BOMBARDIER

Toronto (de Havilland)

PROPRIETARY INFORMATION

PPS 1.36

PRODUCTION PROCESS STANDARD

Forming of Titanium and Titanium Alloys

Issue 11
- This standard supersedes PPS 1.36, Issue 10.
- Vertical lines in the left hand margin indicate technical changes over the previous issue.
- Direct PPS related questions to PPS.Group@aero.bombardier.com or (416) 375-4365.
- 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 the forming 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 must 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 1.07 for the procedure and requirements for dimpling of titanium alloys.

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

1.1.4 Refer to PPS 1.35 for the procedure and requirements for machining of titanium and titanium alloys.

1.1.5 Procedure or requirements specified in a Bombardier BAPS, MPS, LES or P. Spec. **do not** supersede the procedure or requirements specified in this PPS.

2 Hazardous Materials

2.1 Before receipt at Bombardier Toronto (de Havilland), all materials must be approved and assigned Material Safety Data Sheet (MSDS) numbers by the Bombardier Toronto (de Havilland) 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 (de Havilland) Environment, Health and Safety Department.

3 References

3.1 ASTM E8 - Tension Testing of Metallic Materials.

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

3.3 DS 50 - Fits and Tolerances - *Bombardier Toronto (de Havilland) Design Standard*.

3.4 PPS 1.07 - Dimpling Ferrous, Nickel and Titanium Alloys.

3.5 PPS 1.35 - Machining of Titanium Alloy.

3.6 PPS 13.22 - Application of Fit-Up Forces.

3.7 PPS 13.26 - General Subcontractor Provisions.

3.8 PPS 13.39 - Bombardier Toronto Engineering Process Manual.

3.9 PPS 20.03 - Fluorescent Penetrant Inspection.

3.10 PPS 27.04 - Edge Finishing Titanium Alloy Parts.

3.11 PPS 30.14 - Heat Treatment of Titanium and Titanium Alloys.

3.12 PPS 31.09 - Cleaning of Titanium and Titanium Alloys.

4 Materials, Equipment and Facilities

4.1 Materials

4.1.1 Titanium and titanium alloys as specified on the engineering drawing.

4.1.2 Hot forming lubricant, chloride free (e.g., Everlube Corp. of America Formkote T-50). Hot forming lubricants used in the forming of titanium alloys as specified in this PPS must be free of chlorides and must not ignite or break down at the forming temperatures specified herein.

4.1.3 Argon gas, Technical grade (e.g., MIL-A-18455).

4.1.4 Superplastic forming lubricants:

- Yttria Powder, -325 mesh, 99.9% purity.
- Boron Nitride, commercial powder, 99% minimum purity.

4.1.5 Cotton gloves (e.g., DSC 422-1).

4.1.6 Cold forming lubricant, chloride free (e.g., petroleum jelly). Cold forming lubricants used in the forming of titanium alloys as specified in this PPS must be free of chlorides.

4.2 Equipment

4.2.1 Forming machines, furnaces, hand held tools, form blocks, bladders, lubricants and dies as necessary to meet the requirements of this standard.

4.3 Facilities

4.3.1 This PPS has been categorized as a “Controlled Special Process” according to PPS 13.39 and as such only facilities specifically approved according to PPS 13.39 are authorized to perform forming of titanium and titanium alloys according to this PPS.

4.3.2 Bombardier subcontractors must direct requests for approval to Bombardier Aerospace Supplier Quality Management. Bombardier Aerospace facilities must 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 must 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 must be detailed in the facility report. Based upon the facility report, Bombardier Toronto (de Havilland) Materials Technology may identify additional qualification and/or process control test requirements. During the facility survey, the facility requesting qualification must 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 Unless otherwise specified by Bombardier Aerospace Supplier Quality Management, for approval of subcontractor facilities to perform forming 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 must meet the requirements specified in section 6.

5 Procedure

5.1 General

5.1.1 At room temperature, commercially pure titanium is similar in formability to 1/4 hard cold rolled stainless steel, although springback is slightly higher (20 to 30 percent of the bend angle). Alloyed grades of titanium are similar in formability to full hard cold rolled stainless steel. Refer to Table 1 for a listing of the relative formability of the most commonly used commercially pure and alloyed grades of titanium.

5.1.2 *Alpha Case* is a hard surface oxide caused by inward diffusion of oxygen during elevated temperature processing.

5.1.3 *Superplastic Forming (SPF)* is an elevated temperature process (1600°F to 1700°F (871°C to 927°C)) used when the greatest degree of formability is required, up to 200% equivalent strain.

5.1.4 *Beta* (β) *Tranus* is the temperature at which the β-phase becomes stable (approximately 1815°F to 1840°F (991°C to 1004°C) for alpha-beta Ti alloys), characterized by an acicular α phase (transformed β) within the microstructure.

