SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE STANDARD

SAE J431 | REV. MAR93

Issued 1935-01
Revised 1993-03-17

Superseding J431 AUG79

Submitted for recognition as an American National Standard

(R) AUTOMOTIVE GRAY IRON CASTINGS

1. *Scope*—This SAE Standard covers the hardness, tensile strength, and microstructural requirements for gray iron sand mold castings used in automotive and allied industries. The chemical requirements for alloy gray iron automotive camshafts are included in the document under castings for special application with controlled composition and microstructure. Appendix A provides general information on application of gray iron in automotive castings and chemical composition to meet hardness, microstructural, and other properties needed for particular service conditions. Casting tensile strength estimates are provided in Appendix A for design reference.

NOTE—This document was rewritten in June 1970 to establish casting hardness as the control parameter for casting strength, implicitly using a single tensile/hardness relationship, developed in a research study, for all grades. New grade designations were assigned at that time. In March 1993 a new grade 1800h was assigned and explicit tensile strength to hardness (t/h) ratio requirements for each grade were incorporated and given statistical limits to increase effectiveness of specification control over strength, machinability, castability, and other properties in castings. The 30 mm sand cast test bar, previously standard in SAE J431 for just tensile strength and eliminated in 1970, was reestablished for t/h control to maximize degree of standardization of the method and interchangeability of irons from foundry to foundry. Data of the 1970 study in combination with other published and unpublished data were analyzed to determine individual t/h limits for each grade. Casting tensile strength estimates given in Appendix A for design reference were revised in March 1993 to provide uniform statistical definition and alignment with casting hardness for all grades.

2. *References*

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J417—Hardness Tests and Hardness Number Conversions

2.1.2 ASTM PUBLICATIONS—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM A 48—Specification for Gray Iron Castings
ASTM A 247—Recommended Practice for Evaluating the Microstructure of Graphite in Iron Castings
ASTM A 438—Transverse Testing of Gray Cast Iron
ASTM E 10—Test for Brinell Hardness of Metallic Materials
ASTM E 562—Determining Volume Fraction by Systematic Manual Point Count

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document. Additional information concerning gray iron castings, their properties, and use can be obtained from:

Metals Handbook, Vol. 1, 10th Edition, ASM International, Materials Park, OH

Cast Metals Handbook, American Foundrymen's Society, Des Plaines, IL

1981 Iron Castings Handbook, Iron Castings Society, Inc., Cleveland, OH

H.D. Angus, Physical and Engineering Properties of Cast Iron, British Cast Iron Research Association, Birmingham, England, 2nd Edition, 1976

Gray, Ductile, and Malleable Iron Castings Current Capabilities, STP-455, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187

G.N.I. Gilbert, Engineering Data on Grey Cast Iron, BCIRA (1977), Alvechurch, Birmingham, England

Tables for Normal Tolerance Limits, Sampling Plans and Screening, R.E. Odeh and D.B. Owen, Marcel Dekker, Inc., New York and Basel, 1980

3. ***Grades***—The specified grades, hardness ranges, tensile to hardness ratio (t/h) minimums, and metallurgical descriptions are shown in Tables 1 and 2 and in Sections 6 and 7.

TABLE 1—GRADES OF GRAY IRON

Grade	Casting Brinell Hardness at Specified Locations[1]	Test Bar t/h Lower Limit[2]	Description
G1800	120 to 187	135	Ferritic-pearlitic
G2500	170 to 229	135	Pearlitic-ferritic
G3000	187 to 241	150	Pearlitic
G3500	207 to 255	165	Pearlitic
G4000	217 to 269	175	Pearlitic

[1] Casting hardness ranges shown allow for a range of casting sizes and/or shakeout conditions and are, therefore, wider than typical for individual part numbers produced with typical chemical control and uniformly cooled. Hardness units are kgf/mm^2.
[2] The t/h limit shown is the -3s value of test samples (3 standard deviations below the mean). Units are psi for tensile strength and kgf/mm^2 for hardness.

