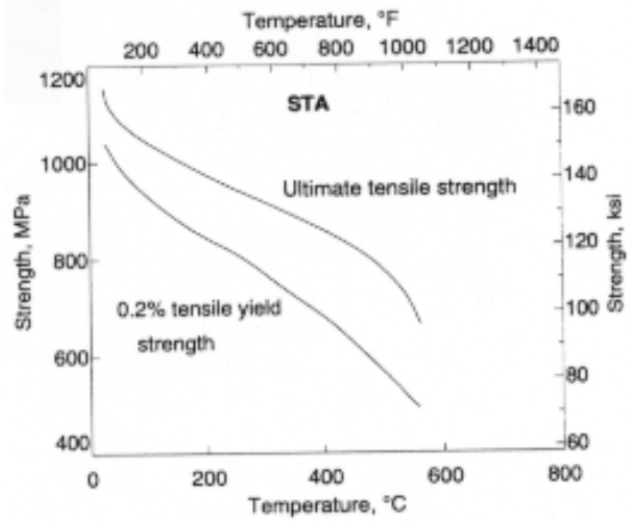


TITAN GRADE 5 AERO

Tensile Strengths - Mill Annealed



Tensile Strengths - STA



Heat Treatment

TITAN GRADE 5 Aero wrought products are typically used in either a mill annealed or solution treated and aged condition. Rapid quenching following solution treatment (water quench or equivalent) is important in order to maximize the formation of alpha' martensite phase, which in turn maximizes the aging response. Other heat treatments used on TITAN GRADE 5 Aero include stress relieving for formed or welded parts, and beta annealing, which is used for improving damage tolerance.

TITAN GRADE 5 Aero, like other titanium alloys, has a high affinity for gases including oxygen, nitrogen and hydrogen. Absorption of oxygen results in the formation of an extremely hard, brittle oxygen-stabilized alpha phase layer known as alpha case upon heating in air.

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TITAN GRADE 5 AERO

Intermediate and final annealing of TITAN GRADE 5 Aero mill products 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 Descaling (Cleaning) Notes).

Mill Anneal	705 – 790°C (1'300 – 1'450°F) 1 – 4 h – air cool (or equivalent)
Solution Treat + Age (STA)	940 – 970°C (1'725 – 1'775°F) 10 min. – water quench (or equiv.) plus 480 – 595°C (900 – 1'100°F) 2 – 8 h – air cool (or equivalent) °C
Stress Relief	480 – 650°C (900 – 1'200°F) 1 – 4 h – air cool (or equivalent)
Beta Anneal	1'035°C (1'900°F) 30 min. – air cool plus 730°C (1'350°F) 2 h – air cool

Hot Working

TITAN GRADE 5 Aero can be hot worked by standard methods such as hot rolling, forging, and hot pressing. Typically, hot working is done high in the alpha/beta temperature range, at approximately 870 – 980°C (1'600 – 1'800°F). Care must be taken to prevent the formation of excessive alpha case, and alpha case must be removed after processing. Hot forming of sheet is typically done at temperatures around 650°C (1200°F). TITAN GRADE 5 Aero has also been successfully processed by superplastic forming, using temperatures in the range of 850°C (1'560°F).

«Warm» Working:
The yield strength of TITAN GRADE 5 Aero in both the annealed and STA conditions drops off rapidly with temperature, making it readily formable at intermediate temperatures. For example, heating to just 427°C (800°F) results in approximately a 40% reduction in yield strength. Warm forming is used extensively in the manufacture of many products, including fasteners, aircraft components, and medical devices.

Cold Working

TITAN GRADE 5 Aero can be cold drawn and extruded, although the cold workability is somewhat limited. Cold forming is sometimes used for parts such as brackets and clips. Due to the low modulus of titanium, springback is an issue in roomtemperature forming. Theoretically, it can be compensated for by over-bending; however, in practice hot sizing is often used to correct for the variability that occurs.

Machinability

Using the rating system based on AISI B1112 steel, the machinability of TITAN GRADE 5 Aero is rated at 22% of B1112. In general, low cutting speeds, heavy feed rates and copious amounts of cutting fluid are recommended. Also, 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 should be used to eliminate the possibility of chloride contamination. It should be noted that titanium chips are highly combustible and appropriate safety precautions are necessary.

Following are typical feeds and speeds for TITAN GRADE 5 Aero.

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TITAN GRADE 5 AERO

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 (inches)	High Speed Tools			Carbide Tools (Inserts)				
	Tool Material	Speed (fpm)	Feed (ipr)	Tool Material	Speed (fpm)			Feed (ipr)
					Brazed	Throw Away	Coated	
Annealed								
0.150	T15, M42	60	0.010	C2	145	195	-	0.008
0.025	T15, M42	70	0.005	C3	170	225	-	0.005
Aged								
0.150	T15, M42	55	0.010	C2	135	165	-	0.008
0.025	T15, M42	65	0.005	C3	160	190	-	0.005

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
Annealed									
T15, M42	C2	55	0.001	0.0015	0.002	0.0025	0.0015	0.001	0.001
T15, M42	C2	110	0.001	0.0015	0.002	0.0025	0.0015	0.001	0.001
Aged									
T15, M42	C2	40	0.001	0.0015	0.002	0.002	0.0015	0.001	0.001
T15, M42	C2	85	0.001	0.0015	0.002	0.002	0.0015	0.001	0.001

