TITANIUM ALLOYS

REV D 20–NOV–1998

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0 REVISION NOTICE

This revision notice provides a brief description of the changes made within this standard. This standard should be reviewed in detail to determine the total extent of the revision. Areas that contain technical changes (changes in requirements) are noted in the margin of this standard with a revision bar.

Revision Synopsis: Revision D is a general technical update, including the addition of Beta 21 sheet, Ti 15V–3Cr–3AL–3Sn and Ti 6Al–2Sn–4Zr–2Mo castings.

Revision Description:

§1: Added references for D6–24956 and D6–24957. Added “drawn” products.

§1.1: Deleted “Special Marine Grade” of Ti 6Al–4V. Changed Extra Low Interstitial content Of $_{02}$ from .13 to .12. Added “Zinc” to the limitations listed in FIGURE 1–1, added coverage for Beta 21S to FIGURE 1–2, and changed Ti 38–6–44 weldability from “limited” to “not weldable”.

§1.2 a.: Added “Zinc” to the list of embrittling materials.

§1.2 b.: Added “fastened joints” to the first sentence.

§1.3: Added references for D6–24956 and D6–24957. Deleted MCIC–HB–02 and D3–6002.

§2.1; Deleted note for maximum hydrogen of 0.0125. FIGURE 2–1: Added “Code A–2” for Ti 5Al–2.5Sn ELI grade.

§2.2: Deleted not for maximum hydrogen of 0.0125. FIGURE 2–2: Changed “A–1” to “A–2” for Ti 5Al–2.5Sn.

§2.3: Deleted not for maximum hydrogen of 0.0125.

§2.3: Deleted not for maximum, hydrogen of 0.0125.
FIGURE 2–3: Changed Mil–T–9047 to AMS 4921 for Ti CP–70, changed Mil–T–9047 to AMS 4926, Deleted Mil–T–9047 for Ti 6Ai–4V, changed Mil–T–9047 to AMS 4978 or AMS 4979 for Ti 6Ai–6V–2Sn, changed Mil–T–9047 to AMS 4975 for Ti 6Ai–2Sn–4Zr2Mo.

§2.4: Deleted note for maximum hydrogen of 0.0125.
FIGURE 2–4: Deleted Mil–T–9047 for Ti 6AL–4V. Added BMS7–348 for Ti 6AL–4V thick forged block. Added ultrasonic inspection to Ti 6AL–2Sn–4Zr–2Mo.

§2.5: Deleted coverage for Tl–CP castings. Changed BMS7–181 to BMS7–310. FIGURE 2–5: Added coverage for Ti 15V–3Cr–3AL–3Sn and Ti 6AL–2Sn–4Zr–2Mo castings.

§2.6: Deleted note for maximum hydrogen of 0.0125.
FIGURE 2–6: Added coverage for Ti 15V–3Cr–3AL–3Sn ducts. Added Flagnote for types and classes. Changed 100F to 200F.

§2.7: Deleted note for maximum hydrogen of 0.0125.
Added coverage for Ti 6AL–4V ELI.

FIGURE 2–8: Changed AMS 4957 to BMS7–310.

FIGURE 2–9: Added Beta 21 S.

FIGURE 2–10: Increase the strength bar for Ti 6AI–2Sn–4Zr–2Mo.

FIGURE 2–11: Deleted TI–CP castings. Added Ti 15V–3Cr–3AI–3Sn and Ti 6AI–2Sn–4Zr2Mo castings. Added Ti 15V–3Cr–3AI–3Sn ducting.

§3.1: Added a caution note for stain induced porosity in plate.

§3.2: Deleted reference to Mil–T–9047. Deleted reference to D6–6002. Added §3.2 b.(1) for BMS7–348 thick section forged block.

§3.3: Deleted coverage for TI–CP castings. Change BMS7–181 to BMS7–310. Changed grades A, B, C, D and E to grades A and B.

§3.4: Changed maximum tube size from 16 to 24. Added types to FIGURE 3–2.

§3.5: Deleted figures for machining allowance and forming allowance. Added new figure for extrusion dimensions.

§3.6: Changed AMS 4957 to BMS7–310.

FIGURE 4–1: Added Superplastic forming.

FIGURE 5–1: Deleted ultrasonic inspection note from Ti 10V–2Fe–3AI. Changed BMS7–181 to BMS7–310. Changed hole size for 1.5 inch to .50 inch. Deleted maximum hydrogen of 0.0125 notes.

1 INTRODUCTION

Titanium and its alloys are characterized by an excellent strength to weight ratio and high corrosion resistance. Alpha alloys are suitable for elevated temperature applications up to about 900°F. The beta alloys should not be used above 500°F except the Beta 21 S alloy in the STOA condition, which may be used up to 1000 °F. Titanium and its alloys exhibit low thermal and electrical conductivity, are non–magnetic and non–toxic. Titanium alloys will emit sparks when struck against other materials or during fracture. The lower strength grades of commercially pure titanium are highly formable, but the higher strength grades and alloy sheet (except Ti–15V–3Cr–3Al–3Sn) may require hot forming for all but gentle contours. Ti–6Al–4V sheet is highly superplastic, permitting forming of complex shapes at elevated temperature. Titanium and its alloys are available as foil, sheet, strip, plate, bar, forgings, wire, tubing, extruded and cast forms. The machinability of titanium alloys in the annealed conditions is comparable to the alloy steels. In the solution treated and aged condition machining is more difficult. Ti–CP (Commercially Pure), Ti–3Al–2.5V, Ti–6Al–4V and Ti–15V–3Cr–3Al–3Sn are readily weldable. The responsible Materials Technology organization should be consulted before calling out welding of other alloys. Most titanium is procured in the condition in which it is used. Thermal treatment requirements of the procured material are called out as part of the raw material note. Physical and mechanical properties of the various alloys are contained in BDM–4000 series and MIL–HDBK–5. Commercial aircraft fracture properties are contained in D6–24956, D6–24957 D6–24958. FIGURE 1–1 summarizes advantages and limitations of titanium. FIGURE 1–2 lists physical properties and other features of several titanium alloys.

1.1 Material Designation

Except for sheet, strip and plate procured per MIL–T–9046 which uses an alpha–numeric code, the commercially pure grades are called out by yield strength and the alloys by composition. For example, Ti–ComPure–70 or Ti–CP–70 indicates commercially pure titanium with a minimum yield strength of 70 ksi. Ti–6Al–4V denotes an alloy containing 6 weight percent aluminum and 4 weight percent vanadium. Special low oxygen grades (with improved stress–corrosion resistance and fracture toughness) are followed by the designation “ELI” indicating Extra Low Interstitial content ($0_2 \leq .12$ %). See FIGURE 1–3 for cross reference to composition classifications of the most commonly used titanium alloys.

FIGURE 1–1 GENERAL ADVANTAGES AND LIMITATIONS OF TITANIUM

Advantages	Limitations
• High strength/weight ratio and toughness to 900°F. • Stronger than aluminum. • Higher operating temperature than aluminum. • Higher strength to weight ratio than steel and nickel–based alloys. • Non–magnetic. • Machining costs comparable with steel. • Comparable thermal expansion with (CFRP) carbon fiber reinforced plastic. • Galvanic compatibility with carbon fiber reinforced plastic. • Excellent corrosion resistance.	• Titanium can be embrittled by: Alcohols (methyl, anhydrous ethyl), Liquid Oxygen, Mercury (mercury vapor), Cadmium, Lead, Zinc, Silver, BMS3–11 Hydraulic Fluid (above 270°F). • Titanium parts must be protected from galling by: Bearings (grease or Teflon lubricated) Bushings Rub strips Wear resistant coating (plasma sprayed chrome oxide) • Titanium can gall during forming.

