BOMBARDIER

Toronto Site

PROPRIETARY INFORMATION

PPS 30.14

PRODUCTION PROCESS STANDARD

HEAT TREATMENT OF TITANIUM AND TITANIUM ALLOYS

Issue 7

- This standard supersedes PPS 30.14, Issue 6.
- Vertical lines in the left hand margin indicate technical changes over the previous issue.
- Direct PPS related questions to christie.chung@aero.bombardier.com or (416) 375-7641.
- This PPS is effective as of the distribution date.

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1 SCOPE

1.1 This Production Process Standard (PPS) specifies the procedure and requirements for heat treatment of titanium and titanium alloys.

1.1.1 This PPS complements the engineering drawings that specify its use as an authorized instruction. The procedure specified in this PPS shall be followed to ensure compliance with all applicable specifications. In general, if this PPS conflicts with the engineering drawing, follow the engineering drawing. The requirements specified in this PPS are necessary to fulfil the engineering design and reliability objectives.

1.1.2 Refer to PPS 13.26 for the subcontractor provisions applicable to this PPS.

1.1.3 Procedure or requirements specified in a Bombardier BAPS, MPS, LES or P. Spec. do not supersede the procedure or requirements specified in this PPS. Similarly, the procedure and requirements specified in this PPS are not applicable when use of a BAPS, MPS, LES or P. Spec. is specified.

2 HAZARDOUS MATERIALS

2.1 Before receipt at Bombardier Toronto, all materials shall be approved and assigned Material Safety Data Sheet (MSDS) numbers by the Bombardier Toronto Environment, Health and Safety Department. Refer to the manufacturer's MSDS for specific safety data on any of the materials specified in this PPS. If the MSDS is not available, contact the Bombardier Toronto Environment, Health and Safety Department.

3 REFERENCES

3.1 AMS 2750 - Pyrometry.

3.2 ASTM E3 - Standard Practice for Preparation of Metallic Specimens.

3.3 ASTM E8 - Standard Test Methods for Tension Testing of Metallic Materials.

3.4 ASTM E1447 - Standard Test Method for Determination of Hydrogen by the Inert Gas Fusion Thermal Conductivity Method.

3.5 BAERD GEN-018 - Engineering Requirements for Laboratories.

3.6 PPS 1.35 - Machining of Titanium Alloy.

3.7 PPS 13.26 - General Subcontractor Provisions.

3.8 PPS 13.39 - Bombardier Toronto Engineering Process Manual.

3.9 PPS 15.01 - Part Marking.

3.10 PPS 17.02 - Abrasive Blasting.

3.11 PPS 20.03 - Fluorescent Penetrant Inspection.

3.12 PPS 31.09 - Cleaning of Titanium and Titanium Alloys.

3.13 PPS 35.09 - Requirements for Titanium Alloy Forgings.

3.14 QDI-09-02 - Process Control - *Bombardier Toronto internal Quality procedure*.

4 MATERIALS, EQUIPMENT AND FACILITIES

4.1 Materials

4.1.1 Allowable inert gases:

- Argon, Compressed Gas Association (CGA) specification G-11.1, Grade C (dewpoint -76°F or below, oxygen 5 ppm maximum) or equivalent.
- Helium, CGA specification G-9.1, Grade C (dewpoint -76°F or below, oxygen 5 ppm maximum) or equivalent.

4.1.2 Scale inhibiting agent (e.g., Turco Pretreat - Henkel product code IDH 596970, or Everlube Products FormKote T-50).

4.1.3 Low viscosity, high speed quenching oil.

4.2 Equipment

4.2.1 Heating Equipment

4.2.1.1 All heat treatment equipment shall meet the requirements of AMS 2750.

4.2.1.2 Furnaces may be electrically heated or use hydrocarbon fuel provided that gases and flame are muffled and do not impinge on part surfaces.

4.2.1.3 The design and construction of the heating equipment shall be such that after the charge has been brought up to temperature, the temperature variation from the specified heat treating temperature, at any point in the working zone and with any charge, does not exceed the tolerances shown in Table I for the particular alloy and heat treatment.

