Designation: A 646/A 646M – 06

Standard Specification for Premium Quality Alloy Steel Blooms and Billets for Aircraft and Aerospace Forgings[1]

This standard is issued under the fixed designation A 646/A 646M; 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 premium quality alloy steel semifinished rolled or forged blooms and billets for reforging into critical parts such as aircraft landing-gear forgings.

1.2 Blooms and billets, hereinafter referred to as blooms, are semifinished steel products, hot rolled or forged to approximate cross-sectional dimensions. Blooms may be square, round, hexagonal, octagonal, or rectangular in section. For the purposes of this specification, minimum bloom section size will be 16 in.^{2} [103 cm^2].

1.3 This specification covers two basic classifications of steel:

1.3.1 *Class I*—Vacuum-induction melted or consumable-electrode vacuum melted, or other suitable processes which will satisfy the quality requirements of this specification.

1.3.2 *Class II*—Air-melted vacuum degassed.

1.3.3 *Class III*—Air melted electric furnace ladle refined and vacuum degassed

1.4 The values stated in either inch-pound or SI (metric) units are to be regarded separately as standards. Within the text and tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5 Unless the order specifies the applicable "M" specification the material shall be furnished to the inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 255 Test Methods for Determining Hardenability of Steel

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings

A 788/A 788M Specification for Steel Forgings, General Requirements

A 604 Test Method for Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets

E 45 Test Methods for Determining the Inclusion Content of Steel

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks

E 214 Practice for Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings

2.2 *AMS Standards:* [3]

AMS 2300 Steel Cleanliness, Premium-Quality

AMS 2301 Steel Cleanliness, Aircraft-Quality

AMS 2304 Steel Cleanliness, Special Aircraft-Quality

3. Terminology

3.1 In addition to the terminology requirements of Specification A 788/A 788M, the following terms that are specific to this specification apply:

3.2 *Definitions:*

3.2.1 *air-melted vacuum-degassed steel*—arc- or induction-furnace-melted steel that is vacuum treated immediately prior to or during the operation of pouring the ingot.

3.2.2 *consumable-electrode vacuum-remelted steel*—metal that has been remelted into a crucible in vacuum from single or multiple electrodes.

3.2.3 *electroslag-melted steel*—metal that has been remelted into a crucible from single or multiple electrodes utilizing an electrical discharge through molten slag as a source of heat.

3.2.3.1 *Discussion*—For the purposes of this specification the parent heat from which any electrode for remelting by the electroslag process has been produced shall have been either melted under vacuum or vacuum degassed immediately prior to or during pouring of the heat.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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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.

[3] Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

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

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3.2.4 *vacuum induction melted steel*—metal that has been melted, refined, and poured from an induction furnace operating under vacuum.

4. Ordering Information and General Requirements

4.1 Material supplied to this specification shall conform to the requirements of Specification A 788/A 788M, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

4.1.1 If the requirements of this specification are in conflict with the requirements of Specification A 788/A 788M, the requirements of this specification shall prevail.

4.2 In addition to the ordering requirements of Specification A 788/A 788M, the following information should be supplied by the purchaser:

4.2.1 Class designation (see 1.3),

4.2.2 Quality level (Table 2), grade designation (Table 1), or detailed chemistry for nonstandard grades,

4.2.3 Desired billet or bloom size,

4.2.4 Weight or quantity and length,

4.2.5 Minimum forging reduction required if ordered size exceeds 225 in.^{2} [1450 cm^2] (see 5.2.2),

4.2.6 Annealing, if required (see 5.3.2),

4.2.7 Macroetch standards of acceptance (see 7.1),

4.2.8 Microcleanliness standards of acceptance (see 7.2),

4.2.9 Specific ultrasonic examination requirements, such as transducer type and size, whether contact or immersion preferred, level of reportable discontinuities and any special surface finish requirements.

