SPECIFICATION FOR STEEL FORGINGS, GENERAL REQUIREMENTS

SA-788/SA-788M

(Identical with ASTM Specification A788/A788M-15.)

Standard Specification for Steel Forgings, General Requirements

1. Scope

1.1 This specification 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 Fittings and 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	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 Steel 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	Specification for Continous 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
A1048/A1048M	Pressure Vessel Forgings, Alloy Steel, Higher Strength Chromium-Molybdenum-Tungsten for Elevated 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.

1.4 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

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

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

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 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 Steel Forgings for Turbine Rotors and Shafts

A833 Practice 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 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
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
A1048/A1048M Specification for Pressure Vessel Forgings, Alloy Steel, Higher Strength Chromium-Molybdenum-Tungsten for Elevated 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)
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)
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)
ASME Boiler and Pressure Vessel Code

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.

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, 16.1.5, and 16.1.6).

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 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 or midway between the inner and outer surfaces of hollow or bored forgings. 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.

TABLE 1 Permissible Variations in Product Analysis for Killed Steel

NOTE 1—This table covers permissible variations in product analysis for most of the elements commonly found in killed steels under the jurisdiction of A01.06. This table is applicable only for those elements for which product analysis variations are permitted by the material specification. The listed variation value is subtracted from the minimum specified limit, or added to the maximum specified limit for the heat analysis in the product specification.

NOTE 2— Product cross-sectional area (taken at right angles to the axis of the original ingot or billet) is defined as either: (*1*) maximum cross-sectional area of rough machined forging (excluding boring), (*2*) maximum cross-sectional area of the unmachined forging, or (*3*) maximum cross-sectional area of the billet bloom or slab.