TITANIUM ALLOYS

1.1 Material Designation (Continued)

FIGURE 1–2 PHYSICAL PROPERTIES AND OTHER FEATURES

Alloy	Thermal Conductivity $\frac{Btu\,10^{-6}\text{–}in}{in^2\text{–}sec\text{–}{}^{o}F}$ 70°F	Coefficient Thermal Expansion (10^{-6} in/in/°F) (70°F–1000°F)	Density lb/in^3	Heat Treatments (4)	Maximum Thickness For Full Strength (STA Cond)	Weldable	Sheet Formability Minimum Bend Radius (T = sheet thickness) (2)
COMMERCIALLY PURE (Ti–ComPure–XX) (3)	265	5.3	.163	annealed	NA	fully	1T to 3T
ALPHA Ti–6Al–2Sn–4Zr–2Mo	93	4.6	.164	single, duplex or triplex anneal	NA	limited	4.5T to 3T
Ti–5Al–2.5Sn	105	5.5	.161	annealed	NA	weldable	4.5T to 5T
ALPHA–BETA Ti–3Al–2.5V	111	5.5	.162	annealed or CWSR	N/A	weldable	NA
Ti–6Al–4V	95	5.3	.160	annealed, STA, Beta annealed	.75 inch	weldable	3T to 5 T
Ti–6Al–6V–2Sn	74	5.6	.164	annealed or STA	1.5 inches	limited	3T to 4T
BETA Ti–10V–2Fe–3Al	95	5.4	.168	STA	3 inches	limited	NA
BETA 21 S (15Mo–3Al–2Nb–.25Si)	100	4.7	.178	STA, STOA	.125 inch	weldable	3T
Ti–15V–3Cr–3Al–3Sn	111	5.6	.172	STA	.125 inch	weldable	2T
Ti–3Al–8V–6Cr–4Mo–4Zr	81	5.4	.174	STA	NA	not weldable	NA

(1) Average values between 70°F and 1000°F.
(2) Refers to forming in the annealed condition except for Ti–15V–3Cr–3Al–3Sn which is formed in the solution treated condition.
(3) XX refers to the minimum yield strength in ksi.
(4) STA – Solution Treated and Aged
STOA – Solution Treated and Overaged
CWSR – Cold Worked and Stress Relieved

1.1 Material Designation (Continued)

FIGURE 1–3 CROSS–REFERENCE OF COMPOSITION DESIGNATIONS FOR TITANIUM ALLOYS

	MIL–T–9046D	MIL–T–9046E	MIL–T–9046F	MIL–T–9046G	MIL–T–9046H	MIL– T–9046J
Commercially Pure (All Grades & Types	Type I Commercially Pure Ti	Alpha Alloys Comp. 1	Type I Commercially Pure Ti	Commercially Pure Ti	Type I Commercially Pure Ti	Commercially Pure Alloys
	Comp. A–unalloyed	Comp. 1–unalloyed	Comp. A Comp. B Comp. C	N/A	Comp. A or CP–A Comp. B or CP–B Comp. C or CP–C	CP–3 CP–1 CP–4
Ti–6Al–4V	Type III Alpha–Beta Ti Alloy	Alpha–Beta Alloys	Type III Alpha–Beta Ti Alloys	Alpha–Beta Ti Alloys	Type III Alpha–Beta Ti Alloys	Alpha–Beta Alloys
	Comp. A–6Al–4V Comp. B–6Al–4V (ELI)	Comp. 6–6Al–4V Comp. 7–7Al–4V (ELI)	Comp. C–6Al–4V Comp. D–6Al–4V (ELI)	6Al–4V 6Al–4V (ELI)	Comp. C–6Al–4V Comp. D–6Al–4V (ELI)	AB–1 AB–2
Ti–6Al–6V–2Sn	Comp. C–6Al–6V–2Sn	Comp. 8–6Al–6V–2Sn	Comp. E–6Al–6V–2Sn	6Al–6V–2Sn	Comp. E–6Al–6V–2Sn	AB–3
Ti–6Al–2Sn–4Zr–2Mo	Comp. I–6Al–2Sn–4Zr–2Mo	Comp. 11–6Al–2Sn–4Zr–2Mo	Comp. G–6Al–2Sn–4Zr–2Mo	6Al–2Sn–4Zr–2Mo	Comp. G–6Al–2Sn–4Zr–2Mo	AB–4

1.2 Environmental Considerations

a. Service Environment – Below approximately 500°F, all titanium alloys have excellent resistance to general corrosion by sea water, atmospheric conditions, oxidizing acids and alkalies. For special applications where high resistance to stress corrosion and high fracture toughness are required, extra low interstitial (ELI) should be considered. Consult the responsible Materials Technology organization for uses of titanium in operating temperatures above 550°F.

Mercury and its vapors may cause severe embrittlement of titanium alloys. Do not incorporate any device containing mercury or mercury vapor into the design of any component in proximity to titanium structure.

Titanium can be embrittled by cadmium, silver, zinc, lead and lead alloys at elevated temperatures. Titanium components can be embrittled under certain conditions at ambient temperature if in contact with cadmium. The use of cadmium plated titanium components is not allowed. Cadmium plated components which come in contact with titanium are not allowed, except for hydraulic systems where cadmium plated steel fittings may be coupled to titanium fittings and cadmium plated steel or titanium nuts on titanium or steel bolts. MIL–S–5002 prohibits all contact between titanium and cadmium on military programs. Titanium can be embrittled by methyl alcohol and anhydrous ethyl alcohol at room temperature.

Titanium can be embrittled by accumulations of Skydrol hydraulic fluid (BMS3–11) at temperatures above 270°F. See the applicable Design Requirements and Objectives (DR & O) for allowances.

The use of titanium in contact with liquid oxygen should be avoided since the presence of a fresh surface, caused by cracking or abrasion, may initiate a violent reaction.

b. Wear – The use of bare titanium on functional surfaces (sliding, fretting, fastened joints threads without surface treatment etc.) must be avoided because of the tendency of titanium to gall. Pinned joints subject to rotation, vibration or repeated loads must be bushed with unplated aluminum–nickel–bronze or CRES bushings. Bare titanium should not be used for components having sliding surfaces. Coatings are available for certain components, such as spherical bearings and anti–friction coatings must be used on threaded fasteners. See BDM–1280 Finishes for specific definition of coating requirements. Consult the responsible Materials and Processes organization for special applications.

1.3 References

- MIL–HDBK–5, Military Standardization Handbook Metallic Materials and Elements for Aerospace Vehicle Structures.
- D6–24958, Damage Tolerance Methods and Allowables.
- D6–1276, Control of Materials and Processes for Designated Parts of Boeing Products: Forged and Machined.
- D6–24956, Structural Design and Durability
- D6–24957, Structural Fatigue Methods and Allowables

2 MATERIAL SELECTION

This subsection provides information for selection of titanium alloys.

2.1 Flat Products: Foil, Sheet and Strip

Ti–CP is considered foil at gages of 0.008 inches or less and Ti–3Al–2.5V and Ti–6Al–4V are considered foil at gages less than 0.016 inch. Sheet is defined as up to 0.187 inch thick. Selection criteria are given in FIGURE 2–1.

FIGURE 2–1 FLAT PRODUCTS: FOIL, SHEET AND STRIP (CONTINUED ON NEXT PAGE)

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–CP (70 TYS)	A	A	BMS7–211, Comp 1, Cond A, Type A or Type B	Foil for honeycomb core for Ti sandwich structures.	Ti–CP (70 TYS) is used where the higher strength of Ti–3Al–2.5V is not required. Ti–CP is lower cost than Ti–3Al–2.5V. Must specify Type A for close tolerance or Type B for standard thickness tolerance.
Ti–3Al–2.5V	A	A	BMS7–211, Comp 2, Cond A, Type A or Type B		
Ti–CP (40 TYS	A	A	MIL–T–9046, Ti–CP, Code CP–3, Cond A	Water tanks, scuff plates, door sills, lavatory plumbing, firewalls, ducting, misc. formed parts.	Generally used for formed parts requiring good corrosion resistance. CP–3 for maximum cold formability. Formability decreases as strength increases with the other grades. Comp. CP–2 and CP–1 limited to gentle contours. Complex shapes require hot forming.
Ti–CP (55 TYS)	A	A	MIL–T–9046, Ti–CP, Code CP–2, Cond A		
Ti–CP (70 TYS)	A	A	MIL–T–9046, Ti–CP, Code CP–1, Cond A		

2.1 Flat Products: Foil, Sheet and Strip (Continued)

FIGURE 2–1 FLAT PRODUCTS: FOIL, SHEET AND STRIP (CONTINUED)

