Designation: A788/A788M – 18b

Standard Specification for Steel Forgings, General Requirements[1]

This standard is issued under the fixed designation A788/A788M; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This specification[2] covers a group of common requirements that, unless otherwise specified in the individual product specification, shall apply to steel forgings under any of the following specifications issued by ASTM:

ASTM Designation	Title
A266/A266M	Carbon Steel Forgings for Pressure Vessel Components
A288	Carbon and Alloy Steel Forgings for Magnetic Retaining Rings for Turbine Generators
A289/A289M	Alloy Steel Forgings for Nonmagnetic Retaining Rings for Generators
A290/A290M	Carbon and Alloy Steel Forgings for Rings for Reduction Gears
A291/A291M	Steel Forgings, Carbon and Alloy, for Pinions, Gears, and Shafts for Reduction Gears
A336/A336M	Alloy Steel Forgings for Pressure and High-Temperature Parts
A372/A372M	Carbon and Alloy Steel Forgings for Thin-Walled Pressure Vessels
A427/A427M	Wrought Alloy Steel Rolls for Cold and Hot Reduction
A469/A469M	Vacuum-Treated Steel Forgings for Generator Rotors
A470/A470M	Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts
A471/A471M	Vacuum-Treated Alloy Steel Forgings for Turbine Rotor Disks and Wheels
A504/A504M	Wrought Carbon Steel Wheels
A508/A508M	Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels
A521/A521M	Steel, Closed-Impression Die Forgings for General Industrial Use
A541/A541M	Quenched and Tempered Carbon and Alloy Steel Forgings for Pressure Vessel Components
A579/A579M	Superstrength Alloy Steel Forgings
A592/A592M	High-Strength Quenched and Tempered Low-Alloy Steel Forged Parts for Pressure Vessels
A646/A646M	Premium Quality Alloy Steel Blooms and Billets for Aircraft and Aerospace Forgings
A649/A649M	Forged Steel Rolls Used for Corrugating Paper Machinery
A668/A668M	Steel Forgings, Carbon and Alloy, for General Industrial Use
A711/A711M	Steel Forging Stock
A723/A723M	Alloy Steel Forgings for High-Strength Pressure Component Application
A729/A729M	Carbon and Alloy Steel Axles, Heat Treated, for Mass Transit and Electric Railway Service
A765/A765M	Carbon Steel and Low-Alloy Steel Pressure-Vessel-Component Forgings with Mandatory Toughness Requirements
A768/A768M	Vacuum-Treated 12 % Chromium Alloy Forgings for Turbine Rotors and Shafts
A837/A837M	Steel Forgings, Alloy, for Carburizing Applications
A859/A859M	Age-Hardening Alloy Steel Forgings for Pressure Vessel Components
A891/A891M	Precipitation Hardening Iron Base Superalloy Forgings for Turbine Rotor Disks and Wheels
A909/A909M	Steel Forgings, Microalloy, for General Industrial Use
A940/A940M	Vacuum Treated Steel Forgings, Alloy, Differentially Heat Treated, for Turbine Rotors
A965/A965M	Steel Forgings, Austenitic, for Pressure and High Temperature Parts
A982/A982M	Steel Forgings, Stainless, for Compressor and Turbine Airfoils
A983/A983M	Continuous Grain Flow Forged Carbon and Alloy Steel Crankshafts for Medium Speed Diesel Engines
A986/A986M	Magnetic Particle Examination of Continuous Grain Flow Crankshaft Forgings
A1021/A1021M	Martensitic Stainless Steel Forgings and Forging Stock for High-Temperature Service
A1049/A1049M	Stainless Steel Forgings, Ferritic/Austenitic (Duplex), for Pressure Vessels and Related Components

1.2 In case of conflict in requirements, the requirements of the individual product specifications shall prevail over those of this specification.

1.3 The purchaser may specify additional requirements (see 4.2.3) that do not negate any of the provisions of either this specification or of the individual product specifications. The acceptance of any such additional requirements shall be dependent on negotiations with the supplier and must be included in the order.

[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.

Current edition approved Nov. 1, 2018. Published November 2018. Originally approved in 1984. Last previous edition approved in 2018 as A788/A788M–18a. DOI: 10.1520/A0788_A0788M-18B.

[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA–788 in Section II of that code.

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

1.4 If, by agreement, forgings are to be supplied in a partially completed condition, that is, all of the provisions of the product specification have not been filled, then the material marking (see Section 17) and certification (see Section 16) shall reflect the extent to which the product specification requirements have been met.

