



Designation: B988 – 18 (Reapproved 2022)

Standard Specification for Powder Metallurgy (PM) Titanium and Titanium Alloy Structural Components¹

This standard is issued under the fixed designation B988; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers powder metallurgy (PM) structural components fabricated from:

1.1.1 Commercially pure (CP) (that is, unalloyed) titanium powder,

1.1.2 Pre-alloyed powders.

1.1.3 Mixtures of elemental powders or mixtures of elemental powders and pre-alloyed powders.

1.2 This specification covers:

1.2.1 *Grade 1 PM*—Unalloyed titanium,

1.2.2 *Grade 2 PM*—Unalloyed titanium,

1.2.3 *Grade 3 PM*—Unalloyed titanium,

1.2.4 *Grade 4 PM*—Unalloyed titanium,

1.2.5 *Grade 5 PM*—Titanium alloy (6 % aluminum, 4 % vanadium),

1.2.6 *Grade 9 PM*—Titanium alloy (3 % aluminum, 2.5 % vanadium),

1.2.7 Ti-6Al-4V PM Low Interstitial (LI),

1.2.8 Ti-6Al-6V-2Sn PM.

1.3 The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recom-*

mendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*²

[B243 Terminology of Powder Metallurgy](#)

[B311 Test Method for Density of Powder Metallurgy \(PM\) Materials Containing Less Than Two Percent Porosity](#)

[B348 Specification for Titanium and Titanium Alloy Bars and Billets](#)

[B923 Test Method for Metal Powder Skeletal Density by Helium or Nitrogen Pycnometry](#)

[B962 Test Methods for Density of Compacted or Sintered Powder Metallurgy \(PM\) Products Using Archimedes' Principle](#)

[E8/E8M Test Methods for Tension Testing of Metallic Materials](#)

[E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications](#)

[E539 Test Method for Analysis of Titanium Alloys by Wavelength Dispersive X-Ray Fluorescence Spectrometry](#)

[E1409 Test Method for Determination of Oxygen and Nitrogen in Titanium and Titanium Alloys by Inert Gas Fusion](#)

[E1447 Test Method for Determination of Hydrogen in Reactive Metals and Reactive Metal Alloys by Inert Gas Fusion with Detection by Thermal Conductivity or Infrared Spectrometry](#)

[E1941 Test Method for Determination of Carbon in Refractory and Reactive Metals and Their Alloys by Combustion Analysis](#)

[E2371 Test Method for Analysis of Titanium and Titanium Alloys by Direct Current Plasma and Inductively Coupled Plasma Atomic Emission Spectrometry \(Performance-Based Test Methodology\)](#)

¹ This specification is under the jurisdiction of ASTM Committee B09 on Metal Powders and Metal Powder Products and is the direct responsibility of Subcommittee B09.11 on Near Full Density Powder Metallurgy Materials.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

E2626 Guide for Spectrometric Analysis of Reactive and Refractory Metals (Withdrawn 2017)³
3. Terminology

3.1 *Definitions*—Definitions of powder metallurgy terms can be found in Terminology **B243**.

4. Ordering Information

4.1 Orders for components under this specification should include the following information, or portions of it, as agreed to between purchaser and producer:

- 4.2 Grade or alloy composition (see Section 6 and **Table 1**).
- 4.3 Mechanical properties (see Section 8 and **Table 2**).
- 4.4 Density (see **7.1**).
- 4.5 Component description (see Section 9).
- 4.6 Processing route (see Section 5).
- 4.7 Certification (see Section 12).

4.8 *Sampling*—Sample size for determining chemical composition will be decided by purchaser and producer. Methods for chemical analysis are referenced in **10.1.1**.