Alloy	Condition		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–6Al–4V	A	A	MIL–T–9046, Ti–6Al–4V, Code AB–1, Cond A.	Doublers, firewalls, fail-safe straps, stiffeners, fairings, clips, brackets, hot formed parts, sheet structure in exhaust.	Used for general high strength applications up to 600°F. Very complex shapes can be produced by superplastic forming.
Ti–6Al–4V	STA or A (2)	STA	MIL–T–9046, Ti–6Al–4V, Code AB–1, Cond A or STA.	Similar to annealed but higher strength.	Limited applications due to distortion problems inherent with heat treated sheet. If doing mild forming, may purchase in solution treated (ST) condition, form and then age to achieve stress relief and strength. Will not get STA properties in a weld region. Ti–15V–3Cr–3Al–3Sn is recommended if high strength is required.
Ti–6Al–6V –2 Sn	ST or STA (2)	STA	MIL–T–9046, Ti–6Al–6V–2Sn, Code AB–3, Cond ST or STA	Same as above but higher strength than Ti–6Al–4V–STA.	Same as Ti– 6Al–4V STA. This alloy is not weldable. Ti–15V–3Cr–3Al–3Sn is recommended if high strength is required.
Ti–15V–3Cr–3Al–3Sn	ST	STA	BMS7–281	Doublers, straps, stiffeners, fairings, clips, brackets, springs, etc.	This alloy has room temperature formability similar to Ti–CP, especially, for brake formed parts. After forming it can be heat treated to a minimum UTS of 150 ksi BMS7–281 material has lower yield strength in ST condition for better formability.
	ST	STA	AMS 4914 (Lower strength than BMS7–281)		

2.1 Flat Products: Foil, Sheet and Strip (Continued)

FIGURE 2–1 FLAT PRODUCTS: FOIL, SHEET AND STRIP (CONCLUDED)

Alloy	Condition (2)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–6Al–2Sn–4Zr–2Mo	A DA TA	DA TA	MIL–T–9046, Ti–6Al–2Sn–4Zr–2 Mo, Code AB–4, Cond A, DA or TA	Structures for high temperature applications DA – 800° to 950°F TA – 800° to 1050°F	This alloy may be used at temperatures 800–1050°F.
Ti–5Al–2.5Sn	A	A	MIL–T–9046, Ti–5Al–2.5Sn, Code A–1, Cond STD or Code A–2, Cond. ELI	Cryogenic applications	Good weldability and toughness at low temperatures.
Beta 21S	ST	STA–1000 STA–1100 STOA	BMS7–334	Plug & Nozzle	Beta 21 S is the only alloy resistant to skydrol at elevated temperature (270° F and greater).

(1) Heat treat conditions:

A	– annealed
ST	– solution treated
STA	– solution treated and aged
BA	– annealed above beta–transus temperature
DA	– duplex annealed
TA	– triplex annealed
CWSR	– cold worked and stress relieved
STA–1000	– Solution Treated and Aged at 1000 F
STA–1100	– Solution Treated and Aged at 1100 F
STOA	– Solution Treated and Overaged

(2) Depending on forming, machining and/or strength requirements of the finished product, the raw material may need to be purchased in the annealed or ST condition.

2.2 Plate

Selection criteria for Plate are given in FIGURE 2–2.

FIGURE 2–2 PLATE (CONTINUED ON NEXT PAGE)

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–CP (70 TYS)	A	A	MIL–T–9046, Ti–CP, Code CP–1, Cond A	Fittings and bosses, primarily in lavatory area or air conditioning systems.	Use where lightweight and corrosion resistance are required.
Ti–5Al–2.5Sn	A	A	MIL–T–9046, Ti–5Al–2.5Sn ELI, Code A–2, Cond A	Cryogenic applications	Good weldability and toughness at low temperatures. Difficult to roll See Materials Technology.
Ti–6Al–4V	A	A	MIL–T–9046, Ti–6Al–4V, Code AB–1, Cond A.	Small machined structural fittings and bosses, I–beams, I–beam webs, and hydraulic fittings where the higher strength can provide weight savings.	Use in areas where the higher strength can provide weight savings.
Ti–6Al–4V	ST, STA, A (2)	STA	MIL–T–9046, Ti–6Al–4V, Code AB–1, Cond A ST or STA.		Use in areas where the higher strength can provide weight savings. May purchase in annealed or ST condition depending on strength requirements and purchased thickness. Could require rough machining prior to heat treatment to achieve desired strength. Annealed Ti–6Al–6V–2Sn recommended if lower strength does not present weight penalty. Distortion may occur.
Ti–6Al–4V (ELI)	BA	BA	AMS 4905 (3)		Use as above in areas where high toughness is required.

2.2 Plate (Continued)

FIGURE 2–2 PLATE (CONCLUDED)

Alloy	Condition		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–6Al–6V–2Sn	A	A	MIL–T–9046, Ti–6Al–6V–2Sn, Code AB–3, Cond A	Small machined structural fittings and bosses, I–beams and I–beam webs where the higher strength can provide weight savings.	Preferable from manufacturing standpoint to Ti–6Al–4V, STA.
	ST, (2) STA or A	STA	MIL–T–9046, Ti–6Al–6V–2Sn, Code AB–3, Cond ST, STA or A		Same rough machining comments as for Ti–6Al–4V, STA. Strength is thickness dependant.

(1) Heat treat conditions:

A – annealed
ST – solution treated
STA – solution treated and aged
BA – annealed above beta–transus temperature
DA – duplex annealed
TA – triplex annealed
CWSR – cold worked and stress relieved

(2) Depending on forming, machining and/or strength requirements of the finished product, the raw material may need to be purchased in the annealed or ST condition.

(3) Ultrasonic Inspect per MIL–STD–2154 Type I, Class A.

2.3 Bar–Rolled and Drawn

Selection criteria for Bar are given in FIGURE 2–3.

NOTE: It is not normally desirable to machine parts out of bar due to extensive machining time required and amount of chips generated. Forgings are preferred.

2.3 Bar–Rolled and Drawn (Continued)

FIGURE 2–3 BAR

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–CP–70	A	A	AMS 4921 (2) Ti–CP–70 Cond A	Similar to Ti–CP–70 plate applications, but larger components	Use in areas requiring high corrosion resistance and minimum weight when the strength is adequate.
Ti–5Al–2.5Sn	A	A	AMS 4926 Ti–5Al–2.5Sn Cond A	Cryogenic applications	Difficult to roll. Good low temperature toughness and weldability. See Materials Technology.
Ti–6Al–4V	A	A	AMS 4928, Ultrasonic inspect per MIL–STD–2154, Type I, Class A. Notch rupture test not required.	Structural fittings, hydraulic fittings, and miscellaneous machined hardware requiring the higher strength.	Most commonly used structural titanium alloy. If MIL–T–9047 is specified, ultrasonic inspection note is not required.
Ti–6Al–6V–2Sn	A, ST or STA	STA	AMS 4978 Ti–6Al–6V–2Sn, Cond A, ST or STA	Same as Ti–6Al–4V	Higher strength than Ti–6Al–4V. Not weldable. Purchased condition dependent on raw material thickness and property requirements. Distortion may occur on machining.
	STA	STA	AMS 4779 STA (2)		
Ti–6Al–2Sn–4Zr–2Mo	A DA	DA	AMS 4975 (2) Ti–6Al–2Sn–4Zr–2Mo, Cond A or DA	Structures for high temperature applications DA – 800 to 950°F	This alloy can be used at temperatures 800 – 950°F. Should not be used structurally with significant loading above 900°F.

(1) Heat treat conditions:

A – annealed
ST – solution treated
STA – solution treated and aged
BA – annealed above beta–transus temperature
DA – duplex annealed
TA – triplex annealed
CWSR – cold worked and stress relieved

(2) Ultrasonic inspect per MIL–STD–2154, Type 1, Class A.

2.4 Forged Blocks, Forged Bar, Hand Forgings and Die Forgings

Selection criteria for Block, Hand and Die forgings are given in FIGURE 2–4 . (see specification, material call–out notes).

FIGURE 2–4 FORGED BLOCK FORGED BAR; HAND AND DIE FORGINGS (CONTINUED ON NEXT PAGE)

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–6Al–4V	A	A	AMS 4928, (3)	Primary uses are in landing gear associated structure such as landing gear beam, links, struts, trunnion support, nacelle or strut areas where elevated temperature properties are required. Flap structures, hydraulic fittings.	AMS 4928 is used for non–designated die forgings.
	A	A	BMS7–247		Use BMS7–247 for designated die forgings per D6–1276. Thickness limited to 4 inches.
	BA AS FORGED	BA	BMS7–269 STD or ELI		Specify BMS7–269 for designated per D6–1276 or non–designated forgings requiring improved damage tolerance capabilities (i.e., high fracture toughness, high stress corrosion resistance and high fatigue crack growth resistance).ELI grade has higher damage tolerance than standard grade.
Ti–6AL–4V	A	A	BMS7–348	Bulkheads	For forged block over 6 inches thick.

