

Automotive Austempered Ductile (Nodular) Iron Castings (ADI)

1. **Scope**—This SAE Standard covers the mechanical and physical property requirements for Austempered Ductile Iron (ADI) castings used in automotive and allied industries. Specifically covered are:
- Hardness
 - Tensile Strength
 - Yield Strength
 - Elongation
 - Modulus of Elasticity
 - Impact Energy
 - Microstructure

In this document SI units are primary and in-lb units are derived. Appendix A provides general information and related resources on the microstructural, chemical and heat treatment requirements to meet the mechanical properties needed for ADI in particular service conditions and applications.

2. **References**

- 2.1 **Applicable Publications**—The following publications form a part of this specification to the extent specified herein.

- 2.1.1 **ASTM PUBLICATIONS**—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM A 247—Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings
ASTM A 536—Standard Specification for Ductile Iron Castings
ASTM E 10—Standard Test Method for Brinell Hardness of Metallic Materials
ASTM E 23—Standard Test Methods for Notched Bar Impact Testing of Metallic Materials
ASTM E 111—Standard Test Method for Young's Modulus, Tangent Modulus and Chord Modulus

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2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this specification.

2.2.1 ASM PUBLICATIONS—ATTN: MSC/Book Order, ASM International, PO Box 473, Novelty, OH 44072-9901.

ASM Metals Handbook, Vol. 1 Properties and Specifications. Iron and Steel. Ninth Edition, ASM International 1996 Materials Park, OH 44073-0002.

ASM Specialty Handbook, Cast Irons. ASM International 1996 Materials Park, OH 44073-0002.

2.2.2 OTHER PUBLICATIONS

1st International Conference on Austempered Ductile Iron: Your Means to Improved Performance, Productivity and Cost. American Society for Metals Highway/Off-Highway Vehicles Committee Materials systems and Design Division. April 2-4, 1984 Chicago, IL. ASM International, Materials Park, OH 44073-0002.

2nd International Conference on Austempered Ductile Iron: Your Means to Improved Performance, Productivity and Cost. Sponsored by ASME – Gear Research Institute, ASME – Design Division, AMAX, Inc. March 17-19, 1986, Ann Arbor, MI. ASME – Gear Research Institute c/o Pennsylvania State University, Applied Research Laboratory, P.O. Box 30, State College, PA 16804-0030.

www.ductile.org/didata Chapter IV- Austempered Ductile Iron (Ductile Iron Society (US) website)

3. Grades—The specified grades, hardness and mechanical properties are shown in Table 1.

TABLE 1—MINIMUM MECHANICAL PROPERTIES FOR AUSTEMPERED DUCTILE IRON

Grade	Hardness HBN (dia. in mm) (MPa)	Tensile Strength (1)(2) MPa	Tensile Strength (1)(2) ksi	Yield Strength (1)(2) MPa	Yield Strength (1)(2) ksi	% Elongation Elasticity (1)(2)	Modulus of Elasticity (1)(2)(3) GPa	Modulus of Elasticity (1)(2)(3) psi	Impact Energy ⁽⁴⁾ Joules	Impact Energy ⁽⁴⁾ ft-lb
AD 900	269-341: (3.70-3.30) (2640-3340)	900	130	650	90	9	148	21.5 x 10 ⁶	100	75
AD1050	302-375: (3.50-3.15) (2690-3680)	1050	150	750	110	7	148	21.5 x 10 ⁶	80	60
AD1200	341-444: (3.30-2.90) (3340-4350)	1200	175	850	125	4	148	21.5 x 10 ⁶	60	45
AD1400	388-477: (3.10-2.80) (3800-4680)	1400	200	1100	155	2	148	21.5 x 10 ⁶	35	25
AD1600	402-512: (3.05-2.70) (3940-5020)	1600	230	1300	185	1	148	21.5 x 10 ⁶	20	15

