



Brake Rotors - Gray Cast Iron

1 Scope

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Material Description. Gray cast iron.

1.2 Symbols. Not applicable.

1.3 Applicability. This standard specifies material and product requirements for all unventilated and ventilated brake disks for automotive industries. The gray iron rotors are specified by chemistry, mechanical properties, microstructures and quality requirements.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

ASTM A48	ASTM E322	ISO 185	ISO 6506
ASTM A247	ASTM E1019	ISO 945	ISO 6892

2.2 GM Standards/Specifications.

GMW3059	GMW16218	GMW16369
GMW15632	GMW16284	

2.3 Additional References.

- Safety and Industrial Hygiene (S&IH) Technical Standard (TS), S&IH TS 3.4-160-02

3 Requirements

3.1 Material. Unalloyed and low alloyed gray cast iron with predominantly Type A graphite and pearlitic matrix shall be used for brake rotors.

3.2 Chemical Composition. The casting producer shall measure chemical compositions for all elements except carbon, with samples taken from the melt and solidified in a metallic chill die.

Spectrographic analysis of chemistry shall be measured in accordance with procedures, master samples and calibration per ASTM E322.

Carbon levels shall be measured using either thermal analysis or C and S analyzer, and shall be measured in accordance with procedures, master samples and calibration per ASTM E1019.

The compositions listed in the tables reflect those of finished castings. Additional care should be taken to understand the silicon levels of parts that utilize late process inoculation.

When using optical emission spectroscopy to analyze a finished casting for chemical composition, a piece of the casting shall be remelted so a chilled sample is obtained.

3.2.1 Chemical Composition – Initial Selection. The desired chemical compositions for various grades are listed in Table 1. During initial design stages, the supplier should develop an aim chemical composition to achieve the mechanical properties per Table 1. The chemical compositions in Table 1 are typical and considered secondary to the mechanical properties, with the exception of the carbon equivalent (CE) which is mandatory. The aim chemistry for validation samples should take into account that production parts will need to be produced

with minimal variation from the validation samples. The stated minimum Chromium levels for grades G205SP-R1 and G250SP-R1 are mandatory.

The global grades are given in Table 1.

Table 1: Gray Cast Iron for Integral Hub and Disc Castings and Disc Brake Rotors

GMW16394 Grades		G135SP-R1 Note 1	G180SP-R1 Note 1	G205SP-R1 Note 2	G250SP-R1
Mandatory Mechanical Properties					
Ultimate Tensile Strength, Minimum, R _m	N/mm ²	135	180	205	250
Wedge Compression Strength, R _{mk}	N/mm ²	110 minimum	140 minimum	145 minimum	N/A
Hardness ^{Note 3}	HBW	156 to 207	183 to 223	187 to 229	197 to 235
Difference in HBW at Friction Surface, 15° Increments, (ΔHBW) ^{Note 4}	HBW	15 max.	15 max.	15 max.	15 max.
Acceptable Microstructure		See Table A1			
Chemical Composition ^{Note 5}					
Carbon Equivalent (CE) ^{Note 6} (Mandatory)	% by mass	4.30 to 4.60	4.10 to 4.40	3.90 to 4.30	3.80 to 4.20
Carbon		3.65 to 3.95	3.65 to 3.95	3.20 to 3.50	3.10 to 3.40
Silicon		1.75 to 1.95	1.00 to 1.30	1.90 to 2.40	1.90 to 2.40
Manganese		0.50 to 0.80	0.50 to 0.80	0.45 to 0.90	0.60 to 0.90
Sulfur		0.12 max.	0.12 max.	0.12 max.	0.12 max.
Phosphorus		0.10 max.	0.10 max.	0.10 max.	0.1 max.
Chromium ^{Note 7}		0.25 max.	0.25 max.	0.15 to 0.40	0.25 to 0.40
Copper		0.40 max.	0.60 max.	0.60 max.	0.60 max.
Tin		0.07 max.	0.07 max.	0.07 max.	0.07 max.

Note 1: These grades are used for brake rotors requiring exceptional damping properties.

Note 2: A variation of this is a low alloyed grade G205SP-R1-A, with copper 0.40% to 0.55% and chromium 0.40% to 0.55%. The stated minimums for copper and chromium are mandatory.