2.4 Forged Blocks, Forged Bar, Hand Forgings and Die Forgings (Continued)

FIGURE 2–4 FORGED BLOCK; HAND AND DIE FORGINGS (CONCLUDED)

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–6Al–6V–2Sn	STA OR A (2)	STA	AMS 4979, Ultrasonic inspect notes identical to (3)	Landing gear area and flap area – torsion links, drag struts, bell–cranks, gimbal fittings. Used where added strength produces weight savings. Strength is thickness dependant.	May have to rough machine prior to heat treatment. UTS of 170 ksi attainable to 2″ at time of heat treat. Distortion may occur on machining.
Ti–6Al–2Sn–4Zr–2Mo	STA , AS FORGED	STA	AMS 4976 (3)	Structures for high temperature applications. STA – 800 to 950°F	This alloy can be used at temperatures 800 – 950°F. Should not be used structurally with significant loads above 900°F.
Ti–10V–2Fe –3Al	STA, AS FORGED	STA	BMS7–260	Landing gear support structure, slat support structure. Strut fittings.	Offers excellent weight savings over steels at strengths up to 220–240 ksi if not stiffness critical. Forgings having thickness greater than 3 inches must be purchased in “As Forged” condition and rough machined to less than 3 inches before heat treatment.

(1) Heat treat conditions:

A – annealed
ST – solution treated
STA – solution treated and aged
BA – annealed above beta–transus temperature
DA – duplex annealed
TA – triplex annealed
CWSR – cold worked and stress relieved

(2) Depending on forming, machining and/or strength requirements of the finished product, the raw material may need to be purchased in the annealed or ST condition.

(3) Block and Hand Forgings “Ultrasonic inspect per MIL–STD–2154, Type I, Class A”. For Die Forgings, ultrasonic inspect billet stock per MIL–STD–2154, Type I, Class A.

2.5 Castings

Selection criteria for Castings are given in FIGURE 2–5.

FIGURE 2–5 CASTINGS

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–6Al–4V	A	A	BMS7–310 Grade _	Complex thin–wall shapes, missile fins, housings, structural elements	Use for shapes difficult to forge and which would entail high machining costs. Consult the responsible Materials Technology organization for proper use considerations.
Ti–6Al–2Sn–4Zr 2Mo	STOA	STOA	BMS7–336, Grade _	Heat Shields	High Temperature applications up to 900°F.
Ti–15V–3CR–3Al–3Sn	STA	STA	BMS7–324, Grade _	APU, Cargo Handling	Higher strength than Ti–6Al–4V. Use up to 1 inch thick

(1) Heat treat conditions:

A – annealed
ST – solution treated
STA – solution treated and aged
BA – annealed above beta–transus temperature
DA – duplex annealed
TA – triplex annealed
CWSR – cold worked and stress relieved

2.6 Tubing, Ducting

Selection criteria for Tubing and Ducting are given in FIGURE 2–6. (see specification, material call–out notes).

FIGURE 2–6 TUBING AND DUCTING

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–CP (25 TYS)	A	A	BMS7–21, Grade I (4)	Pneumatic ducting for air conditioning, anti–icing, etc.	This is the preferred grade for ducting which must be formed. (3)
Ti–CP (40 TYS)	A	A	BMS7–21, Grade II (4)		Not quite as formable as Ti–CP (25 TYS), may require hot forming. (3)
Ti–CP (70 TYS)	A	A	BMS7–21, Grade III (4)		Use for straight sections only. Grade III material may be susceptible to H_2 embrittlement after long time exposure to 300–400°F under sustained loading.(2)
Ti–3Al–2.5V	CWSR	CW SR	BMS7–234, Grade I (5)	Hydraulic tubing	All tube except 1/4″ diameter should be specified as Grade I. the 1/4″ tubing can only be purchased in Grade II
Ti–3Al–2.5V	A	A	BMS7–234, Grade II (5)		
Ti–6Al–4V	A	A	BMS7–202	Structural tubing such as torque tube.	Welded tubing; not intended for hydraulic systems.
Ti 15V–3Cr–3Al–3Sn	St	STA	BMS7–333	Environmental Control Systems Ducts.	Higher strength than Ti–Cp, but more difficult to form.

(1) Heat treat conditions:

- A – annealed
- ST – solution treated
- STA – solution treated and aged
- BA – annealed above beta–transus temperature
- DA – duplex annealed
- TA – triplex annealed
- CWSR – cold worked and stress relieved

(2) CAUTION: Do not use Grade III in applications that will be exposed to temperatures above 200F.

(3) CAUTION: Welded ducting used in applications above 200F requires stress relieving per BAC5613 after welding.

(4) Callout includes Type 1, 2 or 3, and Class I, II or III.

(5) Callout includes Type 1, 2 or 3.

2.7 Extrusions

Selection criteria for Extrusions are given in FIGURE 2–7.

FIGURE 2–7 EXTRUSIONS

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–CP (70 TYS)	A	A	MIL–T–81556, Com. Pure Ti, CP–1, Cond. A.	Same as for Ti–6Al–4V where lower strength is sufficient	Use where material and machining cost savings can be achieved over hogging out of bar or plate. Machining allowance of approx. 0.125 on all surfaces required (See §3.5) Use ELI for maximum toughness and stress corrosion resistance.
Ti–5Al–2.5Sn	A	A	MIL–T–81556, Ti–5Al–2.5Sn, Code A–1, Cond. A.	Same as for Ti–6Al–4V and cryogenic applications	
Ti–6Al–4V	A	A	AMS 4935 (2)	Use where long, constant or nearly constant cross sections, or many similar parts such as brackets or clips are required.	
Ti–6A–4V (ELI)	A	A	MIL–T–81556 Ti–6Al–4V ELI Code AB–2 Cond A		
	STA	STA	AMS 4934, (2)		
Ti–6Al–6V–2Sn	A	STA	MIL–T–81556, Ti–6Al–6V–2Sn Code AB–3 Cond A or STA	Same as for Ti–6Al–4V	

(1) Heat treat conditions:

A – annealed
ST – solution treated
STA – solution treated and aged
BA – annealed above beta–transus temperature
DA – duplex annealed
TA – triplex annealed
CWSR – cold worked and stress relieved

(2) Ultrasonic inspect billet stock per MIL–STD–2154, Type I Class A.

2.8 Spring Wire

Selection criteria for Spring wire are given in FIGURE 2–8 .

FIGURE 2–8 SPRING WIRE

Alloy	Condition (1)		Specification, Material Call–Out	Applications	Comments
	Purchase	Use			
Ti–3Al–8V–6Cr–4Mo–4Zr	ST and Cold Worked	STA	BMS7–320	Compression, tension or torsion springs for areas such as door counterbalances, bungies, flight controls, landing gear, etc.	Use of Ti springs can result in about 60–70% weight savings in 50% less volume over steel springs. Use BMS7–320 for wire diameter of thickness 0.625 and less. Use AMS 4958 for greater than 0.625 thickness.
	Hot Rolled	STA	AMS 4958		