4.9 Number of tensile tests required as mutually agreed upon by purchaser and producer.

5. Materials and Manufacture

5.1 Structural components may be fabricated from powders by processing to a near-net or net shape with final machining performed if required. Powders may include titanium, pre-alloyed titanium alloys, master alloys, and other elemental powders. The consolidation method shall be sufficient to achieve the final mechanical properties specified. The processing method may include any combination of cold compaction (for example, cold isostatic pressing, uniaxial pressing), powder roll compaction, hot compaction (for example, hot isostatic pressing, powder forging, and pneumatic isostatic forging), sintering, and heat treatment.

6. Chemical Composition

6.1 Chemical composition shall conform to the requirements of **Table 1**. The purchaser may negotiate with the producer for other chemical requirements.

6.2 Chemical analysis shall be made in accordance with Test Methods **E2371**, **E1409**, **E1447**, **E1941**; alternatively, Test Method **E539**, or any other standard method mutually agreed upon between the purchaser and producer. Alternative techniques are discussed in Guide **E2626**.

7. Physical Properties

7.1 *Density*—This specification covers high-and full-density parts with no interconnected porosity.

7.2 Minimum density shall be sufficient to meet the mechanical properties of **Table 2** or as specified in the purchase order or contract.

7.3 Density shall be determined in accordance with Test Methods **B311**, **B923**, or **B962**.

NOTE 1—Refer to Refs **(1-11)**⁴ for supplemental material property information.

8. Mechanical Properties

8.1 Tensile tests shall be performed using standardized test bars in accordance with Test Methods **E8/E8M** produced from the same powder lot as the components.

8.2 Alternatively, when standardized test bars are not available, or when specified by the purchaser, testing may be performed on material extracted from actual components of the same lot.

NOTE 2—Test specimens may be machined from PM parts or blanks. The test results, however, may differ from compacted test specimens.

9. Dimensions, Mass, and Permissible Variations

9.1 Dimensions and tolerances of the structural components shall be indicated on drawings accompanying the purchase order or contract.

³ The last approved version of this historical standard is referenced on www.astm.org.

⁴ The boldface numbers in parentheses refer to the list of references at the end of this standard.

TABLE 1 Chemical Composition Requirements^A

NOTE 1—Additional compositions may be added with future revisions.

| Composition, Weight % | N, max | C, max | H, max | Fe | O, max | Al | V | Sn | Cu | Cr | Nb | Residual max ea. |
|----------------------------|--------|--------|--------|----------|--------|-----------|-----------|---------|----------|----|----|------------------|
| Grade 1 PM | 0.03 | 0.08 | 0.015 | 0.20 max | 0.18 | — | — | — | — | — | — | 0.1 |
| Grade 2 PM | 0.03 | 0.08 | 0.015 | 0.30 max | 0.25 | — | — | — | — | — | — | 0.1 |
| Grade 3 PM | 0.05 | 0.08 | 0.015 | 0.30 max | 0.35 | — | — | — | — | — | — | 0.1 |
| Grade 4 PM | 0.05 | 0.08 | 0.015 | 0.50 max | 0.40 | — | — | — | — | — | — | 0.1 |
| Grade 5 PM (Ti-6Al-4V) | 0.05 | 0.08 | 0.015 | 0.40 max | 0.30 | 5.50–6.75 | 3.50–4.50 | — | — | — | — | 0.1 |
| Grade 9 PM (Ti-3Al-2.5V) | 0.03 | 0.08 | 0.015 | 0.25 max | 0.30 | 2.50–3.50 | 2.00–3.00 | — | — | — | — | 0.1 |
| Ti-6Al-4V, LI ^B | 0.03 | 0.08 | 0.0125 | 0.25 max | 0.20 | 5.50–6.75 | 3.50–4.50 | — | — | — | — | 0.1 |
| Ti-6Al-6V-2Sn | 0.04 | 0.1 | 0.015 | 0.35–1.0 | 0.30 | 5.0–6.0 | 5.0–6.0 | 1.5–2.5 | 0.35–1.0 | — | — | 0.1 |

^A For the purpose of determining conformance with this specification, measured values shall be rounded “to the nearest unit” in the last right-hand digit used in expressing the specification limit in accordance with the rounding method of Practice **E29**. The specified elements of the chemical composition for the Grades in **Table 1** reference the chemical compositions from Specification **B348**.

