Designation: A1095 – 15

Standard Specification for High-Silicon Molybdenum Ferritic Iron Castings[1]

This standard is issued under the fixed designation A1095; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers castings made of high-silicon molybdenum ferritic iron, commonly known as SiMo. This specification includes castings with microstructures of spheroidal graphite (SG) SiMo iron, compacted graphite (CG) SiMo iron, and mixed graphite or medium-nodularity graphite (MG) SiMo iron. MG iron microstructure comprises a mixture of spheroidal and compacted graphite shapes. This standard specifies the condition, chemical composition, microstructure, and other technical requirements of three grades of ferritic cast irons, specified as SG SiMo, MG SiMo, and CG SiMo.

1.2 No precise quantitative relationship can be stated between the properties of iron in the various locations of the same casting or between the properties of castings and those of a test specimen cast from the same iron.

1.3 The values stated in SI units are to be regarded as standard. All chemical compositions are in mass percentage. No other units of measurement are included in this standard.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A247 Test Method for Evaluating the Microstructure of Graphite in Iron Castings

A395 Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures

A476/A476M Specification for Ductile Iron Castings for Paper Mill Dryer Rolls

A536 Specification for Ductile Iron Castings

A834 Specification for Common Requirements for Iron Castings for General Industrial Use

A842 Specification for Compacted Graphite Iron Castings

A897/A897M Specification for Austempered Ductile Iron Castings

D1976 Test Method for Elements in Water by Inductively-Coupled Argon Plasma Atomic Emission Spectroscopy

D5381 Guide for X-Ray Fluorescence (XRF) Spectroscopy of Pigments and Extenders

E8/E8M Test Methods for Tension Testing of Metallic Materials

E10 Test Method for Brinell Hardness of Metallic Materials

E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials

E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

E351 Test Methods for Chemical Analysis of Cast Iron—All Types

E1184 Practice for Determination of Elements by Graphite Furnace Atomic Absorption Spectrometry

E1999 Test Method for Analysis of Cast Iron by Spark Atomic Emission Spectrometry

2.2 *SAE (Society of Automotive Engineers) International Standards:*

J434 Automotive Ductile (Nodular) Iron Castings

J1887 Automotive Compacted Graphite Iron Castings

J2582 Automotive Ductile Iron Castings for High Temperature Applications

2.3 *Federal Standard:*

FED-STD-123 Marking for Shipment (Civil Agencies)

2.4 *American National Standard:*

MIL-STD-129 Military Marking for Shipment and Storage

2.5 *Other Publications:*

AFS (American Foundry Society), Foundrymen's Guide to Ductile Iron Microstructures, 1984

AFS, Iron Castings Engineering Handbook, 2004

ASM Specialty Handbook, Cast Irons, 1999

ASM Specialty Handbook, Heat-Resistant Materials, 1999

ASM Handbook, Casting, Volume 15, 1998

3. Ordering Information

3.1 Orders for materials to this specification shall include the following information:

3.1.1 ASTM designation and year of issue,

[1] This test method is under the jurisdiction of ASTM Committee A04 on Iron Castings and is the direct responsibility of Subcommittee A04.02 on Malleable and Ductile Iron Castings.

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

3.1.2 Grade of silicon-molybdenum ferritic iron required,
3.1.3 Chemical composition requirements (see Section 5),
3.1.4 Microstructure and mechanical requirements (see Sections 6 and 7),
3.1.5 Drawing and test coupon criteria (see Section 8),
3.1.6 Special requirements, if desired (see Sections 9 and 11),
3.1.7 Certification if so designated by purchaser (see Section 12), and
3.1.8 Special preparation for delivery, if required (see Section 14).

4. Materials and Manufacture

4.1 The manufacturer shall produce high-silicon molybdenum iron castings with a microstructure consisting of a predominantly ferritic matrix in the as-cast condition. Small amounts of flake graphite in the surface reaction zone are allowed only when agreed between the manufacturer and purchaser.