4.2.1.4 Air or inert atmosphere furnaces shall have a means of re circulating the gases.

4.2.1.5 Use automatic controlling and recording temperature measuring instruments, preferably of the potentiometric type. Adequately protect thermocouples located in the working zone.

4.2.2 Quenching Equipment

4.2.2.1 Suitable tanks for water quenching, equipped with temperature gauges. Tanks shall be of sufficient size such that the parts are completely immersed and can freely move and the necessary quench rates are attained. Quenching water temperature at the completion of the quenching operation shall not exceed 100°F. Quenching oil temperature shall be maintained between 75 and 100°F throughout the quenching operation. Do not use molten salt baths for quenching.

4.2.2.2 Ensure adequate circulation of the quenching medium. Air agitation is prohibited. Equip tanks with temperature indicators of ±5°F accuracy minimum.

4.2.2.3 Locate quenching and handling equipment so that the load is transferred from the heating medium to the quenching medium within the specified quench delay times.

4.2.2.4 Vacuum furnaces shall be equipped for drop bottom quenching.

4.2.2.5 Quench delay times are specified in Flow Chart 3.

4.2.3 Miscellaneous Equipment

4.2.3.1 Suitable trays, hangers and racks for proper material handling.

4.2.4 Approval of Equipment

4.2.4.1 All equipment and facilities shall be approved by Bombardier as meeting the requirements of this PPS and applicable facility Quality Instructions (e.g., QDI-09-02).

4.3 Facilities

4.3.1 This PPS has been categorized as a Controlled Critical Process according to PPS 13.39 and as such only facilities specifically approved according to PPS 13.39 are authorized to perform heat treatment of titanium and titanium alloys according to this PPS.

4.3.2 Bombardier subcontractors shall direct requests for approval to Bombardier Aerospace Supplier Quality Management. Bombardier Aerospace facilities shall direct requests for approval to the appropriate internal Quality Manager.

4.3.3 Facility approval shall be based on a facility report, a facility survey and completion of a qualification test program, if required. The facility report shall detail the materials and equipment to be used, the process sequence to be followed and the laboratory facilities used to show compliance with the requirements of this PPS. Any deviation from the procedure or requirements of this PPS shall be detailed in the facility report. Based upon the facility report, Bombardier Toronto Engineering may identify additional qualification and/or process control test requirements. During the facility survey, the facility requesting qualification shall be prepared to demonstrate their capability. Once approved, no changes to subcontractor facilities may be made without prior written approval from Bombardier Aerospace Supplier Quality Management.

4.3.3.1 For approval of subcontractor facilities to perform heat treatment of titanium and titanium alloys according to this PPS, completion of a test program and submission of suitable test samples representative of production parts is required. Test samples shall meet the requirements specified in section 6.

4.3.3.2 As part of the qualification test program, the facility shall supply Bombardier with all available hydrogen pick-up test data and batch release data (including metallography and tensile tests) for either the last 50 consecutive production batches or the last 2 years.

4.3.3.3 All testing and evaluation specified herein shall only be performed by Bombardier Toronto Materials Laboratory or by laboratories accredited according to BAERD GEN-018.

5 PROCEDURE

5.1 General

5.1.1 Take care to prevent titanium from coming into contact with lubricants, chlorides, chlorinated hydrocarbons and halogen containing compounds.

5.1.2 Machine test samples according to PPS 1.35.

5.1.3 Records shall be maintained of all heat treat operations, including work order number, part number, material specification, furnace or bath, size of charge, heating time, soaking time and temperature and cooling time (when cooled in furnace).

5.1.4 Vacuum atmospheres may be used if the pressure in the heat treating volume does not exceed 1×10^{-4} torr.

5.1.5 Do not use endothermic, exothermic, hydrogen, nitrogen, disassociated ammonia or combustion products atmospheres for heat treatment of titanium or titanium alloys.

5.1.6 Except when heat treating parts above 1500°F, an air atmosphere may be used in either an electric or combustion heated furnace (if using a combustion heated furnace, ensure that the flame is isolated from the working zone). Ensure that the alpha case requirements of section 6 are met. Air atmospheres used at temperatures above 1000°F will result in heat treat discolouration.