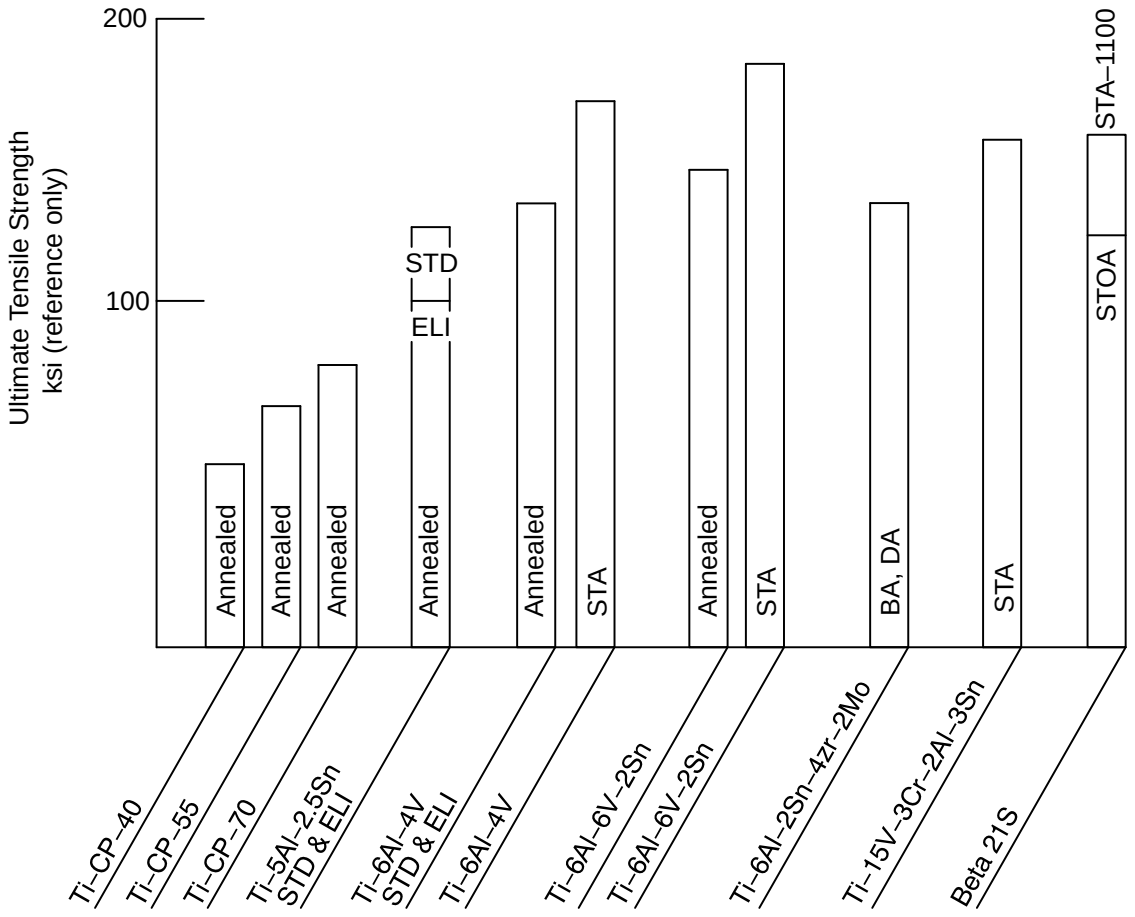
(1) Heat treat conditions:

A – annealed
ST – solution treated
STA – solution treated and aged
BA – annealed above beta–transus temperature
DA – duplex annealed
TA – triplex annealed
CWSR – cold worked and stress relieved

2.9 Comparative Strengths

Comparative tensile strengths of the various alloys and forms of titanium are shown in FIGURE 2–9, FIGURE 2–10, FIGURE 2–11, FIGURE 2–12.

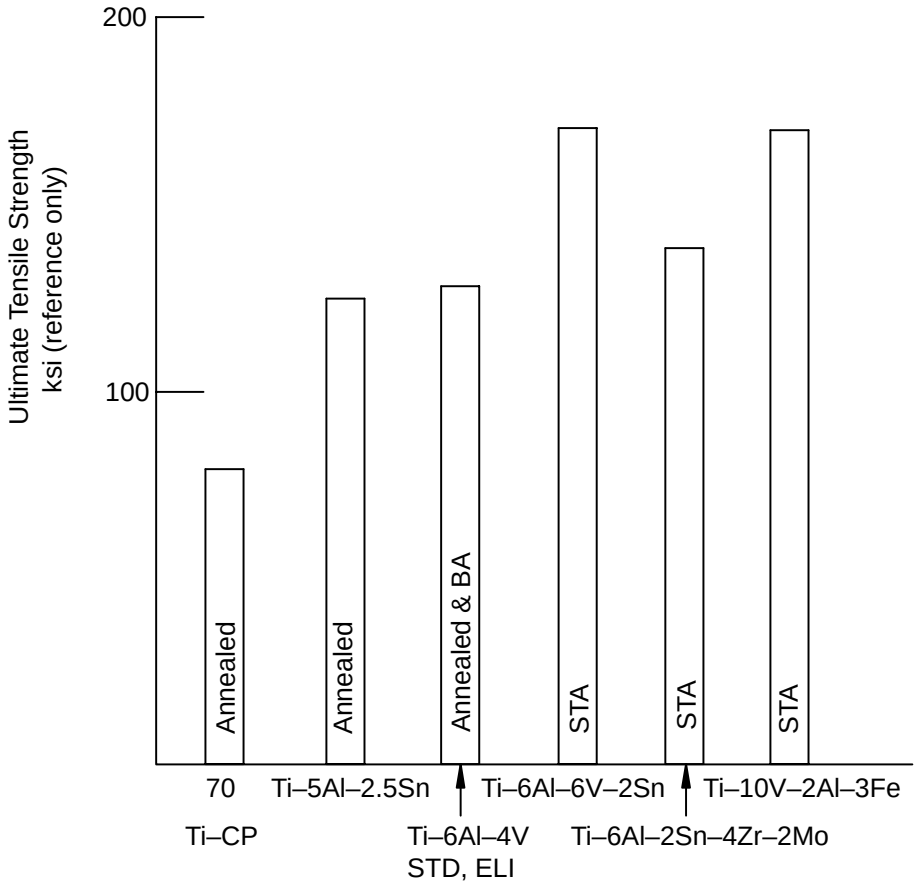
FIGURE 2–9 COMPARATIVE STRENGTH: FOIL, SHEET AND PLATE①



Heat treat conditions:
A – annealed
ST – solution treated
STA – solution treated and aged
BA – annealed above beta–transus temperature
DA – duplex annealed
TA – triplex annealed
CWSR – cold worked and stress relieved

① Approximate values for general comparison only. See BDM–4XXX for design allowables for flight materials and BDM–5XXX for design allowables for ground support equipment.

FIGURE 2–10 COMPARATIVE STRENGTH: BAR AND FORGING (1)

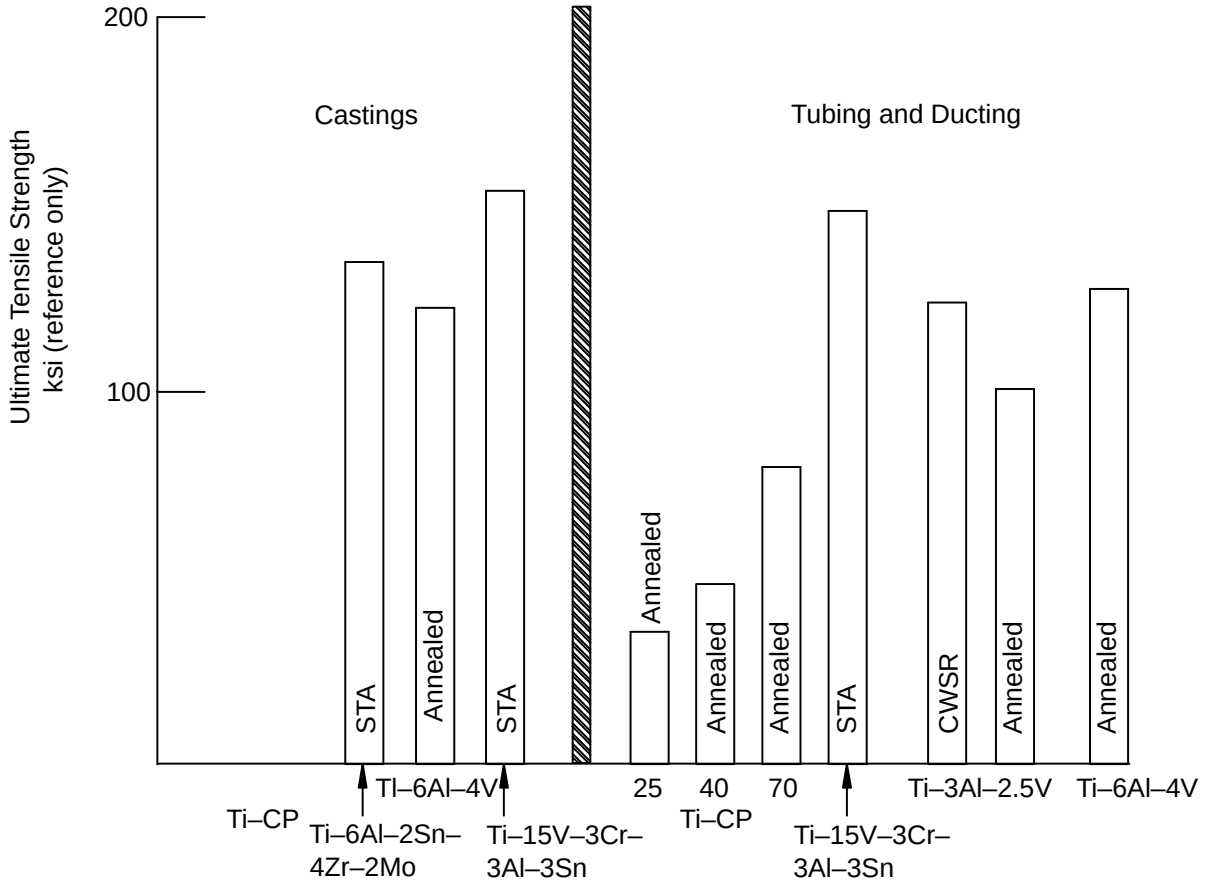


Heat treat conditions:

A	– annealed
ST	– solution treated
STA	– solution treated and aged
BA	– annealed above beta–transus temperature
DA	– duplex annealed
TA	– triplex annealed
CWSR	– cold worked and stress relieved

(1) Approximate values for general comparison only. See BDM–4XXX for design allowables for flight materials and BDM–5XXX for design allowables for ground support equipment.