1.5 As noted in the Certification Section (16), the number and year date of this specification, as well as that of the product specification, are required to be included in the product certification.

1.6 When the SI version of a product specification is required by the purchase order, Specification A788/A788M shall be used in conjunction with Test Methods A1058 instead of Test Methods and Definitions A370.

1.7 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.8 *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.*

1.9 *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 Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

A266/A266M Specification for Carbon Steel Forgings for Pressure Vessel Components
A275/A275M Practice for Magnetic Particle Examination of Steel Forgings
A288 Specification for Carbon and Alloy Steel Forgings for Magnetic Retaining Rings for Turbine Generators
A289/A289M Specification for Alloy Steel Forgings for Nonmagnetic Retaining Rings for Generators
A290/A290M Specification for Carbon and Alloy Steel Forgings for Rings for Reduction Gears
A291/A291M Specification for Steel Forgings, Carbon and Alloy, for Pinions, Gears and Shafts for Reduction Gears
A336/A336M Specification for Alloy Steel Forgings for Pressure and High-Temperature Parts
A370 Test Methods and Definitions for Mechanical Testing of Steel Products
A372/A372M Specification for Carbon and Alloy Steel Forgings for Thin-Walled Pressure Vessels
A388/A388M Practice for Ultrasonic Examination of Steel Forgings
A427/A427M Specification for Wrought Alloy Steel Rolls for Cold and Hot Reduction (Withdrawn 2018)[4]
A469/A469M Specification for Vacuum-Treated Steel Forgings for Generator Rotors
A470/A470M Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts
A471/A471M Specification for Vacuum-Treated Alloy Steel Forgings for Turbine Rotor Disks and Wheels
A504/A504M Specification for Wrought Carbon Steel Wheels
A508/A508M Specification for Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels
A521/A521M Specification for Steel, Closed-Impression Die Forgings for General Industrial Use (Withdrawn 2018)[4]
A541/A541M Specification for Quenched and Tempered Carbon and Alloy Steel Forgings for Pressure Vessel Components
A551/A551M Specification for Carbon Steel Tires for Railway and Rapid Transit Applications
A579/A579M Specification for Superstrength Alloy Steel Forgings
A592/A592M Specification for High-Strength Quenched and Tempered Low-Alloy Steel Forged Parts for Pressure Vessels
A646/A646M Specification for Premium Quality Alloy Steel Blooms and Billets for Aircraft and Aerospace Forgings
A649/A649M Specification for Forged Steel Rolls Used for Corrugating Paper Machinery
A668/A668M Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use
A711/A711M Specification for Steel Forging Stock
A723/A723M Specification for Alloy Steel Forgings for High-Strength Pressure Component Application
A729/A729M Specification for Carbon and Alloy Steel Axles, Heat-Treated, for Mass Transit and Electric Railway Service
A751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
A765/A765M Specification for Carbon Steel and Low-Alloy Steel Pressure-Vessel-Component Forgings with Mandatory Toughness Requirements
A768/A768M Specification for Vacuum-Treated 12 % Chromium Alloy Forgings for Turbine Rotors and Shafts (Withdrawn 2018)[4]
A833 Test Method for Indentation Hardness of Metallic Materials by Comparison Hardness Testers
A837/A837M Specification for Steel Forgings, Alloy, for Carburizing Applications
A859/A859M Specification for Age-Hardening Alloy Steel Forgings for Pressure Vessel Components
A891/A891M Specification for Precipitation Hardening Iron

[3] 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.

[4] The last approved version of this historical standard is referenced on www.astm.org.