		Permissible Variation Over the Specified Maximum Limit or Under the Specified Minimum Limit					
Element	Maximum or Specified Range—I	Up to and incl 100 in.^{2} [650 cm^2][A]	Over 100[A] to 200 in.^{2} incl [650 to 1300 cm^2]	Over 200 in.^{2} to 400 in.^{2} incl [1300 to 2600 cm^2]	Over 400 in.^{2} to 800 in.^{2} incl [2600 to 5200 cm^2]	Over 800 in.^{2} to 1600 in.^{2} incl [5200 to 10300 cm^2]	Over 1600 in.^{2} [over 10300 cm^2]
Carbon	Up to and incl 0.05	0.005	0.005	0.005	0.01	0.01	0.01
	0.06 to 0.10, incl	0.01	0.01	0.01	0.01	0.01	0.01
	0.11 to 0.25, incl	0.02	0.03	0.03	0.04	0.05	0.05
	0.26 to 0.55, incl	0.03	0.04	0.04	0.05	0.06	0.06
	0.56 and over	0.04	0.05	0.05	0.06	0.07	0.07
Manganese	Up to and incl 0.90	0.03	0.04	0.05	0.06	0.07	0.08
	0.91 and over	0.06	0.06	0.07	0.08	0.08	0.09
Phosphorus	Up to and incl 0.05	0.008	0.008	0.010	0.010	0.015	0.015
Sulfur	Up to and incl 0.030	0.005	0.005	0.005	0.005	0.006	0.006
	0.031 to 0.060 incl	0.008	0.010	0.010	0.010	0.015	0.015
Silicon	Up to and incl 0.35	0.02	0.03	0.04	0.04	0.05	0.06
	0.36 and over	0.05	0.06	0.06	0.07	0.07	0.08
Nickel	Up to and incl 1.00	0.03	0.03	0.03	0.03	0.03	0.03
	1.01 to 2.00, incl	0.05	0.05	0.05	0.05	0.05	0.05
	2.01 to 5.30, incl	0.07	0.07	0.07	0.07	0.07	0.07
	5.31 to 10.00, incl	0.10	0.10	0.10	0.10	0.10	0.10
	10.01 and over	0.15	0.15	0.15	0.15	0.15	0.15
Chromium	Up to and incl 0.90	0.03	0.04	0.04	0.05	0.05	0.06
	0.91 to 2.10, incl	0.05	0.06	0.06	0.07	0.07	0.08
	2.11 to 10.00, incl	0.10	0.10	0.12	0.14	0.15	0.16
	10.01 to 15.00, incl	0.15	0.15	0.15	0.17	0.17	0.19
	15.01 to 20.00, incl	0.20	0.20	0.20	0.22	0.24	0.24
	20.01 and over	0.25	0.25	0.25	0.27	0.27	0.29
Molybdenum	Up to and incl 0.20	0.01	0.02	0.02	0.02	0.03	0.03
	0.21 to 0.40, incl	0.02	0.03	0.03	0.03	0.04	0.04
	0.41 to 1.15, incl	0.03	0.04	0.05	0.06	0.07	0.08
	1.16 to 5.50, incl	0.05	0.06	0.08	0.10	0.12	0.12
Vanadium	Up to and incl 0.10	0.01	0.01	0.01	0.01	0.01	0.01
	0.11 to 0.25, incl	0.02	0.02	0.02	0.02	0.02	0.02
	0.26 to 0.50, incl	0.03	0.03	0.03	0.03	0.03	0.03
	0.51 to 1.25, incl	0.04	0.04	0.04	0.04	0.04	0.04
Columbium (Niobium)	Up to and incl 0.14	0.02	0.02	0.02	0.02	0.03	0.03
	0.15 to 0.50, incl	0.06	0.06	0.06	0.06	0.07	0.08
Titanium	Up to and incl 0.85	0.05	0.05	0.05	0.05	0.05	0.05
Cobalt	Up to and incl 0.25	0.01	0.01	0.01	0.01	0.01	0.01
	0.25 to 5.00, incl	0.07	0.07	0.07	0.08	0.08	0.09
	5.01 to 10.00, incl	0.14	0.14	0.14	0.16	0.16	0.18
Tungsten	Up to and incl 1.00	0.05	0.05	0.05	0.06	0.06	0.07
	1.01 to 4.00, incl	0.09	0.09	0.10	0.12	0.12	0.14
Copper	Up to and incl 1.0	0.03	0.03	0.03	0.03	0.03	0.03
	1.01 to 2.00, incl	0.05	0.05	0.05	0.05	0.05	0.05
	2.01 to 5.00, incl	0.07	0.07	0.07	0.07	0.07	0.07
Aluminum	Up to and incl 0.03	0.01	0.01	0.01	0.01	0.01	0.01
	Over 0.03 to 0.05, incl	0.01	0.01	0.02	0.02	0.03	0.03
	0.06 to 0.15, incl	0.02	0.02	0.02	0.03	0.03	0.03
	0.16 to 0.50, incl	0.05	0.05	0.06	0.07	0.07	0.08
	0.50 to 2.00, incl	0.10	0.10	0.10	0.12	0.12	0.14
Zirconium	Up to and incl 0.15	0.01	0.01	0.01	0.01	0.01	0.01
Nitrogen	Up to 0.02 incl	0.005	0.005	0.005	0.005	0.005	0.005
	Over 0.02 to 0.19, incl	0.01	0.01	0.01	0.01	0.01	0.01
	Over 0.19 to 0.25, incl	0.02	0.02	0.02	0.02	0.02	0.02
	Over 0.25 to 0.35, incl	0.03	0.03	0.03	0.03	0.03	0.03
	Over 0.35 to 0.45, incl	0.04	0.04	0.04	0.04	0.04	0.04

[A] When the product size range up to 100 in.^{2} [650 cm^2] is deleted, then the 100 to 200-in.^{2} [650 to 1300 cm^2] column shall be changed to read up to and including 200 in.^{2} [1300 cm^2].

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 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.

10.2 *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 a fracture appearance of 55 % shear fracture satisfies a requirement of $FATT_{50}$ at 100°F [38°C].

10.3 *Retests*—If the results of the tests do not conform to the requirements specified, retests are permitted as outlined in Test Methods and Definitions A370 or as follows:

10.3.1 If the percentage of elongation or reduction of area of any tension test specimen is less than specified because a flaw becomes evident in the test specimen during testing, a retest shall be allowed provided that the defect was not attributable to ruptures, cracks, or flakes in the steel.

