INTERNATIONAL STANDARD

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Compacted (vermicular) graphite cast irons — Classification

Fontes à graphite vermiculaire (compacté) — Classification

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 16112 was prepared by Technical Committee ISO/TC 25, *Cast irons and pig irons*, Subcommittee SC 7, *Compacted graphite cast irons*.

Introduction

This International Standard 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 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.

Some material grades may be suitable for pressure applications.

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

Annex B (informative) gives information on a procedure to determine the graphite nodularity of the microstructure.

Annex C (informative) gives information on the influence of metallurgical variables on the machinability in compacted (vermicular) graphite cast irons.

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

Annex E (informative) provides cross-references of ISO 16112 grade designations to other standard grades of compacted (vermicular) graphite cast iron

Documents used in the preparation of this International Standard are listed in the Bibliography for reference purposes.

Compacted (vermicular) graphite cast irons — Classification

1 Scope

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

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

— separately cast samples,

— cast-on samples, or

— samples cut from a casting.

2 Normative references

The following referenced documents are indispensable for the application 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, *Cast iron — Designation of microstructure of graphite*

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

ISO 6892, *Metallic materials — Tensile testing at ambient 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.

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

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

4 Designation

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

5 Order information

The following information shall be supplied by the purchaser:

a) the complete designation of the material;

b) any special requirements which have to 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 International Standard 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 may be agreed between the manufacturer and the purchaser.

7 Requirements

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 may be used to establish process capability to meet the tensile property requirements.

7.1 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.

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

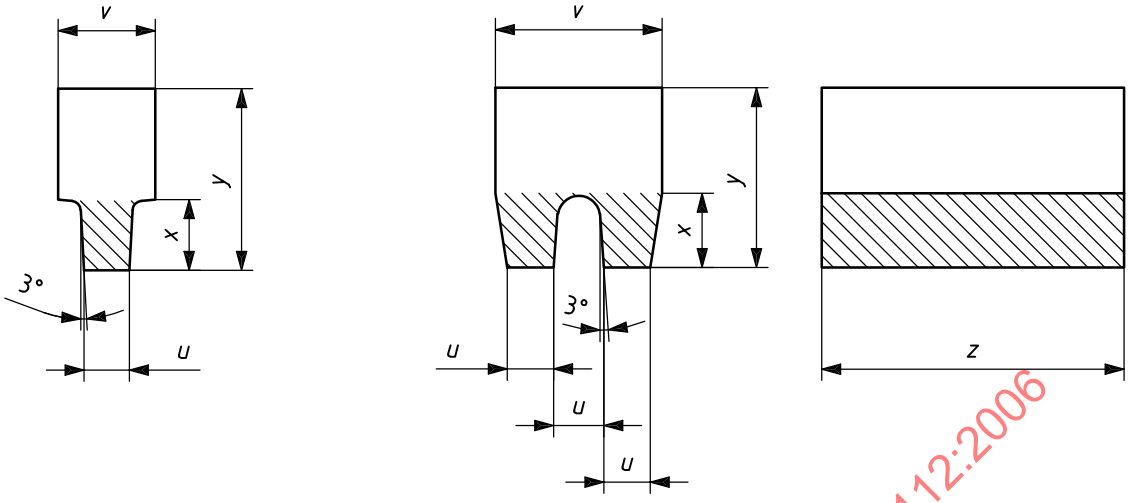
Material designation	Tensile strength R_m N/mm^2 min.	0,2 % proof strength $R_{p0,2}$ N/mm^2 min.	Elongation A % min.	Typical Brinell hardness range HBW 10/30
ISO 16112/JV/300/S	300	210	2,0	140 to 210
ISO 16112/JV/350/S	350	245	1,5	160 to 220
ISO 16112/JV/400/S	400	280	1,0	180 to 240
ISO 16112/JV/450/S	450	315	1,0	200 to 250
ISO 16112/JV/500/S	500	350	0,5	220 to 260

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 1 N/mm^2 is equivalent to 1 MPa.

NOTE 4 Brinell hardness values are provided as a guideline only.



a) **Types I, IIa, and III**

b) **Type IIb**

Dimensions in millimetres

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.

