



P.O. Box 460, 530 34TH Avenue SW
Albany, OR 97322
Phone (Casting Sales): 541-812-7241 Fax: 541-812-7446

Approved for Distribution
By Quality Assurance

Smels 4/27/10
(Name) (Date)

**ATI - WAH-CHANG
MATERIAL SPECIFICATION**

SPECIFICATION: **OMC-105**
REVISION: **L**
DATE: **April 2010**
PAGE: **1 of 10**

TITLE: TITANIUM AND TITANIUM ALLOY CASTINGS

1. SCOPE

- 1.1 This specification outlines casting descriptions and manufacturing methods used to produce titanium and titanium alloy rammed graphite castings meeting ASTM B 367 for commercial and military applications. References and practices may be specific to each application.

2. REFERENCES: The following publications form a part of this specification to the extent specified herein. Unless otherwise denoted in the Purchase Order, the latest approved revisions shall prevail.

ASTM B367	Standard Specification for Titanium and Titanium Alloy Castings
ASTM E94	Standard Gauge for Radiography Examination
ASTM E446	Reference Radiographs for Steel Castings, Vol II
ASTM E186	Reference Radiographs for Steel Castings, Vol I, II
ASTM E280	Reference Radiographs for Steel Castings, Vol I
ASTM E1320	Reference Radiographs for Titanium Castings, Vol I, II
MSS SP-55	Visual Method for Surface Evaluation of Surface Irregularities
ASTM E 8	Test Methods of Tension Testing of Metallic Materials
ASTM E 10	Test Methods for Brinell Hardness of Metallic Materials
ASME Section IX	Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators
S9074-AQ-GIB-010/248	Requirements for Welding and Brazing Procedure and Performance Qualification
S9074-AR-GIB-010/278	Requirements for Fabrication Welding and Inspection, and Casting Inspection and Repair For Machinery, Piping, and Pressure Vessels
T9074-AS-GIB-010/271	Requirements for Nondestructive Testing Methods

3. CLASSIFICATION OF TITANIUM CASTINGS

The following pattern classes are designed to recognize responsibility for dimensional control between the customer and Wah Chang. The definition of pattern classes does not negate good workmanship and foundry practice on the part of Wah Chang.

- 3.1 Class I: Castings made to this designation are "products of the pattern" as supplied by the customer. Dimensioning of the pattern equipment and/or castings will not be provided. The customer assumes the responsibility that resultant castings will meet dimensional requirements.



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3.2 Class II: Utilizing the customer supplied pattern, Wah Chang will dimensionally inspect the pattern and recommend modifications as necessary to produce a dimensionally acceptable casting to the applicable casting drawing requirements, providing, the casting tolerances of the customer supplied casting drawing fall within the dimensional control criteria of Para. 4 herein. The cost for this service will vary depending upon the complexity of the pattern equipment. In the event of necessary pattern modifications, the customer shall be notified in writing. All modifications and related costs must be approved in writing by the customer prior to implementing the modifications. If requested by the customer at the time of placement of the Purchase Order, a first article dimensional casting layout will be performed and will be available for customer review.

3.3 Class III: Wah Chang will provide the pattern equipment and insure that the resulting castings will meet the dimensional tolerances of the applicable casting drawing providing the casting tolerances of the customer supplied casting drawing fall within the dimensional control criteria of Para. 4 herein. A first article dimensional casting layout will be performed on castings produced from this equipment. Upon request, the dimensional report will be available for customer review.

4. DIMENSIONAL CONTROL:

Unless otherwise agreed upon and specified in the Purchase Order, the following dimensional criteria shall supercede drawing dimensions for Class II and Class III castings.

4.1 Minimum Section Thickness: 3/16", 1/8" if less than one square inch of surface.

4.2 Base Tolerance:

Up to one linear inch	± 1/32"
1 inch up to 10 inches	± 1/16"
10 inches up to 20 inches	± 1/8"
20 inches up to 60 inches	± 3/16"

4.3 Additional Tolerances:

4.3.1 For dimensions across the parting line: ± 1/8"

4.3.2 Added tolerance for dimensions affected by parting line and parallel to the parting line (mismatch)

Less than 10"	± 1/16"
10" and above	± 1/8"



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- 4.4 Radius Dimensions: General radius to conform to base dimensions.
Sharp to 1/8" radius $\pm$ 1/32" (convex)
Up to 1/2" fillet radius $\pm$ 1/32" (concave)
- 4.5 Finish Stock: Nominal 1/8" on all machined surfaces on dimensions less than 12 inches.
Nominal 3/16" – 1/4" on all machined surfaces greater than 12".
- 4.6 Angles: $\pm$ 1 degree.