4.2.10 Hardenability standards of acceptance (see 8.1), and

4.2.11 Any supplementary requirements desired.

5. Manufacture

5.1 *Melting Practice*:

5.1.1 The steel making provisions of Specification A 788/A 788M shall apply, except for the following modifications;

5.1.1.1 Class I material shall be manufactured by the vacuum-induction-melting process or by the consumable-electrode vacuum-melting (VAR) process. By agreement other processes such as electroslag or electron-beam melting may be considered acceptable.

5.1.1.2 Class II material shall be manufactured by an electric-furnace vacuum-degassed process.

5.1.1.3 Class III material shall be manufactured by the electric furnace process with ladle refining and vacuum degassing.

TABLE 1 Maximum Permissible Discontinuities in Ultrasonic Examination

Quality Level	Response, in. [mm]		Stringers, Length in. [mm]
	Single Discontinuities	Multiple Discontinuities	
AA	3/64 [1.0]	2/64 [0.8]	2/64 –½ [1.0–12.0]
A	5/64 [2.0]	3/64 [1.0]	3/64 –1 [1.0–25]
B	8/64 [3.0]	5/64 [2.0]	5/64 –1 [2.0–25]
C	12/64 [5.0]	8/64 [3.0]	8/64 –1 [3.0–25]

5.2 *Hot-Working Procedure*:

5.2.1 Blooms may be either hot rolled or forged.

5.2.2 Blooms having cross-sectional areas ranging from 16 to 225 in.^{2} [100 to 1450 cm^2] when made from air-melt ingots shall have at least 2 to 1 reduction of area from ingot to bloom. On blooms exceeding 225 in.^{2} [1450 cm^2] forging reduction requirements shall be by agreement. Ingot-to-final forging reduction is not included in this requirement.

5.3 *Heat Treatment*:

5.3.1 Unless otherwise specified all material purchased to this specification will be furnished in the as forged or rolled (untreated) condition. In this condition some grades may not be soft enough for cold sawing, and may be prone to cracking.

5.3.2 When specified, the material may be ordered annealed or normalized and tempered to a maximum Brinell Hardness, as specified in Table 2 or by agreement.

5.3.3 Material shall be furnished in condition to withstand, for an indefinite time, exposure to all climatic conditions without developing any external or internal cracks. The method of cooling after hot working or of heat treatment before shipment shall be optional with the manufacturer, who shall be responsible (in the same manner as for discontinuities disclosed after delivery) for cracks which may develop before material is subjected to reheating. When a specific heat treatment or conditioning of material is specified by the purchaser, the manufacturer shall be responsible only for carrying out those specific operations and not for any cracking that may subsequently develop.

6. *Chemical Requirements* Chemical Requirements

6.1 *General Requirements*:

6.1.1 Table 1 lists standard grades of alloy steel that are currently produced in premium quality; however, it is not the intent of this specification to restrict application only to the materials listed in Table 1.

6.1.2 When a standard grade is ordered, the analysis shall conform to the requirements as to chemical composition prescribed in Table 1 for the ordered grade.

6.1.3 The steel, when ordered to other than a standard analysis, shall conform to the requirements of the order.

6.2 *Heat Analysis*:

6.2.1 The heat analysis obtained from sampling in accordance with Specification A 788/A 788M shall comply with Table 1 for standard grades, or to the requirements of the order.

6.3 *Product Analysis*:

6.3.1 The purchaser may use the product analysis provision of Specification A 788/A 788M to obtain a product analysis from a billet or bloom representing each heat or multiple heat.

7. Quality Evaluation Tests

7.1 *Macroetch*—Macroetch inspection shall be required for all material furnished to this specification. Samples representing the top and bottom of each ingot shall be examined. Macroetching shall be performed in accordance with Method E 381 and Test Method A 604, as applicable. Standards of acceptance shall be specified by the purchaser in the order.

