INTERNATIONAL STANDARD

ISO 16112

Second edition
2017-02

Compacted (vermicular) graphite cast irons — Classification

Fontes à graphite vermiculaire (compacté) — Classification

Reference number
ISO 16112:2017(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 25, *Cast irons and pig irons*.

This second edition cancels and replaces the first edition (ISO 16112:2006), which has been technically revised with the following changes:

— Brinell hardness values have been moved from Table 1 and Table 2 to Table A.1;

— property values for cast-on samples with relevant wall thickness $t \leq 12{,}5$ mm have been removed from Table 2 because all data entries for $t \leq 12{,}5$ mm were the same as the values for relevant wall thickness 12,5 mm $< t \leq 30$ mm;

— Annex B has been expanded to provide a more comprehensive explanation of the nodularity evaluation technique;

— Annex C has been deleted and replaced because the series production experience gained since the first publication of ISO 16112 in 2006 has surpassed the scope of the annex.

Introduction

This document deals with the classification of compacted (vermicular) graphite cast irons (CGI) in accordance with the mechanical properties of the material.

The properties of compacted (vermicular) graphite cast irons depend on their graphite and matrix microstructure.

The mechanical properties of the material can be evaluated on machined test pieces prepared from

— separately cast samples,

— samples cast in the mould alongside the casting, with a joint running system, hereafter called side-by-side samples, or

— samples cast onto either the casting or the running system, hereafter referred to as cast-on samples, or

— samples cut from a casting (only when an agreement is made between the manufacturer and the purchaser).

The material grade is defined by mechanical properties measured on machined test pieces prepared from separately cast samples, cast-on samples, or samples cut from the casting by agreement between the manufacturer and the purchaser.

Annex A provides typical properties for compacted (vermicular) graphite cast irons obtained in separately cast test bars.

Annex B provides information on a procedure to determine the graphite nodularity of the microstructure.

Annex C provides information on properties and examples for typical applications of compacted (vermicular) graphite cast irons.

Annex D provides cross-references of ISO 16112 grade designations to other national and international standard grades of compacted (vermicular) graphite cast iron.

References used in the preparation of this document are listed in the Bibliography.

Compacted (vermicular) graphite cast irons — Classification

1 Scope

This document specifies five grades of compacted (vermicular) graphite cast irons.

This document specifies five grades based on the minimum mechanical properties measured on machined test pieces prepared from

— separately cast samples,

— side-by-side cast samples,

— cast-on samples, or

— samples cut from a casting.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 945-1, *Microstructure of cast irons — Part 1: Graphite classification by visual analysis*

ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO/TR 15931, *Designation system for cast irons and pig irons*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
compacted (vermicular) graphite cast iron
cast material, iron and carbon based, the carbon being present mainly in the form of compacted (vermicular) graphite particles that appear vermicular on a two-dimensional plane of polish, the graphite particles being embedded in a matrix consisting of ferrite, ferrite/pearlite, or pearlite

Note 1 to entry: Reference micrographs are provided in Annex B.

3.2
graphite modification treatment
process that brings the liquid iron into contact with a substance to produce graphite in the predominantly compacted (vermicular) form during solidification

3.3
separately cast sample
sample cast in a separate sand mould under representative manufacturing conditions and material grade

3.4
side-by-side cast sample
sample cast in the mould alongside the casting, with a connected but separate running system

3.5
cast-on sample
sample attached directly to the running system or the casting

3.6
sample cut from the casting
sample obtained directly from the casting

3.7
relevant wall thickness
section of the casting, agreed between the manufacturer and the purchaser, to which the determined mechanical properties shall apply

Note 1 to entry: The cooling rate of the relevant wall thickness can be used to determine the size of separately cast or cast-on samples to ensure representative microstructures and properties.

4 Designation

The material is designated according to ISO/TR 15931. The relevant designations are given in Tables 1 and 2.

In the case of test pieces prepared from separately cast samples, the letter "S" is added at the end of the grade designation. In the case of test pieces prepared from side-by-side or cast-on samples, the letter "U" is added at the end of the grade designation.

5 Order information

The following information shall be supplied by the purchaser:

a) the complete designation of the material;

b) any special requirements which shall be agreed upon between the manufacturer and the purchaser.

All agreements between the manufacturer and the purchaser shall be made by the time of acceptance of the order.

6 Manufacture

The method of producing compacted (vermicular) graphite cast iron and its chemical composition shall be left to the discretion of the manufacturer, who shall ensure that the requirements of this document are met for the material grade specified in the order.

NOTE When compacted (vermicular) graphite cast iron is to be used for special applications, the chemical composition and heat treatment can be agreed upon between the manufacturer and the purchaser.

7 Requirements

7.1 General

The minimum tensile properties of compacted (vermicular) graphite cast irons shall be as specified in Tables 1 and 2.

Production test results shall meet the minimum tensile property requirements specified in Table 1 or Table 2. Statistical analysis methods shall be used to establish process capability to meet the tensile property requirements.

7.2 Test pieces machined from separately cast samples

The minimum measured mechanical properties of compacted (vermicular) graphite cast irons, determined using test pieces machined from separately cast samples according to Figure 1, Figure 2 or Figure 3 shall be as specified in Table 1. The material designation is based on the minimum mechanical properties obtained in cast samples with a thickness of 25 mm. This designation is irrespective of the type of cast sample.

Table 1 — Mechanical properties measured on test pieces machined from separately cast samples