1. Applied to equivalent thickness of up to 64 mm (2.5 in). For equivalent thickness greater than 64 mm (2.5 in), the mechanical properties will be mutually agreed upon by the manufacturer and the purchaser.
2. The property requirements in this standard are based on separately cast test bars. Casting properties and microstructure may vary due to chemistry, section size, cooling rates and other parameters. It is desired that the test bars be designed to reflect the properties of the castings they represent. The casting process for the test bars shall be agreed upon between the manufacturer and purchaser. Refer to ASTM A 536.
3. The Young's Modulus (E) was determined by the procedure defined in ASTM E 111.
4. Values obtained using unnotched Charpy bars tested at 22 °C ± 2 °C (72 °F ± 4 °F). The values in the table are the average of the three highest of four tested samples. For details of Charpy test refer to ASTM Impact Test (ASTM E 23).

4. Hardness

- 4.1 The area or areas on the castings where hardness is to be checked shall be established by agreement between the manufacturer and purchaser.
- 4.2 The foundry shall exercise the necessary controls and inspection techniques to insure compliance with the specified hardness range for the application. Brinell hardness shall be determined according to ASTM E 10 Test for Brinell Hardness of Metallic Materials, after sufficient material has been removed from the casting surface to insure representative hardness readings. The 10 mm ball and 3000 kg load shall be used unless otherwise specified and agreed upon.

5. Heat treatment

- 5.1 Castings produced in accordance with this document shall be heat treated by an austempering process consisting of heating the castings to a fully austenitic condition, then holding for a time sufficient to saturate the austenite with carbon, then cooling (at a rate sufficient to avoid the formation of pearlite) to a temperature above the martensite start temperature (Ms), and isothermally transforming the matrix structure for a time sufficient to produce the desired properties. This process shall produce a microstructure that is substantially ausferrite (acicular ferrite and austenite).
- 5.2 Appropriate heat treatment for removal of residual stresses, or to improve machinability shall be specified by agreement between the manufacturer and the purchaser.
- 5.3 Re-austempering of components or any deviation from the established heat treating process is permissible only with the expressed approval of the casting purchaser.

6. Microstructure

- 6.1 The graphite component of the microstructure shall consist of at least 80% spheroidal graphite conforming to Types I and II per ASTM A 247.
- 6.2 The cooling rate within some sections may not be sufficient to avoid the formation of pearlite or other high temperature transformation products. In such cases, the maximum acceptable quantities of these microconstituents and the location(s) within the casting may be established by agreement between the heat treater, the manufacturer and the purchaser.
- 6.3 Minor amounts of martensite may be present in the microstructure of Grades 1400 and 1600. Acceptable quantities of martensite may be established by agreement between the heat treater, the manufacturer and the purchaser.
- 6.4 The microstructure shall be substantially free of undesirable microconstituents, the details of which are agreed upon between the heat treater, the manufacturer and the purchaser.

- 7. **Quality Assurance**—It is the responsibility of the manufacturer to demonstrate process capability. The specimen(s) used to do so shall be of a configuration and from a location agreed upon between the manufacturer and the purchaser. Sampling plans shall be agreed upon between the heat treater, the manufacturer and the purchaser. The manufacturer shall employ adequate controls to ensure that the parts conform to the agreed upon requirements.

8. General

- 8.1 Castings furnished to this standard shall be representative of good foundry practice and shall conform to dimensions and tolerances specified on the casting drawing.
- 8.2 Minor surface discontinuities usually not associated with the structural functioning may occur in castings. These imperfections are often repairable; however, repairs should be made only in areas and by methods approved by the purchaser. Welding repair is not acceptable after Austempering.
- 8.3 Additional casting requirements, such as vendor identification, other casting information, and special testing, may be agreed upon by the purchaser and the supplier. These should appear as additional product requirements on the casting drawing.