Note 3: Hardness indicated is on finish machined surface of casting. Cast surface hardness may be higher.

Note 4: Measured on friction surface every 15 degrees with a 5 mm ball and a 750 kg load (see Appendix A, Data Sheet A2 for reporting format).

Note 5: Chemical composition is typical, however carbon equivalent is mandatory.

Note 6: Carbon equivalent, $CE = C\% + (Si\% + P\%)/3$.

Note 7: The stated minimums for chromium are mandatory.

Note: HBW = Brinell Hardness – Hard Metal Ball, Max. = Maximum, N/A = Not Available.

3.2.2 Restriction of Composition. All rotors are expected to be produced with the same alloying system as validation samples. To show compliance to this the levels of CE, C, Si, Mn, Cu, Sn, Cr and will be restricted to the ranges listed in Table 2. The supplier is to develop maximum and minimum limits that adhere to these ranges.

3.2.3 Documentation of Restricted Composition. The supplier shall document, prior to delivery of castings, the limits on chemical composition that shall be controlled in production.

The restricted ranges that are chosen for these elements shall be documented in the GM engineering drawing and other equivalent part specification documents.

The restricted composition shall also be reported in Production Part Approval Process (PPAP) documents as indicated in Appendix A, Data Sheet A1.

Table 2: Gray Cast Iron Composition Restriction Ranges

Element		Restricted Composition Range ^{Note 1}	Primary Effect of Element (Informative)
Carbon Equivalent (CE)	% by Mass (Calculated)	0.30	Volume of graphite, Young's Modulus and Frequency Response Function (FRF)
Carbon	% by Mass	0.30	Graphitizer
Silicon	% by Mass	0.30	Graphitizer
Manganese	% by Mass	0.30	Produces MnS for machinability, Pearlite stabilizer
Copper	% by Mass	0.15	Pearlite stabilizer, (graphitizer)
Tin	% by Mass	0.040	Pearlite stabilizer (carbide stabilizer)
Chromium	% by Mass	0.15	Pearlite stabilizer (carbide stabilizer)
Phosphorous	% by Mass	0.030	Produces Phosphide eutectic
Sulphur	% by Mass	0.040	Produces MnS for Machinability

Note 1: Range is the difference between agreed upon maximum and minimum.

3.3 Tensile Strength and Hardness.

3.3.1 Tensile Strength. The ultimate tensile strength specified for rotors shall be measured and met by taking test pieces machined from the brake surfaces of the castings. The specified tensile strength requirements shall be determined by a statistically significant sampling of test pieces that were machined from castings.

The mechanical properties shall meet or exceed the minimum product requirements. Irrespective of the sampling frequency used by the supplier, all parts are expected to meet the requirements. The standard dimensions and testing procedure for test samples and machined test pieces are described in the ISO 185 and ISO 6892. The validity of tests and applicability of any retests shall be in accordance with ISO 185.

It is preferred to use a round specimen. When a round specimen is not practical a flat specimen may be used. An alternate to tensile test using flat specimen is Wedge Compression test (as described by the VDG P340 specification using an adaptive fixture described or equipment by Feinmechanik Ralf Kogel, Germany, and Instrument for wedge-type compression tests KDG 3/30). A specimen size of 50Lx20Wx6.5T (mm) is supported in between two opposed knife edges at 40 mm apart. The specimen size is somewhat arbitrary and the overall length is governed by the host casting and the capacity of the testing unit frame. The specimen length allows several comparison tests to be performed in order to improve variability. The conversion equation tabulated here shall be considered valid for specimens between 6 mm and 7 mm in thickness. A force is applied at its midpoint and the fracture load is measured. The wedge compression strength (R_{mk}) is computed by dividing the fracture load with the area of cross section of the specimen. Tensile strength correlates with wedge compression strength by:

$$R_m = (R_{mk} \times 1.86) - 66$$

For compliance purpose the tensile strength is reported by testing an excised test coupon from castings. However, the casting producer may use a separately cast test bar per ISO 185 or ASTM A48 to assess the quality of the material and melt from which the casting is poured. The properties of the pieces machined from the castings may vary from those machined from separately cast test samples because of cooling rate and section size variations and the variance in the method of making the separately cast test bar.

