



High Temperature Resistant Cast Iron

1 Scope

This material specification covers castings made of high temperature resistant iron as used in automotive and allied industries, including the mechanical properties from separately cast Y-block test samples and compositional requirements in the product castings. Any specific requirements for the whole or a critical section of a casting shall be identified on the engineering drawing.

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 Purpose/Material Description. Grades of nodular iron and one (1) of compacted graphite iron are addressed. High temperature nodular iron is alloyed with additional silicon, molybdenum and sometimes other elements to provide improved properties at elevated temperatures. Nodular iron is produced by treating molten iron of appropriate base metal composition with magnesium. The higher silicon and molybdenum level give the iron better resistance to scaling and better dimensional stability while improving resistance to creep and elevated temperature strength.

Compacted graphite iron production is similar to nodular iron with the addition of rare earth elements, but it also requires another alloying element such as titanium to minimize the formation of spheroidal graphite. The graphite structure and resulting properties of the iron are an intermediate between gray and ductile irons.

1.2 Symbols. Not applicable.

1.3 Applicability. High temperature resistant cast iron is used for those applications which require a higher resistance to heat, resistance to scaling and dimensional stability at elevated temperatures. Exhaust manifolds and turbo charger housings are the typical applications for this iron.

2 References

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

2.1 External Standards/Specifications.

AIGI CQI-9	ASTM E1010	ISO 945-1	ISO 6506-1
ASTM E8	ASTM E1019	ISO 945-4	ISO 6892-1
ASTM E322	ASTM E1999	ISO 1083	

2.2 GM Standards/Specifications.

GMW3059

2.3 Additional References.

- SAE (SAE international) Technical Paper 2002-01-2115

3 Requirements

3.1 Requirements on Delivery. Refer to Appendix C, Table C1 for a summary of all requirements.

3.1.1 Chemical Requirements. Silicon and molybdenum compositions are the most critical requirements necessary to meet the high temperature properties, thus these elements are mandatory requirements. The remaining compositional elements shown in Table 1 are interrelated with section size and casting cooling rate and shall be considered secondary to the final mechanical properties.

3.1.1.1 Carbon Equivalent (CE). Castings with wall thicknesses < 25 mm shall target a CE = 4.7% but shall not exceed 4.9%. The CE for wall thickness ≥ 25 mm will need to be negotiated with the supplier. The higher the CE, the greater will be the propensity of the iron to form unwanted graphite phenomenon such as exploded graphite, chunky graphite or flotation graphite. The lower limit of CE is controlled by the silicon chemistry requirement. There may be occurrences in which the CE is to target < 4.7% due to casting defects and component geometry. When this is the case, the CE target shall be communicated to and approved by GM engineering. CE is determined by the equation:

$$CE = \%C + \frac{(\%Si + \%P)}{3}$$

Where:

%C = Percent Carbon

%P = Percent Phosphorus

%Si = Percent Silicon

3.1.1.2 Part Specific Chemistry. If any other mandatory composition is required, that composition shall be agreed upon between the GM Design Release Engineer (DRE), GM Product Program Materials Engineer, and the casting supplier and is to be documented on the engineering drawing, in the Statement of Requirements (SOR), in the Data Creation Standards (DCS) Material/General notes in the math file, and other equivalent part specification documents. The same agreement and drawing documentation are required when specifying a more restrictive chemistry range for the mandatory elements, silicon and molybdenum.

3.1.1.3 Spectrographic Chemical Analysis. The compositions listed in Table 1 reflect those of finished castings. When using optical emission spectroscopy to analyze a finished casting for chemical composition, a piece of the casting shall be re-melted so a chilled sample can be obtained. All spectrographic analysis shall be taken from a chilled sample. Spectrographic analysis of chemistry shall be measured in accordance with procedures, master samples, and calibration per ASTM E322 or ASTM E1999. Carbon levels shall be measured using either thermal analysis, or Carbon and Sulfur analyzer, and shall be measured in accordance with procedures, master samples, and calibration per ASTM E1019.

3.1.1.4 Spectrometric Chemical Analysis. Spectrometric analysis of chemistry shall be measured in accordance with procedures, master samples and calibration per ASTM E1010 and ASTM E1999. Carbon levels shall be measured in accordance with standard procedures, master samples and calibration per ASTM E1019 or ASTM E1999.