5.1.5 As titanium is susceptible to surface contamination which may cause cracking during fabrication or in service, take the following precautions during all stages of the forming process:

- Do not use tools, locating pins, nuts, bolts, shop aids, clamps, fixtures or other assembly or installation tooling plated with any of the following materials: lead, zinc, cadmium, bismuth, tin or silver.
- The use of colour change or wax melt type temperature indicators is prohibited.
- If multi-stage forming is required, carry out intermediate stress relief according to PPS 30.14 to prevent cracking.
- It is acceptable to use soft metal dies (e.g., Kirksite) for cold (room temperature) forming operations but not for forming processes which require a dwell time at elevated temperatures (i.e., hot sizing).
- Always wear clean cotton gloves when handling titanium and titanium alloy parts.

5.1.6 The following abbreviations define the heat treat conditions of titanium and titanium alloys:

- A - Annealed
- ST - Solution Treated
- STA - Solution Treated and Aged.

Table 1 - Relative Formability

<table>
<tr><th rowspan="2">MATERIAL GRADE</th><th colspan="3">SPECIFICATION</th><th rowspan="2">COMMERCIAL DESIGNATION</th><th rowspan="2">MATERIAL FORMABILITY</th></tr>
<tr><th colspan="2">OLD CLASSIFICATION</th><th>NEW CLASSIFICATION</th></tr>
<tr><td rowspan="3">Commercially Pure</td><td rowspan="3">MIL-T-9046 Type I</td><td>COMP A</td><td>CP-3</td><td>Ti - 40</td><td rowspan="3">Readily formable at room temperature</td></tr>
<tr><td>COMP C</td><td>CP-2</td><td>Ti - 55</td></tr>
<tr><td>COMP B</td><td>CP-1</td><td>Ti - 70</td></tr>
<tr><td rowspan="2">Alloyed Grade</td><td>MIL-T-9046 Type II</td><td>COMP A</td><td>A-1</td><td>Ti-5AL-2.5 Sn</td><td>Formable at room temperature, hot forming recommended for complex shapes</td></tr>
<tr><td>MIL-T-9046 Type III</td><td>COMP C</td><td>AB-1</td><td>Ti-6AL-4V</td><td>Hot Formable, Superplastic Formable (Note 1)</td></tr>
<tr><td colspan="6">Note 1. Material used for Superplastic forming must be of a suitable grain size and quality.</td></tr>
</table>

5.2 Preparation of Parts and Equipment

5.2.1 Prepare parts for forming as follows:

Step 1. Ensure parts have been deburred and edge finished according to PPS 27.04.

Step 2. Remove any contaminants or foreign residue (i.e., dirt, scale, machining lubricants, finger prints, etc.) from the parts by cleaning according to PPS 31.09.

Step 3. Ensure the part is thoroughly dry

Step 4. Coat the part with a thin uniform layer of forming lubricant. If cold forming, use of forming lubricant is optional

Step 5. Allow sufficient time to elapse for the solvent carrier of the forming lubricant to evaporate.

5.2.2 Before use, ensure that tooling fixtures and forming equipment are clean and free of any foreign materials (e.g., dirt, oil, water, machining lubricants other than forming lubricants, etc.).

5.3 Cold (Room Temperature) Forming

5.3.1 Refer to Table 2 and Table 3 for the limits on stretching and press forming titanium at room temperature. Material in conditions outside the limits specified must be hot formed/sized according to section 5.4.

5.3.2 Provided the limits specified in Table 2 and Table 3 are met, the following are acceptable:

- A brake press or rolls may be used for forming straight sections requiring only single axis bending.
- Curved flanges may be cold formed using mechanical dies.
- Angles, shapes and **simple** double curvature skins may be cold formed on a stretch press or bulge form, however, **severe** forms may require hot sizing according to section 5.4. Provide sufficient allowance for springback.
- Pre-formed parts may be joggled at room temperature.
- The rubber press may be used for pre-forming parts before hot forming according to section 5.4.

5.3.3 If possible, orient the major bend axis of the part at right angles to the direction of rolling.

Table 2 - Limits for Cold (Room Temperature) Joggling

MATERIAL	CONDITION	THICKNESS	"A" MINIMUM	"D" MAXIMUM	"L" MINIMUM	BEND RADIUS
Ti-40	Annealed	0.050" Max	4D	4T	5D	4T Minimum
Ti-55						
Ti-70			6D	3T		
Ti-6Al-4V	Annealed	0.050" Max	8D	2 1/2T	6D	5T Minimum
Ti-5Al-2.5 Sn			6D	3T		