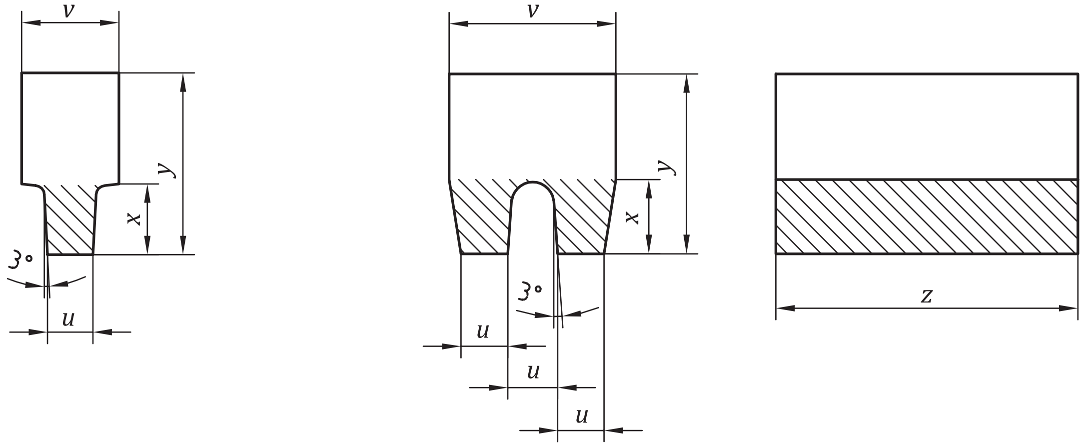
Material designation	**Tensile strength** R_m MPa min	**0,2 % proof strength** $R_{p0,2}$ MPa min	**Elongation** A % min
ISO 16112/JV/300/S	300	210	2,0
ISO 16112/JV/350/S	350	245	1,5
ISO 16112/JV/400/S	400	280	1,0
ISO 16112/JV/450/S	450	315	1,0
ISO 16112/JV/500/S	500	350	0,5

NOTE 1 The values for these materials apply to castings cast in sand moulds of comparable thermal behaviour. Subject to amendments agreed upon in the order, they can apply to castings obtained by alternative methods.

NOTE 2 Whatever the method used for obtaining the castings, the grades are based on the mechanical properties measured on test pieces machined from samples separately cast in a sand mould or a mould of comparable thermal behaviour.

NOTE 3 Tensile testing requires sound test pieces in order to ensure pure uniaxial stress during the test.

Dimensions in millimetres



a) Types I, IIa and III **b) Type IIb**

Dimension	Type			
	I	IIa	IIb	III
u	12,5	25	25	50
v	40	55	90	90
x	30	40	40 to 50	60
y[a]	80	100	100	150
z[b]	A function of the test-piece length			

[a] For information only.

[b] *z* shall be chosen to allow a test piece of the dimensions shown in Figure 5 to be machined from the sample.

Figure 1 — Separately cast or side-by-side cast samples (option 1)

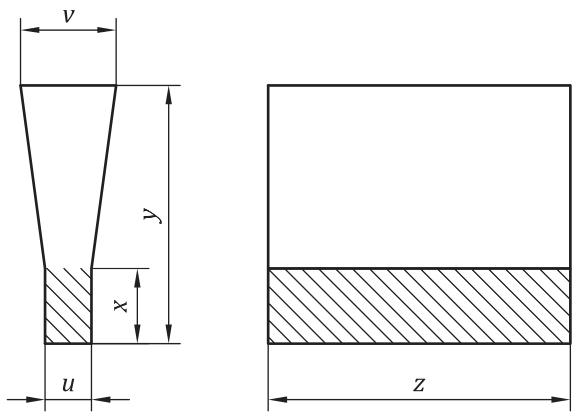
The thickness of the sand mould surrounding the samples shall be

— 40 mm minimum for types I, IIa and IIb, or

— 80 mm minimum for type III.

NOTE For the manufacture of thin-walled castings or castings in metal moulds, the tensile properties can, by agreement between the manufacturer and the purchaser, be determined on test pieces taken from samples of thickness, *u*, less than 12,5 mm.

Dimensions in millimetres



Dimension	Type			
	I	II	III	IV
u	12,5	25	50	75
v	40	55	100	125
x	25	40	50	65
y[a]	135	140	150	175
z[b]	A function of the test-piece length			

[a] For information only.

[b] *z* shall be chosen to allow a test piece of the dimensions shown in Figure 5 to be machined from the sample.

Figure 2 — Separately cast or side-by-side cast samples (option 2)

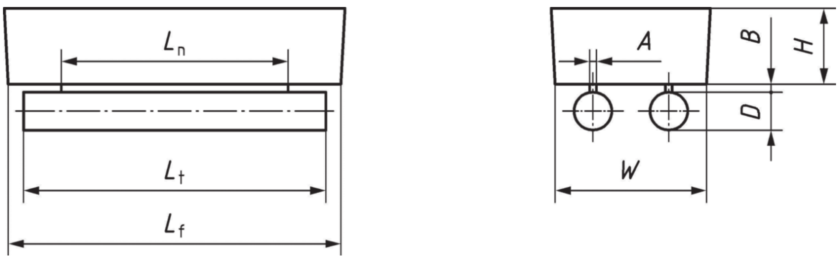
The thickness of the sand mould surrounding the samples shall be

— 40 mm minimum for types I and II, or

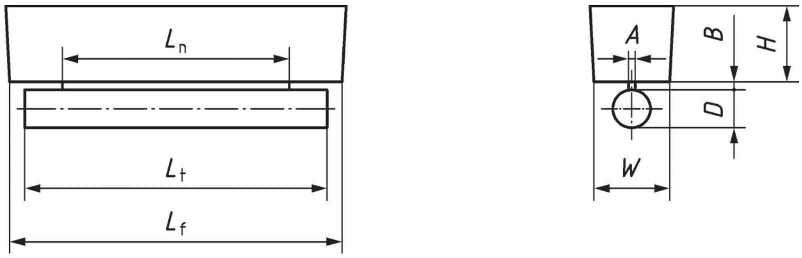
— 80 mm minimum for types III and IV.

NOTE For the manufacture of thin-walled castings or castings in metal moulds, the tensile properties can, by agreement between the manufacturer and the purchaser, be determined on test pieces taken from samples of thickness, *u*, less than 12,5 mm.

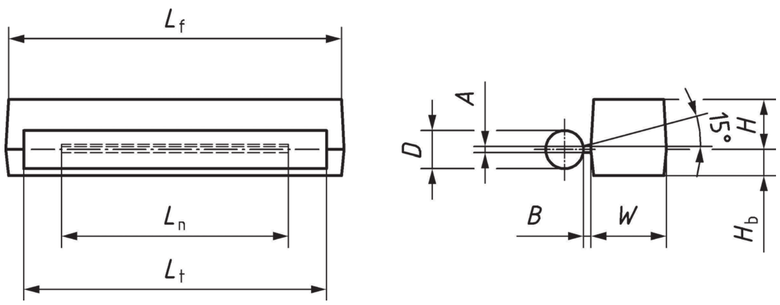
Dimensions in millimetres



a) Type a



b) Type b



c) Type c

Type	*A*	*B*	*D*	*H*	H_b	L_f	L_n	L_t	*W*
a	4,5	5,5	25	50	—	L_t + 20	L_t − 50	[a]	100
b	4,5	5,5	25	50	—	L_t + 20	L_t − 50		50
c	4,0	5,0	25	35	15	L_t + 20	L_t − 50		50

[a] L_t shall be chosen to allow a test piece of dimensions shown in Figure 5 to be machined from the cast sample.