Base Superalloy Forgings for Turbine Rotor Disks and Wheels
A909/A909M Specification for Steel Forgings, Microalloy, for General Industrial Use
A939/A939M Practice for Ultrasonic Examination from Bored Surfaces of Cylindrical Forgings
A940/A940M Specification for Vacuum Treated Steel Forgings, Alloy, Differentially Heat Treated, for Turbine Rotors (Withdrawn 2017)[4]
A941 Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys
A965/A965M Specification for Steel Forgings, Austenitic, for Pressure and High Temperature Parts
A966/A966M Practice for Magnetic Particle Examination of Steel Forgings Using Alternating Current
A982/A982M Specification for Steel Forgings, Stainless, for Compressor and Turbine Airfoils
A983/A983M Specification for Continuous Grain Flow Forged Carbon and Alloy Steel Crankshafts for Medium Speed Diesel Engines
A986/A986M Specification for Magnetic Particle Examination of Continuous Grain Flow Crankshaft Forgings
A991/A991M Test Method for Conducting Temperature Uniformity Surveys of Furnaces Used to Heat Treat Steel Products
A1021/A1021M Specification for Martensitic Stainless Steel Forgings and Forging Stock for High-Temperature Service
A1049/A1049M Specification for Stainless Steel Forgings, Ferritic/Austenitic (Duplex), for Pressure Vessels and Related Components
A1058 Test Methods for Mechanical Testing of Steel Products—Metric
E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
E112 Test Methods for Determining Average Grain Size
E165/E165M Practice for Liquid Penetrant Examination for General Industry
E380 Practice for Use of the International System of Units (SI) (the Modernized Metric System) (Withdrawn 1997)[4]
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials
E428 Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing
E1290 Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement (Withdrawn 2013)[4]
E1820 Test Method for Measurement of Fracture Toughness
E1916 Guide for Identification of Mixed Lots of Metals

2.2 *Other Standards:*

ANSI/ASME B46.1 Surface Texture (Surface Roughness, Waviness and Lay)[5]
ASME Boiler and Pressure Vessel Code[6]
SAE AMS 2750 Pyrometry[7]

3. Terminology

3.1 Terminology A941 is applicable to this specification. Additional terms and wording more applicable to forgings are as noted in this section.

3.2 *Forging Definitions:*

3.2.1 *steel forging, n*—the product of a substantially compressive plastic working operation that consolidates the material and produces the desired shape. The plastic working may be performed by a hammer, press, forging machine, or ring rolling machine, and must deform the material to produce an essentially wrought structure.

3.2.1.1 *Discussion*—Hot rolling operations may be used to produce blooms or billets for reforging.

3.3 *Forging Geometries:*

3.3.1 *bar forging, n*—forging that has no bore and having an axial length greater than its maximum cross sectional dimension.

3.3.1.1 *Discussion*—More than one cross sectional shape or size may be included. Sometimes referred to as a solid forging.

3.3.2 *disk forging, n*—forging, sometimes referred to as a pancake forging, that has *(a)* an axial length appreciably less than its diameter, *(b)* may be dished on one or both faces, and *(c)* final forging includes upsetting operations to reduce the height of the stock and increase its diameter.

3.3.2.1 *Discussion*—Since much of the hot working is done in axially compressing the stock, the central area may not receive sufficient consolidation. To counter this effect, consideration is usually given to the initial saddening (see 3.3.6) of the ingot or billet.

3.3.3 *hollow forging, n*—forging (also known as a shell forging or a mandrel forging) in which *(a)* the axial length is equal to or greater than the diameter, and *(b)* the forging length and wall thickness are produced by hot working over a mandrel (usually water cooled) such that the bore diameter remains essentially the same as that of the mandrel.

3.3.3.1 *Discussion*—Unless a hollow ingot has been used, the starting slug is hot trepanned or punched after upsetting and the bore diameter adjusted to suit the forging mandrel. The outside diameter may be contoured if required. The workpiece is forged between the upper die and lower dies while the mandrel is supported by cranes or manipulators to facilitate rotation.

3.3.4 *ring forging, n*—type of hollow forging in which *(a)* the axial length is less than the diameter, *(b)* the wall thickness is reduced, and *(c)* the outside diameter is increased by hot working between the top die and a mandrel supported on temporary saddles.

3.3.4.1 *Discussion*—Forging between the top die and the mandrel enables the ring diameter to be increased while reducing the wall thickness, without increasing the axial length.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[6] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

[7] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

3.3.5 *ring rolling, n*—involves the use of specialized equipment whereby a hot punched, trepanned, or bored disk is *(a)* hot worked between a powered outer roller and an idling inner roller, such that the wall thickness is reduced and the outside diameter is increased, and *(b)* the axial length of the ring is not intended to increase and may be contained by a radially oriented tapered roller.

3.3.6 *saddening, n*—term used in the open die forging industry to describe the initial hot working of an ingot for surface compaction and flute working surface prior to full working of the ingot cross section.

3.3.6.1 *Discussion*—The term is also extended to initial hot working intended to give consolidation of ingot central areas prior to upsetting when making products such as turbine and generator rotors and tube sheets.

3.3.7 *slab forging, n*—forging, sometimes referred to as a forged plate, that is usually square or rectangular in shape, with a thickness appreciably smaller than the other dimension. The hot working may include upsetting.

3.4 *billets and blooms, n*—interchangeable terms representing hot-worked semi-finished product intended as a starting stock for making forgings.

