**Ti-3Al-8V-6Cr-4Mo-4Zr (Beta C™)**

### Type Analysis

<table>
<thead>
<tr>
<th>Type Analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single figures are nominal except where noted.</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon (Maximum)</td>
<td>0.05 %</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>3.50 to 4.50 %</td>
</tr>
<tr>
<td>Aluminum</td>
<td>3.00 to 4.00 %</td>
</tr>
<tr>
<td>Zirconium</td>
<td>3.50 to 4.50 %</td>
</tr>
<tr>
<td>Iron (Maximum)</td>
<td>0.30 %</td>
</tr>
<tr>
<td>Hydrogen (Maximum)</td>
<td>0.030 %</td>
</tr>
<tr>
<td>Other, Total (Maximum)</td>
<td>0.40 %</td>
</tr>
<tr>
<td>Chromium</td>
<td>5.50 to 6.50 %</td>
</tr>
<tr>
<td>Titanium</td>
<td>Balance</td>
</tr>
<tr>
<td>Vanadium</td>
<td>7.50 to 8.50 %</td>
</tr>
<tr>
<td>Nitrogen (Maximum)</td>
<td>0.03 %</td>
</tr>
<tr>
<td>Oxygen (Maximum)</td>
<td>0.120 %</td>
</tr>
<tr>
<td>Yttrium (Maximum)</td>
<td>0.005 %</td>
</tr>
<tr>
<td>* Other, Each (Maximum) = 0.150%</td>
<td></td>
</tr>
</tbody>
</table>

### 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.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Concentration</th>
<th>Temperature</th>
<th>Corrosion Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfuric Acid</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Hydroxide</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea Water</td>
<td>Excellent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>Excellent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfuric Acid, aerated</td>
<td>5%</td>
<td>boiling</td>
<td>1.65, 73</td>
</tr>
<tr>
<td>Sulfuric Acid + 50 g/l FeCl₃</td>
<td>10%</td>
<td>boiling</td>
<td>0.05, 2.0</td>
</tr>
</tbody>
</table>

**Properties**

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>4.83</td>
</tr>
<tr>
<td>Density</td>
<td></td>
</tr>
<tr>
<td>Solution Annealed</td>
<td>0.1740 lb/in³</td>
</tr>
<tr>
<td>Solution Treated &amp; Aged</td>
<td>0.1740 lb/in³</td>
</tr>
<tr>
<td>Mean Specific Heat (73°F)</td>
<td>0.1230 Btu/lb/°F</td>
</tr>
<tr>
<td>Mean CTE (73 to 212°F)</td>
<td>4.60 x 10⁻³ in/in/°F</td>
</tr>
<tr>
<td>Thermal Conductivity (73°F)</td>
<td>43.02 BTU-in/hr/ft²/°F</td>
</tr>
<tr>
<td>Modulus of Elasticity (E)</td>
<td></td>
</tr>
<tr>
<td>Overaged</td>
<td>13.2 x 10⁻³ ksi</td>
</tr>
<tr>
<td>Solution Annealed</td>
<td>11.4 x 10⁻³ ksi</td>
</tr>
<tr>
<td>Solution Treated &amp; Aged</td>
<td>14.4 x 10⁻³ ksi</td>
</tr>
<tr>
<td>Modulus of Rigidity (G) (Solution Treated and Aged)</td>
<td>5.60 x 10⁻³ ksi</td>
</tr>
<tr>
<td>Beta Transus</td>
<td>1325 to 1375 °F</td>
</tr>
<tr>
<td>Liquidus Temperature</td>
<td>3000 °F</td>
</tr>
</tbody>
</table>
Ti-3Al-8V-6Cr-4Mo-4Zr (Beta C™)

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic Modulus GPa</th>
<th>psi x 10^6</th>
<th>Shear Modulus GPa</th>
<th>psi x 10^6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Annealed</td>
<td>78.91</td>
<td>11.4-13.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Solution Treated + Aged</td>
<td>99-124</td>
<td>14.4-18.0</td>
<td>39-43</td>
<td>5.6-6.3</td>
</tr>
<tr>
<td>Overaged</td>
<td>91-96</td>
<td>13.2-14.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CP Titanium</td>
<td>103-107</td>
<td>15.0-15.5</td>
<td>45</td>
<td>6.5</td>
</tr>
<tr>
<td>Ti 6Al-4V</td>
<td>105-116</td>
<td>15.2-16.8</td>
<td>41-45</td>
<td>5.9-6.5</td>
</tr>
<tr>
<td>Most Steels</td>
<td>190-215</td>
<td>27.6-31.2</td>
<td>74-83</td>
<td>10.7-12.0</td>
</tr>
<tr>
<td>Nickel Alloys</td>
<td>200-222</td>
<td>29.0-32.2</td>
<td>76-85</td>
<td>11.0-12.3</td>
</tr>
</tbody>
</table>

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 (Klc) 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)

![Graph showing the aging response of Ti-3-8-6-4-4 with varying hydrogen content. The graph plots UTS (ksi and MPa) against aging time (hours) for different hydrogen concentrations (80 ppm, 150 ppm, 300 ppm, 550 ppm).]
Elevated Temperature Mechanical Properties for Ti-3-8-6-4-4