PREPARED BY THE SAE METALS TECHNICAL COMMITTEE DIVISION 9—
AUTOMOTIVE IRON AND STEEL CASTINGS

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APPENDIX A

AUSTEMPERED DUCTILE (NODULAR) IRON
(A material description not a part of the document)

A.1 Definition and Classification—Austempered Ductile Iron (ADI) is produced by heat-treating Ductile (Nodular) Iron using the austempering Process, (as exemplified in A.5), a specialized, isothermal heat treatment. When compared to conventional ductile iron, ADI can have over twice the strength for a given level of ductility. ADI can have fatigue strength comparable to that of cast and forged steels and that strength can be greatly enhanced by subsequent grinding, fillet rolling or shot peening. Although the first commercial application of ADI did not occur until 1972, the material has found applications in virtually every industrial market segment. Its principal attribute is its ability to replace steel forgings, castings and weldments at equal or lesser weight and at a reduced cost. It is also typically much less costly than aluminum and, with its high strength-to-weight ratio it has replaced cast aluminum parts at equal weight in some automotive applications.

The ausferrite matrix in ADI undergoes a strain transformation hardening when exposed to a high normal force. That effect makes machining of ADI challenging, but knowledge of this effect allows the machinist to adjust the feeds, speeds and tool angles to adequately compensate. This same strain transformation hardening is what gives ADI wear resistance better than its bulk hardness would indicate.

Other attributes of the material include, good noise dampening, fracture toughness and low temperature properties, and reasonable stiffness.

A.2 Suggested Foundry Requirements for Ductile Iron that is to be Austempered (ADI)—ADI can be produced successfully from ductile iron castings with a wide range of chemistries and configurations. Although there is no optimum recipe for ADI castings, those produced to the following parameters have been shown to yield excellent results.

A.2.1 Casting Quality—The castings should be free of non-metallic inclusions, carbides, shrink and dross. Proper purchasing, storage and use of charge materials will minimize the occurrence of carbides and gas defects. Proper molding control will minimize surface defects and other sub-surface discontinuities. The castings should be properly gated and poured using consistent and effective treatment and inoculation techniques to yield shrink free castings. Any of the aforementioned non-conforming conditions will reduce the “toughness” of an ADI component (even if adequate for conventional ductile). The following are recommended as a minimum:

Nodule Count	100 / mm ²
Nodularity	85%

A.2.2 Carbon Equivalent—The carbon equivalent (CE) can be approximated by the relationship:

$CE = \%C + 1/3 (\%Si)$. It should be controlled as follows in Table A1.

TABLE A1—SUGGESTED CARBON EQUIVALENT RANGES FOR VARIOUS SECTION SIZES

Section Size	CE Range
0-13 mm (0-1/2 in)	4.4 – 4.6
13-51 mm (½ in-2 in)	4.3 – 4.6
Over 51 mm (2 in)	4.3 – 4.5

A.2.3 Chemistry Control—Good ductile iron practice should prevail for ductile iron that is to be austempered. Alloying elements such as Mo, Cu and Ni should be added only when additional hardenability is required for heavier sections. This increased “hardenability” is required only to avoid the formation of pearlite during quenching. Ultimately the amount of alloying required, (if any), will be a function of the alloys in one’s base metal, the part configuration and the austempering process used. The proper alloy configuration should be determined jointly by the foundry and the heat-treating source. Addition of the aforementioned alloys when not required does not enhance the properties of ADI but merely adds to the cost of the iron. Composition guidelines are recommended below in Tables A2 and A3:

TABLE A2—SUGGESTED TARGETS AND CONTROL RANGES FOR INTENTIONALLY ADDED ELEMENTS

Intentionally Added Elements	Suggested Target	Typical Control Range
C Carbon	3.6%	±0.20%
Si Silicon	2.5%	±0.20%
Mg Magnesium	(%S x 0.76) + 0.025%	±0.005%
Mn Manganese ⁽¹⁾	0.30%	±0.05%
Cu Copper	0.80% maximum (only as needed)	±0.05%
Ni Nickel	2.00% maximum (only as needed)	±0.10%
Mo Molybdenum	0.30% max. (only as needed)	±0.03%

1. Up to a section size of approximately 13 mm (0.51 in), Mn targets as high as 0.60% can be used successfully. In section sizes over 13 mm (0.51 in) (or in the presence of Mo or other carbide formers) the Mn target should be reduced to 0.35% or less to minimize the formation of cell boundary carbides which may negatively affect component machinability and ductility.