7.2 *Microcleanliness*—All material furnished to this specification shall be inspected for microcleanliness. At least one sample shall be removed from a location midway between the

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TABLE 2 Chemical and Hardness Requirements[A]

Proprietary Name or Grade	Grade No.	Composition, %										Maximum Annealed Brinell Hardness
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molybdenum	Vanadium	Others	
3310	1	0.08–0.13	0.45–0.60	0.015max	0.012 max	0.20–0.35	3.25–3.75	1.40–1.75	. . .	. . .	. . .	262
9310	2	0.08–0.13	0.45–0.65	0.015 max	0.012 max	0.20–0.35	3.00–3.50	1.00–1.40	0.08–0.15	. . .	. . .	262
4620	3	0.17–0.22	0.45–0.65	0.015 max	0.012 max	0.20–0.35	1.65–2.00	. . .	0.20–0.30	. . .	. . .	229
8620	4	0.18–0.23	0.70–0.90	0.015max	0.012 max	0.20–0.35	0.40–0.70	0.40–0.60	0.15–0.25	. . .	. . .	229
4330 Mod.	5	0.28–0.33	0.75–1.00	0.015 max	0.012 max	0.20–0.35	1.65–2.00	0.70–0.95	0.35–0.50	0.05–0.10	. . .	285
4335 Mod.	6	0.33–0.38	0.60–0.90	0.015 max	0.012 max	0.40–0.60	1.65–2.00	0.65–0.90	0.30–0.40	0.17–0.23	. . .	285
4340	7	0.38–0.43	0.65–0.85	0.015 max	0.012 max	0.20–0.35	1.65–2.00	0.70–0.90	0.20–0.30	. . .	. . .	285
300 M	8	0.38–0.43	0.65–0.90	0.012 max	0.012 max	1.45–1.80	1.65–2.00	0.70–0.95	0.35–0.45	0.05–0.10	. . .	285
D6AC	9	0.45–0.50	0.60–0.90	0.010 max	0.010 max	0.15–0.30	0.40–0.70	0.90–1.20	0.90–1.10	0.08–0.15	. . .	285
H-11	10	0.38–0.43	0.20–0.40	0.015 max	0.015 max	0.80–1.00	. . .	4.75–5.25	1.20–1.40	0.40–0.60	. . .	235
4130	11	0.28–0.33	0.40–0.60	0.015 max	0.012 max	0.20–0.35	. . .	0.80–1.10	0.15–0.25	. . .	. . .	229
4140	12	0.38–0.43	0.75–1.00	0.015 max	0.012 max	0.20–0.35	. . .	0.80–1.10	0.15–0.25	. . .	. . .	235
98BV40	13	0.40–0.46	0.75–1.00	0.015 max	0.012 max	0.50–0.80	0.60–0.90	0.80–1.05	0.45–0.60	0.01–0.06	0.0005 min, Boron	285
6150	14	0.48–0.53	0.70–0.90	0.015 max	0.012 max	0.20–0.35	. . .	0.80–1.10	. . .	0.15 min	. . .	235
52100	15	0.98–1.10	0.25–0.45	0.015 max	0.010 max	0.20–0.35	. . .	1.30–1.60	. . .	. . .	. . .	302
HP 9-4-20	16	0.17–0.23	0.20–0.40	0.010 max	0.010 max	0.10 max	8.5–9.5	0.65–0.85	0.90–1.10	0.06–0.12	Co 4.25–4.75	341
HP 9-4-30	17	0.29–0.34	0.10–0.35	0.010 max	0.010 max	0.10 max	7.0–8.0	0.90–1.10	0.90–1.10	0.06–0.12	Co 4.25–4.75	341
Marage 200	18	0.03 max	0.10 max	0.010 max	0.010 max	0.10 max	17.0–19.0	. . .	3.0–3.50	. . .	Co 8.0–9.0 Ti 0.10–0.25 Al 0.05–0.15 B, Zr, Ca added	321
Marage 250	19	0.03 max	0.10 max	0.010 max	0.010 max	0.10 max	17.0–19.0	. . .	4.6–5.2	. . .	Co 7.0–8.5 Ti 0.30–0.50 Al 0.05–0.15 B, Zr, Ca added	321
Marage 300	20	0.03 max	0.10 max	0.010 max	0.010 max	0.10 max	18.0–19.0	. . .	4.7–5.2	. . .	Co 8.5–9.5 Ti 0.50–0.80 Al 0.05–0.15 B, Zr, Ca added	321
Nit. 135	21	0.38–0.43	0.50–0.70	0.015 max	0.012 max	0.20–0.40	. . .	1.40–1.80	0.30–0.40	. . .	Al 0.95–1.30	285