10.3.2 If the average impact energy value meets the specification requirements, but the energy value for one specimen is below the specified minimum value for individual specimens prescribed in the material specification, a retest is permitted. This shall consist of two impact specimens from a location adjacent to and on either side of the specimen that failed. Each of the retested specimens must exhibit an energy value equal to or greater than the minimum average value required by the product specification.

11. Reheat Treatment

11.1 If the results of the initial mechanical tests do not conform to the specified requirements, the forgings may be heat treated (if initially tested in the as-forged condition) or reheat treated (if heat treated prior to initial testing).

12. Repair Welding

12.1 Repair welding of forgings is not permitted unless specifically allowed by the product specification (see also 4.2.4).

13. Dimensions and Finish

13.1 The forgings shall conform to the dimensions, tolerances, and finishes required by the ordering information (4.1.2). Supplementary Requirements S5 or S6, concerning straightening of forgings, may be used.

13.2 When surface finish, roughness, or texture is specified in a steel forging product standard, unless otherwise required by the purchaser, the roughness average (Ra), as defined in ANSI/ASME B46.1, shall be used (see 4.1.2).

14. Inspection

14.1 The manufacturer is responsible for the performance of all inspection and test requirements specified. The absence of any inspection requirements in the specification shall not relieve the contractor of the responsibility for ensuring that all products comply with all requirements of the contract. The manufacturer may use his own or any other suitable facilities for the performance of the inspection and test requirements unless disapproved by the purchaser at the time the order is placed.

14.2 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with the material specification.

14.3 Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations.

15. Rejection

15.1 Any rejection based on the presence of an injurious defect found subsequent to acceptance at the manufacturer's works or based on the results of a product analysis made in accordance with 8.4 shall be reported to the manufacturer.

15.2 Disposition of forgings rejected by the purchaser under 15.1 shall be as agreed upon between manufacturer and the purchaser.

16. Certification

16.1 The manufacturer shall furnish to the purchaser the number of copies of the material test report specified in the ordering information (4.1.4). The following items shall be reported:

16.1.1 Purchase order number,

16.1.2 Forging identification number,

16.1.3 The product specification number, including the year date and revision letter if any, as well as the appropriate class, type, and grade,

16.1.3.1 Reference to Specification A788/A788M including the year date together with the applicable revision letter, if any, of the revision used shall be a part of the certification.

16.1.4 Heat number and analysis,

16.1.5 Results of the required acceptance tests for mechanical properties,

16.1.6 Results of any required nondestructive examinations,

16.1.7 Final heat treatment cycle including austenitizing and tempering temperatures and holding times and cooling methods if required by the product specification or 4.2.3,

16.1.8 Extent to which the forging is incomplete with respect to the product specification (see 1.4 and 16.1.7), and

16.1.9 Results of any supplementary and additional test requirements that were specified.

16.1.10 The material test report may be sent to the purchaser in electronic form from an electronic data interchange (EDI) transmission, and this shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document shall meet the requirements of the invoked ASTM standard(s) and conform to any existing EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

17. Packaging and Package Marking

17.1 Each forging shall be legibly identified as required by the product specification and instructions from the purchaser. When not otherwise defined, each forging shall be identified by the manufacturer as follows:

17.1.1 Manufacturer's name or symbol.

17.1.2 Manufacturer's identification or heat number.

17.1.3 Product specification number.

17.1.4 The class, grade, and type identification as appropriate.

17.1.5 Purchaser's identification (4.2.3).

17.1.6 Location of stamping (4.2.3).

17.1.7 Incomplete forging (1.4). The marking shall include the suffix Y immediately following the ASTM number, and preceding any other suffix. This suffix shall not be removed until the material specification requirements have been completed and the material test report supplemented.

17.2 Marking shall be done by impression stamping or other acceptable means specified in the product specification or order. Bar coding is an acceptable supplemental identification method. The purchaser may specify in the order a specific bar coding system to be used. The bar coding system, if applied at the discretion of the supplier, should be consistent with one of published industry standards for bar coding.

17.3 The specification year date, and revision letter are not required to be marked on the forgings.

18. Keywords

18.1 general delivery requirements; steel forgings—alloy; steel forgings—carbon

SUPPLEMENTARY REQUIREMENTS

(GENERAL)

The following supplementary general requirements are common to the forging specifications listed in this specification. These and other limitations or tests may be performed by agreement between the supplier and purchaser. The additional requirements shall be specified in the order, and shall be completed by the supplier before the shipment of the forgings.