TABLE 2—BRAKE DRUMS AND CLUTCH PLATES FOR SPECIAL SERVICE

Grade	C %, min	Casting Brinell Hardness at Specified Locations[4]	Test Bar t/h Lower Limit[5]	Microstructure Graphite[2]	Microstructure Matrix[3]
G1800h	3.50	163 to 223	100	Type VII A, B, and C size 1-3	Lamellar pearlite
G2500a	3.40	170 to 229	135	Type VII A distribution size 2-4	Lamellar pearlite. Ferrite if present not to exceed 15%
G3500b	3.40[1]	207 to 255	150	Type VII A distribution size 3-5	Lamellar pearlite. Ferrite or carbide if present not to exceed 5%
G3500c	3.50[1]	207 to 255	140	Type VII A distribution size 3-5	Lamellar pearlite. Ferrite or carbide if present not to exceed 5%

[1] Grades G3500b and G3500c normally require alloying to obtain the specified hardness at the high carbon levels specified.
[2] See ASTM A 247.
[3] See ASTM E 562.
[4] Casting hardness ranges shown allow for a range of casting sizes and/or shakeout conditions and are, therefore, wider than typical for individual part numbers produced with typical chemical control and uniformly cooled. Hardness units are kgf/mm^2.
[5] The t/h limit shown is the -3s value of test samples (3 standard deviations below the mean). Units are psi for tensile strength and kgf/mm^2 for hardness.

4. Hardness and Tensile Strength to Hardness Ratio

4.1 The area or areas on the casting where hardness is to be checked shall be established by agreement between supplier and purchaser.

4.2 The foundry shall exercise the necessary controls and inspection techniques to insure compliance with the specified hardness range and t/h lower limit. Brinell hardness is considered standard and shall be determined according to ASTM E 10 after sufficient material has been removed from the casting surface to insure representative hardness readings. The 10 mm ball and 3000 kgf load shall be used unless physically precluded by section size.

4.2.1 When a hardness testing method other than the Brinell test with 10 mm ball and 3000 kgf must be used, conversion to the 3000 kgf, 10 mm ball Brinell equivalent shall be by an applicable conversion table in SAE J417 or by on-site calibration using standard Brinell bars.

4.3 Tensile test values shall be obtained by separately cast 30 mm test bars (type "B") in accordance with ASTM A 48 except sampling frequency shall be as needed for statistical analysis to determine conformance of t/h ratio with requirements of this document and specimen shall be at room temperature, defined as between 10 and 35 °C, during the test.

4.4 Test bar hardness shall be taken on the tensile test bar between bar center and midpoint of the as-cast radius, and between 50 mm and 75 mm from the as-cast bar end as shown in Figures 1 and 2. The specimen shall be at room temperature, defined as between 10 and 35 °C, during the test.