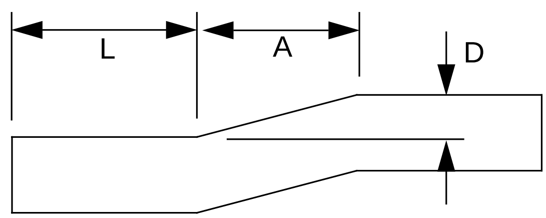


Table 3 - Cold (Room Temperature) Bend, Stretch And Shrink Limits

MATERIAL	CONDITION	MAXIMUM SHRINK (%)	MAXIMUM STRETCH (%)	BEND RADIUS (MINIMUM)	BEND ANGLE (MAXIMUM)
Ti-40	A	4	15	3T	105°
Ti-55					
Ti-70	A	3.5	12	4T	
Ti-6Al-4V	A	1	4	5T	
	ST	0.5		6T	
Ti-5Al-2.5 Sn	A	1	4	5T	

5.4 Hot Forming and Hot Sizing

5.4.1 Hot sizing is a final forming operation, accomplished by clamping formed parts in suitable moulds, jigs or fixtures before heating. Hot sizing allows creep flow of the material, reducing springback.

5.4.2 It is acceptable to form parts using heated dies or platens.

5.4.3 It is not acceptable to use the open flame method for heating parts.

5.4.4 Refer to Table 4 for the minimum elevated temperature bend radius.

5.4.5 Refer to Table 5 for the time and temperature limits for hot forming and hot sizing.

5.4.6 Refer to Table 6 for the elevated temperature limits for stretching and press forming.

5.4.7 Refer to Table 7 for hot joggling limits for extruded shapes and pre-formed sheet.

Table 4 - Hot Forming Bend Radii

MATERIAL CONDITION	MINIMUM BEND RADII
A	2T
ST	3T
STA	

Table 5 - Time and Temperature Limits for Hot Forming and Hot Sizing

MATERIAL	STARTING CONDITION	FINAL CONDITION	FORMING TEMPERATURE (Note 1)	MAXIMUM TIME AT TEMPERATURE (Note 2)
Ti-40/Ti-55	A	A	900°F - 1300°F (482°C - 704°C)	60 minutes
Ti-70	A	A	900°F - 1300°F (482°C - 704°C)	60 minutes
Ti-6Al-4V	A	A	1375°F - 1475°F (746°C - 802°C)	60 minutes
	ST	STA	975°F - 1025°F (524°C - 552°C)	240 minutes (Note 3)
	STA	STA	975°F - 1025°F (524°C - 552°C)	240 minutes
Ti-5Al-2.5 Sn	A	A	1150°F - 1500°F (621°C - 816°C)	45 minutes

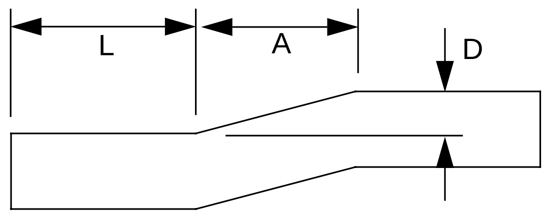
Note 1. Parts formed at temperatures lower than specified value must be stress relieved after forming.
Note 2. Maximum time at temperature may be accumulated over a maximum of 2 cycles.
Note 3. If the total time is not used in the forming cycle, the remaining time must be used in the aging cycle.

Table 6 - Hot Forming Stretch and Shrink Limits

MATERIAL	CONDITION	TEMPERATURE	MAXIMUM SHRINK (%)	MAXIMUM STRETCH (%)
Ti-40/Ti-55	A	1275°F ± 25 F° (691°C ± 14 C°)	4	25
		600°F ± 25 F° (316°C ± 14 C°)	2	18
Ti-70	A	1275°F ± 25 F° (691°C ± 14 C°)	3	20
		600°F ± 25 F° (316°C ± 14 C°)	1.5	8
Ti-6Al-4V	A	1425°F ± 50 F° (774°C ± 28 C°)	2	12
	STA	1000°F ± 25 F° (538°C ± 14 C°)	2	8
Ti-5Al-2.5 Sn	A	1475°F ± 25 F° (802°C ± 14 C°)	4	25

Table 7 - Limits for Hot Joggling

MATERIAL	FORM AND CONDITION	THICKNESS	"A" MINIMUM	"D" MAXIMUM	"L" MINIMUM	BEND RADIUS
Ti-40	Annealed and extruded shapes only	0.050" Maximum	3D	2T	3D	2T
Ti-55						
Ti-70						
Ti-5Al-2.5 Sn						
Ti-6Al-4V	Annealed, extruded shapes and roll form sections	0.050" Maximum	3D	2T	3D	2T
	Extruded and Rolled shapes -ST, STA		4D	3T	4D	2T



5.5 Superplastic Forming

5.5.1 Superplastic form each part according to the forming technique sheet certified according to the requirements specified on the engineering drawing. Complete forming operations at 1600°F to 1700°F(871°C to 927°C). Refer to the forming technique sheet for the maximum time at temperature and the number of cycles.