TABLE A3—SUGGESTED MAXIMUMS AND CONTROL RANGES FOR TRACE AND TRAMP ELEMENTS

Trace or Tramp Elements	Suggested Target (or maximum)	Typical Control Range
Sn Tin	0.02% maximum	±0.003%
Sb Antimony	0.002% maximum	±0.0003%
P Phosphorus	0.04% maximum	
S Sulfur	0.02% maximum	
O Oxygen	50 ppm maximum	
Cr Chromium	0.10% maximum	
Ti Titanium	0.040% maximum	
V Vanadium	0.10% maximum	
Al Aluminum	0.050% maximum	
As Arsenic	0.020% maximum	
Bi Bismuth	0.002% maximum	
B Boron	0.002% maximum	
Cd Cadmium	0.005% maximum	
Pb Lead	0.002% maximum	
Se Selenium	0.030% maximum	
Te Tellurium	0.020% maximum	

Other “nodulizing elements”, (like, calcium, strontium, barium, yttrium, lanthanum and cerium), should be present only to the extent that they are used to replace Mg in nodulization. In any case, the amount of residual Mg plus the amounts of these elements should not exceed 0.06%. Carbide forming elements (such as Cr, Ti, V, etc.) tend to be additive in effect with Mn and/or Mo and one should be aware of this in alloy design to avoid the formation of carbides in the casting.

A.2.4 Prior Microstructure—The time required to saturate the matrix with carbon during austenitizing and the growth of the casting during austempering will be affected by the pearlite/ferrite ratio of the casting prior to heat treatment. A consistent pearlite/ferrite ratio is particularly important if the castings are machined prior to austempering. A consistent pearlite/ferrite ratio in the casting prior to austenitizing will result in consistent growth during austempering.

A.2.5 Thermal Behavior of ADI—The designer should be aware that the coefficient of thermal expansion for ADI can be 5 to 20% greater than that of steel or ductile iron (depending on the grade of ADI selected). This increased thermal expansion must be addressed in close tolerance designs that will see significant temperature fluctuations in service.

Furthermore, the ausferrite microstructure is generally stable to very low temperatures but, in elevated temperature service, will eventually exhibit a lowering of properties if continually operated at temperatures approaching the temperature at which the casting was austempered.

The preceding guidelines have been prepared as useful parameters for production. Good ADI can, and is, being produced from ductile iron not meeting these criteria, however, these criteria represent sound, commercial practices known to produce good results. They do not constitute a guarantee of final properties.

A.3 Microstructure

A.3.1 The microstructure of the various grades of ADI consists of spheroidal graphite in a matrix of carbon stabilized austenite and acicular ferrite – otherwise known as ausferrite. (See Figures A1 to A5).

A.3.2 The different grades of ADI are dependent upon the quench temperature of the heat treatment. The quench temperature affects the formation of the ausferrite matrix.

A.3.3 The following figures show typical microstructures of each grade of ADI.