4.2 High-silicon ferritic SiMo iron castings are typically supplied in the as-cast condition. If heat treatment is agreed between the manufacturer and purchaser, castings can be either fully or subcritically annealed. The recommended heat treatment practice is provided in Appendix X3.

5. Chemical Composition

5.1 Chemical requirements for each grade are specified in Table 1. Chemical composition shall be determined from chilled disk samples or samples representative of the castings and in accordance with the applicable sections of Test Methods D1976, E351, and E1999, Practice E1184, and Guide D5381.

5.2 When agreed between the manufacturer and purchaser, chemistry control ranges may be tighter than those specified in Table 1.

5.3 Controlling the carbon equivalent is important to achieve uniform graphite distribution and to minimize solidification shrinkage and graphite flotation. The carbon equivalent control range shall be established by the manufacturer to produce castings that meet the chemical composition ranges in Table 1, the microstructure requirements in Section 6, and the mechanical properties in Table 2.

TABLE 1 Chemical Composition Requirements

	Type		
	SG SiMo	MG SiMo	CG SiMo
Element	Composition (mass %)		
Carbon	2.90–3.70	2.80–3.60	2.70–3.50
Silicon	3.50–4.80	3.50–4.80	3.50–4.80
Molybdenum	0.40–1.50	0.40–1.50	0.40–1.50
Titanium	0.05 max	0.10 max	0.25 max
Magnesium	0.06 max	0.05 max	0.04 max
Manganese	0.50 max	0.50 max	0.50 max
Nickel	0.50 max	0.50 max	0.50 max
Copper	0.30 max	0.30 max	0.30 max
Tungsten	0.30 max	0.30 max	0.30 max
Vanadium	0.10 max	0.10 max	0.10 max
Niobium	0.30 max	0.30 max	0.30 max
Chromium	0.50 max	0.50 max	0.50 max
Phosphorus	0.02–0.05	0.05 max	0.05 max
Sulfur	0.02 max	0.02 max	0.02 max
Iron	balance	balance	balance

TABLE 2 Tensile and Hardness Requirements

Testing Temperature	Grade	SG SiMo	MG SiMo	CG SiMo
Room temperture	Tensile strength, min, MPa	500	450	400
	Yield strength, min, MPa	420	400	350
	Elongation in 25 mm or 50 mm, min, %	6.0	4.0	1.5
	Brinell hardness, HBW	190–270	190–270	190–270

5.4 Chromium can improve heat resistance of SiMo iron castings. Annealing heat treatments should be utilized if Cr content exceeds 0.10 %.

5.5 The total concentrations of alloy elements including Mo, Mn, Ni, Cu, W, V, Nb, and Cr shall not exceed 2.5 %.

5.6 The lower limit of phosphorus for SG SiMo iron is specified to eliminate the brittleness at medium temperature of approximately 425°C.

6. Microstructure

6.1 The matrix requirements for the three grades of SiMo irons are the same: predominantly ferritic, a maximum 5 % primary carbides, and adjacent to the cell boundaries, a maximum 30 % Mo-rich precipitates.

6.2 All the three grades of SiMo iron castings for which chemical composition is specified in Table 1 shall be substantially free of flake, exploded, chunky, crab, spiky, and floatation graphite. Flake graphite is permitted in the surface reaction zone to a maximum depth of 0.30 mm for sections ≤10 mm and to a maximum depth of 0.60 mm for sections >10 mm.

6.3 For SG SiMo iron, the graphite in the microstructure shall consist of a minimum 80 % Type I and Type II graphite according to Test Method A247.

6.4 For CG SiMo iron, the graphite in the microstructure shall consist of a minimum 60 % Type IV graphite; the remaining graphite shall be a combined maximum 40 % Type I, Type II, and Type III graphite according to Test Method A247 and Specification A842.