Tensile Properties vs. Temperature
ST Condition \(^{(2)}\)

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Strength, ksi</th>
<th>%RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

Tensile Properties vs. Temperature
STA Condition \(^{(2)}\)

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Strength, ksi</th>
<th>%RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Condition</th>
<th>Diameter</th>
<th>Tensile Properties after Aging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
<td>in.</td>
</tr>
<tr>
<td>AMS 4957</td>
<td>≤4.75</td>
<td>≤0.187</td>
</tr>
<tr>
<td>Solution Treated, Cold Drawn and Aged at 510-565°C (950-1050°F), 6-10 hrs, Air Cool</td>
<td>4.75-9.50</td>
<td>0.187-0.375</td>
</tr>
<tr>
<td></td>
<td>9.50-15.8</td>
<td>0.375-0.625</td>
</tr>
<tr>
<td>AMS 4958</td>
<td>25.4 and under</td>
<td>1.00 and under</td>
</tr>
<tr>
<td>Solution Treated and Aged at 454-565°C (850-1050°F) 6-20 hrs, Air Cool</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 55-85°C (100-150°F) 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

<table>
<thead>
<tr>
<th>Solution Treatment</th>
<th>Temperature</th>
<th>Time</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>788-927°C (1450-1700°F)</td>
<td>10-60 min.—air cool (or equivalent) or faster</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aging</td>
<td>455-593°C (850-1100°F)</td>
<td>6-14 hr.—air cool (or equivalent)</td>
<td></td>
</tr>
</tbody>
</table>

### 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.
Ti-3Al-8V-6Cr-4Mo-4Zr (Beta C™)

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

<table>
<thead>
<tr>
<th>Depth of Cut (Inches)</th>
<th>High Speed Tools</th>
<th>Carbide Tools (Inserts)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tool Material</td>
<td>Speed (fpm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.150 .025</td>
<td>T15, M42</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>.150 .025</td>
<td>T15, M42</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35</td>
</tr>
</tbody>
</table>

### Turning—Cut-Off and Form Tools

<table>
<thead>
<tr>
<th>Tool Material</th>
<th>High Speed Carbid Tools</th>
<th>Speed (fpm)</th>
<th>Feed (ipr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T15, M42</td>
<td>C2</td>
<td>35</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>.0015</td>
</tr>
<tr>
<td>T15, M42</td>
<td>C2</td>
<td>30</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>.0015</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tool Material</th>
<th>Form Tool Width (Inches)</th>
<th>Feed (ipr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/16</td>
<td>1/8</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td>1/4</td>
</tr>
<tr>
<td></td>
<td>1/4</td>
<td>1/2</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1 1/2</td>
</tr>
<tr>
<td></td>
<td>1 1/2</td>
<td>2</td>
</tr>
</tbody>
</table>

### Rough Reaming

<table>
<thead>
<tr>
<th>Tool Material</th>
<th>Speed (fpm)</th>
<th>Carbide Tools</th>
<th>Speed (fpm)</th>
<th>Feed (ipr) Reamer Diameter (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1/8</td>
</tr>
<tr>
<td>T15, M42</td>
<td>30</td>
<td>C2</td>
<td>75</td>
<td>.002</td>
</tr>
<tr>
<td>T15, M42</td>
<td>20</td>
<td>C2</td>
<td>50</td>
<td>.002</td>
</tr>
</tbody>
</table>
Weldability

Ti-3Al-8V-6Cr-4Mo-4Zr (Beta C™) 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-3Al-8V-6Cr-4Mo-4Zr. 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-3Al-8V-6Cr-4Mo-4Zr. Welding is not recommended for STA material because of the likelihood of a localized difference in mechanical properties.

Other Information

Wear Resistance

Ti-3Al-8V-6Cr-4Mo-4Zr 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/hydrofluoric 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-3Al-8V-6Cr-4Mo-4Zr and other beta alloys are greater than for other Ti alloys.

Titanium and its alloys are also susceptible to hydrogen embrittlement. Ti-3Al-8V-6Cr-4Mo-4Zr, 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-3Al-8V-6Cr-4Mo-4Zr (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**

- Bar-Rounds
- Dynalube Coil
- Plate
- SMART Coil® Titanium Coil
- Wire

- Bar-Shapes
- Ingot
- Sheet
- Weld Wire
- Wire-Shapes

**References**

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

- Aerospace Structural Metals Handbook, Volume 4, CINDAS/Purdue University, 1998
- Specifications Book, International Titanium Association, 1999
- Beta-C™ is a registered trademark of RMI Corporation, Niles, OH
- Metcut Research Associates Inc. data
- Beta Titanium Alloys in the 1980’s, TMS/AIME, 1984
- Boeing Company Design Manual BDM-1566
- Dynamet technical publications and unpublished data
Ti-3Al-8V-6Cr-4Mo-4Zr (Beta C™)

Results in a dark stained surface, which can be removed by swabbing with a second etchant consisting of 1% hydrofluoric acid and 49% water. Alpha case and 8% Mo-6.6-4.4 carbon/oxide grain and grain boundaries below the surface. In the STA condition, alpha case can be difficult to detect.

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