Note: These dimensions are not limiting to the process, but represent capabilities without trial and correction effort.

5. PART IDENTIFICATION

5.1 Identification nomenclature shall be cast or marked using low stress steel stamps and/or vibratory pencil in a location indicated on the part drawing. If the location is not provided, nomenclature shall be located if possible in a non-machined area. Identification shall include;

- ASTM Specification Number
- Material Grade Symbol (i.e.; C2)
- Manufacturer's Name or Mark
- Pattern Number
- Part Identification Number (traceable to the heat/pour number)

6. CHEMICAL COMPOSITION (see TABLE I)

- 6.1 Samples for chemical analysis shall be obtained from the pour being represented and shall be in the "as-cast" condition.
- 6.2 Methods for chemical analysis shall be by standard Wah Chang analytical procedures.
- 6.3 Variations to chemical composition requirements may be obtained with prior arrangement between Wah Chang and the Purchaser. Variations must be defined in the Purchase Order.
- 6.4 "Other elements," if referenced in the chemical table are elements that may be present in a metal or alloy in small quantities inherent to the manufacturing process, but not added intentionally.



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6.5 Alloys other than those listed in the following table may be produced with prior arrangement between Wah Chang and the purchaser.

TABLE I							
ELEMENT	CP GRADE C-2	CP GRADE C-3	6Al-4V GRADE C-5	Ti-Pd GRADE C-7	Ti-Pd GRADE C-8	Ti GRADE C-12	Ti425 GRADE C-38
Nitrogen (max)	0.05	0.05	0.05	0.05	0.05	0.05	.03
Carbon (max)	0.10	0.10	0.10	0.10	0.10	0.10	.08
Hydrogen (max)	0.015	0.015	0.015	0.015	0.015	0.015	.015
Iron (max)	0.20	0.25	0.40	0.20	0.25	0.30	1.2-1.8
Oxygen (max)	0.40	0.40	0.25	0.40	0.40	0.25	0.20-0.30
Aluminum			5.52- 6.75				3.5-4.5
Vanadium			3.5 - 4.5				2.0-3.0
Palladium (min)				0.12	0.12		
Nickel						0.6-0.9	
Molybdenum						0.2-0.4	
Other Elements (each) max *	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other Elements (total) max *	0.4	0.4	0.4	0.4	0.4	0.4	0.4
All values are reported in Weight %							

* Need not be reported. By agreement between supplier and purchaser, analysis may be required and limits established for elements or compounds not specified in this table.

7. MECHANICAL PROPERTIES (see TABLE II)

7.1 Mechanical properties are obtained and certified from standard cylindrical specimens poured at the same time and in the same manner as the castings they represent. Because of varying section thickness and cooling rates associated with cast products, property differences may be noted where cast part conditions vary from test material conditions.

7.1.1 Where test plans outside the requirements of ASTM B367 are requested, it is recommended that casting trials be run to reflect the merits of the customer's part design as related to mechanical property performance.

7.2 Tension test specimens shall be machined and tested in accordance with ASTM E-8, "Tension Testing of Metallic Materials." Tensile properties will be developed using a strain rate of 0.003 to 0.007 inches per inch per minute through the yield strength and then increased to produce failure within one additional minute.

7.3 Hardness tests shall be an average of three Brinell (10/3000/30) impressions per heat in accordance with ASTM E 10. The test may be conducted on the casting or representative test specimen.