Porosity, shrink or other discontinuities within a test piece represents an invalid test, thus the data shall be discarded. The viewing of such discontinuities shall be done without the use of any magnifying device.

If a test specimen fails to meet a specific tensile requirement for an unknown reason, two more retests can be run from the same material. If both retest pieces pass the tensile requirement, the material will be deemed acceptable.

3.3.2 Hardness. Brinell hardness shall be taken in accordance with ISO 6506. The hardness shall be met on finish machined castings. For day-to-day foundry process control, the casting surface hardness is usually measured. To prepare the casting for load impression a representative depth of ~1 mm shall be removed from the surface. A smooth surface shall be established to improve the measurement accuracy. The hardness on the un-machined rotor surface may be higher. When the foundry measures casting surface hardness for day-to-day foundry process control, a correlation shall be established between the finish machined and as-cast surface hardness.

In unusual cases where the specified hardness and tensile strength cannot be met simultaneously, a revised hardness range shall be established by agreement between the purchaser and supplier based on measurements of the finish machined rotors. The tensile strength will take precedence over hardness.

3.3.2.1 For optimum rotor performance the hardness variation on the rotor surface shall be kept to a minimum. The variation on any one brake surface (in board or out board) shall be a maximum of 15 HBW. To comply with this requirement the hardness shall be measured on 3 selected diameters, at 15 degree increments on a brake friction surface as indicated in Figure 1. The 3 selected diameters shall coincide with the inner diameter (ID), mid-point and outer diameter (OD) of the pad contact surface on the rotor. It is the expectation of the buyer that the casting supplier will adopt suitable gating and risering techniques to produce rotors with the required uniform hardness.

The hardness variation test measurements shall be performed for initial tooling and process validation. The 15 HBW maximum variation for the specific brake surface shall be demonstrated through PPAP. The measurement surface must be machined to the machined rotor dimensions and polished with 220 grit paper or finer to achieve the required accuracy. The indentation diameter shall be measured to minimum accuracy of 0.02 mm ($\pm 0.5\%$ of diameter of indentation per ISO 6506-2). To improve the measurement accuracy, the measurement equipment should have better Gauge Repeatability and Reproducibility capability.

The measurement shall start from the Riser/Flow-off contact position designated as the zero degree/12 o'clock position of the rotor. The casting supplier must provide a permanent cast mark which is preserved on the machined rotor indicating the Riser/Flow-off contact position.

The measurements are done every 15° on a diameter near ID mid-point and near OD of each of the in board (IB) and out board (OB) brake surfaces as indicated in the attached sketch. The recommended procedure requires the use of a 5 mm diameter ball and a 750 kg load for measurement. In the case of vented rotors, the measurement shall be done as close to the joining ribs as possible to provide firm support for accurate measurement (especially when a 10 mm diameter ball and a 3000 kg load is used due to equipment availability). Due to rib spacing, one may not be able to hold the 15° increment requirement exactly, and in such cases, the measurement shall be done at the nearest 15° interval.

The hardness reporting format is indicated in Appendix A, Data Sheet A2.

Note: The uniformity measurement may be done at the foundry before stress relieving if used.

3.4 Microstructure. The required microstructure for various grades of rotors is indicated in Table 3. The microstructure shall consist of predominantly Type A flake graphite (as described in ISO 945) in a matrix of pearlite. Quantitative metallography shall treat graphite and matrix separately such that the total of fractions of each graphite flake type (A, B, C, D, and E) shall equal 100% and total of fractions of each matrix phase (e.g., ferrite, pearlite, carbide, Steadite, etc.,) shall equal to 100%.

The microstructure reporting format is indicated in Appendix A, Data Sheet A3 and Table A1.

3.5. Frequency Response Function (FRF). FRF expresses the rotor structural response to an applied force as a function of frequency. FRF helps to identify at what excitation frequency of an applied force coincide with the natural frequency of rotor causing the rotor to resonate producing brake squeal. Modal analysis provides the information about the natural frequencies and corresponding mode shapes, based on the collection of FRFs at multiple measurement points. Once modal analysis is performed, FRF can provide necessary natural frequency information for each mode. To minimize brake noise, the natural frequencies of rotor should be separated from those of other parts of the corner assembly. The natural frequency of rotor is mainly governed by mass and stiffness. Since carbon equivalent influences the Young's modulus, and in turn the stiffness, it is important to keep CE in a narrow range. The modal frequency measurement may become a requirement in the part drawing. Disc brake component modal analysis is outlined in GMW15632.