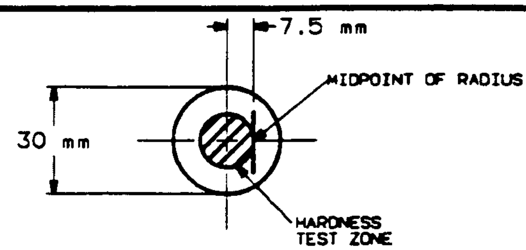

FIGURE 1—TEST BAR HARDNESS RADIAL TEST ZONE

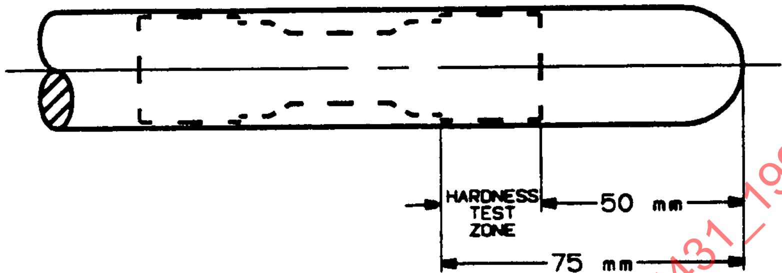

FIGURE 2—TEST BAR HARDNESS LONGITUDINAL TEST ZONE IN RELATION TO TENSILE SPECIMEN

4.5 Conformance with t/h ratio requirements shall be determined by statistical analysis of production samples. The property level at three standard deviations below the sample mean shall be at or above the minimum limit for the grade. Any statistically valid method may be used to determine sample size and procedure to control representativeness of samples with respect to production. The sample size and procedure described in Appendix A1.5 shall be the referee method.

5. *Heat Treatment*

5.1 Unless otherwise specified, castings of grades G1800 and G2500 may be annealed in order to meet the desired hardness range.

5.2 Appropriate heat treatment for removal of residual stresses, or to improve machinability or wear resistance, may be specified. Heat-treated castings must meet hardness requirements of the specified grade.

6. *Microstructure*

6.1 The microstructure of gray iron shall consist of flake graphite in a matrix of ferrite or pearlite or mixtures thereof.

6.2 As graphite size and shape somewhat affect hardness-strength ratio and other properties, the type, size, and distribution of the graphite flakes at a designated location on the casting may be specified by agreement between supplier and purchaser in accordance with ASTM A 247.

6.3 Unless otherwise specified, the matrix microstructure of castings covered by this document shall be substantially free of primary cementite and/or massive steadite. Castings in grades G1800 and G2500 may have a matrix of ferrite and/or pearlite. Grades G3000, G3500, and G4000 shall be pearlitic in matrix structure in accordance with Table 2.

7. *Casting for Special Applications With Controlled Composition and Microstructure*

7.1 Heavy-Duty Brake Drums and Clutch Plates

7.1.1 These castings are considered as special cases and are covered in Table 2.

7.2 Alloy Gray Iron Automotive Camshafts

7.2.1 These castings are considered as special cases.

7.2.2 GRADE DESIGNATION—G4000d.

7.2.3 CHEMICAL COMPOSITION—Alloy gray iron camshafts shall contain alloys within the ranges shown in Table 3.

TABLE 3—CHEMICAL COMPOSITION

Alloy	Wt %
Chromium	0.85 to 1.50%
Molybdenum	0.40 to 0.60%

7.2.4 CASTING HARDNESS—241 to 321 kgf/mm^2 determined on a bearing surface or as agreed by supplier and purchaser. Lower limit of test bar tensile/hardness ratio of G4000d shall be 165.

7.2.5 MICROSTRUCTURE—Extending 45 degrees on both sides of the centerline of the cam nose and to a minimum depth of 1/8 in (3.2 mm) the surface shall consist of primary carbides (of acicular or cellular form or a mixture thereof) and graphite in a fine pearlitic matrix. The graphite shall be Type VII A and E distribution, 4 to 7 flake size according to ASTM A 247. The amount of primary carbides and location at which the structure is checked shall be a matter of agreement between the supplier and the purchaser.

7.2.6 SELECTIVE HARDENING—The cam areas of camshaft castings are usually selectively hardened by flame or induction hardening by the supplier. The depth and surface hardness of the hardened case shall be as agreed by supplier and purchaser.

8. *Quality Assurance*—Sampling plans are a matter of agreement between supplier and purchaser. The supplier shall employ adequate equipment and controls to insure that parts conform to agreed upon requirements.

9. *General*

9.1 Castings furnished to this document shall be representative of good foundry practice and shall conform to dimensions and tolerances specified on the casting drawing.

9.2 Minor imperfections usually not associated with the structural functioning may occur in castings. These imperfections often are repairable; however, repairs should be made only in areas and by methods approved by the purchaser.

9.3 Additional casting requirements such as vendor identification, other casting information, and special testing, may be agreed upon by purchaser and supplier. These should appear as product specifications on the casting or part drawing.