5.1.7 If heat treating parts above 1500°F, use a vacuum or an inert atmosphere in an electrically heated furnace.

5.1.8 Before heat treatment, any atmosphere that was previously used to heat treat non-titanium alloys shall be purged from the furnace with a minimum of 2 furnace volumes of air or inert gas. When purging an air atmosphere, the furnace may be held at the soaking temperature of the intended load. When purging an inert atmosphere, ensure that the furnace is charged cold, then purged with air or inert gas while cold.

5.2 Preparation of Material

5.2.1 General

5.2.1.1 Before heat treatment, ensure that all parts are identified according to PPS 15.01.

5.2.1.2 Before heat treatment, clean all parts according to PPS 31.09.

5.2.1.3 Before heat treating parts 1000°F and above in an air atmosphere, process parts as follows:

Step 1. Clean parts according to PPS 31.09 ensuring that part surfaces are water break-free and free from any contaminants including fingerprints, shop soil, etc.

Step 2. Within 4 hours of cleaning, apply scale inhibiting protective coating according to section 5.2.2. If the parts are stored longer than 4 hours, solvent clean the surfaces according to PPS 31.17 immediately before applying the protective coating. Application of the coating is not required if, after heat treatment, parts will be machined all over by 0.010" minimum.

Step 3. Verify that the protective coating is free of blisters, continuous, adherent and meets the minimum thickness specified. If necessary, remove the protective coating by alkaline cleaning according to PPS 31.09 and re-apply.

5.2.2 Application of Scale Inhibiting Protective Coating

5.2.2.1 For application of scale inhibiting protective coating, apply Turco Pretreat, FormKote T-50 or an alternative product which will serve the same function. Apply Turco Pretreat scale inhibiting protective coating by spray according to paragraph 5.2.2.3. Apply FormKote T-50 according to paragraph 5.2.2.4. Apply alternative scale inhibiting protective coating according to the manufacturers instructions.

5.2.2.2 The coating need not be removed and re-applied between each stage of a multiple stage heat treatment process. However, inspect the coating and repair if damaged before each stage of the heat treatment process to ensure the integrity of the coating.

5.2.2.3 Spray apply Turco Pretreat as follows:

Step 1. Thoroughly mix Turco Pretreat before use.

Step 2. Dilute Turco Pretreat with the solvent specified in PPS 31.17 to the desired viscosity (approximately 30 to 40 seconds measured with a No. 1 Zahn cup).

Step 3. For parts to be heat treated below 1450°F, spray apply to achieve a dry film thickness of 0.0002" to 0.0005". For parts to be heat treated at 1450°F and above, spray apply in two cross coats to achieve a total dry film thickness of 0.0005" to 0.001".

Step 4. Allow the parts to air dry for a minimum of 10 minutes before handling and for at least 24 hours before exposure to heat treat conditions.

Step 5. If required, wrap with protective paper or plastic.

5.2.2.4 Apply FormKote T-50 as follows:

Step 1. Thoroughly stir FormKote T-50 before removal from its original container. Do not dilute.

Step 2. Spray apply to achieve a dry film thickness of 0.0004" minimum. If two coats are required, apply the second coat after flash-off of the first coat is complete.

Step 3. Allow the part to air dry for 30 minutes minimum.

5.3 Heat Treatment Handling

5.3.1 When handling titanium, take care to prevent contamination of the part with grease, oil, fingerprints or any other substances which may be detrimental to the part properties.

5.3.2 Examine and clean heat treatment fixtures before processing parts. Ensure that any areas of the fixtures that come into contact with the parts are free of loose scale, dirt, oil, water, or any materials that are volatile or that may spall at the heat treatment temperature.

5.3.3 Place or hang parts in suitable racks or supports in a manner that allows free circulation of the heating and quenching media and minimizes distortion and warpage during heating and quenching.