[A] If any of the following elements are not specified, the following maximum limits shall apply: Nickel 0.35 %; Chromium 0.20 %; Molybdenum 0.06 %; Copper 0.35 %.

center and outside surface representing the top and bottom of the first and last ingots of each heat or from an ingot from each plate for bottom poured ingots. For blooms produced from continually cast material the samples shall represent the beginning and end of each strand produced from the heat. The specimens shall be prepared and rated by the procedure described in Method A of Test Methods E 45. The polished face shall be longitudinal to the direction of maximum hot working. All specimens shall be prepared and rated in accordance with Test Methods E 45, using Method D (Modified JK Chart) for Class I steel and Method A (JK Chart) for Classrs II and III steel. Standards of acceptance shall be specified by the purchaser in the order.

7.3 *Nondestructive Testing, Ultrasonic Inspection*:

7.3.1 *General*:

7.3.1.1 All material ordered to this specification shall be subjected to ultrasonic examination. Inspection may be performed by either the immersion or the contact method providing that the manufacturer can ensure adequate resolution of the applicable reference standards with the chosen method.

7.3.1.2 The usage of reference blocks containing flat-bottomed holes for calibration is the preferred method for evaluation of discontinuity size up to billet cross-sectional dimensions of approximately 12 in. [300 mm]. With larger sizes, it is recognized that reference block fabrication becomes difficult and in general a back reflection method of calibration can be used as an alternative as referenced in 7.3.6.3.

7.3.2 *Immersion Examination Procedure*—This method is recommended for material where the cross-sectional dimension to be inspected is less than approximately 8 in. [200 mm]. Material inspected by the immersion method shall be performed in accordance with the procedure outlined in Practice E 214.

7.3.3 *Contact Examination Procedure*—Material inspected by the contact method shall be performed in accordance with the procedure outlined in Practice E 114 or Practice A 388/A 388M.

7.3.4 *Scanning*—Blooms shall be examined using the straight-beam (longitudinal-wave) technique. Blooms having parallel surfaces shall be scanned from two adjacent sides, excluding ends. Cylindrical blooms shall be scanned a minimum of 180° around the circumference, with the beam directed along the radius, noting that an axial scan from the end faces is not normally applicable.

7.3.5 *Quality Levels and Reference Standards*:

7.3.5.1 The reference blocks shall be fabricated in accordance with the procedures of Practice E 127, with the exception of surface finish. Transducer contact surfaces of the product and the reference block should be comparable roughness. Flatbottom hole sizes shall be in accord with the applicable quality level specified in Table 2.

7.3.5.2 A comparison of the back reflections between equivalent thicknesses of the reference block material and the actual material to be tested, without change in instrument

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setting shall not show a variation in excess of 25 %. Reference blocks which do not meet the comparison requirement shall not be used for the specific part to be inspected.

7.3.6 *Evaluation of Discontinuities*:

7.3.6.1 When inspecting material to the flat-surface standards, estimate the size of a discontinuity by comparing its response to that of a flat-surface standard of the same depth, except as follows:

Depth of Discontinuity, in. [mm]	Allowable Difference, ± in. [mm]
Less than 1 [25]	⅛ [3]
1 to 3 [25 to 75]	¼ [6]
Greater than 3 [75]	½ [12]
Greater than 6 [150]	1 [25]

7.3.6.2 As an alternative, a distance-amplitude correction (DAC) curve or circuitry may be used.

7.3.6.3 Material having a cross-sectional dimension exceeding 12 in. [300 mm] may be examined by the following procedure, using the back-reflection method, instead of preparing large reference blocks by agreement between manufacturer and purchaser. A straight-beam longitudinal-wave search unit shall be placed on the material under test in a discontinuity-free area having a satisfactory surface condition to produce the desired result. The type, size and frequency of the transducer shall be mutually agreed upon as required by the specific situation. The instrument sensitivity shall be adjusted so that the height of the first back reflection occupies at least 75 %, but less than 100 %, of the full screen amplitude. The reporting levels and acceptability limits in terms of discontinuity size shall be mutually agreed upon prior to order placement.