10. Notes

10.1 Marginal Indicia—The (R) is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

PREPARED BY THE SAE IRON AND STEEL EXECUTIVE COMMITTEE

APPENDIX A
GRAY IRON
(A material description and not a part of the document)

A.1 Definition and Control of Gray Iron

A.1.1 Gray iron is a cast iron in which the graphite is present in flake form instead of nodules or spheroids as in malleable or ductile iron. Because its graphite has this flake structure, gray iron exhibits much greater sensitivity of mechanical properties to carbon content than malleable or ductile. As in malleable and ductile the metallic matrix in which the graphite of gray iron resides is normally either eutectoid or hypo-eutectoid silicon steel with a working range of hardness of about 150 to 600 kgf/mm^2. In special cases the matrix may be martensitic or hyper-eutectoidal with working hardness up to about 800 kgf/mm^2.

A.1.2 Gray iron naturally divides into a family or series of grades having different tensile strength to hardness (t/h) ratios uniformly regulated by eutectic graphite content up to the eutectic composition as shown in Figure A1 with carbon equivalent (CE) as the graphite parameter. Little change in t/h occurs with CE increase above the eutectic. Constant t/h lines of this figure are essentially lines of constant graphite effect on mechanical properties. Properties sensitive to both graphite and matrix, such as tensile strength and hardness, are proportional to their matrix counterparts—matrix tensile strength and matrix hardness—along constant t/h lines. Elastic modulus and damping capacity vary mainly only with graphite and are, therefore, highly constant along the constant t/h lines. Since these lines are also lines of constant eutectic graphite and CE, the most important castability parameters, they are logical grade lines for foundry control as well as for mechanical property control.

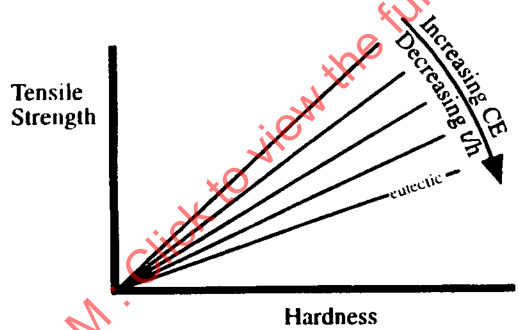

FIGURE A1—CHARACTERISTIC t/h RATIOS OF GRAY IRONS

A.1.2.1 The units of t/h ratio in this document are psi over kgf/mm^2, reflecting customary use in the U.S. of psi for tensile strength and the metric kgf/mm^2 for Brinell stress, i.e., hardness. In the metric countries, where identical units have historically been used for both tensile strength and hardness, the t/h ratio is dimensionless.

A.1.3 Effective specification control of gray iron requires joint classification by at least two property parameters. Limited effectiveness of single parameter control is illustrated in Figures A2 and A3. Figure A2 exemplifies grading by tensile strength alone—any given grade so defined is seen to traverse a wide range of hardness and, therefore, machinability. In Figure A3 hardness is used as a single defining property and a wide range of possibilities exists for tensile strength. In both cases t/h ratio and, therefore, elastic modulus, damping capacity, and castability are seen to be out of control. Figure A4 illustrates improved control obtainable by specifying two property parameters. In this example t/h ratio and hardness are the joint control parameters. Tensile strength is now singularly defined and, in general, all properties including castability are under control.