S1. Residual Elements

S1.1 Small quantities of certain unspecified elements may be present in carbon and low alloy steel forgings. These elements are considered as incidental and may be present to the following maximum amounts:

Copper	0.35 %
Nickel	0.30 %
Chromium	0.25 %
Molybdenum	0.10 %
Vanadium[A]	0.03 %

[A] Unless Supplementary Requirement S2 is required.

S2. Unspecified Elements

S2.1 Vanadium used for grain refinement or deoxidation shall not exceed 0.08 %.

S3. Sequential or Continuous Strand Casting

S3.1 When multiple heats of the same chemical composition range are sequentially strand cast, the heats shall be separated by an established procedure such that intermix material will not be supplied.

S4. Intercritical Heat Treatment

S4.1 The austenitizing stage in the heat treatment of ferritic forgings is intended to be done at suitable temperatures above the upper critical temperature (Ac_3) for the heat of steel involved, that is, full austenitization. However, when multiple austenitizing stages are used the temperature for the last may be set between the upper (Ac_3) and lower (Ac_1) critical temperature for partial austenitizing. Such cycles shall be followed by tempering within the temperature limits required by the material specification.

S5. Straightening of Forgings

S5.1 Unless otherwise specified by Supplementary Requirement S6, straightening of forgings after heat treatment for properties shall be performed at a temperature which is not more than 100°F [55°C] below the final tempering temperature. Following straightening, forgings shall be stress relieved at a temperature of 50 to 100°F [30 to 55°C] below the final tempering temperature and shall be reported on the material test report. Any straightening performed before heat treatment for properties does not require an intermediate stress-relief heat treatment.

S6. Post-Heat Treatment Straightening of Forgings

S6.1 Straightening after heat treatment for specified properties is not permitted without prior approval by the purchaser.

S7. Fracture Toughness Test

S7.1 The purchaser shall specify one or more of the following test methods for fracture toughness determination. Required information including test temperature, conditioning, environment, and acceptance criteria shall be provided as necessary.

S7.2 Determination of the plane strain fracture toughness in accordance with Test Method E399.

S7.3 Fracture toughness determination in accordance with Test Method E1820.

S7.4 Crack-tip opening displacement determination in accordance with Test Method E1290.

S8. Vacuum Degassing

S8.1 The vacuum degassing requirements of 5.2 shall apply.

S9. Vacuum Carbon Deoxidation

S9.1 The molten steel shall be vacuum carbon deoxidized (VCD) during processing, in which case the silicon content shall be 0.10 % maximum.

S10. Restricted Phosphorus and Sulfur, Levels A or B

S10.1 For level A, the phosphorus and sulfur levels shall be limited as follows:

		Heat	Product
Level A	P	0.015 % maximum	0.018 % maximum
	S	0.018 % maximum	0.021 % maximum

S10.2 For level B, the phosphorus and sulfur levels shall be limited to the following:

		Heat	Product
Level B	P	0.012 % maximum	0.015% maximum
	S	0.015% maximum	0.018 % maximum

S11. Restricted Copper, Levels A or B

S11.1 For level A, the heat and product analyses limits for copper shall be 0.15 % maximum.

S11.2 For level B, the heat and product analyses limits for copper shall be 0.10 % maximum.

S12. Tension Specimens for Hubbed Flat Heads and Tube Sheets

S12.1 For hubbed tube sheets and flat heads to be used in ASME Boiler and Pressure Vessel Code construction, an axial tension specimen shall be taken as close as possible to the hub and either inboard or outboard of it, using a sub size specimen if necessary. The longitudinal axis of the specimen shall be parallel to the length of the hub, as shown in Fig. S12.1.

S12.2 By agreement with the purchaser, this test orientation may replace a specified tension test specimen, provided that other location criteria are met.