7.3.7 *Acceptance Criteria (Table 1)*:

7.3.7.1 Any single discontinuity response that exceeds that of the single discontinuity standard for the applicable quality level shall be unacceptable.

7.3.7.2 Any multiple discontinuity, that is, any two that have an indicated distance between centers of less than 1 in. [25 mm] and whose responses equal or exceed that of the "multiple discontinuity" standard for the applicable quality level, shall be unacceptable.

7.3.7.3 Any stringer discontinuity whose response *and* length exceeds that of the standard for the applicable quality level shall be unacceptable.

8. Heat Treatment Quality

8.1 *Hardenability*—All heats of material produced to this specification shall be tested for hardenability in accordance with Test Methods A 255. The standards of acceptance shall be by agreement.

8.2 Supplementary requirement S2 provides for demonstration of the mechanical property capability of the material and should be specified if this information is needed.

9. Permissible Variations in Weight

9.1 The permissible variation from the specified or theoretical weight of the blooms or billets shall be ±5 % for individual pieces or for lots of less than 20 tons [18 t]. For lots of 20 tons [18 t] or over, the permissible variation shall be ±2.5 % of the specified or theoretical weight of the lot.

9.2 The term "lot" is defined as all the blooms or billets of the same nominal cross-sectional dimensions and specified piece weight in a shipment.

10. Finish and Appearance

10.1 The material shall be free from rejectable discontinuities.

10.2 Conditioning, cutting, or parting of material may be done by scarfing or flame cutting. Methods involving preheating and temperature control necessary to avoid any damage to flame-cut material shall be employed.

10.3 The surface of the billet or bloom must be adequate for ultrasonic examination to the applicable reference standard. In some cases, a smooth ground or milled surface may be necessary for adequate penetration and resolution.

10.4 Material may be conditioned to remove rejectable surface discontinuities, provided the depth of conditioning does not exceed 1⁄16 in. [1.5 mm] for each inch of dimension concerned, up to a maximum depth of ¾ in. [20 mm], and provided that the width of the conditioning is at least four times its greatest depth. The maximum depth of conditioning on two parallel sides at opposite locations shall not exceed 1½ times the maximum allowed for one side.

11. Marking, Inspection, Rejection, Inspection, and Certification

11.1 Marking, rejection, inspection, and certification shall be in accordance with the requirements of Specification A 788/A 788M.

12. Keywords

12.1 aerospace application; alloy steels; consumable electrode remelted; electric furnace; ladle refined; premium quality; reforging stock; steel billets; steel blooms; vacuum degassed; vacuum melted

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SUPPLEMENTARY REQUIREMENTS

These requirements shall not apply unless specified in the order.

S1. Magnetic Particle Cleanliness

S1.1 When specified, each heat of billet or bloom material shall be examined in accordance with Aeronautical Material Specification AMS 2300 for Class I, AMS 2301 for Class II, or AMS 2304 for Class III.

S2. Mechanical Property Capability

S2.1 When specified, mechanical property testing may be required to represent the capability of the material to respond to the final heat treatment to be performed on the end product. The purchaser shall specify the details of the capability heat treatment along with minimum property levels to be achieved after heat treatment.

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 646/A 646M – 04) that may impact the use of this standard. (Approved Dec. 1, 2006.)

(*1*) Section 6.1.4 deleted.
(*2*) SI values correction within table in 7.3.6.1.
(*3*) Correction of aluminum requirement for Marage 200 in Table 2.

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