6.5 For MG SiMo iron, the graphite in the microstructure shall consist of a minimum 40 % of Type I and Type II graphite according to Test Method A247 and a range of 30 to 60 % Type IV graphite according to Test Method A247 and Specification A842.

6.6 The volume fraction of graphite is typically in the range of 8 to 14 %. Graphite structure evaluations using image analysis should only be done by agreement between the manufacturer and purchaser.

7. Mechanical Properties

7.1 Tensile testing specimens shall be taken from separately cast coupons unless otherwise agreed between the manufacturer and purchaser. Brinell hardness testing specimens may be test coupons or castings or both (see Section 8).

7.2 The iron as represented by the test specimens shall conform to the requirements in Table 2 for tensile properties and hardness at room temperature. The tensile testing shall proceed in accordance with Test Methods E8/E8M for room temperature and Test Method E21 for elevated temperature. If the test results fail to conform to the requirements, two retests shall be performed with specimens removed from test coupons or castings produced using the same casting conditions. If either retest fails to meet the specification requirements, the castings represented by these test specimens shall be subject to rejection.

7.3 Yield strength shall be determined using the 0.2 % offset method in accordance with Test Methods E8/E8M. Brinell hardness shall be determined in accordance with Test Method E10.

7.4 The tensile properties at 425°C are listed in Table 3 for reference (nonmandatory) information to monitor the possible brittleness at medium temperature. The medium temperature is defined in the range of 350 to 500°C.

8. Test Coupons

8.1 Test coupons for microstructure determination and mechanical properties testing may be separately cast or attached to castings. Separately cast test coupons shall be poured from the same iron as the castings they represent. This means the same chemical composition, the same inoculation practice, and an equivalent cooling rate. The details of test coupons including coupon type, size, location, sampling methods and other coupon-related control plans shall be agreed between the manufacturer and purchaser.

8.2 The type of metallographic specimen used shall be agreed between the manufacturer and purchaser. Three types of metallographic specimens may be used: (1) separately cast coupons, (2) a test lug cast with castings or attached to the pouring basin or cup, and (3) specimens cut from castings.

8.3 Separately cast test coupons shall be Y-blocks, keel blocks, or modified keel blocks in accordance with Specifications A395, A476/A476M, A536, A842, and A897/A897M.

TABLE 3 Tensile Properties at 425°C for References

Testing Temperature	Grade	SG SiMo	MG SiMo	CG SiMo
425°C	Tensile strength, min, MPa	400	380	360
	Yield strength, min, MPa	340	320	300
	Elongation in 25 mm or 50 mm, min, %	5.0	4.0	1.5

8.3.1 The bottom Y-block thickness shall be 13 mm for casting thickness <13 mm, 25 mm for casting thickness 13 to 38 mm, and 75 mm for casting thickness >38 mm.

8.3.2 Leg thickness of keel blocks shall be 25 mm for casting thickness 13 to 38 mm. For other casting thickness, the keel block thickness shall be changed according to 8.3.1.

8.3.3 Modified keel blocks of 25 mm bar diameter can be substituted for the 25-mm Y-block or the 25-mm keel block.

8.3.4 The coupon molds shall have a thickness equal or greater than the coupon thickness. The coupons shall be left in the mold until they have cooled to a black color (≤500°C).

8.3.5 If the test bars show obvious defects, additional bars shall be cut from other test blocks representing the same iron.

8.4 When castings made in accordance with this specification are produced by spheroidization directly in the mold, the manufacturer may use either separately cast test coupons or test specimens cut from castings. When separately cast test coupons are used, selection shall be according to 8.1. If test bars are to be cut from castings, test bar location shall be agreed between the manufacturer and purchaser and shall be indicated on the casting drawing or model.

9. Additional Tests

9.1 In addition to the chemical, microstructure and mechanical requirements in Sections 5 – 7, other special tests such as nondestructive testing (radiographic soundness, liquid penetrant examination, magnetic particle inspection, leakage testing) may be agreed between the manufacturer and purchaser. Refer to Specification A834 for a list of common requirements for iron castings not specifically referenced elsewhere in this specification.