FIGURE 2–11 COMPARATIVE STRENGTH: CASTINGS, TUBING AND DUCTING (1)

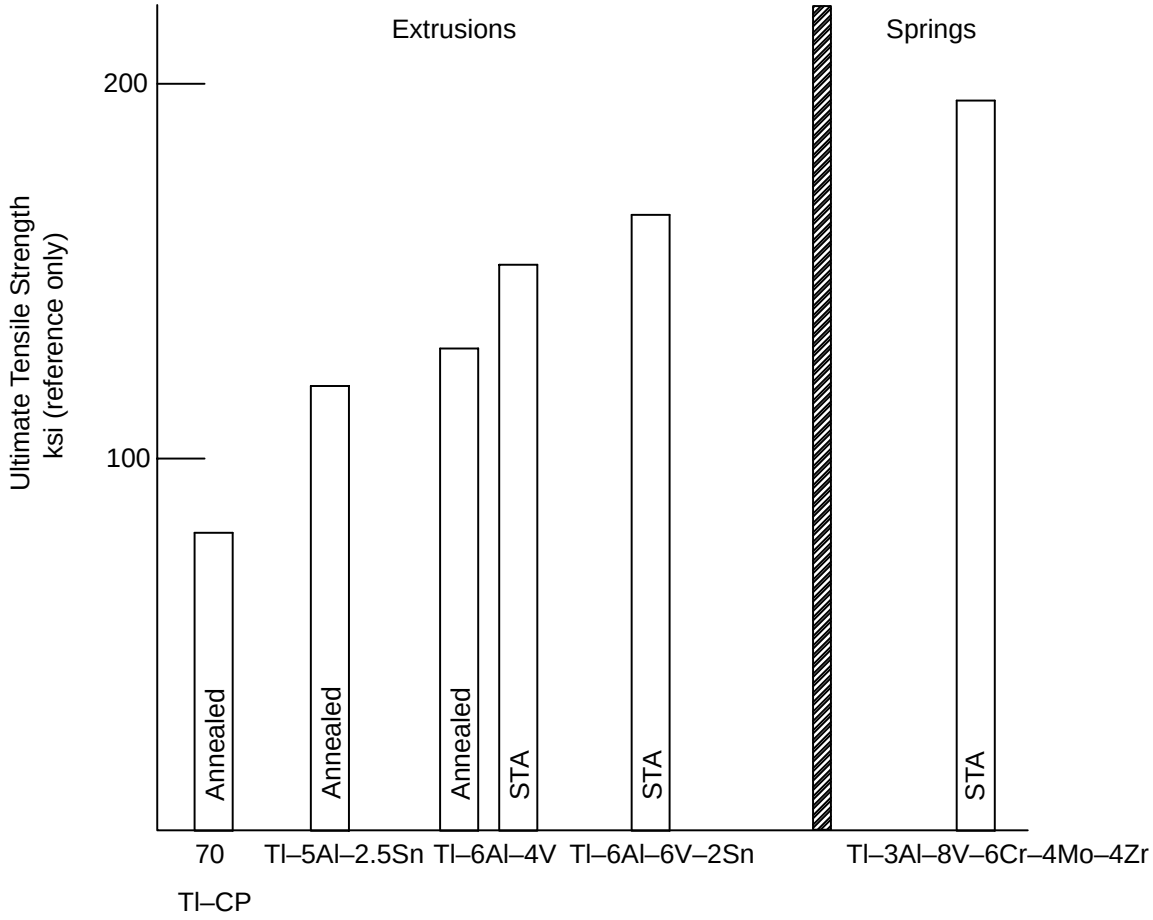


Heat treat conditions:

A	– annealed
ST	– solution treated
STA	– solution treated and aged
BA	– annealed above beta–transus temperature
DA	– duplex annealed
TA	– triplex annealed
CWSR	– cold worked and stress relieved

(1) Approximate values for general comparison only. See BDM–4XXX for design allowables for flight materials and BDM–5XXX for design allowables for ground support equipment.

FIGURE 2–12 COMPARATIVE STRENGTH: EXTRUSIONS AND SPRINGS (1)



Heat treat conditions:
A – annealed
ST – solution treated
STA – solution treated and aged
BA – annealed above beta–transus temperature
DA – duplex annealed
TA – triplex annealed
CWSR – cold worked and stress relieved

(1) Approximate values for general comparison only. See BDM–4XXX for design allowables for flight materials and BDM–5XXX for design allowables for ground support equipment.

3 DESIGN INFORMATION

3.1 Sheet, Plate and Bar

The “as received” surface of titanium plate, bar, block and extrusions requires 100% machining. For plate a minimum machining allowance of 0.02 inch per surface is required to remove surface irregularities. Plate with a special 2D finish (see ASTM A480) can be procured which eliminates the need for machining. The 2D callout should also be used procuring plate when as–received surfaces will be chem–milled. Additional stock is required to allow for flatness deviations (See FIGURE 3–1).

Special requirements for plate greater than 3 inches thick may be needed due to possible strain induced porosity. See Materials Technology.

Parts requiring complex forming or bend radii tighter than permitted for cold forming require a note for hot forming, with manufacturing concurrence.

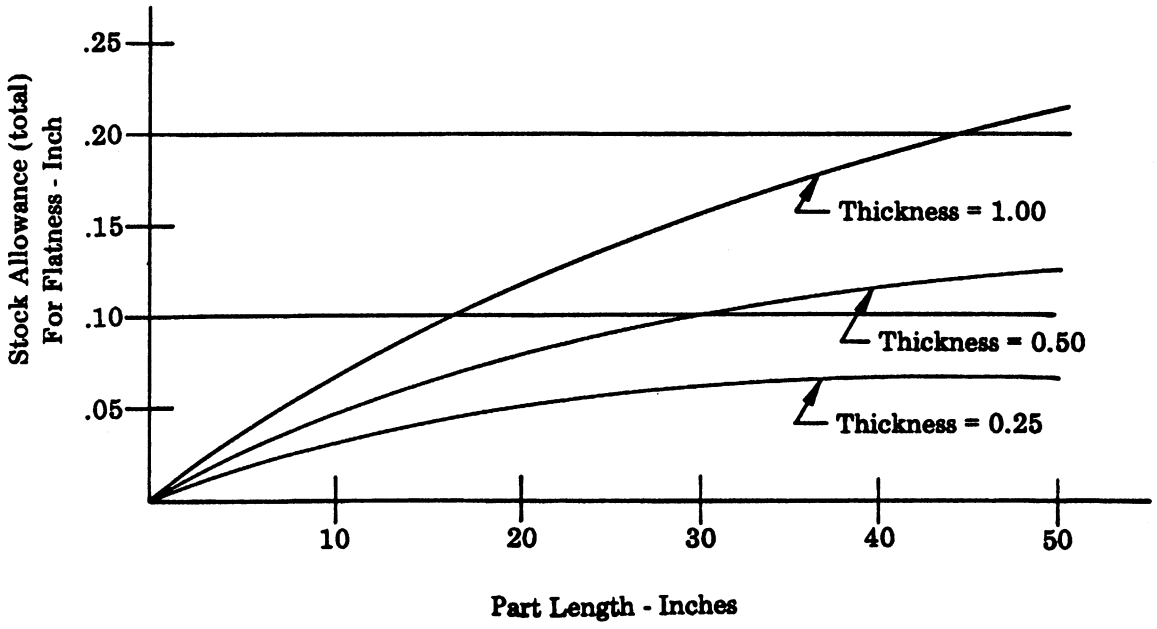
Parts fabricated by superplastic forming need to specify a surface roughness value and minimum gage in critical areas to assure excess thinning does not occur. A full cut–up from the first part is recommended for metallurgical and properties evaluation.