Figure 3 — Separately cast or side-by-side cast samples (option 3)

The thickness of the sand mould surrounding the samples shall be at least 40 mm.

7.3 Test pieces machined from side-by-side and cast-on samples

The minimum mechanical properties of compacted (vermicular) graphite cast irons, determined using test pieces machined from side-by-side cast samples according to Figure 1, Figure 2 or Figure 3, or to cast-on samples according to Figure 4, shall be as specified in Table 2.

The material designation is based on the minimum mechanical properties obtained in samples with a relevant wall thickness of 25 mm. This designation is irrespective of the type of cast sample.

Table 2 — Mechanical properties measured on test pieces machined from side-by-side samples or cast-on samples

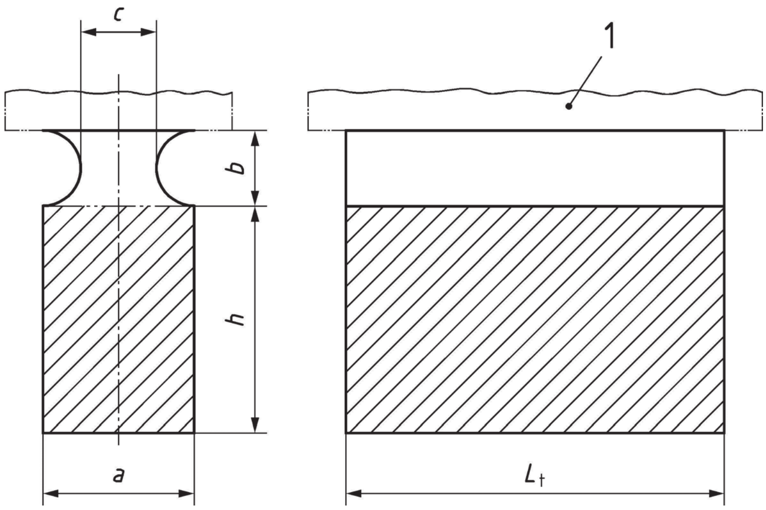
Material designation	Relevant wall thickness t mm	Tensile strength R_m MPa min	0,2 % proof strength $R_{p0,2}$ MPa min	Elongation A % min
ISO 16112/JV/300/U	12,5 < t ≤ 30	300	210	2,0
	30 < t ≤ 60	275	195	2,0
	60 < t ≤ 200	250	175	2,0
ISO 16112/JV/350/U	12,5 < t ≤ 30	350	245	1,5
	30 < t ≤ 60	325	230	1,5
	60 < t ≤ 200	300	210	1,5
ISO 16112/JV/400/U	12,5 < t ≤ 30	400	280	1,0
	30 < t ≤ 60	375	260	1,0
	60 < t ≤ 200	325	230	1,0
ISO 16112/JV/450/U	12,5 < t ≤ 30	450	315	1,0
	30 < t ≤ 60	400	280	1,0
	60 < t ≤ 200	375	260	1,0
ISO 16112/JV/500/U	12,5 < t ≤ 30	500	350	0,5
	30 < t ≤ 60	450	315	0,5
	60 < t ≤ 200	400	280	0,5

NOTE 1 The mechanical properties of test pieces machined from cast-on samples can be different from the properties of the casting itself, but usually give a better approximation than those obtained from separately cast samples. Additional values are given in Annex A for guidance.

NOTE 2 The percentage reduction in mechanical properties in thick sections depends upon the casting geometry and its cooling conditions.

NOTE 3 For relevant wall thickness greater than 200 mm, the manufacturer and the purchaser can agree on the type and size of the cast sample and the minimum values to be obtained.

Dimensions in millimetres



Key

1 casting or running system

Type	Relevant wall thickness of castings *t*	*a*	*b*	*c*	*h*	L_t
			max	min		
A	$t \leq 12,5$	15	11	7,5	20 to 30	a
B	$12,5 < t \leq 30$	25	19	12,5	30 to 40	a
C	$30 < t \leq 60$	40	30	20	40 to 65	a
D	$60 < t \leq 200$	70	52,5	35	65 to 105	a

[a] L_t shall be chosen to allow a test piece of a dimension shown in Figure 5 to be machined from the sample.

Figure 4 — Cast-on sample

The thickness of the sand mould surrounding the samples shall be

— 40 mm minimum for types A and B, and

— 80 mm minimum for types C and D.

NOTE If smaller dimensions are agreed, the following relationships apply:

$b = 0,75 \times a$ and $c = 0,5 \times a$.

7.4 Test pieces machined from samples cut from a casting

Samples obtained directly from the casting best represent the properties of the casting itself. If applicable, the manufacturer and the purchaser shall agree on:

— the locations on the casting where the samples shall be taken;

— the mechanical properties that shall be measured;

— the values of these mechanical properties (for information, see Annex A).

NOTE 1 The properties of castings can vary depending on the complexity of the castings and variation in their section thicknesses and cooling rates.

NOTE 2 Samples cut from a casting often have a slower cooling rate than separately cast samples. Therefore, the mechanical properties are often lower, even if the section thickness and microstructure are similar.

NOTE 3 Mechanical properties for test pieces cut from a casting are affected not only by material properties (subject of this document) but also by the local casting soundness (outside the scope of this document).

7.5 Hardness

Casting hardness shall be specified only when agreed between the manufacturer and the purchaser. The Brinell hardness values provided in Annex A are for guidance only.

7.6 Graphite structure

The graphite particles in compacted (vermicular) graphite cast irons shall be predominantly in the vermicular form (form III according to ISO 945-1) when viewed on a two-dimensional plane of polish. A maximum of 20 % of the graphite particles, in sections representative of the relevant wall thickness, may be of form VI, form V or form IV according to ISO 945-1. In compacted (vermicular) graphite cast irons, particles similar to form V and form IV can be referred to as “intermediate” particles, as defined in Annex B.

Samples for metallographic examination shall be taken from locations agreed between the manufacturer and the purchaser.