5.5.2 An argon shroud must be used when Superplastic forming.

5.5.3 Maintain the following parameters within the specified tolerance during the forming operation:

- Strain rate: ....± 5 mm/min of pre-set value (if applicable)
- Pressure-time profile:..............± 5 ft/lb of pre-set value
- Temperature profile: ....± 25 F° (± 14 C°) of the pre-set value
- Total time of forming cycle:......± 2 minutes of the set time

5.5.3.1 Ensure the strain rate, pressure time profile, temperature profile and the total time of the forming process are monitored and recorded.

5.5.4 To reduce hydrogen concentration levels, it is recommended to use vacuum degassing (vacuum annealing) as the final processing step in Superplastic forming.

5.6 Post Forming Operations

5.6.1 After forming process parts as follows:

Step 1. If necessary, hand dress parts to correct the forming angles, to remove waviness from flanges or to improve joggle definition using masonite or plastic faced tools on form blocks. **Do not** hand dress conical flutes incorporated into shrink flanges to dispose of excess material, to improve the appearance of the flute or to change the flute radius.

Step 2. Except as noted below, stress relieve cold formed or straightened parts according to PPS 30.14:

- Parts with straight line bends do not require stress relief.
- Contoured skins with a radius of 40" and greater, do not require stress relief.

Step 3. Remove foreign material, surface contamination, die pick-up, alpha case, residue, etc. by cleaning/etching parts according to PPS 31.09. Handle cleaned parts with clean cotton gloves.

Step 4. Wrap the parts with neutral Kraft paper or plastic to protect the surface.

6 Requirements

6.1 After forming and chemical processing (i.e., stress relief, etching, cleaning, etc.) check formed parts as specified in Table 8. Off-cut material from formed parts that has accompanied the parts throughout all processing may be used for batch testing.

6.2 Formed parts must conform to the dimensional requirements of the engineering drawing and the tolerance requirements of DS50. Slight deviations from the specified contour or fit which can be eliminated by application of fit-up forces according to PPS 13.22 are acceptable.

6.3 The material thickness of the parts after forming must meet the requirements specified on the engineering drawing and the thinning limits specified in Table 9.

6.4 Finished parts shall be clean and free of foreign residue or material.

6.5 For superplastic forming (SPF), a technique sheet must be prepared and maintained for each part. Before use, SPF technique sheets must be certified. If there are any changes to the parameters specified on the SPF technique sheet or a change in the manufacturing process the SPF technique sheet must be re-certified. SPF technique sheets must be certified or re-certified as follows:

Step 1. Prepare an actual part or parts for testing. For initial certification of an SPF technique sheet prepare a minimum of two actual parts for testing. For re-certification of an SPF technique sheet prepare at least one actual part for testing.

Step 2. Submit the part or parts to fluorescent penetrant inspection according to PPS 20.03.

Step 3. Submit the part or parts to metallographic examination, tensile testing and hydrogen analysis as specified in Table 8 at each of the locations specified on the engineering drawing.

Table 8 - Requirements for Formed Parts

FORMING METHOD	METALLOGRAPHIC INSPECTION	TENSILE TESTING ACCORDING TO ASTM E8	HYDROGEN ANALYSIS ACCORDING TO ASTM E1442	FLUORESCENT PENETRANT INSPECTION ACCORDING TO PPS 20.03
cold formed	n/a	n/a	n/a	100% of batch required
hot formed/sized	one test specimen per batch (Note 1)	one test specimen per batch	n/a	100% of batch required
superplastic formed	one test specimen per batch (Note 2)	one test specimen per batch	one test specimen per batch (Note 3)	100% of batch required

Note 1. Check for surface contamination.

Note 2. Parts with microstructural evidence of alpha case or of heating above the beta transus, as indicated by a transformed beta microstructure, are not acceptable. The location and number of microstructural tests shall be as specified by the forming technique sheet.

Note 3. Hydrogen concentration shall not exceed 125 ppm.

Table 9 - Metal Thinning Limits

MATERIAL	CONDITION	MAXIMUM THINNING
Ti-40	A	25%
Ti-55		
Ti-70	A	20%
Ti-6Al-4V	A	15%
	ST	
	STA	12%
Ti-5Al-2.5 Sn	A	20%

7 Safety Precautions

7.1 Observe general shop safety precautions when performing the procedure specified herein.

7.2 Forming lubricants can be extremely toxic, therefore, avoid skin contact with forming lubricants. If skin contact does occur, take the steps recommended by the applicable MSDS immediately.

8 Personnel Requirements

8.1 This PPS has been categorized as a “Controlled Special Process” by PPS 13.39. Refer to PPS 13.39 for personnel requirements.