5.3.4 Except when using a vacuum furnace, load parts by opening the furnace door, inserting the parts and closing the furnace door as rapidly as possible. When loading and unloading parts, avoid causing nicks or other damage to the surface of finished parts. When loading parts having a heat treatment protective coating, take care to avoid damaging the coating.

5.3.5 Except for vacuum furnaces, before loading, ensure the furnace is operating at the middle of the specified temperature range before loading it. If using a vacuum furnace, loading parts at room temperature is acceptable. Set temperature control instruments at the correct operating temperature.

5.4 Heating and Soaking

5.4.1 Soak parts at the required temperature for not less than the specified time.

5.4.2 The soaking time commences when, after loading the furnace, the temperature has returned to the middle of the specified range.

5.5 Annealing

5.5.1 Anneal parts according to Flow Chart 1.

5.6 Stress Relieving

5.6.1 Stress relieve parts according to Flow Chart 2. When stress relieving material in the solution heat treated or precipitation age hardened condition, aging or over aging will occur according to paragraph 5.8.3 and paragraph 5.8.4.

5.7 Solution Heat Treatment

5.7.1 Solution heat treat parts according to Flow Chart 3.

5.8 Aging

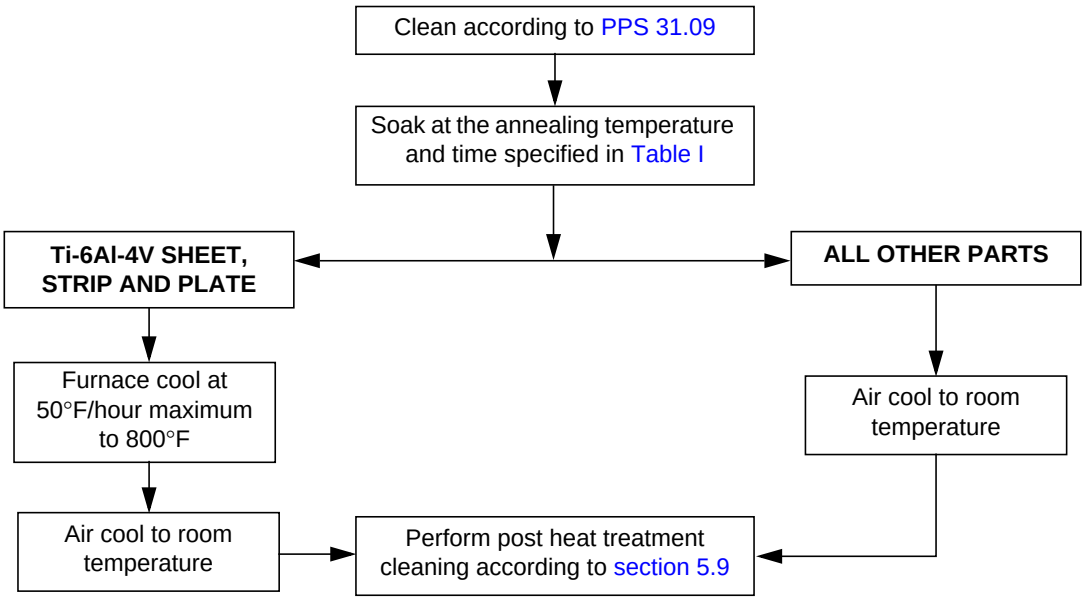
5.8.1 Ensure that material is in the solution heat treated condition before aging.

5.8.2 Age parts according to Flow Chart 4.

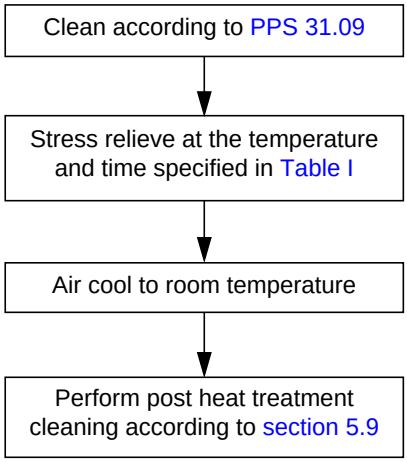
5.8.3 When stress relieving or hot forming material in the solution heat treated condition and the total time at temperature is less than the aging time specified in Table I, heat treat parts for the remaining time to the fully aged condition.