^B LI = low interstitial.

TABLE 2 Tensile Requirements^A

| Classification (PM designation) | Yield Strength (0.2 % Offset) (min) MPa | Tensile Strength (min) MPa | Elongation in 25 mm, % (min) | Reduction in Area, % (min) |
|------------------------------------|---|----------------------------------|------------------------------------|----------------------------------|
| Grade 1 PM100 | 138 | 240 | 24 | 30 |
| Grade 1 PM90 | 124 | 216 | 22 | 27 |
| Grade 2 PM100 | 275 | 345 | 20 | 30 |
| Grade 2 PM90 | 248 | 311 | 18 | 27 |
| Grade 3 PM100 | 380 | 450 | 20 | 30 |
| Grade 3 PM90 | 342 | 405 | 18 | 27 |
| Grade 4 PM100 | 483 | 550 | 18 | 30 |
| Grade 4 PM90 | 435 | 495 | 16 | 27 |
| Grade 5 PM100 | 828 | 895 | 10 | 25 |
| Grade 5 PM90 | 745 | 806 | 9 | 23 |
| Grade 9 PM100 | 483 | 620 | 15 | 25 |
| Grade 9 PM90 | 435 | 558 | 14 | 23 |
| Ti-6Al-4V LI PM100 | 759 | 828 | 10 | 15 |
| Ti-6Al-4V LI PM90 | 683 | 745 | 9 | 14 |
| Ti-6Al-6V-2Sn PM100 | 883 | 958 | 13 | 13 |
| Ti-6Al-6V-2Sn PM90 | 795 | 862 | 12 | 12 |

^A PM100 denotes equivalence to Specification B348 tensile properties, and PM90 denotes 90 % of Specification B348 tensile properties.

10. Sampling

10.1 Chemical Analysis:

10.1.1 A sample from the lot shall be analyzed in accordance with Test Methods E2371, E1409, E1447 and E1941. Alternatively, Test Method E539 or any other standard method mutually agreed upon between the purchaser and producer may be used. Definitions of powder metallurgy terms (for example, “lot”) can be found in Terminology B243.

10.1.2 Compliance to the chemical compositions identified in Table 1 is required unless otherwise specified by purchaser.

10.2 Mechanical Testing:

10.2.1 Compliance to the mechanical properties identified in Table 2 is required unless otherwise specified in purchase order or contract. Tensile testing shall be performed in conformance with Test Methods E8/E8M. The purchaser and producer should determine the number of tensile tests required.

10.2.2 Test bars shall be produced by the same processing route as the components.

10.3 Density shall be measured in accordance with Test Methods B311, B923, or B962.

11. Inspection

11.1 Products will be free of defects that are observable by visual examination and detrimental to usage, such as seams, laminations, pits, cracks, and surface inclusions.

12. Certification

12.1 The producer shall supply at least one copy of the report certifying that the material has been manufactured, inspected, sampled and tested in accordance with the requirements of this specification, and that the results of chemical analysis, tensile, and other tests meet the requirements of this specification for the grade specified. When specified in the purchase order or contract, a report of test results shall be furnished.

12.2 Basic chemical composition as shown in Table 1 will be tested and reported. Additional elements will be measured and reported as requested by purchaser.

13. Keywords

13.1 CIP; cold isostatic pressing; compaction; HIP; hot isostatic pressing; PIF; pneumatic isostatic forging; powder forging; powder metallurgy; powder roll compaction; pre-alloyed powder; sinter; structural components; Ti Grade 1; Ti Grade 2; Ti Grade 3; Ti Grade 4; Ti-6Al4V; Ti-6Al-6V-2Sn; Ti 3Al2.5V; titanium; titanium alloys; titanium powder