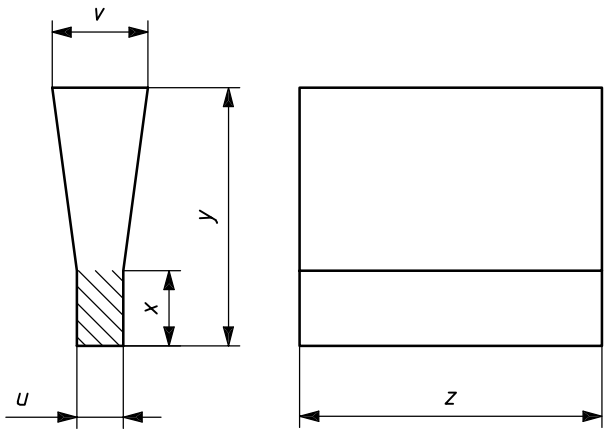
The thickness of the sand mould surrounding the samples shall be

— 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 may, by agreement between the manufacturer and the purchaser, be determined on test pieces taken from samples of thickness, u, less than 12,5 mm.

Figure 1 — Separately cast samples (option 1)



Dimensions in millimetres

Dimension	Type		
	I	II	III
u	12,5	25	50
v	40	55	100
x	25	40	50
y [a]	135	140	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.

The thickness of the sand mould surrounding the samples shall be

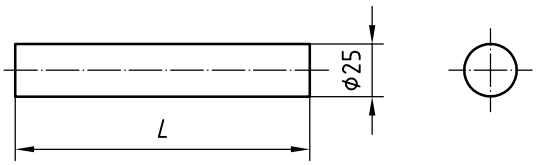
— 40 mm minimum for types I and II, or

— 80 mm minimum for type III.

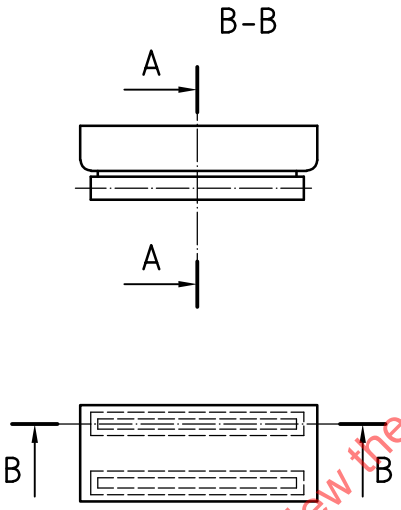
NOTE For the manufacture of thin-walled castings or castings in metal moulds, the tensile properties may, by agreement between the manufacturer and the purchaser, be determined on test pieces taken from samples of thickness, u, less than 12,5 mm.

Figure 2 — Separately cast samples (option 2)

Dimensions in millimetres



a) Sample — Minimum sample length L = 150 mm



b) Schematic drawing of one type of mould, given as an example

Figure 3 — Separately cast samples (option 3)