3.4.1 *Discussion*—No size limitations are assumed for either term. Cast shapes produced by a continuous casting process, without subsequent work, are considered to be ingots for the purposes of this specification, and if supplied as billets or blooms must carry the descriptor *Cast* Billet or *Cast* Bloom.

3.5 *Definitions of Terms Specific to This Standard:*

3.5.1 *bottom pouring, n*—steel from a single heat, or from a multiple heat tapped into a common ladle (see 8.1.1 and 8.1.2), introduced into ingot mold(s) such that they are filled from the bottom up. One or more molds can be set up on an individual plate, and more than one plate may be poured in sequence from a heat.

3.5.2 *ingot, n*—the product obtained when molten steel, upon being cast into a mold, is subsequently capable of being wrought in conformance with 3.1. Open-ended molds, which are usually cooled and used, for example, in the continuous casting of steel, are considered to be included in this definition.

3.5.3 *intercritical heat treatment, n*—use of a multi-stage heat treatment procedure in which the material is first austenitized at a temperature above the upper critical temperature (Ac3) followed by cooling below the lower critical temperature (Ac1). The material is then reheated to a temperature in the intercritical range between the Ac1 and the Ac3 and again cooled below the Ac1, followed by subcritical tempering in the range specified in the material specification.

3.5.3.1 *Discussion*—This procedure is generally applicable to low hardenability carbon and low alloy steels that would usually have a microstructure of ferrite and pearlite in the heat treated section size of the component being heat treated.

3.5.4 *precipitation deoxidation, n*—steelmaking process in which primary deoxidation is achieved by the addition of strong deoxidizing agents, such as aluminum, early in the process, and holding the steel in the molten state for sufficient time for the products of deoxidation to separate from the melt to the slag.

3.5.5 *sequential or continuous strand casting, n*—steel from several heats poured consecutively into a cooled open-ended mold to form a continuous cast product with a change from heat to heat along its length (see 8.1.5).

3.5.6 *strand casting, n*—steel from one heat poured into a cooled open-ended mold to form a continuous strand or strands.

3.5.7 *vacuum carbon deoxidation (VCD), n*—steelmaking process in which primary deoxidation occurs during vacuum treatment as a result of the carbon-oxygen reaction. In order for primary deoxidation to occur during vacuum treatment, deoxidizing agents such as aluminum or silicon are not to be added to the melt in any significant amount prior to the vacuum treatment operation.

4. Ordering Information

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for forgings under the applicable product specification. Such requirements to be considered include, but are not restricted to, the following:

4.1.1 Quantity,

4.1.2 Dimensions, including tolerances and surface finishes.

4.1.3 Specification number with type, class, and grade as applicable (including year date), and should include:

4.1.4 Number of copies of the material test report.

4.1.5 Choice of testing track from the options listed in Test Methods A1058 when forgings are ordered to a suffix M product standard. If the choice of test track is not made in the ordering information then the default ASTM track shall be used as noted in Test Methods A1058.

4.2 Additional information including the following may be added by agreement with the supplier:

4.2.1 Type of heat treatment when alternative methods are allowed by the product specification,

4.2.2 Supplementary requirements, if any, and

4.2.3 Additional requirements (see 1.4, 16.1.6, 16.1.7, and 16.1.9).

4.2.4 Repair welding NOT permitted.

4.3 For dual format specifications, unless otherwise specified, the inch-pound units shall be used.

5. Melting Process

5.1 Unless otherwise specified in the product specification, the steel shall be produced by any of the following primary processes: electric-furnace, basic oxygen, vacuum-induction (VIM), or open-hearth. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting, using electro slag remelting (ESR) or vacuum arc remelting (VAR).

5.1.1 The steel shall be fully killed.

5.2 The molten steel may be vacuum-treated prior to or during pouring of the ingot.

5.2.1 When vacuum treatment of the molten steel is required by the product specification the following conditions shall apply:

5.2.1.1 When the vacuum stream degassing process is used, the vacuum system must be of sufficient capacity to effect a blank-off pressure low enough (usually less than 1000 µm) to break up the normal tight, rope-like stream of molten metal into a wide-angled conical stream of relatively small droplets. The capacity of the system must also be sufficiently high to reduce the initial surge pressure at the start of the pour to a low level within 2 min.