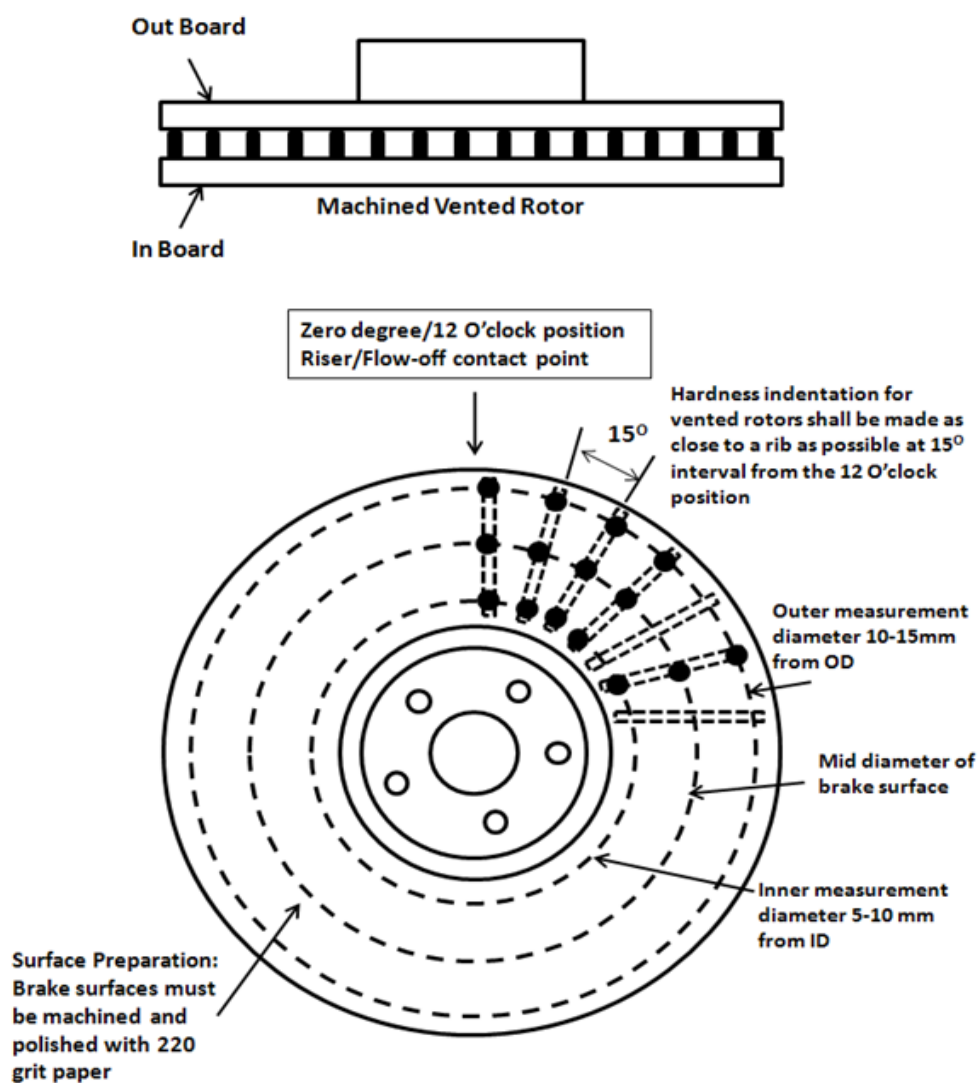


Figure 1: Hardness Measurement for Uniformity

Table 3: Areas of Observation and Acceptable Microstructure for Brake Rotors Note 1, Note 2