Table 1: Chemical Composition in Percent by Mass Note 1, Note 4

Element	HTN480-8 SiMo	HTN550-4 High Si High Mo SiMo	HTN550-5 High Si SiMo	HTN400-3 GJV SiMoNi Note 2	HTN550-0.5 SiMoNi SR Note 3	HTN550-0.4 SiMo1000
Carbon	3.20 to 3.70	3.20 to 3.70	3.20 to 3.60	3.0 to 3.6	2.9 to 3.3	3.0 to 3.9
Silicon Note 5	3.75 to 4.50	4.25 to 4.65	4.00 to 5.00	4.0 to 5.0	4.4 to 5.0	2.0 to 3.4
Manganese	0.50 Maximum	0.50 Maximum	0.50 Maximum	0.40 Maximum	0.40 Maximum	0.40 Maximum
Sulfur	0.02 Maximum	0.02 Maximum	0.02 Maximum	-	-	0.02 Maximum
Magnesium	0.03 to 0.05	0.03 to 0.05	0.03 to 0.05	-	-	0.03 to 0.065
Molybdenum Note 5	0.50 to 1.10	0.8 Minimum	0.75 to 1.25	1.0 Maximum	1.0 Maximum	0.6 to 1.0
Phosphorus	0.04 Maximum	0.04 Maximum	0.04 Maximum	-	-	0.08 Maximum
Nickel	-	-	-	0.40 Maximum	1.3 Maximum	1.0 Maximum
Aluminum	-	-	-	-	-	2.8 to 3.8
Titanium	-	-	-	0.2 Maximum	-	-

Note 1: The compositions listed in Table 1 are typical requirements with the exception of silicon and molybdenum which are mandatory.

Note 2: Compact Graphite Iron called out in German vermicular.

Note 3: SR = Scale Resistant.

Note 4: Chemical Composition in weight percent.

Note 5: Chemistry per Optical Spectroscopy (OES) ASTM E1010 and ASTM E322 or ASTM E1999.

GJV = Compacted Graphite Iron called out in German vermicular.

HTN = High Temperature Nodular (Iron).

3.1.2 Mechanical Requirements. Mechanical properties are important to casting performance, thus the specific mechanical properties (at $+23\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$) listed in Table 2 for each grade are mandatory requirements. Mechanical properties are obtained from test pieces that are machined from separately cast Y-shaped test samples, described in ISO 1083 standard, or test bars that are cast in a production mold (co-cast), or taken from the part itself. The Y-shaped test samples shall be cast at the end of the treatment batch. The mechanical properties shall meet or exceed the minimum requirements for each grade when tested per ISO 6892-1. The final sampling plan shall have agreement between the GM DRE, GM Supplier Quality Engineer (SQE), GM Product Program Materials Engineer and the casting supplier. The validity of tests and applicability of any retests shall be in accordance with ISO 1083.

Table 2: Mechanical Properties ^{Note 3}

Property	Unit ^{Note 1}	HTN480-8 SiMo	HTN550-4 High Si High Mo SiMo	HTN550-5 High Si SiMo	HTN400-3 GJV SiMoNi	HTN550-0.5 SiMoNi SR	HTN550-0.4 SiMo1000
Minimum Tensile Strength	N/mm ²	480	550	550	400	550	550
Minimum Yield Strength	N/mm ²	380	480	480	300	500	500
Minimum Elongation	%	8	4	5	3	0.5	0.4
Hardness, HBW	10/3000	192 to 262	217 to 285	201 to 241	195 to 245	260 to 310	220 to 290
Hardness BHD ^{Note 2}	mm	3.75 to 4.35	3.60 to 4.10	3.90 to 4.25	Not applicable	Not applicable	Not applicable
Modulus of Elasticity	GPa	160 to 180	160 to 180	160 to 180	160 to 180	160 to 180	160 to 180
Poisson's Ratio		0.28	0.28	0.28	0.28	0.28	0.28

Note 1: Conversions : 1 N/mm² = 1 MPa = 145 psi.

Note 2: Brinell Hardness Diameter (BHD) values shown use a 10 mm ball and a 3000 kg load. Reference ISO 6506-1 for minimum thicknesses required when using this diameter and load.

Note 3: These properties shall not be used for analysis or design.

3.1.2.1 Hardness. Brinell hardness shall be taken in accordance with ISO 6506-1. The material hardness requirements described in Table 2 shall be met on both the test sample and its represented castings. Since casting hardness will vary throughout the part due to differences in section size and cooling rates, the specific test location on the casting shall have agreement between the GM Product Program Materials Engineer, GM DRE, GM SQE and the casting supplier and shall be identified on the engineering drawing, in the SOR, in the DCS Material/General notes in the math file, and other equivalent part specification documents. To prepare the casting surface for the load impression, grind or machine to a representative depth of approximately 1.5 mm from the surface. Other hardness methods, such as cast surface penetrators, can be used if these methods are validated against ISO 6506-1 with a correlation study and are agreed upon by the GM Product Program Materials Engineer.