S13. Charpy Impact Tests

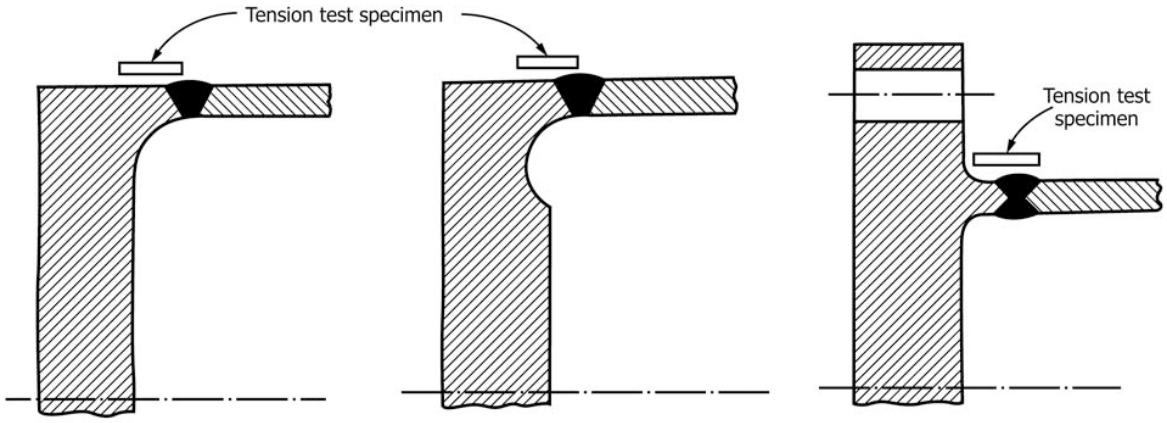
S13.1 Charpy impact tests shall be made. The number, orientation and location of the tests shall be specified along with the test temperature and the applicable acceptance criteria for absorbed energy, fracture appearance, lateral expansion, or both.

S13.2 The specimens shall be machined and tested in accordance with Test Methods and Definitions A370 or Test Methods A1058 in accordance with the purchase order.

S14. Charpy V Notch Impact Transition Curve

S14.1 Sufficient impact tests shall be made from the forging material to establish a transition temperature curve based upon one or several of the following criteria:

S14.1.1 Absorbed energy (ft·lbf [J]) (See Test Methods E23 or, if required by the purchase order, Test Methods A1058),



NOTE 1—Tension test specimens also may be located inboard of the hub.

FIG. S12.1 Tension Test Specimens

S14.1.2 Fracture appearance (see Supplement 5 of Test Methods and Definitions A370), or

S14.1.3 Lateral expansion.

S14.1.4 The test temperature range shall be wide enough to establish the upper and lower shelf energies, with sufficient testing at intermediate temperatures to permit a smooth curve to be plotted. A minimum test temperature may be set by agreement instead of establishing the lower shelf temperature. The upper shelf energy level is defined as having at least 95 % fibrous fracture and the lower shelf level is defined as showing 5 % or less fibrous fracture.

S14.2 The purchaser shall furnish the manufacturer with details of sample location, number of specimens, heat treatments, and information to be derived from the test.

S15. Grain Size

S15.1 When a grain size range is required, it shall be specified in the ordering information as heat treated or austenitic, and shall be determined by an agreed-upon method from Test Methods E112.

S15.2 Samples for grain size estimation from heat treated products shall be taken from the tension test specimen location.

S16. Rough Machining and Boring

S16.1 The position of the rough machining and boring in the manufacturing sequence shall be specified by the purchaser, particularly with regard to heat treatment for mechanical properties.

S17. Simulated Post-Weld Heat Treatment of Mechanical Test Samples

S17.1 All test coupons shall be subjected to single or multiple heat treatments at subcritical temperatures prior to testing. Such treatments are intended to simulate post-weld or other treatments to which the forgings will be subjected during subsequent fabrication. The purchaser shall furnish the manufacturer with details of the desired heat treatment for the test coupons, including temperatures, times, and cooling rates.

S18. Magnetic Particle Examination

S18.1 All accessible surfaces of the finished forging shall be subject to magnetic particle examination in accordance with Practice A275/A275M.

S18.2 Unless otherwise agreed upon between the manufacturer and the purchaser the wet continuous method shall be used.

S18.2.1 The following conditions are subject to rejection or removal:

S18.2.1.1 Indications with major dimension exceeding 3⁄16 in. [5 mm].