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**TABLE II
MECHANICAL PROPERTY REQUIREMENTS**

GRADE	Tensile Strength Min., (KSI)	Yield Strength 0.2% Offset min., (KSI)	Elongation in 1-in min., (%)	(Supplementary) Hardness HB, max.
CP2 (C-2)	50	40	15	210
CP3 (C-3)	65	55	12	235
6Al-4V (C-5)	130	120	6	365
Ti-Pd (C-7)	50	40	15	210
Ti-Pd (C-8)	65	55	12	235
Ti Grade 12 (C-12)	70	50	8	235
Ti425 (C-38)	130	115	8	365

8. MANUFACTURING PROCESS

8.1 Melting

8.1.1 Material melted for casting shall be accomplished by a melting process suitable for titanium metal.

8.2 Cleaning

8.2.1 Castings shall be cleaned by methods conventionally used for titanium metals. Pickling is a supplementary requirement and must be specified at the time of inquiry and placement of the Purchase Order. When pickling is specified, the party responsible for part dimensions (see Section 2) must be conscious of the impact of material removal as it relates to pattern equipment.

8.2.2 Although castings are produced in an inert chamber, inherent to castings produced in the rammed graphite mold process is a carbon enriched material (alpha case) that exists as a harder layer generally within .002" to .004" of the as-cast surface. This layer is primarily removed in routine sandblasting. The enriched layer diminishes with distance away from the casting surface with matrix material generally reached within .008" to .010". Isolated cases have been observed in titanium alloy 6Al-4V in thick sections where light traces of diffusion extend to .015". When removal of all "alpha case" is essential for design considerations such as low cycle fatigue, or other considerations, Wah Chang will remove alpha case by a combination of sand blasting, and when specified, pickling.



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8.2.3 When required to verify that all "alpha case" has been removed, determination of carbon diffusion depth will be determined in the following manner:

8.2.3.1 For Titanium 6Al-4V and similar alpha/beta alloys, diffusion depth shall be determined by metallographic examination, i.e.; optical microscope.

8.2.3.2 For commercially pure titanium alloys, alpha case is not readily discernible using normal laboratory methods. Based on documented studies, Wah Chang will, when specified, remove a minimum of .015" per surface from the as-cast condition. Certifications will state that .015" has been removed in lieu of stating the material is alpha case free.

8.3 Conditioning

8.3.1 Surface

Surface defects may be removed by grinding and/or cosmetic weldment and/or other processes suitable for titanium metal.

8.3.2 Internal

Weld Repairs shall be made using the Gas Tungsten Arc Process (GTAW). Repairs shall be made in accordance with qualified procedures using qualified welders.

Commercial applications shall utilize procedures and Welder's qualified to ASME Section IX. Weld severity "classification" shall be defined as follows;

Minor:	≤ 20% Wall Thickness
Nominal:	> 20% to 70% Wall Thickness
Major:	> 70% Wall Thickness

"Minor" and "Nominal" repairs shall be made at the discretion of Wah Chang. For "Major" repairs, the customer may request *Pre-Approval* prior to weld.

Government applications shall utilize procedures and Welder's qualified to S9074-AQ-GIB-010/248 (Tech Pub). Weld severity "classification" shall be defined as follows;

Minor:	< 20% wall thickness or 1" depth, whichever is less, and individual repairs do not exceed 4% of the casting surface. Repairs may be performed at the discretion of Wah Chang. See the Tech Pub for further detail.
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- Nominal: > 20% and $\leq$ 50% Wall Thickness. Nominal repairs are those in excess of "Minor" welds but do not exceed half the casting thickness. Repairs may be performed at the discretion of Wah Chang. Weld Maps describing welds shall be provided upon request.
- Special: > 50% Wall Thickness. Customer pre-approval is required prior to weld. Weld Maps describing welds shall be provided upon request.

Hot Isostatic Pressing (HIP) may be used at the discretion of Wah Chang as a method to heal or reduce internal discontinuities in castings.

8.4 Post Weld Heat Treatment

- 8.4.1 Stress relief of titanium Grades C-2, C-3, C-7 and C-8 is not a requirement. The decision for stress relieving shall be made by Wah Chang unless stress relief is requested at the time of inquiry and placement of the Purchase Order. The stress relief cycle shall be performed as specified in the applicable qualified weld procedure.
- 8.4.2 Titanium Grades C-5, C-12, and C-38 castings shall be stress relieved if required after weld repair in accordance with the applicable qualified weld procedure.
- 8.4.2 For commercial castings, Hot Isostatic Pressing (HIP) may be substituted for required heat treatment provided all requirements for that treatment are met and temperatures detrimental to the material properties are not reached.