A method for the metallographic determination of percent nodularity in compacted (vermicular) graphite cast iron microstructures by image analysis is provided in Annex B. The manufacturer and the purchaser shall agree on the graphite structure evaluation method.

Flake (lamellar) graphite (form I according to ISO 945-1) is not permitted, except within the surface rim zone of the casting. Flake graphite is therefore not considered in the calculation of nodularity. If flake graphite is present (except in the surface rim zone), the microstructure shall be rejected and a nodularity assessment shall not be conducted. The thickness of the rim zone shall be agreed between the manufacturer and the purchaser by the time of the acceptance of the order.

Although the conventional definition of compacted (vermicular) graphite cast iron is within the range of 0 % to 20 % nodularity, separate agreement may be made between the manufacturer and the purchaser for other nodularity ranges. However, the maximum nodularity shall not be more than 30 %.

The graphite structure shall be confirmed either by metallographic examination or by non-destructive methods. In case of dispute, the result of the metallographic examination shall prevail.

8 Sampling

8.1 General

Samples shall be provided to represent the castings produced.

Samples shall be made from the same material as that used to produce the castings which they represent (see 8.4).

Several types of samples (separately cast samples, side-by-side samples, cast-on samples or samples cut from a casting) can be used, depending on the mass and the wall thickness of the casting. When the mass of the casting exceeds 2 000 kg and its wall thickness exceeds 60 mm, cast-on samples or samples cut from a casting should preferably be used.

All samples shall be adequately marked to guarantee full traceability to the castings which they represent.

The samples shall be subject to the same heat treatment as that of the castings they represent, if any.

8.2 Cast samples

8.2.1 Frequency and number of tests

Samples representative of the material shall be produced at a frequency in accordance with the in-process quality-assurance procedures adopted by the manufacturer.

In the absence of an in-process quality-assurance procedure or any other agreement between the manufacturer and the purchaser, a minimum of one cast sample shall be produced to confirm the material grade, at a frequency to be agreed between the manufacturer and the purchaser.

8.2.2 Separately cast samples

Separately cast samples shall be cast separately in sand moulds at the same time as the castings. The moulds used to cast the separately cast samples shall have comparable thermal behaviour to the moulding material used to produce the castings.

The samples shall meet the requirements of Figure 1, Figure 2 or Figure 3.

The samples shall be removed from the mould at a temperature similar to that of the castings and shall not exceed 500 °C.

If the graphite modification treatment is carried out in the mould (in-mould method), the samples shall either be

— cast alongside with the castings, with a joint running system, or

— cast separately using a similar treatment method in the sample mould as the method used to produce the castings.

8.2.3 Side-by-side cast samples

Side-by-side cast samples are representative of the castings concurrently cast, and also of all other castings of a similar relevant wall thickness from the same lot.

When mechanical properties are required for a series of castings belonging to the same test unit, the side-by-side cast samples shall be produced from the last mould poured.

The samples shall meet the requirements of Figure 1, Figure 2 or Figure 3.

8.2.4 Cast-on samples

Cast-on samples are representative of the castings to which they are attached, and also of all other castings of a similar relevant wall thickness from the same lot.

When mechanical properties are required for a series of castings belonging to the same test unit, the cast-on samples shall be produced from the last mould poured.

The location of the cast-on samples shall be agreed between the manufacturer and the purchaser, taking into account the shape of the casting and the running system, in order to avoid any unfavourable effect on the properties of the adjacent material.

The samples shall have a general shape as indicated in Figure 4 and the dimensions shown therein. When the mass of the casting exceeds 2 000 kg and its wall thickness exceeds 60 mm, the dimensions of the cast-on sample shall be agreed between the manufacturer and the purchaser.

When castings are to be heat treated, the cast-on samples shall not be separated from the castings until after heat treatment, unless otherwise agreed between the manufacturer and the purchaser.

8.2.5 Test pieces machined from cast samples

The tensile test piece shown in Figure 5 shall be machined from the hatched area of Figure 1, Figure 2, or Figure 4, or from the cylindrical portion of Figure 3.

Unless otherwise specified, the preferred diameter for the tensile test piece shall be used.

8.3 Samples cut from a casting

8.3.1 General

In addition to the requirements of the material, the manufacturer and the purchaser may agree on the properties required at stated locations in the casting. These properties shall be determined by testing test pieces machined from samples cut from the casting at these stated locations. The samples should be as large as possible, with a preferred tensile gauge diameter of 14 mm, while ensuring that the graphite in the test piece is representative of the graphite in the casting and that the test piece does not contain any microstructural elements from the surface rim zone or any other surface defects. Consideration shall be given in the interpretation of results obtained from any test pieces that are smaller than that shown in Figure 5.

8.3.2 Other conditions

The location from which the sample is taken shall be in an area where the casting wall thickness is representative of the relevant wall thickness.

To determine the required size of the test piece, the purchaser shall indicate to the manufacturer which are the important sections of the casting. In the absence of any direction by the purchaser, the manufacturer may select the location and size of the test piece.

8.4 Formation of test units and number of tests

8.4.1 Examples of test units

Examples of test units are as follows:

— castings poured from the same ladle, up to 2 000 kg of fettled castings; this may vary, where practicable, by agreement between the manufacturer and the purchaser;

— a single casting, if its mass equals or exceeds 200 kg;

— when the graphite modification treatment is carried out on less than 2 000 kg of liquid metal in a batch ladle process, the test unit shall be the number of castings produced from that quantity of treated metal.

— when produced from a continuous pouring furnace, the test unit shall be the number of castings produced from the quantity of treated metal in each treatment/transfer ladle used to replenish the furnace.

NOTE After heat treatment, a test unit remains the same, unless different heat treatments have been applied to distinct parts of the test unit. In such cases, these distinct parts become separate test units.

8.4.2 Number of tests per test unit

Sampling and testing shall be carried out in accordance with Clauses 8, 9 and 10. Sampling and testing shall be carried out on each test unit, unless the in-process quality assurance system makes provision for amalgamation of test units. When the graphite modification treatment has been carried out in the mould, the formation of test units and the number of tests shall be agreed between the manufacturer and the purchaser.