S18.2.1.2 Four or more indications exceeding 1⁄16 in. [1.5 mm] in major dimensions that are aligned and separated by 1⁄16 in. [1.5 mm] or less end to end.

S18.2.1.3 Ten or more indications exceeding 1⁄16 in. [1.5 mm] in major dimensions contained in any 6 in.^{2} [40 cm^2] of surface, with the major dimension of this area not to exceed 6 in. [150 mm]. The area shall be taken in the most unfavorable location relative to the indications being evaluated.

S19. Liquid Penetrant Examination

S19.1 All accessible surfaces of the finished forging shall be subject to liquid penetrant examination in accordance with Practice E165/E165M. The penetrant system to be used shall be agreed upon between the manufacturer and purchaser.

S19.2 The following conditions are subject to rejection or removal:

S19.2.1 Indications with major dimensions exceeding 3⁄16 in. [5 mm].

S19.2.2 Four or more indications exceeding 1/16 in. [1.5 mm] in major dimensions that are aligned and separated by 1/16 in. [1.5 mm] or less end to end.

S19.2.3 Ten or more indications exceeding 1/16 in. [1.5 mm] in major dimensions contained in any 6 in.^{2} [40 cm^2] of surface, with the major dimension in this area not to exceed 6 in. [150 mm]. The area shall be taken in the most unfavorable location relative to the indications being evaluated.

S20. Ultrasonic Examination

S20.1 Ultrasonic examination of forgings shall be carried out in accordance with Practice A388/A388M.

S20.2 Unless otherwise agreed upon between the manufacturer and the purchaser, acceptance levels BR or DA shall be specified for the longitudinal wave examination and level S for shear wave examination.

Level BR—Longitudinal Wave

S20.2.1 The back reflection method of tuning shall be used in accordance with Practice A388/A388M.

S20.2.2 In addition to the reportable conditions of the Recording Section of Practice A388/A388M, indications exceeding the resultant back reflection shall be recorded.

S20.2.3 The following conditions are subject to rejection, or repair if applicable.

S20.2.3.1 Complete loss of back reflection accompanied by an indication of a discontinuity. For this purpose, a back reflection less than 5 % of full screen height shall be considered complete loss of back reflection.

S20.2.3.2 An indication equal in amplitude to that of the back reflection established in an indication-free portion of the forging.

Level DA—Longitudinal Wave

S20.2.4 Reference blocks of acoustically similar metal shall be used for calibration. Blocks shall meet one of the following requirements:

S20.2.4.1 A comparison of the back reflections between equivalent thicknesses of the reference block material and the actual forging to be tested, without change in instrument setting shall not show a variation in excess of 25 %.

S20.2.4.2 The reference blocks shall be manufactured from steel that is similar in chemistry and processing history to the production forging being tested. The reference blocks shall be fabricated in accordance with the procedures of Practice E428.

S20.2.4.3 For test sections up to and including 12 in. [300 mm] thick, the reference blocks shall contain a 1/4 in. [6 mm] diameter flat-bottom hole; for over 12 in. [300 mm] up to and including 18 in. [300 to 450 mm], the hole diameter shall be 3/8 in. [10 mm]; and for over 18 in. [450 mm], it shall be 1/2 in. [13 mm].

S20.2.4.4 A distance-amplitude correction curve shall be established for the proper grade of steel and specified hole size.

S20.2.4.5 A forging containing one or more indications equal in amplitude to that of the applicable reference hole, when properly corrected for distance, is subject to rejection, or repair if applicable.

Level S–Shear Wave

S20.2.5 Calibration notches, calibration reference, and method of scanning shall be in accordance with Practice A388/A388M. Unless otherwise agreed upon, a 60° V-notch shall be used.

S20.2.6 A forging containing a discontinuity that results in an indication exceeding the amplitude of the reference line is subject to rejection.

S20.2.7 The report of the ultrasonic examination shall be in compliance with Practice A388/A388M.

S20.2.8 Additional nondestructive examination or trepanning may be employed to resolve questions of interpretation of ultrasonic indications. The manufacturer shall accept responsibility for injurious conditions that will not be removed in final machining.