5.8.4 Stress relieving of material in the aged condition results in an over aged condition and Bombardier Engineering approval is required before carrying out such treatment.

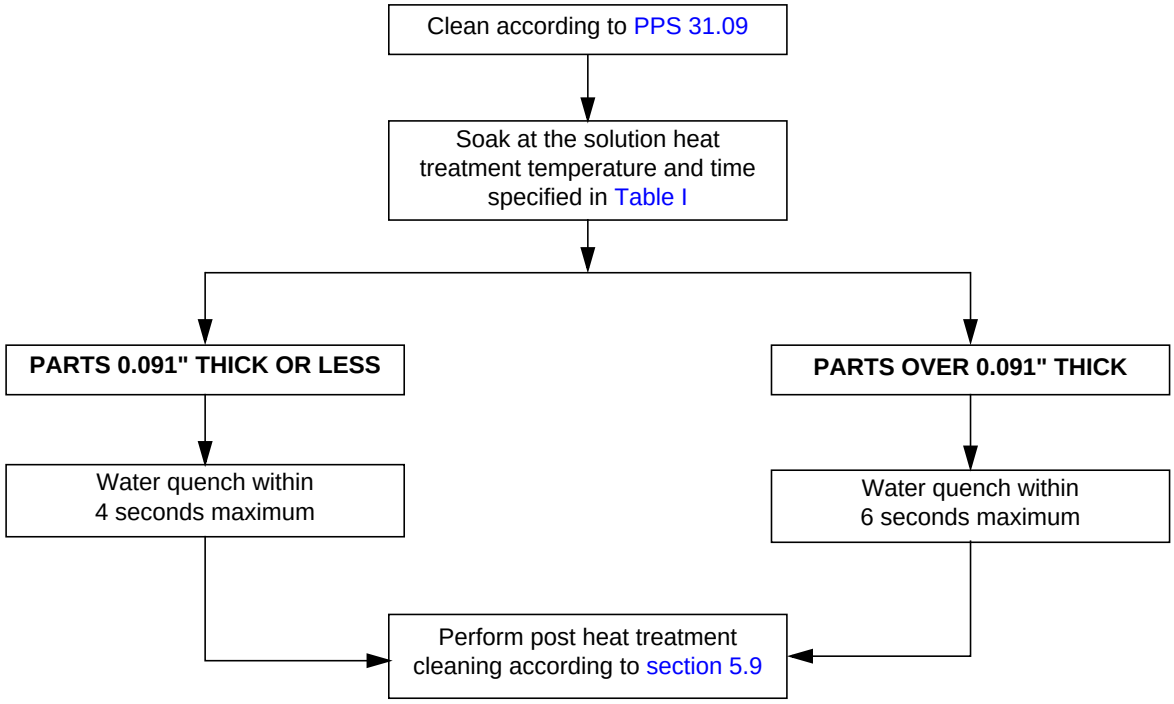
FLOW CHART 1 - ANNEALING



FLOW CHART 2 - STRESS RELIEVING



FLOW CHART 3 - SOLUTION HEAT TREATING



FLOW CHART 4 - AGING

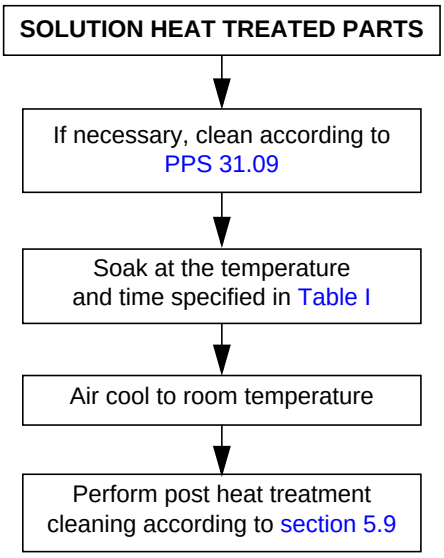


TABLE I - HEAT TREATMENT OF TITANIUM AND TITANIUM ALLOYS

TYPE AND ALLOY	MATERIAL SPECIFICATION	FORM	ANNEALING (Note 1)	STRESS RELIEF (Note 1)	SOLUTION HEAT TREATMENT (Note 1)	AGING (Note 1)
Commercially pure titanium, unalloyed	AMS 4901 and AMS 4902	Sheet, Strip and Plate	1275 ± 25°F for 1 hour	1000 ± 25°F for 30 minutes	—	
Commercially pure titanium, Ti-CP-70	MIL-T-9047	Bar and Forgings	1275 ± 25°F for 1 hour	1000 ± 25°F for 1 hour		
	AMS 4901	Plate	1275 ± 25°F for 1 hour	1000 ± 100°F for 1 hour		
Alpha Ti-5Al-2.5Sn	AMS 4910	Sheet, Strip and Plate	1475 ± 25°F for 1 hour (Note 2)	1100 ± 25°F for 1 hour		
			1525 ± 25° for 15 minutes (Note 3)			
	MIL-T-9047	Bar and Forgings	1500 ± 25° for 1 hour	1100 ± 25°F for 2 hours		
Alpha-Beta Ti-6Al-4V	AMS 4911	Sheet, Strip and Plate	1325 ± 25°F for 1 hour	1100 ± 25°F for 2 hours	1650 ± 25°F for 30 minutes	1000 ± 10°F for 5 hours
	MIL-T-9047	Bar and Forgings	1300 ± 25°F for 2 hours	1100 ± 25°F for 5 hours	1700 ± 25°F for 1 hour	1000 ± 10°F for 5 hours
Beta Ti-11.5Mo-6Zr-4.5Sn	MIL-T-9046 Type IV Comp B	Plate	—		1325 ± 25°F for 15 minutes	1000 ± 10°F for 8 hours

Note 1. Soaking times given are minimums.
Note 2. When annealing in an inert gas or vacuum furnace.
Note 3. When annealing in an air furnace.

5.9 Post Heat Treatment Cleaning

5.9.1 Remove any heat treatment protective coating applied according to section 5.2 by cleaning according to PPS 31.09.

5.9.2 Except as noted below, de-scale parts heat treated in air by etching according to PPS 31.09, abrasive blast cleaning according to PPS 17.02 or machining according to PPS 1.35.