9 Test methods

9.1 Tensile test

The tensile test shall be carried out in accordance with ISO 6892-1. The preferred test-piece diameter is 14 mm but, for technical reasons and for test pieces machined from samples cut from the casting, it is permitted to use a test piece of a different diameter (see Figure 5). In either case, the original gauge length of the test piece shall conform to Formula (1):

$$L_0 = 5{,}65 \times \sqrt{S_0} \text{ or } L_0 = 5 \times d \qquad (1)$$

where

L_0 is the original gauge length;

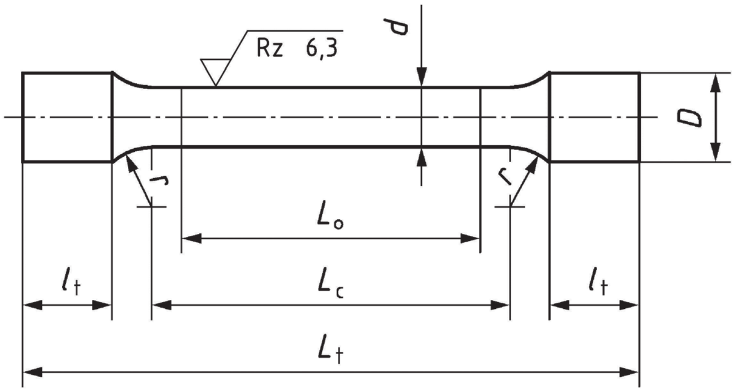
S_0 is the original cross-sectional area of the test piece;

d is the diameter of the test piece along the gauge length.

If the above formula for L_0 is not applicable, then an agreement shall be made between the manufacturer and the purchaser on the dimensions of the test piece.

A test piece with a different gauge length may be agreed between the manufacturer and purchaser.

Dimensions in millimetres



d	L_o	L_c[a] min
5	25	30
7	35	42
10	50	60
14[b]	70	84
20	100	120

[a] In principle.

[b] Preferred dimension.

where

- L_o is the original gauge length; i.e. $L_o = 5 \times d$;
- d is the diameter of the test piece along the gauge length;
- L_c is the parallel length; $L_c > L_o$ (in principle, $L_c - L_o > d$);
- l_t is the grip length of the test piece;
- L_t is the total length of the test piece, which depends on L_c and l_t;
- r is the transition radius, which shall be at least 4 mm;
- Rz is the maximum surface roughness, expressed in µm.

NOTE The method of gripping the ends of the test piece can be agreed between the manufacturer and the purchaser.

Figure 5 — Tensile test piece

9.2 Hardness test

If agreed between the manufacturer and the purchaser, the hardness shall be determined as Brinell hardness in accordance with ISO 6506-1. Alternative hardness tests may also be agreed upon.

The test shall be carried out on the test pieces, or at one or several points on the casting, after preparation of the testing area in accordance with the agreement between the manufacturer and the purchaser.

If the measuring points are not the subject of an agreement, they shall be chosen by the manufacturer.

If it is not possible to carry out the hardness test on the casting, then by agreement between the manufacturer and the purchaser, the hardness test may be carried out on a knob cast-on to the casting.

10 Retests

10.1 Need for retests

Retests shall be carried out if a test is not valid (see 10.2).

Retests are permitted to be carried out if a test result does not meet the mechanical property requirements for the specified grade (see 10.3).

10.2 Test validity

A test is not valid if there is:

a) a faulty mounting of the test piece or defective operation of the test machine;

b) a defective test piece because of incorrect pouring or incorrect machining;

c) a fracture of the test piece outside the gauge length;

d) a casting defect in the test piece, evident after fracture.

In the above cases, a new test piece shall be taken from the same sample or from a duplicate sample cast at the same time. The result of the retest shall be substituted for the result of the invalid test.

10.3 Nonconforming test results

If any test gives results which do not conform to the specified requirements, for reasons other than those given in 10.2, the manufacturer shall have the option to conduct retests. If the manufacturer conducts retests, two retests shall be carried out for each failed test.

If the results of both retests meet the specified requirements, the material shall be deemed to conform to this document.

If the results of one or both retests fail to meet the specified requirements, the material shall be deemed not to conform to this document.

10.4 Heat treatment of samples and castings

Unless otherwise specified, in the case of castings in the as-cast condition with mechanical properties not in conformance with this document, a heat treatment may be carried out.

In the case of castings which have undergone a heat treatment and for which the test results are not satisfactory, the manufacturer shall be permitted to re-heat-treat the castings and the representative samples. In this event, the samples shall receive the same number of heat treatments as the castings.

If the results of the tests carried out on the test pieces machined from the re-heat-treated samples are satisfactory, then the re-heat-treated castings shall be regarded as conforming to the specified requirements or to this document.

The number of re-heat-treatment cycles shall not exceed two.

Annex A
(informative)

Additional information on compacted (vermicular) graphite cast irons

Additional information on mechanical and physical properties of compacted (vermicular) graphite cast irons is given in Table A.1.

Table A.1 — Information on mechanical and physical properties of compacted (vermicular) graphite cast irons

Property	Units	Temperature	Material designation				
			ISO 16112/JV/300	ISO 16112/JV/350	ISO 16112/JV/400	ISO 16112/JV/450	ISO 16112/JV/500
Ultimate tensile strength, R_m [a]	MPa	23 °C	300 to 375	350 to 425	400 to 475	450 to 525	500 to 575
		100 °C	275 to 350	325 to 400	375 to 450	425 to 500	475 to 550
		400 °C	225 to 300	275 to 350	300 to 375	350 to 425	400 to 475
0,2 % proof stress, $R_{p0,2}$ [a]	MPa	23 °C	210 to 260	245 to 295	280 to 330	315 to 365	350 to 400
		100 °C	190 to 240	220 to 270	255 to 305	290 to 340	325 to 375
		400 °C	170 to 220	195 to 245	230 to 280	265 to 315	300 to 350
Elongation, A [a]	%	23 °C	2,0 to 5,0	1,5 to 4,0	1,0 to 3,5	1,0 to 2,5	0,5 to 2,0
		100 °C	1,5 to 4,5	1,5 to 3,5	1,0 to 3,0	1,0 to 2,0	0,5 to 1,5
		400 °C	1,0 to 4,0	1,0 to 3,0	1,0 to 2,5	0,5 to 1,5	0,5 to 1,5
Elastic modulus [a, b]	GPa	23 °C	130 to 145	135 to 150	140 to 150	145 to 155	145 to 160
		100 °C	125 to 140	130 to 145	135 to 145	140 to 150	140 to 155
		400 °C	120 to 135	125 to 140	130 to 140	135 to 145	135 to 150
Brinell hardness		23 °C	140 to 210	160 to 220	180 to 240	200 to 250	220 to 260
Endurance ratio:							
rotating-bending		23 °C	0,50 to 0,55	0,47 to 0,52	0,45 to 0,50	0,45 to 0,50	0,43 to 0,48
tension-compression		23 °C	0,30 to 0,40	0,27 to 0,37	0,25 to 0,35	0,25 to 0,35	0,20 to 0,30
3-point bending		23 °C	0,65 to 0,75	0,62 to 0,72	0,60 to 0,70	0,60 to 0,70	0,55 to 0,65
Poisson's ratio			0,26	0,26	0,26	0,26	0,26
Density	g/cm^3		7,0	7,0	7,0 to 7,1	7,0 to 7,2	7,0 to 7,2
Thermal conductivity	W/(m·K)	23 °C	47	43	39	38	36
		100 °C	45	42	39	37	35
		400 °C	42	40	38	36	34
Thermal expansion coefficient	µm/(m·K)	100 °C	11	11	11	11	11