10. Workmanship, Finish, and Appearance

10.1 The castings shall be free of injurious defects. Surface of the castings shall be free of burnt-on sand and shall be reasonably smooth. Runners, risers, and other cast-on pieces shall be removed. In other respects, the castings shall conform to whatever points may be specifically agreed upon between the manufacturer and the purchaser.

10.2 No repairing by plugging or welding of any kind shall be permitted unless written permission is granted by the purchaser.

11. Inspection and Quality

11.1 At the time of an order, the purchaser should establish an agreement for quality and inspection requirements with the manufacturer.

11.2 Unless otherwise specified in contract or purchase order, the manufacturer shall be responsible for carrying out all the tests and inspections required by this specification. The purchaser reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to the prescribed requirements.

12. Certification

12.1 When specified in the purchase order or contract, the manufacturer's or supplier's certification shall be furnished to

the purchaser stating that samples representing castings have been manufactured, tested, and inspected in accordance with this specification and that the requirements have been met. When specified in the purchase order or contract, a report of the test results shall be furnished.

13. Product Marking

13.1 When the size of the casting permits, each casting shall bear the cast date, the part or pattern number, and the identifying mark of the manufacturer. The cast date may be coded. The cast date, identifying mark of the manufacturer, and the part or pattern number shall be at a location shown on the casting drawing or model, or if not shown on the drawing or model, at a location selected at the discretion of the manufacturer.

14. Packaging and Package Marking

14.1 Unless otherwise stated in the contract or order, cleaning, drying, preservation, and packing of castings for shipment shall be in accordance with the manufacturer's commercial practice. Packaging and marking shall also be adequate to identify the contents and to ensure acceptance and safe delivery by the carrier for the mode of transportation employed.

14.2 *U.S. Government Procurement*—When specified in the contract or purchase order, marking for shipment shall be in accordance with the requirements of FED-STD-123 for civil agencies and MIL-STD-129 for military activities.

15. Keywords

15.1 compacted graphite (CG); high-silicon molybdenum (SiMo) ferritic iron; high temperature applications; mixed graphite or medium-nodularity graphite (MG); spheroidal graphite (SG)

APPENDIXES

(Nonmandatory Information)

X1. MATERIALS PROPERTIES OF SiMo IRON

X1.1 SiMo iron castings provide satisfactory service in many elevated-temperature applications up to approximately 800°C, especially for automotive exhaust components where a moderate heat-resistance is required. Chemical composition and microstructure need to be controlled in order to achieve a high level of balanced properties of SiMo irons.

X1.2 Mechanical properties are greatly influenced by alloying elements and graphite shapes. Molybdenum increases the iron strength at room and elevated temperatures. Silicon has solution strengthening effect until 700°C. However, Si and Mo tend to reduce toughness and elongation at room temperature, especially when concentrations exceed 4.8 % Si, 1.5 % Mo, or both. MG SiMo mechanical properties are between SG and CG SiMo iron. In addition, MG SiMo iron can improve castability and machinability as compared to CG and SG SiMo irons. The brittleness at medium temperature is controlled by graphite nodularity and by residual contents of magnesium, sulfur, and phosphorus. The lower limit of phosphorus of SG SiMo is specified as shown in Table 1 to reduce the brittleness at medium temperature.

X1.3 With respect to the oxidation resistance at high temperatures, SG SiMo iron can exhibit less weight change and less internal oxidation damage compared to CG SiMo. CG SiMo iron can have less external oxide built-up and more oxide adherent than SG SiMo. Oxidation resistance of MG SiMo is between that of SG and CG SiMo irons. In addition, hot oxidation resistance is greatly improved by alloying elements such as silicon.