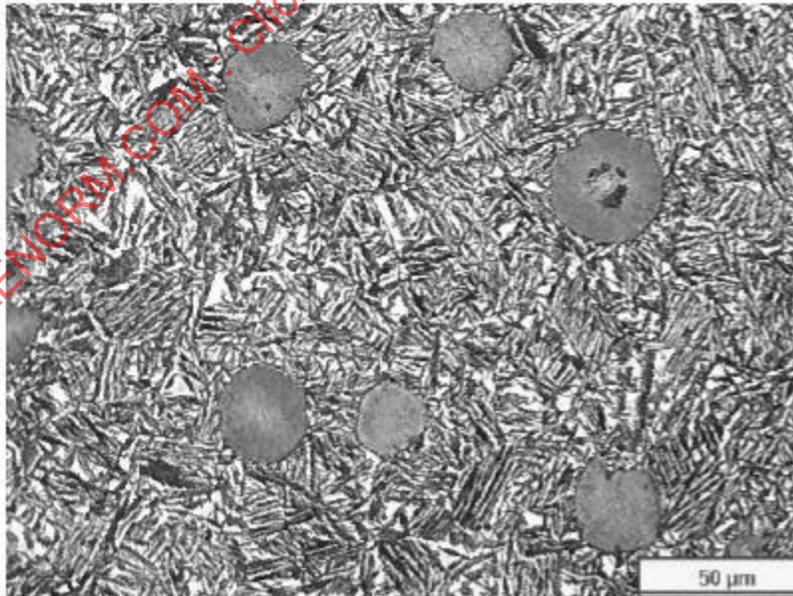


FIGURE A1—GRADE AD900 (TYPICAL MICROSTRUCTURE)

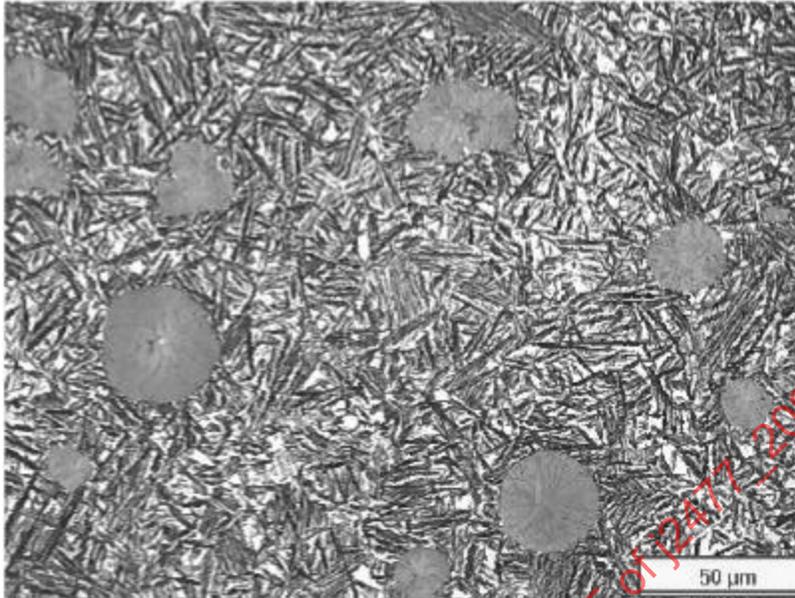


FIGURE A2—GRADE AD1050 (TYPICAL MICROSTRUCTURE)

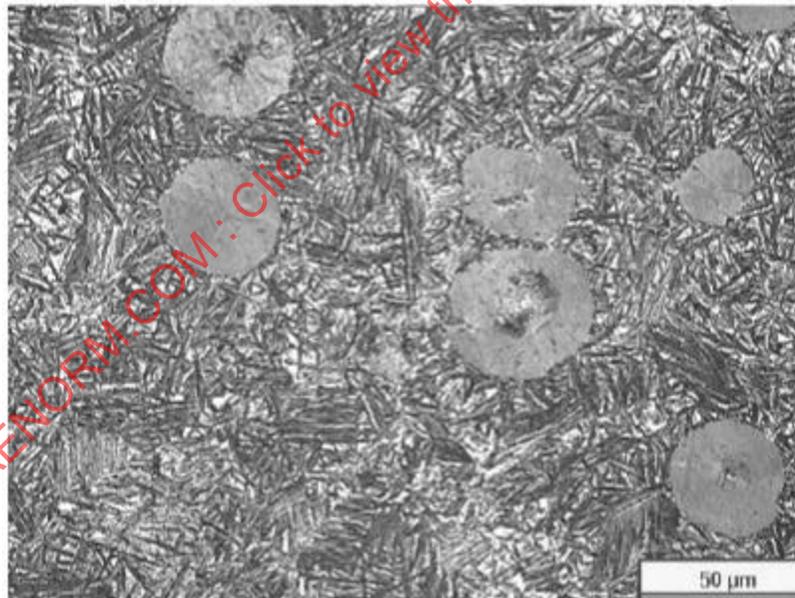


FIGURE A3—GRADE AD1200 (TYPICAL MICROSTRUCTURE)