[a] Wall thickness 25 mm.

[b] Secant modulus (200 MPa to 300 MPa).

Table A.1 *(continued)*

Property	Units	Temperature	Material designation				
			ISO 16112/JV/300	**ISO 16112/JV/350**	**ISO 16112/JV/400**	**ISO 16112/JV/450**	**ISO 16112/JV/500**
		400 °C	12,5	12,5	12,5	12,5	12,5
Specific heat capacity	J/(g·K)	100 °C	0,475	0,475	0,475	0,475	0,475
Matrix structure			predominantly ferritic	ferritic-pearlitic	pearlitic-ferritic	predominantly pearlitic	fully pearlitic

[a] Wall thickness 25 mm.

[b] Secant modulus (200 MPa to 300 MPa).

Annex B
(informative)

Compacted (vermicular) graphite cast iron nodularity evaluation

B.1 The graphite nodularity of compacted (vermicular) graphite cast iron is expressed as the area-percentage of graphite particles that are predominantly spheroidal or nodular in shape (similar to form VI, form V and form IV according to ISO 945-1).

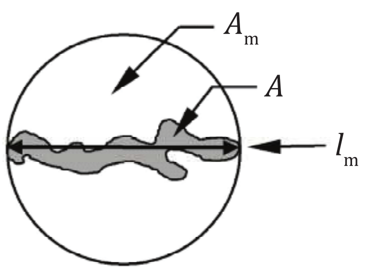
B.2 The level of nodularity depends not only on how the cast iron is prepared (nature of the basic cast iron, residual magnesium content, inoculation level, etc.), but also on the cooling rate of the section in question. Moreover, some degeneration of the graphite in contact with the mould is usually observed, resulting in a certain extent of flake (lamellar) graphite at the surface rim zone of the casting.

B.3 The nodularity percentage is generally determined at ×100 magnification on a polished cut section of the specimen. Accurate analysis requires that the polished surface of the specimen is of sufficient quality to assess the true size and shape of the graphite particles. The nodularity can be measured by chart comparison techniques, semiautomatic image analysis or automatic image analysis.

B.4 To ensure accurate measurement by image analysis, the lighting should have uniform intensity. The grey-scale threshold value should be set such that all graphite particles (foreground) are clearly defined. A minimum field-of-view area of 4 mm^2 is recommended. Pixel size in the image to be analysed should be less than 1 µm. Depending on the image resolution, graphite coarseness and carbon equivalent, more than one measurement field might be required.

B.5 The roundness shape factor is recommended as the basis for nodularity measurement by image analysis. Roundness is defined in the following Formula (B.1) and accompanying illustration, Figure B.1:

$$\text{Roundness} = \frac{A}{A_m} = \frac{4 \times A}{\pi \times l_m{}^2} \tag{B.1}$$



Key

A_m area of circle of diameter l_m

A area of the graphite particle in question

l_m maximum axis length of the graphite particle in question = maximum distance between two points on the graphite particle perimeter

Figure B.1 — Roundness definition

B.6 Graphite particles greater than or equal to 10 µm (l_m ≥ 10 µm) are classified by the roundness shape factor as either nodular, intermediate or compacted (vermicular) graphite as shown in Table B.1. Particles with a maximum axis length less than 10 µm and particles touching the image boundaries are not included in the analysis. Flake graphite and other undermodified structures are also not considered in the analysis because flake graphite is not permitted in the compacted (vermicular) graphite iron structure, except in the surface rim zone (see 7.5). If flake graphite is visually observed, the castings represented by that sample should be rejected. In such cases, the calculation of nodularity is not relevant and should not be conducted.

Table B.1 — Graphite particle classification by roundness shape factor

Roundness shape factor	Graphite form
>0,625 to 1	Nodular
0,525 to 0,625	Intermediate
<0,525	Compacted
Graphite particles with maximum axis length less than 10 µm are not included in the analysis.	

B.7 The introduction of intermediate graphite particles in compacted (vermicular) graphite cast irons accounts for the probability that irregularly shaped graphite particles on the two-dimensional plane of polish are the result of the location at which the compacted graphite cluster is sectioned. As shown in Figure B.2, the graphite shape observed on the plane of polish depends not only on the shape of the graphite but also on how the graphite cluster is sectioned. Different intersection lines can readily cause a well-formed compacted graphite cluster to appear as an irregular nodule, similar to form VI, form V or form IV graphite according to ISO 945-1. Section AA and Section BB could result in a well-formed compacted graphite cluster being wrongly classified as form IV, form V or form VI graphite. Section CC would correctly reveal a vermicular particle on the plane of polish. The coefficient of 0,5 for intermediate particles in the nodularity equation presented in B.8 is applied to account for this probability.