X1.4 Structure stability is mainly referred to the critical temperature Ac1 indicating the onset of phase transformation from ferrite to austenite upon heating at a defined heating rate. For example, the Ac1 of SiMo iron was measured, in accordance with Test Method E228 using a heating rate of 1°C/min, as approximately 815°C for 3.5 % Si, as approximately 840°C for 4.0 % Si, and as approximately 865°C for 4.5 % Si.

X1.5 Thermal conductivity of CG SiMo is higher than that of SG SiMo when the testing temperature is below 400°C. When the temperature exceeds 400°C, the difference in thermal conductivity tends to decrease.

X1.6 Thermal fatigue resistance of SiMo iron castings is influenced by various factors such as chemical composition, microstructure, casting soundness, casting design, and thermal cycling testing methods. SG, MG, and CG SiMo iron can have different application scopes in terms of product design and service conditions.

X1.7 Chemical compositions are specified in Section 5 and Table 1. The effects of elements on SiMo iron and the chemical guidelines are further summarized in Table X1.1.

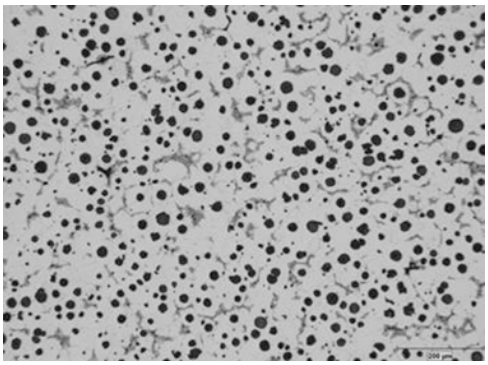
TABLE X1.1 Brief Summary of Effect of Elements on SiMo Iron Castings

Element	Effect on SiMo Iron Castings
C	If excessive levels of carbon are present, graphite flotation can occur and reduce the apparent strength levels. If carbon contents are too low, the shrinkage tendency can increase. Carbon content should be controlled within the specified range in conjunction with the controlling the carbon equivalent.
Si	Silicon plays multiple important roles in SiMo irons: promoting graphite, increasing the Ac1 temperature, stabilizing ferrite, improving hot oxidation resistance, and solution strengthening until 700°C. However, the charpy toughness can decrease dramatically when exceeding 4.80 % Si.
Mo, Cr, W, Nb, and V	These elements are transition metals in Groups 5 and 6 in the periodic table. These elements are carbide formers and ferrite promoters. Of the alloying elements, only Mo is intentionally added in this specification by considering strengthening effectiveness. Cr can improve heat resistance, but an annealing heat treatment should be utilized for SiMo iron castings when exceeding 0.10 % Cr
Mn, Ni, and Cu	These three elements can reduce the Ac1 temperature and ferrite stability to a different extent. As such, they are not intentionally added for SiMo iron castings in this specification.
Mg and REM (Rare Earth Metals)	Mg and REM are graphite spheroidizers. Excessive levels of Mg and REM may cause brittleness at medium temperature and casting defects.
P	A small addition of P can reduce the brittleness at medium temperature for SG iron.
Al and Ti	Both elements are considered to be anti-spheroidizing elements. Aluminum greatly increases heat resistance of SiMo iron but also causes casting difficulties for largescale production. Ti may be added to CG SiMo iron, but SG and MG SiMo irons should be free of Ti additions.
Fe	As the balance, Fe content should be kept approximately 90 % or more.

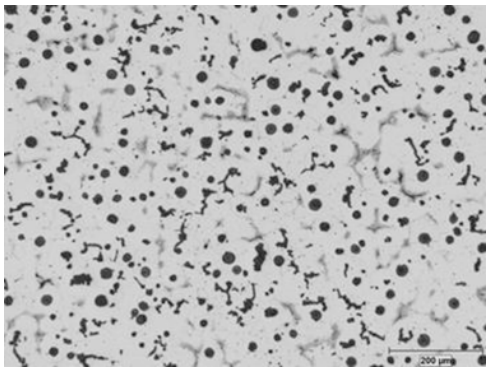
X2. MICROSTRUCTURES OF SILICON-MOLYBDENUM IRON CASTINGS

X2.1 Cast iron microstructures are sensitive to the cooling rate during and after solidification, more specifically changes in section thickness if there is no variation in other processing conditions. Microstructure test specimens should be so selected either to approximate the thickness of the main or controlling section of the casting, or from sections ≤10 mm thick and from sections >10 mm thick.