Rough Reaming

High Speed		Carbide Tool		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	65	C2	200	0.003	0.006	0.010	0.012	0.014	0.016
Aged									
T15, M42	30	C2	160	0.003	0.007	0.010	0.012	0.014	0.016

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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
Annealed									
T15, M42	35	-	0.002	0.004	0.006	0.007	0.008	0.010	0.012
Aged									
T15, M42	30	-	0.002	0.003	0.005	0.006	0.007	0.009	0.010

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
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					
	Tool Material	Speed (fpm)	Feed (ipr) – Cutter Diameter (in.)			
			1/4	1/2	3/4	1 – 2
Annealed						
0.050	T15	90	0.002	0.003	0.005	0.006
Aged						
0.050	T15	75	0.002	0.003	0.004	0.006

Depth of Cut (inches)	Carbide Tools					
	Tool Material	Speed (fpm)	Feed (ipr) – Cutter Diameter (in.)			
			1/4	1/2	3/4	1 – 2
Annealed						
0.050	C2	260	0.002	0.003	0.006	0.008
Aged						
0.050	C2	200	0.002	0.003	0.006	0.008

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TITAN GRADE 5 AERO

Tapping

High Speed Tools	
Tool Material	**Speed (fpm)**
Annealed	
M1, M7, M10 Nitrided	7 – 20
Aged	
M1, M7, M10 Nitrided	3 – 10

Broaching

High Speed Tools		
Tool Material	**Speed (fpm)**	**Chip Load (ipt)**
Annealed		
T15, M42	8	0.003
Aged		
T15, M42	5	0.002

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.

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

Heat Treatment	*Thermal Cycle*	*Removal Required*
Mill Anneal	760°C (1'400°F) 2 h	0.038 mm (0.0015 in.)
Solution Treat + Age (STA)	954°C (1'750°F) 10 min. + 480°C (900°F) 4 h	0.107 mm (0.0042 in.)

Weldability

TITAN GRADE 5 Aero can be welded using TITAN GRADE 5 Aero 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 TITAN GRADE 5 Aero. 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 TITAN GRADE 5 Aero welding applications.

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TITAN GRADE 5 AERO

Wear Resistance

TITAN GRADE 5 Aero, and Ti alloys in general, 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/hydrofluoric acid mixture.

Titanium alloys are 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 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 the formation of alpha case even in the vacuum atmosphere. In addition, chlorides found in some cleaning agents have been associated with SCC of titanium. Thus, 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

- A5.16 (ERTi-5) (Weld Wire)
- AMS 4920 (Forgings)
- AMS 4963 (Bar, Wire, Forgings, Ring, Heat Treatable)
- AMS 4967 (Bar, Wire, Forgings, Ring, STA)
- ASTM B367 (Castings)
- ISO 5832-3
- AMS 4911 (Sheet, Strip, Plate)
- AMS 4928 (Bar, Wire, Forgings, Ring, Annealed)
- AMS 4965 (Bar, Wire, Forgings, Ring, STA)
- ASTM B348 (Bar, Billet)
- ASTM F1472 (All Forms, Annealed)

Forms Manufactured

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

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

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TITAN GRADE 5 AERO

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

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Metals Handbook, Desk Edition, ASM International, 1984
Specifications Book, International Titanium Association, 1999
Metcut Research Associates Inc. data
Dynamet technical papers and unpublished data

Technical Articles

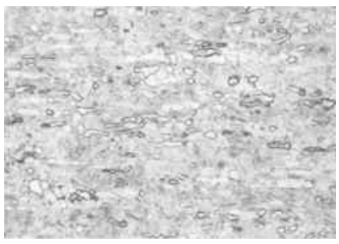
- An Evaluation of Alloys for Golf Club Face Plates
- Higher Performance Material Solutions for a Dynamic Spine Market
- New Requirements for Ferrous-Base Aerospace Alloys
- New, Precision Titanium ULTRABAR™ for Screw Machining Medical and Other Precision Parts
- Selection of High Strength Stainless Steels for Aerospace, Military and Other Critical Applications
- Specialty Alloys And Titanium Shapes To Consider For Latest Medical Materials Requirements
- Toughness Index for Alloy Comparisons

TITAN GRADE 5 Aero 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% hydrofluoric acid plus 2–6% nitric acid in water) is commonly used for determination of general microstructure. For detection of alpha case, Kroll's etch is followed by an ammonium bifluoride solution which stains the entire sample with the exception of any alpha case. Some typical microstructures are illustrated below.

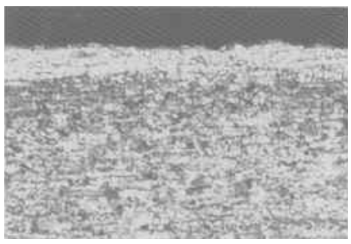
Microstructures of TITAN GRADE 5 Aero (approximate magnification 200X)



TITAN GRADE 5 Aero Mill Annealed Condition



TITAN GRADE 5 Aero STA Condition



Alpha Case in TITAN GRADE 5 Aero

Disclaimer: The information and data presented herein are typical or average values and are not a guarantee of maximum or minimum values. Applications specifically suggested for material described herein are made solely for the purpose of illustration to enable the reader to make his/her own evaluation and are not intended as warranties, either express or implied, of fitness for these or other purposes. There is no representation that the recipient of this literature will receive updated editions as they become available.

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