5.2.1.2 When the vacuum-lift process is utilized, the molten metal shall be repeatedly drawn into the evacuated vessel to give a recirculation factor (see Annex A1) of at least 2.5 to ensure thorough degassing and mixing of the entire heat. The evacuation system shall be capable of reducing the pressure surges, which occur each time a new portion of steel is admitted to the vessel to increasingly lower levels, until a blank-off pressure (usually less than 1000 µm) is achieved signifying the end of the degassing treatment.

5.2.1.3 When the ladle degassing process is used, the evacuation system shall be capable of reducing the system vacuum pressure to a low level (usually less than 1000 µm). The molten metal shall be adequately stirred for a sufficient length of time to maximize exposure to the evacuated atmosphere.

5.2.1.4 Other methods of vacuum treatment may be used if the supplier can demonstrate adequate degassing and acceptable properties in the finished forging to the satisfaction of the purchaser.

6. Forging

6.1 Forgings shall be made in accordance with 3.2.1.

6.2 Because of differences in manufacture, hot-rolled, or hot-rolled and cold-finished bars (semi-finished or finished), billets, or blooms are not considered to be forgings.

6.3 Cold worked forgings shall be made from material previously hot worked by forging or rolling; however, a hot-cold worked forging may be produced in one continuous operation wherein the material is first hot worked and then cold worked by control of the finishing temperature.

7. Cooling Prior to Heat Treatment

7.1 After forging and before reheating for heat treatment, the forgings shall be allowed to cool in such a manner as to prevent injury and, in the case of ferritic forgings, to permit substantially complete transformation of austenite.

8. Chemical Composition

8.1 *Heat Analysis:*

8.1.1 An analysis of each heat of steel shall be made by the steel producer to determine the percentages of those elements specified in the product specification. This analysis shall be made from a test sample preferably taken during the pouring of the heat and shall conform to the requirements of the product specification.

8.1.2 When multiple heats are tapped into a common ladle, the ladle chemistry shall apply. The chemical composition thus determined shall conform to the requirements of the product specification.

8.1.3 For multiple-heat ingots, either individual heat analyses or a weighted average (see Annex A2) may be taken. The results of the method used shall conform to the requirements of the product specification.

8.1.4 With the exception of the product from multiple heats sequentially cast in strand casting machines (see 8.1.5), if the test sample taken for a heat analysis is lost or declared inadequate for chemical determinations, the steel producer may take alternative samples from appropriate locations near the surface of the ingot or forging as necessary to establish the analysis of the heat in question.

8.1.5 For multiple heats sequentially cast in strand casting machines, the heat analysis shall be determined for each individual heat in accordance with 8.1.1 or 8.1.2 if applicable.

8.1.5.1 If, for multiple heats sequentially strand cast, the test sample is lost or declared inadequate for chemical analysis determination, alternative samples, remote from the transition zones, may be taken by the steel producer from the cast material or product of that heat, as defined in 8.2 or 8.3 as appropriate.

8.1.6 *Heat Analysis for Remelted Ingots:*

8.1.6.1 When consumable remelting processes are used, a chemical analysis shall be taken from a remelted ingot (or the product of a remelted ingot) for the remelt heat analysis.

8.1.6.2 When more than one electrode is prepared from a master or parent heat for remelting in the same facility by the same process, then the heat analysis obtained from one remelted ingot, or the product from that ingot, shall be taken as the heat analysis for all of the remelted ingots from that master heat. For analysis from each remelted ingot, see Supplementary Requirement S27.

8.1.6.3 When electrodes from different master heats are remelted sequentially, an analysis shall be made in each zone of the remelted ingot corresponding to at least one electrode from each master heat. The resultant chemical analysis of each zone shall conform to the requirements of the product specification. The heat analysis of the remelted ingot shall be represented by a weighted average (see Annex A2) of the individual chemical analyses for each zone.

8.1.6.4 Limits on aluminum content in remelt ingots shall be set as required in the product specification.

8.2 *Heat Number Assignment for Sequentially Strand Cast Material*—When heats of the same chemical composition are sequentially strand cast, the heat number assigned to the cast product may remain unchanged until all of the steel in the product is from the following heat, except when Supplementary Requirement S3 is invoked.

8.3 *Identification of Material of Different Chemical Composition Ranges, Sequentially Strand Cast*—Because of intermixing in the tun dish, separation and identification of the resultant transition material is required when steels of different chemical composition ranges are sequentially strand cast. The steel producer shall remove the transition material by any established procedure that positively separates the grades.