- It is acceptable, but not mandatory, to de-scale commercially pure titanium parts after stress relief provided that there has been no other scale build-up.

5.9.3 It is acceptable, but not mandatory, to remove straw-coloured oxides from the part surfaces after heat treatment in a vacuum or inert atmosphere by etching according to PPS 31.09 or abrasive blast cleaning according to PPS 17.02.

6 REQUIREMENTS

6.1 General

6.1.1 All testing and evaluation specified herein shall only be performed by Bombardier Toronto Materials Laboratory or by laboratories accredited according to BAERD GEN-018.

6.1.2 Process production parts with a minimum of 2 tensile and 2 metallographic test specimens from the same batch of material. These test specimens shall accompany the represented parts through all processing steps, including heat treatment, forming and chemical processing.

6.1.3 One of each type of specimen shall be tested by the heat treating facility and the results shall be used for the Certificate of Conformance. Submit the remaining test specimens to Bombardier Toronto along with the Certificate of Conformance.

6.1.4 Off-cut material may be used for testing instead of processing separate test specimens.

6.1.5 Test specimens are not required when stress relieving commercially pure titanium.

6.2 Hydrogen Pick-Up

6.2.1 Hydrogen shall not exceed 125 ppm on any titanium part when tested according to ASTM E1447.

6.2.2 Hydrogen will be checked during process qualification and annually thereafter.

6.3 Fluorescent Penetrant Inspection

6.3.1 If specified by the engineering drawing, fluorescent penetrant inspect parts and material according to PPS 20.03.

6.4 Surface Oxidation

6.4.1 There shall be no evidence of alpha case on any titanium parts. Alpha case is an oxygen-enriched alpha structure on the part surface due to oxygen pick-up during heat treatment.