Areas of Observation	Graphite Type and Size (By Material Grade) and as defined by ISO 945			
GMW16394-IR-C-	G135SP-R1	G180SP-R1	G205SP-R1	G250SP-R1
P1	70% Type A minimum, balance Types B and C. Flake size 3 to 8 with 10% maximum size 2 permitted	70% Type A minimum, balance Types B and C. Flake size 3 to 8 with 10% maximum size 2 permitted	70% Type A minimum, balance Types B and C. Flake size 4 to 8 with 20% maximum size 3 permitted	70% Type A minimum, balance Types B and C. Flake size 4 to 8 with 20% maximum size 3 permitted
P2				
P3: From finish machined surface to 3 mm below (Same as Figure B2)	70% Type A minimum, balance Type B and C			70% Type A minimum, balance Type B. Flake size 4 to 8 with 10% maximum size 3 permitted
	Flake size 3 to 8	Flake size 3 to 8	Flake size 4 to 8 with 10% maximum size 3 permitted	
	MATRIX (All Material Grades)			
All Locations	< 10% free ferrite in a matrix of fine to medium pearlite required. < 1% carbide and 1% Steadite permissible. Steadite network not permissible. A small amount of Type E possible in areas with small machining stock (e.g., outer rotor diameter front face)			

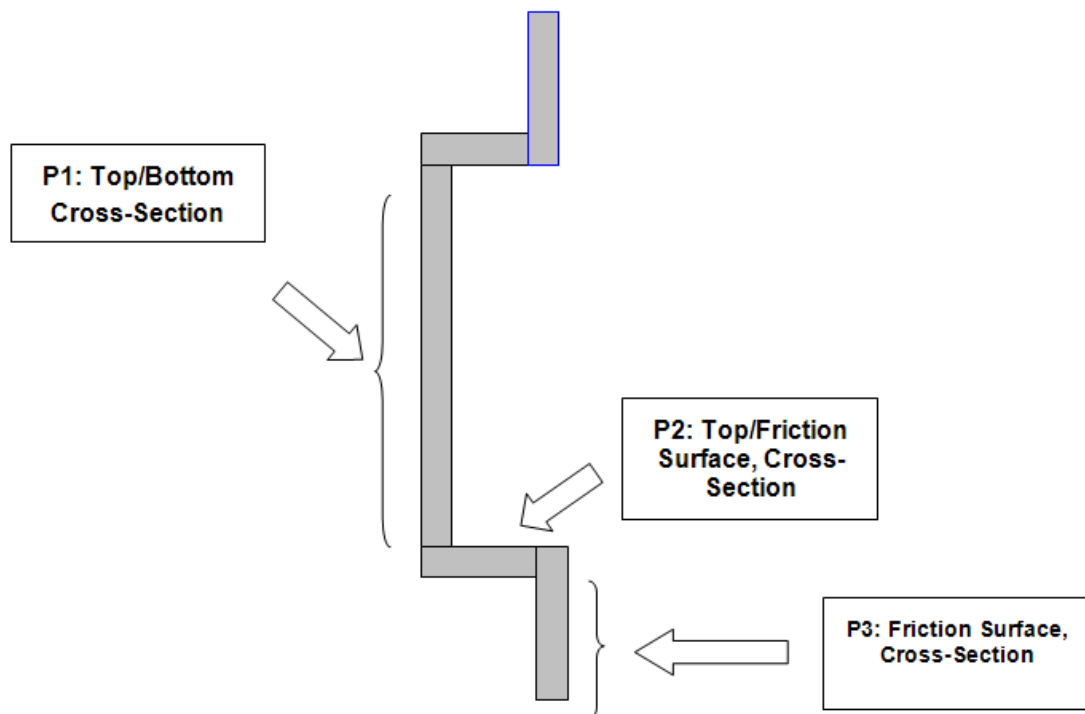
Note 1: Flake size percentages are area percentages.**Note 2:** See Figure 2.

Figure 2: Areas of Observation, Brake Rotor Microstructure

3.6 Castings. Castings shall conform to the dimensions and tolerances specified on the casting drawing. Discontinuities, e.g., cracks, sand and slag inclusions, massive carbides, cold laps, scabs, porosity, etc., detrimental to subsequent processing or to the service for which the castings are intended are not permitted. Casting surfaces shall be smooth and free from scale or burned-on sand. No repairing, plugging or welding of any kind shall be permitted, unless specific permission as to location and procedure to be used has been