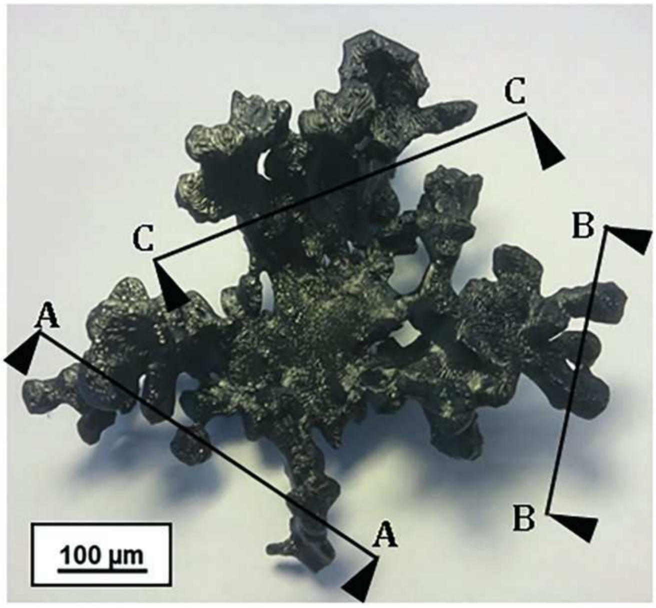


Figure B.2 — Impact of the plane of polish on the observed graphite shape (courtesy of Argonne National Laboratory)

B.8 Percent nodularity is calculated on an area basis using Formula (B.2):

$$\text{Percent nodularity} = \frac{\sum A_{\text{nodules}} + 0{,}5 \times \sum A_{\text{intermediates}}}{\sum A_{\text{all particles}}} \times 100 \qquad \text{(B.2)}$$

where

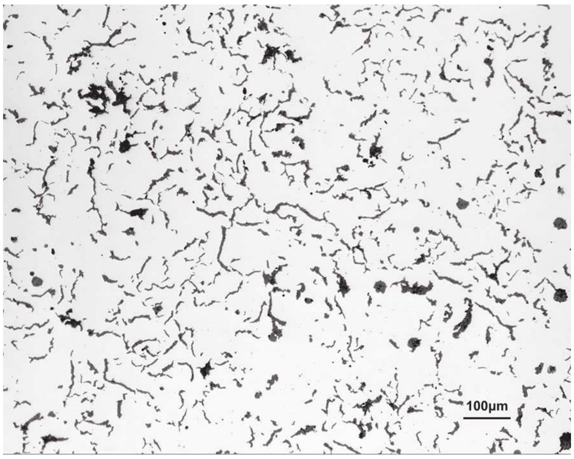
A_{nodules} is the area of particles ($l_m \geq 10$ µm) classified as spheroidal (nodular) graphite;

$A_{\text{intermediates}}$ is the area of particles ($l_m \geq 10$ µm) classified as intermediate forms of graphite;

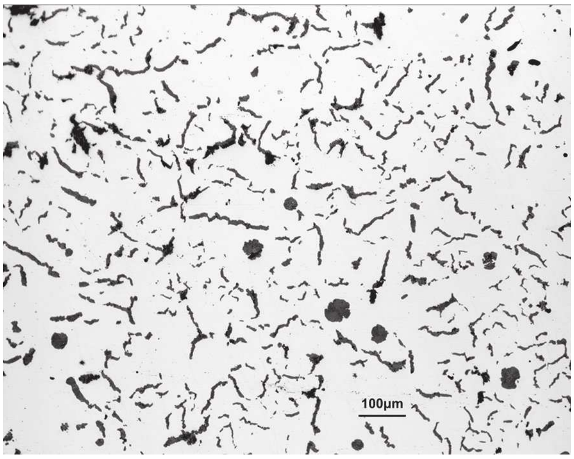
$A_{\text{all particles}}$ is the area of all graphite particles greater than or equal to 10 µm ($l_m \geq 10$ µm).

B.9 The location of the nodularity test shall be agreed between the manufacturer and the purchaser.

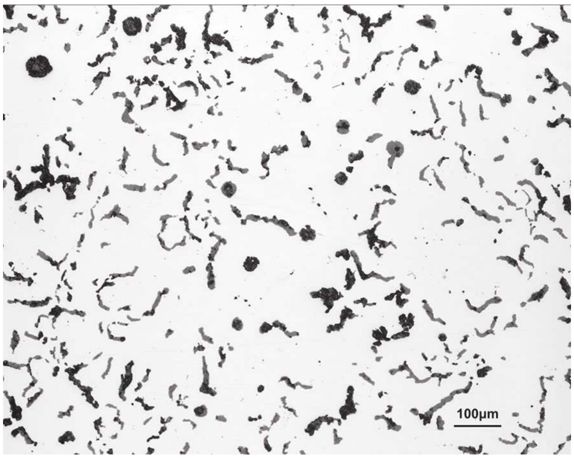
B.10 Typical compacted (vermicular) graphite cast iron microstructures (containing approximately 5 %, 10 %, 15 % and 20 % nodularity) are shown in Figure B.3.



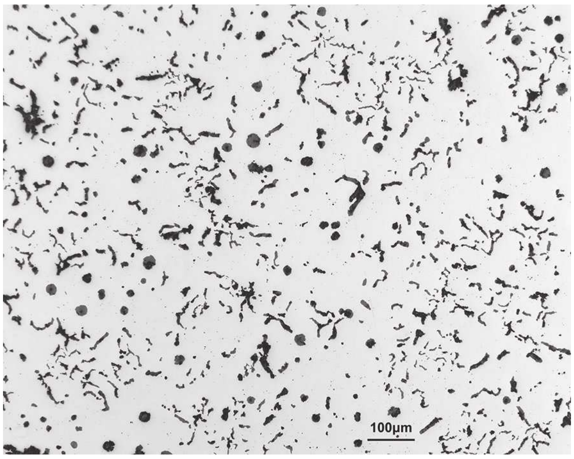
5,7 % nodularity



10,9 % nodularity



14,2 % nodularity



21,5 % nodularity

Figure B.3 — Typical compacted (vermicular) graphite cast iron microstructures

B.11 Graphite particles with different roundness shape factors are shown in Figure B.4.