3.1.2.2 Tensile Strength. All tensile properties shall be per ISO 6892-1 or ASTM E8. Test bars shall be machined from separately cast test samples (Y-blocks) or test samples that are cast in a production mold (co-cast). The test pieces shall comply with the dimensions described in ISO 1083 standard. Test samples represent the quality of the material and melt from which the casting is poured and shall conform to the tensile property requirements listed in Table 2. The manufacturer shall maintain sufficient controls and documentation to assure the GM DRE, GM SQE, and GM Product Program Materials Engineer that properties determined from separately cast or co-cast test samples are representative of the castings shipped.

3.1.2.2.1 Cast Y-block Test Samples. The separately cast samples (Y-blocks) shall be poured into baked, green sand or chemically bonded molds made of a siliceous sand aggregate that is similar to the aggregate used in production molds. The samples shall cool to 480 °C or until a fully gray color is observed. At this time, the samples shall be removed from the mold and allowed to air cool.

3.1.2.2.2 Machined Test Samples. Tensile properties may be specified from test pieces machined from the actual casting. The properties of the pieces machined from the castings may vary from those machined from separately cast samples because of cooling rate and section size variations. When using test pieces machined from the casting, the location of the machined test piece and its specific tensile requirements shall be identified

on the engineering drawing. If test samples are used to qualify castings for specific product requirements, a correlation study shall be completed.

3.1.2.2.3 Nodularizing Treatment of Test Samples. Regarding nodular iron grades, if the nodularizing treatment is carried out in the mold (in-mold method), the separately cast test samples (Y-blocks or test bars) may be cast directly onto the casting using a feeder gate or cast separately in the mold such as to receive the same treated iron as the casting. The separately cast Y-block that is poured in a production mold shall meet the dimensions shown in ISO 1083. When space in a production mold is not available for a Y-block, a separately cast test sample in the mold (co-cast) may be used if it has a minimum diameter of 25 mm and a minimum length of 225 mm.

3.1.2.2.4 Heat Treatment of Test Samples. For heat treated nodular iron, the test samples shall be poured following the same procedure as the as-cast test samples. These test samples shall accompany the represented castings through the heat treatment process before being machined and tested.

3.1.2.2.5 Discontinuities within Test Samples. Porosity, shrink or other discontinuities within a test piece that is not representative of discontinuities seen in production parts represent an invalid test, thus the data shall be discarded. The viewing of such discontinuities shall be done without the use of any magnifying device.

3.1.2.3 Yield Strength. Yield strength per ISO 6892-1 or ASTM E8. The yield strength shall be determined by the 0.2% offset method. Other methods may be used if agreed upon by the GM Product Program Materials Engineer and documented on the engineering drawing, in the SOR, in the DCS Material/General notes in the math file, or other equivalent part specification documents.

3.1.2.4 Percent Elongation. Percent elongation per ISO 6892-1 or ASTM E8. The percent elongation calculation will be based on the ISO 1083 standard in which the original gauge length is 5x that of the gauge diameter.

Note: The ASTM (ASTM International) standard calls for the original gauge length to be 4x that of the diameter.

3.1.3 Physical Requirements. Guide values for physical properties are shown in Appendix A, Table A1. These properties have been gathered from textbooks, not derived from GM laboratory testing, and are for reference only.

3.1.4 Additional Requirements.

3.1.4.1 Microstructure. Quantitative metallography shall treat graphite and matrix separately such that the percentage of the matrix constituents totals 100%. Microstructures will vary throughout the casting due to variations in section size, therefore the control location of the microstructural requirements shall be identified on the engineering drawing. When analyzing the specified control location, at least five (5) fields of view shall be observed to determine that the reported structure is representative of the control area. Microstructures shall not be read at < 1 mm from the cast surface, except for carbides and flotation graphite which may be read to the surface. All microstructural analysis shall be evaluated at a magnification of 100x. However, in the case of laboratory disputes, if it becomes necessary to distinguish between the pearlite and the Moly-rich phases, evaluation must be done at 1000x. Reference SAE 2002-01-2115. Example micrographs showing the difference between pearlite and the Mo-rich phases are in Appendix B, Figure B1 through Figure B4. The microstructural sample shall be taken from the last casting (metal) poured in the treatment batch. In the case of in-mold treatment, the frequency shall be agreed upon between the GM Product Program Materials Engineer and the casting supplier.

The graphite component of the microstructure shall be measured in accordance with ISO 945-1. The percentage of nodularity shall be determined according to ISO 945-4.

Graphite distribution shall be uniform throughout the casting, with no segregation of graphite (flotation graphite) permissible. In the case of a dispute, image analysis of as polished microstructures will be used for quantification of graphite segregation. The amount of graphite in the structure will have < 20% variation (to allow for natural variation, and measurement error) throughout the component.

Free iron carbide is undesirable for machinability performance and shall be $\leq 5\%$ for all grades. See Table 3 for microstructural requirements.