S21. Additional Test Coupon Heat Treatment

S21.1 When subcritical heat treatment, applied to a completed forging during subsequent fabrication, may affect the mechanical properties of the forging, then coupons for the mechanical testing required by the product specification shall be given a laboratory heat treatment, which simulates the anticipated subcritical heat treatment.

S21.2 The purchaser shall specify the required heat treatment temperature range, minimum time at temperature, and the rates of heating and cooling.

S21.3 The required number of test coupons shall be taken from the forging location described in the product specification.

S21.4 The test specimens shall meet the minimum mechanical test requirements of the product specification, as well as those of any additional tests agreed upon between producer and purchaser, after completion of the test coupon heat treatment.

S21.5 The forgings supplied in accordance with this supplementary requirement shall be marked in accordance with 17.1.7.

S21.6 The material test reports shall include the heat treatment of the as-delivered material and the results of the mechanical tests from the test coupons subjected to the purchaser specified heat treatments that represent fabrication.

S22. Ultrasonic Examination from Bore Surface

S22.1 Bored cylindrical forgings shall be examined from the bored surface in accordance with Practice A939/A939M. The acceptance criteria shall be agreed upon between the purchaser and the producer.

S23. Magnetic Particle Examination Using AC Current

S23.1 The designated surfaces of ferromagnetic steel forgings shall be examined at the stage in machining specified by the purchaser in accordance with Practice A966/A966M. The acceptance criteria for the examination shall be specified by the purchaser.

S24. J_{factor}

S24.1 The J_{factor}, calculated by means of the following equation, shall be established for each heat of steel used in forging manufacture:

$$J_{factor} = (Mn + Si)\,(P + Sn) \times 10^4$$

Has been found to be effective in reducing temper embrittlement effects.

S24.2 The purchaser shall specify the required maximum value of J_{factor} in both the inquiry and ordering documents.

S24.3 The determination of the tin content of the steel is necessary for the application of this supplementary requirement even if there is no chemical analysis requirement for tin in the product specification.

Note—In Dr. Paul Bates's paper,[1] it was noted that the Fracture Appearance Transition Temperature (FATT) fell steadily from J_{factor} 120 to 60, but below 20, the drop in FATT was much less apparent.

S25. Positive Material Identification

S25.1 Forgings shall receive positive material identification to ensure that forgings are of the ordered material grade prior to shipment.

S25.2 Forgings shall receive a positive material identification in accordance with Guide E1916.

S25.3 The entire ordered quantity of forgings shall be examined.

S25.4 Forgings not conforming to the ordered grade shall be rejected.

S25.5 Following this material identification examination, acceptable forgings shall be marked as agreed between the purchaser and producer.

S26. Pressure Equipment Directive—Mechanical Testing

S26.1 Charpy impact testing shall be done at the lowest scheduled operating temperature, but not higher than 68°F [20°C].

S26.2 The frequency of Charpy impact testing shall be the same as that specified in the product specification for the tension test, with one Charpy test (3 specimens) for each required tension test.

S26.3 The minimum individual absorbed energy for the Charpy impact test shall be 20 ft·lbf [27 J].

S26.4 The minimum elongation in the tension test shall be measured on a gauge length of five times the diameter of the test specimen (5D), and shall be not less than 14 %.

S26.5 The results of the impact and tension tests shall be included in the product certification.

S27. Heat Analysis for Remelted Ingots

S27.1 Instead of the heat analysis provisions in 8.1.6.2 of Specification A788/A788M for consumable electrode remelting processes, a heat analysis shall be obtained from each remelted ingot (or the product from it) from single master or parent heat.

S27.2 The product analysis provisions of Specification A788/A788M shall not apply.

[1] Bates, P., "The Production of Safety Critical Forgings for Pressure Vessel Applications," *International Forgemasters Conference*, Wiesbaden, Germany, September 2000.