90-1202B EG

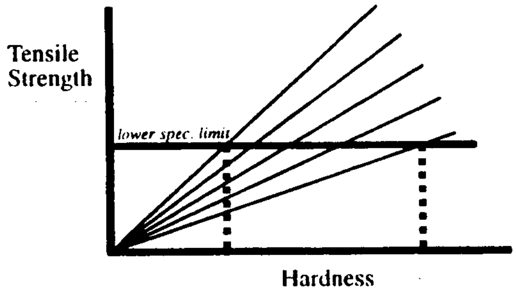

FIGURE A2—GRADING BY TENSILE

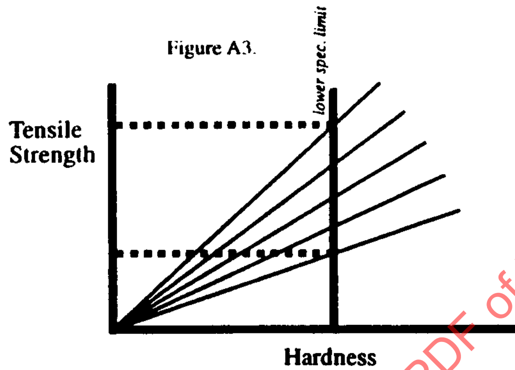

FIGURE A3—GRADING BY HARDNESS

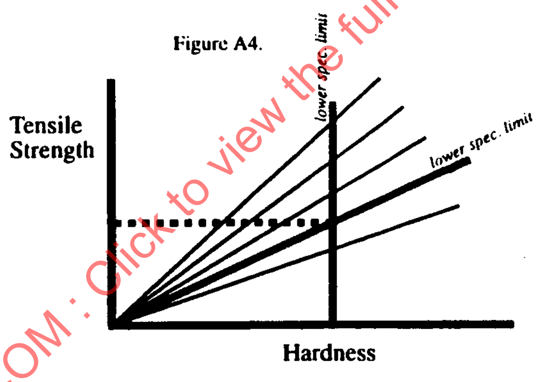

FIGURE A4—GRADING BY t/h RATIO AND HARDNESS

A.1.4 With continuous production processes used for automotive casting production conformance to specification, control limits can be assessed by statistical analysis of samples taken at uniform time intervals throughout the production period. Population limits of samples represent parent production with level of confidence dependent on absolute sample size which, in turn, is dependent on frequency of sampling during a given period. The referee method given in A.1.5 for control of minimum t/h is designed to predict 99% population limits, taken as a sufficiently close approximation of the 6 sigma field, with 95% confidence level in a one-sided normal distribution.

A.1.5 Test bars to confirm t/h conformance shall be poured at uniform times with a minimum frequency of one bar per 8 h shift. All bars poured during the sample period shall be included in the analysis. Sample period shall be any time interval or accumulation of consecutive time intervals during which production takes place with process specifications fixed. Minimum sample size shall be 30 bars.

A.2 Chemical Composition—The ranges in composition generally employed in producing the various grades of most automotive gray iron castings are shown in Table A1. The composition ranges for such special applications as heavy-duty brake drums and clutch plates and camshafts are shown in Table A2 and Table A3, respectively. The contents of certain elements for these applications are critical in terms of service requirements and the ranges are specified in the document.

TABLE A1—TYPICAL BASE COMPOSITIONS, %

Grade	Carbon	Silicon	Manganese	Sulfur, max[1]	Phosphorus, max	Approximate Carbon Equiv.[2]
G1800	3.30 3.60	2.50 2.10	0.50 to 0.80	0.15	0.25	4.10 to 4.30
G2500	3.30 3.60	2.50 2.10	0.60 to 0.90	0.15	0.20	4.10 to 4.30
G3000	3.20 3.50	2.30 1.90	0.60 to 0.90	0.15	0.15	3.9 to 4.20
G3500	3.10 3.45	2.20 1.80	0.60 to 0.90	0.15	0.12	3.8 to 4.15
G4000	3.10 3.40	2.10 1.80	0.70 to 1.00	0.15	0.08	3.8 to 4.10 (usually alloyed)

[1] Typical value.
[2] CE = % C + 1/3% Si

TABLE A2—TYPICAL BASE COMPOSITION OF BRAKE DRUMS AND CLUTCH PLATES FOR SPECIAL SERVICE, %

Grade	Carbon[1]	Silicon[2]	Manganese[2]	Sulfur[3]	Phosphorus, max
G1800h	3.40 min	2.30 to 2.80	0.50 to 0.80	0.14	0.20
G2500a	3.40 min	1.60 to 2.10	0.60 to 0.90	0.12	0.15
G3500b	3.40 min	1.30 to 1.80	0.60 to 0.90	0.12	0.15
G3500c	3.50 min	1.30 to 1.80	0.60 to 0.90	0.12	0.15