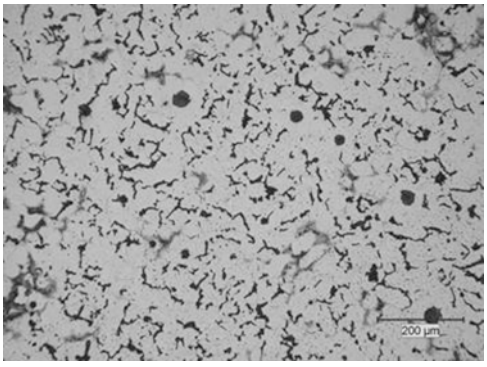
X2.2 Fig. X2.1 shows some representative micrographs of SG, MG, and CG SiMo iron castings. The Mo-rich precipitate phase is indicated by the arrow in micrograph Fig. X2.1(d) at a higher magnification.



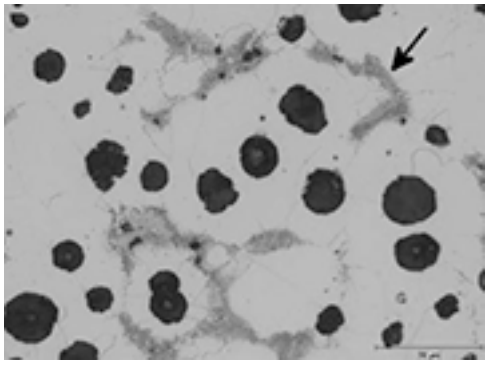
(a) SG SiMo



(b) MG SiMo



(c) CG SiMo



(d) SG SiMo at higher magnification

FIG. X2.1 Representative micrographs with different graphite nodularity of SiMo iron castings in a 13 mm section thickness. The metallographic specimens were etched using 3 % Nital solution. Micrographs (a), (b), and (c) have the same magnification. (d) The Mo-rich precipitates at the cell boundary regions at a higher magnification, as pointed to by an arrow.

X3. RECOMMENDED ANNEALING HEAT TREATMENT PRACTICE FOR SIMO-BASED IRON CASTINGS

X3.1 Full annealing is performed within a dwell temperature in the range of 900 to 950°C, with a holding time of 2 to 3 h per 25 mm section thickness followed by furnace cooling at the cooling rate ≤100°C/h. Castings should not be cooled outside the furnace until the in-furnace temperature has dropped to <650°C, at which time cooling of the castings in still air can be appropriate.

X3.2 Sub-critical annealing is performed within a dwell temperature in the range of 770 to 820°C for a holding time of 2 to 3 h per 25 mm section thickness followed by furnace cooling at the cooling rate ≤100°C/h. Castings should not be cooled outside the furnace until the in furnace temperature has dropped to < 650°C, at which time cooling of the castings in still air can be appropriate.

X3.3 Cast iron tends to form a protective atmosphere in a tight furnace. Subcritical annealing can be performed at the normal atmosphere. Full annealing within a controlled atmosphere (such as neutral, reducing or vacuum atmosphere) can be agreed upon agreement between the manufacturer and purchaser. If there is noticeable oxidation after heat treatment, castings can be cleaned using an adequate blasting method.

X3.4 Castings should be properly supported during heat treatment to prevent possible distortion.

X3.5 Furnace should provide uniform heating and cooling throughout the load. Additional information about annealing heat treatment can be found in publications referenced in 2.5.