3.2 Forgings

a. Forged Block, Hand and Die Forgings

(1) Mill processed (annealed) Ti–6Al–4V die forgings, hand forgings, forged block, plate, bar and extrusions procured in heavy non–symmetrical cross sections may not be in a fully annealed, stress free condition and could distort during machining. Examples of distortion prone parts are parts with pocket sections (overall length of part exceeds 5 times the flange height) and flat parts (such as splice plates and straps, when part length exceeds 10 times the average thickness.) Ti–6Al–4V and Ti–6Al–6V–2Sn in the solution treated and aged condition are more prone to distortion upon machining. Contact manufacturing for estimate of the distortion problems.

FIGURE 3–1 STOCK ALLOWANCE FOR FLATNESS DEVIATIONS



3.2 Forgings (Continued)

(2) Ti–10V–2Fe–3Al forged block should not exceed 5 inches in section size. Forgings and forged blocks having cross sections greater than 3 inches should be procured in “as forged” condition, rough machined to cross sections below 3 inches, then solution treated and aged per BAC5613.

(3) The material note for Ti–6Al–4V forgings purchased to AMS 4928 should indicate no notched stress–rupture test is required . Material purchased to the AMS specification should also specify ultrasonic inspection. When ordering material per BMS7–269 the composition must be specified Ti–6AL–4V or Ti–6Al–4V ELI. The ELI (extra low interstitial) material will have better fracture toughness and stress corrosion resistance.

(4) Beta Annealed forgings which require grain flow sections should contain a caution note to cut out the sections for macroetching before beta annealing.

b. Specific Hand Forging and Forged Block Requirements

NOTE: Hand forgings are distinguished from forged blocks as having a shape other than square or rectangular.

(1) Ti–6Al–4V hand forgings or forged block with cross sections greater than 6 inches thick should be purchased to BMS7–348, which required process control and first article examination for strain Induced Porosity.

(2) Ti–10V–2Fe–3Al forged block and hand forgings will require certification in accordance with BMS7–260.

NOTE: This may also include fracture toughness testing with a minimum specimen size of $0.5 \times 1.2 \times 1.25$ inch.

c. Die Forgings Requirements – For die forgings, prolongations may be required for verification of tensile properties. Utilization of prolongations depends upon criticality and size of the part. When required, this extra material (approximately $1/2 \times 1/2 \times 3$ inches) should be added to the envelope of the forgings, if possible, adjacent to the largest cross–section of the forging. The specimen location and kerf cut location(s) must be indicated on the drawing. For small forgings the prolongation may be omitted and the tensile coupon removed from the forging, or the tensile properties of the heat treated forging stock may be adequate. Unless the forging is a critical part and the properties of the forging itself must be verified it is recommended to obtain the tensile coupon from the forging stock to save the expense of destroying forgings. For beta annealed Ti–6Al–4V forgings, purchased to BMS7–269, and Ti–10V–2Fe–3Al forgings, purchased to BMS7–260, the locations for both tensile and fracture toughness specimens must be specified. Fracture toughness requirements may be waived based on part size and application.

d. Designated Forging Requirements – In addition to the general notes detailed in §4 it is necessary to determine if the forging is to be designated for specific controls per D6–1276 for commercial airplane parts.

Titanium alloys purchased to BMS specifications are recommended for designated die forgings. Specifications BMS7–260 (Ti–10V–2Fe–3Al) and BMS7–269 (Ti–6Al–4V) provide guaranteed fracture toughness, if required, and sampling plans.

e. Precision Forgings – Finished part cost savings through reduced machining may be attainable through the use of precision forgings. The draft of precision forgings may be as low as 1/2 to 1 1/2 degrees. Precision forgings can be made up to a maximum of 50 inches long with plan view areas up to a maximum of 240 sq. in. Selection of precision forged parts should be done in conjunction with the responsible Materials Technology organization and the specific project casting and forging group. Ti–10V–2Fe–3Al is recommended for precision forgings as its lower forging temperatures and flow stresses permit making more complex shapes and somewhat thinner gages.

3.3 Castings

For airplane, missile and space parts, titanium castings of Ti–6Al–4V are available as precision investment castings per BMS7–310. Investment castings are utilized where closer tolerances and thin walls are required. See BDM–1342 for casting design information.

The material callout must include Grade A or B. Most titanium castings are purchased as Grade B. All titanium castings are hot isostatic pressed. (Hot isostatic pressing is a technique used to close internal casting voids providing nearly defect free material). The project casting and forging groups or the responsible Materials Technology organization should be consulted before Grade A castings are specified.

3.4 Design Information for Tubing and Ducting

a. Ti–3Al–2.5V – Ti–3Al–2.5V tubing is used for high pressure hydraulic lines. The tubing is procured to the requirements of BMS7–234 . The standard diameters and wall thicknesses for 2,000, 3,000 and 4,000 psi rated hydraulic tubing are provided in FIGURE 3–2 .

Specify Grade II tubing in accordance with BMS7–234 for size 04 and Grade I tubing in accordance with BMS7–234 for sizes 06 to 24 when designing 3,000 psi systems. Further information regarding minimum bend radii, approved joining methods and general uses of Ti–3Al–2.5V titanium tubing in 3,000 psi hydraulic systems may be found in BDM–1622, “Hydraulic Systems”. Girth welding of this material is controlled by BAC5974.

FIGURE 3–2 WALL THICKNESSES FOR TITANIUM HYDRAULIC TUBING IN ACCORDANCE WITH BMS7–234

Tube Size	Outside Diameter (Inches)	Wall Thickness		
		Rating (psi)		
		2000 (Type 1)	3000 (Type 2)	4000 (Type 3)
04	0.250	– – –	.016	.018
06	0.375	.019	.019	.028
08	0.500	.022	.026	.035
10	0.625	.023	.032	.044
12	0.750	.027	.039	.052
14	0.875	.032	– – –	.061
16	1.000	.036	.051	.070
20	1.250	.045	– – –	.087
24	1.500	.054	– – –	– – –

b. Ti–6Al–4V – Ti–6Al–4V tubing may be used for structural applications. Limit use to straight runs. Procure per BMS7–202.

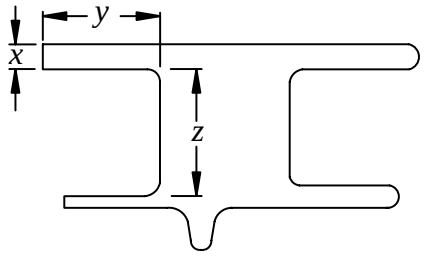
c. Commercially Pure Titanium – Commercially pure titanium tubing is used for pneumatic ducting and is procured per BMS7–21. Forming and non–welded joining methods are specified in BAC5001. Girth welding of this tubing is controlled by BAC5975 ducting. Welded ducting used in applications above 200°F requires stress relieving per BAC5613 after welding.

Fabrication and assembly of ducts should be controlled per BAC5001.

3.5 Extrusions

Extrusions of Ti–6Al–4V require overall material removal by machining. Extrusion drawing should be reviewed to the following criteria and FIGURE 3–3:

FIGURE 3–3 EXTRUSION TOLERANCES



- Allow for 0.125 metal removal from all surfaces to account for surface roughness, straightness, flatness.
- Angular Tolerance +/– 2 degrees
- Corner Radii Tolerance +/– 0.031 inch
- Fillet Radius Tolerance +/– 0.062 inch
- Minimum leg thickness 0.188 inch
- Maximum leg aspect ratio 12 to 1 (y/x less than 12)
- Minimum corner radii 0.062 inch
- Minimum fillet radii 0.188
- Maximum Die tongue aspect ratio 1.5 to 1 (y/z less than 1.5)
- Drawing Tolerance per AMS 2245

Consult the responsible Materials and Process group for detailed information. Extrusions require callouts for machining per BAC5492 and penetrant inspection per BAC5423.