9. CASTING GRADES

9.1 Standard

9.1.1 Internal Standards

Standard grade castings do not receive Nondestructive Testing such as dye penetrant and/or radiography unless requested at the time of inquiry and placement of the Purchase Order.

9.1.2 Surface Standards

Standard grade castings shall be visually inspected and evaluated in accordance with MSS SP-55, unless otherwise requested at the time of inquiry and placement of the Purchase Order. Castings are typically shipped in a sandblasted condition.



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9.2 Premium

9.2.1 Internal Standards

Unless otherwise specified by the customer and acknowledged, the extent of radiographic examination shall be the maximum practical volume of the casting. If the geometry of the part is such that radiography of certain areas is impractical or not possible, such areas shall be noted on the Radiographic Shooting Sketch (RSS). The RSS and Film Interpretation Report shall be provided to the customer.

Radiographic (RT) acceptance criteria shall be in accordance with Table III, unless otherwise specified by the customer contract.

Areas identified on the customer supplied drawing as being machined surfaces (on the finished part) shall meet the requirements of the applicable internal standard.

Reference Radiographs ASTM E-446, 186, 280 (Steel) and ASTM E-1320 (Titanium) are provided in the table. The titanium plate standards (E-1320) were selected based on their similarity in size and distribution to the discontinuities displayed in E-446 (for thicknesses less than or equal to two inches). In this thickness range, either standard reference may be referenced on the Purchase Order. For section thicknesses greater than two inches, the applicable steel reference standard should be utilized.

TABLE III					
ASTM STANDARD ⇒	E - 446	E - 186	E - 280		E - 1320
MATERIAL THICKNESS ⇒	< 2"	2" - 4.5"	> 4.5"		< 2"
DISCONTINUITY TYPE ↓				DISCONTINUITY TYPE ↓	
Category A	2	2	2	Scattered Gas Holes	5
Gas Porosity				Clustered Gas Holes	5
Category B	2	2	2	More Dense Inclusions	8
Sand & Slag Inclusions				Less Dense Inclusions	7
Category C	2	2	2	Centerline Shrinkage	6
Shrinkage (CA, CB, CC, CD)				Shrinkage Cavity	2
				Scattered Shrinkage Cavity	5
Categories D,E,F not acceptable					



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9.2.2 Surface Standards

Penetrant Inspection: All castings will receive Visible Dye Liquid Penetrant Inspection (PT) unless otherwise specified by the customer contract. Components with *relevant indications* will be evaluated against the customer specified acceptance criteria. For product with no customer specified acceptance criteria, all surfaces examined shall be free of;

- Cracks
- Linear indications greater than 1/8" in length
- Rounded indications greater than 3/16". In addition no more than three aligned rounded indications separated by 1/16" or less, edge to edge

9.2.3 Castings will be shipped in a sandblasted condition unless otherwise specified and agreed upon.

9.3 Special Requirements

- 9.3.1 Additional requirements may be applied to either Standard or Premium castings if specified by the Purchaser at the time of inquiry and placement of the Purchase Order.
- 9.3.2 Wah Chang reserves the right to perform ASTM B367 supplementary processes or examination to insure casting integrity.
- 9.3.3 Source Inspection is permitted but must be requested at the time of the inquiry and placement of the Purchase Order. Any testing carried out for the inspecting company that is duplication will be subject to additional charges. Delays caused by Source Inspection will be added to the acknowledged leadtime.

10. CERTIFICATIONS

- 10.1 A Material Certification Report of chemical analysis and other tests specified by the Purchaser shall be provided.
- 10.2 When radiography is specified, certification shall include final film of the finished casting and the shooting technique.



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Initiated By:

A handwritten signature in black ink, appearing to read "Gregg Holman".

Gregg Holman
Process Engineer, Castings

Approved By:

A handwritten signature in black ink, appearing to read "Randy Bentz".

Randy Bentz
Manager, Casting Operations

Approved By:

A handwritten signature in black ink, appearing to read "Moe Belushi".

Moe Belushi
Level III Examiner

Approved By:

A handwritten signature in black ink, appearing to read "Gary Arbuckle".

Gary Arbuckle
Director, Quality Systems