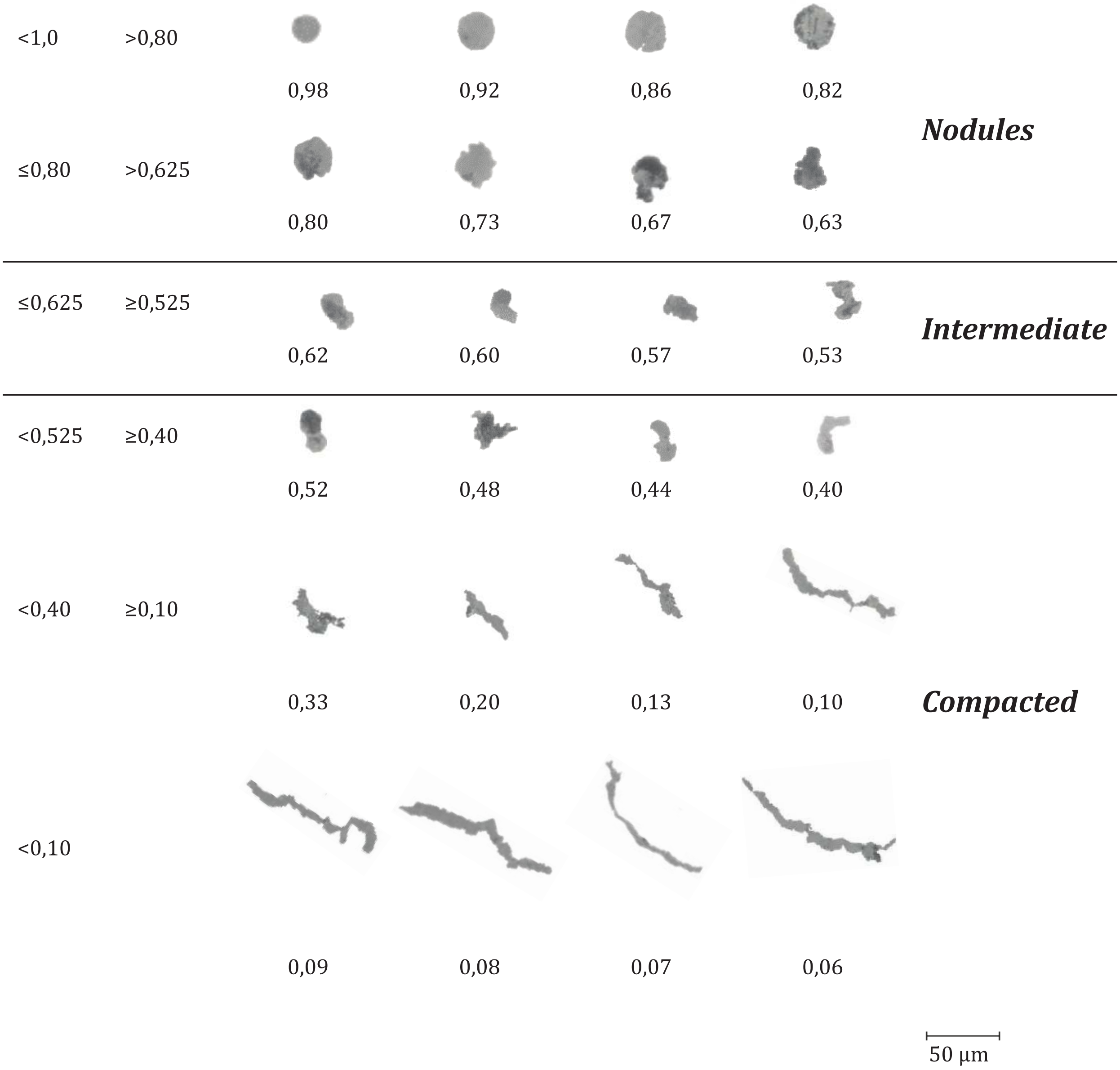


Figure B.4 — Visual representation of graphite particles categorized by roundness shape factor

Annex C
(informative)

Compacted (vermicular) graphite cast irons — Properties and typical applications

Table C.1 gives information about the properties and typical applications of compacted (vermicular) graphite cast irons.

Table C.1 — Properties and typical applications of compacted (vermicular) graphite cast irons

Material designation	Properties	Examples of typical applications
ISO 16112/JV/300	Lowest strength and highest ductility. High thermal conductivity and low elastic modulus minimize the accumulation of thermally induced stresses. Predominantly ferritic matrix minimizes growth during prolonged exposure to elevated temperatures.	Exhaust manifolds and turbocharger housings Clutch components Cylinder heads for large marine and stationary engines
ISO 16112/JV/350	Strength higher than alloyed grey cast iron with good ductility. Better castability, mould yield and machinability than spheroidal graphite cast iron.	Bedplates, brackets and couplings Clutch components Cylinder blocks and heads for large marine and stationary diesel engines Ingot moulds
ISO 16112/JV/400	Combination of strength, stiffness and thermal conductivity. Good wear resistance.	Automotive cylinder blocks and heads Bedplates, brackets and couplings Truck brake drums Pump housings and hydraulic components Ingot moulds
ISO 16112/JV/450	Higher strength, stiffness and wear resistance than ISO 16112/JV/400, although less machinable.	Automotive cylinder blocks and heads Cylinder liners Train brake discs Pump housings and hydraulic components
ISO 16112/JV/500	Highest strength and lowest ductility. Highest wear resistance and lowest machinability.	Highly stressed automotive cylinder blocks Cylinder liners

Annex D
(informative)

Cross-references of ISO 16112 grade designations to other standard grades of compacted (vermicular) graphite cast iron

Table D.1 provides a selection of approximate cross-references of ISO 16112 grade designations to standard grades of compacted (vermicular) graphite cast iron.

These cross-references are only approximations. Differences exist between the specification requirements, which should be considered when using the information to evaluate potential grade substitutions.

Table D.1 — Approximate cross-references of ISO 16112 grade designations to other standard grades of compacted (vermicular) graphite cast irons

ISO 16112	ASTM A842–11[2]	EN 16079[3]	JIS G 5505[4]	GB/T 26655–2011[5]	SAE J1887[6]
ISO 16112/JV/300	300	EN-GJV-300	*FCV 300*	RuT300A	C300
ISO 16112/JV/350	350	EN-GJV-350	*FCV 350*	RuT350A	C350
ISO 16112/JV/400	400	EN-GJV-400	*FCV 400*	RuT400A	C400
ISO 16112/JV/450	450	EN-GJV-450	*FCV 450*	RuT450A	C450
ISO 16112/JV/500	—	EN-GJV-500	*FCV 500*	RuT500A	—

Bibliography

[1] ISO/TR 945-2, *Microstructure of cast irons — Part 2: Graphite classification by image analysis*

[2] ASTM A842-11, *Standard specification for compacted graphite iron castings*

[3] EN 16079, *Founding — Compacted (vermicular) graphite cast irons*

[4] JIS G 5505, *Compacted (vermicular) graphite cast irons*

[5] GB/T 26655-2011, *Compacted (vermicular) graphite cast irons*

[6] SAE J1887, *Automotive compacted graphite iron castings*

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