8.4 *Product Analysis:*

8.4.1 An analysis may be made by the purchaser from a forging representing each heat or multiple heat (see 8.1). Samples for analysis may be taken from the forging or from a full-size prolongation. The sampling location shall be at any point from the midradius to the outer surface of disk or other solid forgings. For hollow or bored forgings, the sampling location shall be at any point from the midwall of the hollow configuration to the outer surface. The analysis may also be taken from a mechanical test specimen or the mechanical test location as defined in the product specification.

8.4.2 The chemical composition thus determined shall conform to the heat analysis requirements of the forging specification subject to the permissible variations specified in Table 1, for those elements listed in the product specification. Limitations on the application of the allowances in Table 1 may be made in the product specification for specified elements.

8.4.3 Limits on formula calculations involving elemental contents shall apply only to the heat analysis, unless agreed upon between supplier and purchaser. Where limits on formula calculations involving elemental contents apply to product analysis by such agreement, permissible variations in the formula calculation results beyond the limits for the heat analysis shall also be agreed upon between supplier and purchaser. Examples of such formula calculations include, but are not limited to, the following:

$$\text{carbon equivalent CE} = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 \quad (1)$$

$$\text{J factor} = (Mn + Si) \times (P + Sn) \times 10^4 \quad (2)$$

requirements for specific elemental balance or sufficiency, typically related to Ti, Nb, or Al and interstitials C and N, such as Nb = 5 × C minimum. (3)

8.5 *Residual and Unspecified Elements*—Provisions for the limitation of certain residual and unspecified elements have been made in Supplementary Requirements S1 and S2, respectively.

8.6 Grade substitution is not permitted.

8.7 *Method of Analysis*—Methods included in Test Methods, Practices, and Terminology A751 shall be used for referee purposes.

9. Heat Treatment

9.1 Heat treatment shall be performed as specified in the product specification. Supplementary Requirement S4 concerns a specialized heat treat process (see 3.5.3) whose application will be controlled in the product specification. Unless otherwise specified during a heat treating hold cycle, the recorded furnace temperature shall be within ±25 °F [±15 °C] of the controlling set point temperature. Material shall be heat treated in the working zone of a furnace that has been surveyed in accordance with Test Method A991/A991M or AMS 2750 provided that the working zone was established using a variation of ±25 °F [±15 °C] or less from the furnace set point.

10. Mechanical Testing

10.1 *Test Methods*—Except as specified in 4.1.5 or 10.2.1 and 10.2.2, all tests shall be conducted in accordance with Test Methods and Definitions A370. When forgings are ordered to SI requirements (M suffix standard) Test Methods A1058 shall be used (see 4.1.5).

10.1.1 In addition to the hardness testing provisions of Test Methods and Definitions A370 or, when required, Test Methods A1058, comparison hardness testing in accordance with Practice A833 may be used in determining the hardness of forgings.

10.1.2 It can be impractical to hardness test larger forgings by any other method than portable hardness testing. Product standards that state a required hardness result of HBW or HRC can have this value tested per the portable hardness testers in Test Methods and Definitions A370. The hardness results must be presented and reported according to Test Methods and Definitions A370, Portable Hardness Testing.

10.1.3 Unless otherwise specified, the forging weight and dimension (diameter, length, etc.) used for determining the number and the location of mechanical properties refer to the weight and dimension at the time of heat treatment, excluding test prolongation(s). For forgings heat treated as a multiple forging, the weight and dimensions of the multiple forging shall be used.

10.2 *Fracture Appearance Transition Temperature ($FATT_n$)*—For a product specification (including M suffix SI specifications) that requires the determination of the fracture appearance transition temperature ($FATT_n$) where n is the required minimum percentage of shear fracture as measured on the fracture surface of a Charpy V-notch sample by one of the methods described in Test Methods and Definitions A370, the Charpy test specimen location and orientation shall be as specified in the product standard.

10.2.1 When the actual fracture appearance transition temperature is required, break at least four specimens that have been taken from a comparable location. Test each specimen at a different temperature such that the percentage of shear fracture will be both above and below the value of n, but within a range of ±0.60 times that of the specified value of n. It is desirable that two of the specimens will have values of cleavage fracture above the value of n, and two will have values below this level. Plot the percentage shear fracture against test temperature and determine the transition temperature by interpolation (extrapolation is not permitted).

10.2.2 When rather than calling for an actual $FATT_n$ as described in 10.2.1, the product specification requires a minimum $FATT_n$ at a given temperature then, unless otherwise specified, a single test run at the required temperature satisfies the requirement provided that the fracture appearance value is at least n. For example, a single test run at 100 °F [38 °C] with