3.6 Springs

Titanium springs are very efficient. They can be fabricated to occupy only one–half the volume and as little as 30% of the weight of steel springs. Titanium springs are fabricated from Ti–3Al–8V–6Cr–4Mo–4Zr (also referred to as Ti–38–6–44 or Beta–C) wire per BMS7–320 or hot rolled rod per AMS 4958 for wire 0.625 inches and larger in diameter. The following notes are recommended in addition to those required by the spring drawing:

Material – Ti–3Al–8V–6Cr–4Mo–4Zr wire per BMS7–320 or AMS 4958 (as applicable).

After coiling, age per BMS7–320 or AMS 4958 (as applicable). Age two specimens from the same lot of wire with each treat lot of springs to verify tensile properties.

Remove heat treat scale by abrasive cleaning per BAC5753, Method 4, and etching per BAC5753, Method 2.

Visible tool marks and scratches are prohibited. Surface roughness 63 R_a prior to shot peening. Penetrant inspect per BAC5423 before shot peening. Shot peen per BAC5730. Extend the spring as required to achieve good shot peen coverage.

4 PROCESSING

Processing recommendations are shown in FIGURE 4–1.

FIGURE 4–1 PROCESSING TITANIUM

Process	Process Recommendations
Cutting and Machining	Requirements for all machining processes, blanking, shearing, turning, milling, drilling grinding, sanding, etc. are controlled by BAC5492. BAC5492 contains three machining classes with different machining and surface finish requirements. The class selection should be based on performance requirements of the part as follows: Class 1 is a premium–quality classification for localized areas or details that are especially fatigue– critical or have a high tensile stress concentration. Class 2 is a general classification specified for most structural applications. Class 3 is a noncritical classification specified for parts noncritical in fatigue or stress concentration. Class 1 should be primarily used only for critical structure that is not shot peened because of higher machining cost than Classes 2 or 3. Thermal cutting is controlled by BAC5928. See BDM–1326.
Forming	Room temperature or elevated temperature forming is controlled by BAC5300. Super Plastic Forming is per BAC5636 See BDM–1310, BDM–1311, or BDM–1312.
Shot Peening	BAC5730 controls the shot peening process. See BDM–1374.
Thermal Treatment	Heat treatment of titanium alloys, stress relieving, annealing, solution treating and aging is controlled by BAC5613. Stress relieving is required following welding and room temperature forming of alloy parts.
Welding	Most titanium alloys may be fusion welded. Contact the responsible materials and processes technology organization for information. See BDM–1404. BAC5975 controls fusion welding. BAC5974 controls Girth Welding
Finishes	Titanium alloys are very corrosion resistant but may require finishing for wear resistance or galvanic isolation.. See BDM–1280.
Inspection	Ultrasonic inspect billet stock per MIL–STD–2154, Type I, Class A if procured to an AMS specification. All machined parts should be penetrant inspected per BAC5423.

4.1 Machining

The fatigue properties of titanium alloys are greatly affected by the method of machining. BAC5492 lists the machining requirements for titanium. Grinding of the finished surface is not allowed on structural or fatigue components because of adverse effects on fatique properties. Sanding of the finished surface on fatigue critical components requires shot peening to restore fatigue properties.

5 DRAWING REQUIREMENTS AND NOTES

FIGURE 5–1 DRAWING REQUIREMENTS AND NOTES (CONTINUED ON NEXT PAGE)

Note required on all drawings (Completely specify material, alloy, form, size, material specification, type/composition, condition as purchased.)		Example: Ti–6Al–4V PLATE (Size) PER MIL–T–9046, CODE AB–1, Condition A Ti–10V–2Fe–3Al FORGING PER BMS7–260, STA. Ti–6Al–4V FORGING PER AMS 4928, ULTRASONIC INSPECT BILLET STOCK PER MIL–STD–2154, TYPE I, CLASS A. Ti–6Al–4V CASTING PER BMS7–310, GRADE B.
Notes required on all machined part drawings. (See BAC5492)		MACHINE PER BAC5492 CLASS _____. PENETRANT INSPECT PER BAC5423 BREAK SHARP EDGES .0X/.0Y OR .00X MINIMUM. (When different than BAC5492.)
Note required on parts operating at or above 550°F.		**CAUTION** THIS PART WILL OPERATE AT OR ABOVE 550°F. DO NOT USE CHLORINATED FLUIDS IN THE FABRICATION OF THIS PART.
Examples of some other drawing notes	Rough Blanking	ROUGH BLANKING BY FLAME CUTTING SHALL BE PER BAC5928. OR LASER TRIMMING PER BAC5982 CLASS _____.
	Thermal Treatment	SOLUTION TREAT AND AGE PER BAC5613 STRESS RELIEVE PER BAC5613 (Cold formed sheet parts and welded ducting per BMS7–21) AGE PER BAC5613 AFTER FORMING (For Ti–15V–3Cr–3Al–3Sn, STA) SOLUTION TREAT AND AGE PER BAC5613 AFTER ROUGH MACHINING TO MEET THE FOLLOWING REQUIREMENTS: (UTS xxx ksi, TYS xxx ksi, Elongation xx %) (FOR Ti–6Al–4V or Ti–6Al–6V–2Sn)

5 DRAWING REQUIREMENTS AND NOTES (CONTINUED)

FIGURE 5–1 DRAWING REQUIREMENTS AND NOTES (CONTINUED)

Examples of some other drawing notes	Shot Peening (See BDM–1374)	SHOT PEEN ALL OVER PER BAC5730, ( ) INTENSITY, ( ) COVERAGE SHOT PEEN ALL EXTERNAL SURFACES (EXCEPT THREADS) PER BAC5730. ( )INTENSITY), ( ) COVERAGE GLASS BEAD PEEN THIS SURFACE PER BAC5961. ( ) INTENSITY, ( ) COVERAGE Holes less than .50 inch diameter that require shot peening need a specific drawing callout. Holes .50 inches or greater in diameter that do not require shot peening should be specifically exempted from peening.
Examples of some other drawing notes	Ti–10V–2Fe–3Al forgings with thickness greater than 3 inches.	Ti–10V–2Fe–3Al FORGING PER BMS7–260 EXCEPT IN THE AS–FORGED CONDITION.
	Machined parts made from Ti–10V–2Fe–3Al forgings greater than 3 inches thick.	ROUGH MACHINE TO LESS THAN 3 INCHES SECTION THICKNESS AND SOLUTION HEAT TREAT AND AGE PER BAC5613. FINISH MACHINE PER BAC5492, CLASS (SPECIFY).
	Ti–10V–2Fe–3Al forgings ≤ 3 in. thick.	Ti–10V–2Fe–3Al FORGING PER BMS7–260 CONDITION STA .
	Ti–6Al–4V Beta Annealed forgings with section thickness greater than 4.0 inches.	Ti–6Al–4V ELI FORGING PER BMS7–269 AS–FORGED ROUGH MACHINE TO LESS THAN 4.0 INCH SECTION THICKNESS AND BETA ANNEAL PER BAC5613. FINISH MACHINE PER BAC5492, CLASS (SPECIFY).
	Ti–6Al–4V Beta Annealed forging with section thickness less than 2.0 inches.	Ti–6Al–4V or Ti–6Al–4V ELI FORGING PER BMS7–269, BETA ANNEALED

5 DRAWING REQUIREMENTS AND NOTES (CONTINUED)

FIGURE 5–1 DRAWING REQUIREMENTS AND NOTES (CONCLUDED)

Examples of some other drawing notes	Forgings without prolongations, but large enough for tensile coupon to be removed.	TENSILE COUPON TO BE SAMPLED PER _____(2)_____. (1) (2)
	Ti–10V–2Fe–3Al forgings without prolongations, and too small for tensile coupon to be removed.	TENSILE PROPERTY VERIFICATION SHALL BE ACCOMPLISHED BY FORGING APPROPRIATE SIZE BLANKS AT THE SAME TEMPERATURE AND WITH COMPARABLE DEFORMATION AND FROM THE SAME HEAT LOT AS THE FORGING, USING THE SAMPLING PLAN IN _____(2)_____. (1)
Other requirements	Military	Drawing callout of process specifications should take the following form, e.g. PROCESS PER (2) ((3)MANDATORY FOR BOEING INTERNAL USE)

(1) Fracture toughness may also be required per BMS7–260 or BMS7–269.

Applicable material specification.

(2) If compliance with MIL–STD–970 is required, enter the appropriate government or industry specification. If such compliance is not required, or there is no appropriate government/industry specification, enter the Boeing process specification and omit the parenthetical callout.

(3) Enter the Boeing process specification.