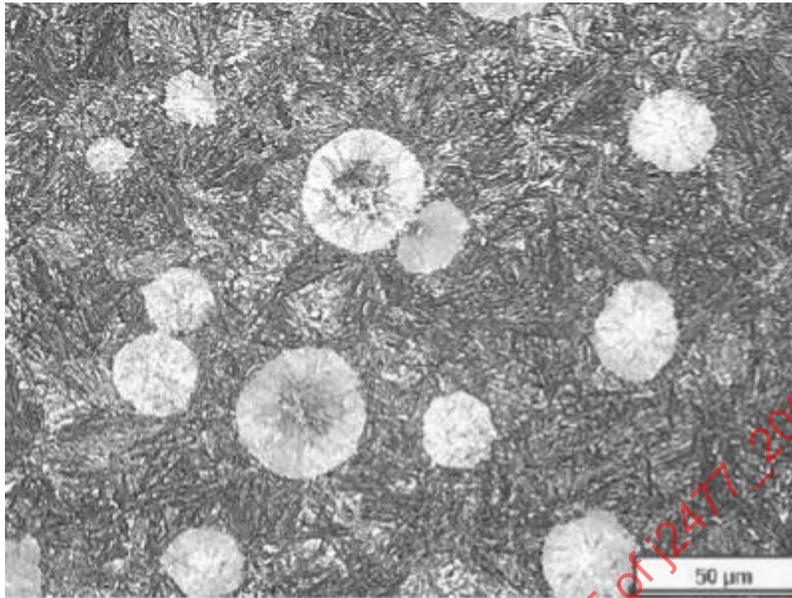


FIGURE A4—GRADE AD1400 (TYPICAL MICROSTRUCTURE)

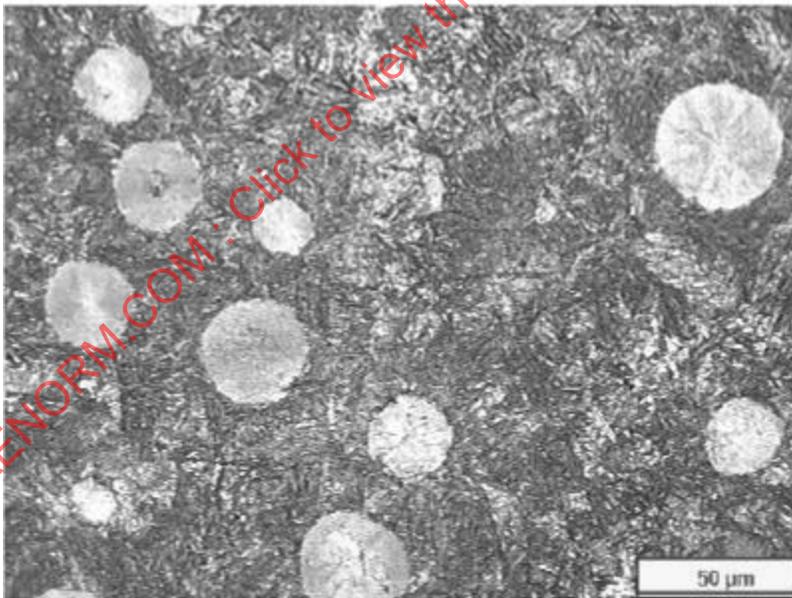


FIGURE A5—GRADE AD1600 (TYPICAL MICROSTRUCTURE)