ANNEXES

(Mandatory Information)

A1. RECIRCULATION FACTOR

A1.1 The recirculation factor for the vacuum lift process is obtained as follows:

$$\frac{\text{Tons (kg) of Steel Lifted per Cycle} \times \text{Number of Cycles}}{\text{Heat Weight in Tons [kg]}}$$

A2. EXPLANATORY NOTE FOR WEIGHTED AVERAGE ANALYSIS

A2.1 A weighted average analysis is mandatory whenever an ingot is poured from the combination of two or more heats wherein the resultant chemistry of the ingot assumes an identity attributable to each heat involved in the combination. It is necessary to make this determination to ensure that each element in the official chemistry is represented by proportion to its amount in each individual furnace heat. An example of the determination of a weighted average analysis for an ingot made from a three-heat combination pour with varying weights and chemistry involved in each heat is shown below:

Furnace	Heat[A] Weight, tons	Individual Heat Chemistry, %								
		C	Mn	P	S	Si	Ni	Cr	Mo	V
A	25	0.20	0.50	0.010	0.020	0.34	0.92	0.32	0.12	0.03
B	50	0.25	0.50	0.013	0.015	0.38	0.98	0.32	0.12	0.02
C	50	0.25	0.50	0.015	0.018	0.38	0.94	0.34	0.13	0.02
	125[B]									

[A] This is individual heat contribution to the total ingot weight.
[B] Total ingot weight.

Step # 1—Determine furnace factor (FF) for each heat based on weight.

Furnace A = 25/125 = 20 %
Furnace B = 50/125 = 40 %
Furnace C = 50/125 = 40 %

$$\mathrm{FF} = \frac{(\text{Individual Fnce Ht. Wt})}{(\text{Combined Heat Weight})} \times 100\,\%$$

Step # 2—Calculate the weighted average for each element. Examples for several elements shown below:

$$\text{Weighted avg} = \text{sum of } (\%\ \text{element in each furnace heat} \times \mathrm{FF})$$

° Weighted avg of Carbon (weighted avg):
Furnace A—0.20 % × 20 % = 0.04 %
Furnace B—0.25 % × 40 % = 0.10 %
Furnace C—0.25 % × 40 % = 0.10 %
Add to get weighted avg of 0.24 %

° Weighted avg of manganese:
Furnace A—0.50 % × 20 % = 0.10 %
Furnace B—0.50 % × 40 % = 0.20 %
Furnace C—0.50 % × 40 % = 0.20 %
Add to get weighted avg of 0.50 %

° Weighted avg of phosphorus:
Furnace A—0.010 % × 20 % = 0.002 %
Furnace B—0.013 % × 40 % = 0.0052 %
Furnace C—0.015 % × 40 % = 0.006 %
Add to get weighted avg of 0.013 %[A]

[A] (Round to significant figures in accordance with Practice E380.)
° The same procedure is used for all of the other elements.

A3. REQUIREMENTS FOR THE INTRODUCTION OF NEW MATERIALS

A3.1 New materials may be proposed for inclusion in specifications referencing this specification of general requirements subject to the following conditions:

A3.1.1 Application for the addition of a new grade to a specification shall be made to the chair of the subcommittee that has jurisdiction over that specification.

A3.1.2 The application shall be accompanied by a statement from at least one user indicating that there is a need for the new grade to be included in the applicable specification.

A3.1.3 The application shall be accompanied by test data as required by the applicable specification. Test data from a minimum of three test lots, as defined by the specification, each from a different heat, shall be furnished.

A3.1.4 The application shall provide recommendations for all requirements appearing in the applicable specification.

A3.1.5 The application shall state whether or not the new grade is covered by patent.

A4. REQUIREMENTS FOR THE INTRODUCTION OF MATERIALS FROM OTHER A01 OR B02.07 SPECIFICATIONS

A4.1 Wrought materials that are already covered by another A01 or B02.07 specification may be proposed for inclusion in specifications referencing this specification of general requirements subject to the following conditions:

A4.1.1 Application for the addition of a grade that is already covered in another A01 or B02.07 specification shall be made to the chair of the subcommittee that has jurisdiction over the specification to which the addition is being proposed.

A4.1.2 The chemical requirements, the specified mechanical properties, and the heat treatment requirements of the grade being added shall be the same as those for the grade in the A01 or B02.07 specification in which the grade is presently covered.

A4.1.3 The application shall provide recommendations for all requirements appearing in the applicable specification.

A4.1.4 The application shall state whether or not the grade is covered by patent.