6.4.2 Parts heat treated in an inert atmosphere that display any surface discolouration darker than straw colour (e.g., light violet, dark violet, blue or gray) are not acceptable.

6.5 Metallography

6.5.1 Prepare metallographic test specimens according to ASTM E3.

6.5.2 Metallographic specimens shall reveal a microstructure typical of the alloy they represent.

6.5.3 When heat treating alpha-beta alloys, there shall be no evidence the beta transus temperature has been exceeded (i.e., a transformed beta microstructure).

6.6 Tensile Testing

6.6.1 Tensile test specimens according to ASTM E8.

6.6.2 Mechanical properties shall comply with the requirements of the engineering drawing or those properties specified in Table II.

6.6.3 Tensile test forgings according to PPS 35.09.

6.7 Aging

6.7.1 Age solution heat treated parts as specified herein. Parts shall not be used in the solution heat treated condition.

7 SAFETY PRECAUTIONS

7.1 Safety precautions applicable to the materials and procedures specified herein shall be defined by the subcontractor performing the work for Bombardier Toronto.

8 PERSONNEL REQUIREMENTS

8.1 This PPS has been categorized as a Controlled Critical Process according to PPS 13.39. Refer to PPS 13.39 for additional personnel requirements. Certified and/or qualified personnel shall have a good working knowledge of the following, as applicable:

- engineering drawings, work order instructions and PPS sections regarding the heat treatment of titanium and titanium alloys.
- how to set up and operate heat treat furnaces, thermocouples, quenching and rinsing equipment.
- physical and mechanical properties of titanium and titanium alloys.
- definitions, significance and application of alloying elements, solution heat treatment, annealing, stress relieving, aging, cooling and quenching.

TABLE II - MECHANICAL PROPERTIES OF SOLUTION HEAT TREATED AND AGED TITANIUM

TYPE & ALLOY	MATERIAL SPECIFICATION	FORM	SECTION AS HEAT TREATED		MINIMUM TENSILE STRENGTH (ksi)	MINIMUM YIELD STRENGTH 0.2% offset (ksi)	MINIMUM ELONGATION (Note 2)	MINIMUM REDUCTION IN AREA
			thickness	width				
Alpha-beta Ti-6Al-4V	AMS 4911	Sheet & strip	up to 0.032"	---	160	145	3.0%	---
			0.033" - 0.049"				4.0%	
			0.050" and over				5.0%	
		Plate	0.1875" - 0.750"	---	160	145	8.0%	
			0.751" - 1.000"		150	140	6.0%	
			1.001" - 2.000"		145	135	6.0%	
			2.001" - 4.000"		130	120	6.0%	
	MIL-T-9047	Bar & forging	up to 0.500"	0.501" - 8.000"	160	150	10.0%	25.0%
			0.501" - 1.000"	1.001" - 4.000"	155	145	10.0%	20.0%
			0.501" - 1.000"	4.001" - 8.000"	150	140	10.0%	20.0%
			1.001" - 1.500"	1.501" - 4.000"	150	140	10.0%	20.0%
			1.001" - 1.500"	4.001" - 8.000"	145	135	10.0%	20.0%
			1.501" - 2.000"	2.001" - 4.000"	145	135	10.0%	20.0%
			1.501" - 2.000"	4.001" - 8.000"	140	130	10.0%	20.0%
			2.001" - 3.000"	3.001" - 8.000"	135	125	10.0%	20.0%
			3.001" - 4.000"	4.001" - 8.000"	130	120	8.0% (6.0%)	15.0% (10.0%)
Beta Ti-11.5Mo-6Zr-4.5Sn	MIL-T-9046 Type IV Comp B	Plate	0.1875" - 4.000"	---	180	170	6.0%	---

Notes: 1. Mechanical properties apply to both longitudinal and transverse directions unless otherwise shown in this Table. Values in brackets apply to the short transverse direction.
2. % elongation in 4D, 2 inches or 4.5√A, as applicable.