Alloy may be added as required.
[1] Mandatory
[2] As required
[3] Typical value

TABLE A3—TYPICAL CHEMICAL COMPOSITION OF ALLOY GRAY IRON AUTOMOTIVE CAMSHAFTS, GRADE G4000D, %

Constituent	Wt %
Total Carbon	3.10 to 3.60
Silicon	1.95 to 2.40
Manganese	0.60 to 0.90
Phosphorus	0.10 max
Sulfur	0.15 max
Chromium	0.85 to 1.50
Molybdenum	0.40 to 0.60
Nickel	0.20 to 0.45
Copper	Residual

A.2.1 The specific composition range for a given grade may vary according to the prevailing or governing section size of the castings being produced.

A.2.2 Alloying elements such as chromium, copper, nickel, tin, molybdenum, or other elements may be employed to meet the specified hardness or microstructural requirements or to provide the properties needed for particular service conditions.

A.3 Microstructure

A.3.1 The microstructure of the various grades of gray iron are generally a mixture of flake graphite in a matrix of ferrite, pearlite, or tempered pearlite. The relative amounts of each of these constituents depend on the analysis of the iron, casting design, and foundry techniques as they affect solidification and subsequent cooling rate and heat treatments if any.

A.3.2 The distribution and size of graphite flakes, like the matrix structure of gray iron, depends greatly on the solidification rate and cooling rate of the casting. If a section solidifies very rapidly, an appreciable amount of carbide causing a mottled fracture or chilled corners can be present. If a section cools slowly, as in a massive heavy section casting, an appreciable amount of ferrite may be present. In like manner, light sections will contain small graphite flakes while graphite will form in much larger flakes if the same iron is poured into a heavy casting.

A.3.3 For these reasons the strength and hardness of gray iron are greatly influenced by the rate of cooling during and after solidification, the design and nature of the mold and the casting, and by other factors such as inoculation practice, in addition to the composition of the iron.

A.3.4 Alloying with nickel, chromium, molybdenum, tin, copper, or other alloys usually promotes a more stable pearlitic structure and is often done to obtain increased hardness, strength, and wear resistance, especially in heavy sections subjected to severe service.

A.3.5 Alloying is sometimes used to obtain structures containing a controlled percentage of carbides, as in camshaft or valve lifter castings.

A.3.6 Primary carbides and/or pearlite can be decomposed by appropriate heat treatment. Gray irons of suitable composition and structure can be hardened by liquid quenching, or by flame or induction selective hardening.

A.4 Mechanical Properties

A.4.1 The tensile strength minimums listed in Tables A4 and A5 are valid estimates for design purposes in casting sections up to 30 mm diameter, i.e., 15 mm equivalent thickness, when hardness and t/h requirements of the grade are both met with population means centered in the ranges shown. Some degree of confirmation by laboratory and/or service testing of actual parts is always necessary with new designs and/or foundry processes.

TABLE A4—TYPICAL MECHANICAL PROPERTIES FOR DESIGN PURPOSES[1]

Grade	Hardness Range kgf/mm²	t/h Range psi / kgf/mm²	Tensile Strength Lower Limit psi (MPa) for Hardness Range[3]	Transverse Strength,[2] min, lb (kN)	Deflection,[2] min, in (mm)
G1800	120 to 187	135 to 185	17 800 (123)	1720 (7.65)	0.14 (3.6)
G2500	170 to 229	135 to 185	24 500 (169)	2000 (8.90)	0.17 (4.3)
G3000	187 to 241	150 to 200	29 500 (204)	2200 (9.79)	0.20 (5.1)
G3500	207 to 255	165 to 215	35 400 (244)	2450 (10.90)	0.24 (6.1)
G4000	217 to 269	175 to 215	39 500 (273)	2600 (11.56)	0.27 (6.9)

1 The reported mechanical properties were determined on separately cast 1.2 in D (30 mm D) test bars and may vary throughout the casting depending on composition and cooling rate. Heavy wall (slowly cooled) castings may exhibit lower properties.
2 See ASTM A 438 for information concerning the B transverse test bar and the transverse test.
3 Lower limit of tensile strength with same probability as lower limits shown for hardness and t/h and with mean hardness at center of range shown.

TABLE A5—TYPICAL MECHANICAL PROPERTIES FOR DESIGN PURPOSES FOR BRAKE DRUMS, CLUTCH PLATES, AND SPECIAL SERVICE[1]

Grade	Hardness Range kgf/mm²	t/h Range psi / kgf/mm²	Tensile Strength Lower Limit psi (MPa) for Hardness Range[3]	Transverse Strength,[2] min, lb (kN)	Deflection,[2] min, in (mm)
G1800h	163 to 223	100 to 150	17 500 (121)	1720 (7.65)	0.14 (3.6)
G2500a	170 to 229	135 to 180	24 500 (169)	2000 (8.90)	0.17 (4.3)
G3500b	207 to 255	150 to 190	32 400 (223)[4]	2400 (10.68)	0.24 (6.1)
G3500c	207 to 255	140 to 170	30 800 (212)[4]	2400 (10.68)	0.24 (6.1)

[1] The reported mechanical properties were determined on separately cast 1.2 in D (30 mm D) test bars and may vary throughout the casting depending on composition and cooling rate. Heavy wall (slowly cooled) castings may exhibit lower properties.

[2] See ASTM A 438 for information concerning the transverse test bar and the transverse test.

[3] Lower limit of tensile strength with same probability as lower limits shown for hardness and t/h and with mean hardness at center of range shown.

[4] Higher tensile estimate of 35 000 psi minimum for 3500b and 3500c given in previous revisions was applicable only with casting hardness in the upper half of the 207 to 255 range which is normal for 30 mm test bars made with these irons.

A.4.2 Tensile to hardness ratio (t/h) of cast iron is determined by graphite structure. In gray iron the dominant structural aspect affecting t/h is comprised of the length, width, and quantity of graphite flakes. The primary process control parameter determining this aspect is carbon equivalent. Inoculation practice, alloy content, and casting thickness are important secondary factors. Tests of the casting thickness effect on t/h up to 100 mm equivalent wall thickness have indicated t/h in gray iron may decline with increasing casting thickness but usually does not decline to less than about 80% of the value in 15 mm equivalent thickness; however, when heavy sections much greater in equivalent thickness than 15 mm are critically stressed, the actual t/h level in the part should be checked.

A.4.3 Units of the t/h ratio used in this document are psi over kgf per mm². Multiplying t/h ratio by Brinell Hardness in kgf/mm² therefore gives tensile strength in psi. The standard value of Brinell Hardness is the value for 3000 kgf load and 10 mm ball as specified in ASTM E 10.

A.4.4 Tensile strength of cast iron is jointly determined by t/h ratio and hardness. The estimated tensile strength minimums given in Tables A4 and A5 are the equal probability values calculated assuming the full ranges of hardness and t/h shown with means at midpoint of these ranges. Assuming normal distribution, probabilities of the minimums given for tensile strength, hardness, and t/h ratio are all equal, i.e., if the hardness and t/h ratio minimums are at three standard deviations from their means the tensile strength minimum is also three standard deviations from its mean. With normal distribution the minimums for t/h ratio and hardness will not occur simultaneously except at some lower probability. For this reason multiplying minimum hardness shown by minimum t/h ratio shown will give a tensile strength value typically 5 to 10% lower than the equal probability tensile strength minimum shown. For cases in which the actual production range of t/h or hardness is concentrated in some lower portion of the range shown this lower tensile value should be assumed.