7.2 Test pieces machined from cast-on samples

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

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

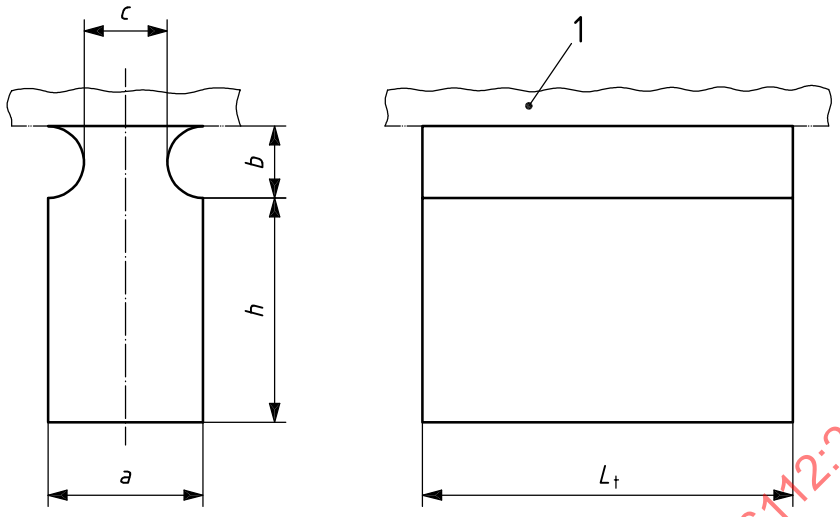
Material designation	Relevant wall thickness t mm	Tensile strength R_m N/mm^2 min.	0,2 % proof strength $R_{p0,2}$ N/mm^2 min.	Elongation A % min.	Typical Brinell hardness range HBW 10/30
ISO 16112/JV/300/U	$t \leqslant 12,5$	300	210	2,0	140 to 210
	$12,5 < t \leqslant 30$	300	210	2,0	140 to 210
	$30 < t \leqslant 60$	275	195	2,0	140 to 210
	$60 < t \leqslant 200$	250	175	2,0	140 to 210
ISO 16112/JV/350/U	$t \leqslant 12,5$	350	245	1,5	160 to 220
	$12,5 < t \leqslant 30$	350	245	1,5	160 to 220
	$30 < t \leqslant 60$	325	230	1,5	160 to 220
	$60 < t \leqslant 200$	300	210	1,5	160 to 220
ISO 16112/JV/400/U	$t \leqslant 12,5$	400	280	1,0	180 to 240
	$12,5 < t \leqslant 30$	400	280	1,0	180 to 240
	$30 < t \leqslant 60$	375	260	1,0	180 to 240
	$60 < t \leqslant 200$	325	230	1,0	180 to 240
ISO 16112/JV/450/U	$t \leqslant 12,5$	450	315	1,0	200 to 250
	$12,5 < t \leqslant 30$	450	315	1,0	200 to 250
	$30 < t \leqslant 60$	400	280	1,0	200 to 250
	$60 < t \leqslant 200$	375	260	1,0	200 to 250
ISO 16112/JV/500/U	$t \leqslant 12,5$	500	350	0,5	220 to 260
	$12,5 < t \leqslant 30$	500	350	0,5	220 to 260
	$30 < t \leqslant 60$	450	315	0,5	220 to 260
	$60 < t \leqslant 200$	400	280	0,5	220 to 260

NOTE 1 The mechanical properties of test pieces machined from cast-on samples may not reflect exactly the properties of the casting itself, but may be a better approximation than those obtained from a separately cast sample. 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 1 N/mm^2 is equivalent to 1 MPa.

NOTE 4 Brinell hardness values are provided as a guideline only.



Key

1 casting (or running system)

Dimensions in millimetres

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

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

$$b = 0,75 \times a \text{ and } c = \frac{a}{2}$$

Figure 4 — Cast-on sample

7.3 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 location(s) on the casting where the sample(s) shall be taken;

— the mechanical properties that shall be measured;

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

NOTE The properties of castings may not be uniform, depending on the complexity of the castings and variation in their section thicknesses.

7.4 Hardness

Casting hardness shall be specified only when agreed between the manufacturer and the purchaser. The Brinell hardness values in Tables 1 and 2 are provided for guidance only.

7.5 Graphite structure

Compacted (vermicular) graphite cast irons shall have a minimum of 80 % of the graphite particles in the vermicular form (form III in accordance with ISO 945), when viewed on a two-dimensional plane of polish. The remaining 20 % of the graphite particles should be of form VI or form V in accordance with ISO 945.

NOTE This 20 % maximum nodularity gives rise to the common reference to the determination of compacted (vermicular) graphite cast iron microstructure according to “percent nodularity”.

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 informative Annex B.

Flake (lamellar) graphite (form I and form II according to ISO 945) is not permitted, except within the surface rim zone of the casting.

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.

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 casting(s) produced.

Samples shall be made from the same material as that used to produce the casting(s) which they represent (see 8.5).

Several types of samples (separately cast 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 200 mm, cast-on samples or samples cut from a casting should preferably be used.

8.2 Separately 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 tensile test sample shall be produced to confirm the material, at a frequency to be agreed between the manufacturer and the purchaser.

8.2.2 Samples and test pieces

The 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 ºC.

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

— either 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.

The samples shall be given the same heat treatment, if any, as the castings which they represent.

The tensile test piece shown in Figure 5 shall be machined from a sample shown in Figure 1 and Figure 2 (hatched part) or from the two cylindrical portions of the sample shown in Figure 3. Unless otherwise agreed, the choice of sample (Figure 1, Figure 2 or Figure 3) is left to the discretion of the manufacturer.

8.3 Cast-on samples

8.3.1 Frequency and number of tests

Cast-on samples are representative of the castings to which they are attached, and also of all other castings of a similar wall thickness from the same lot, or produced during the same time interval in accordance with the in-process quality-assurance procedure used by the manufacturer.

Cast-on samples 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 tensile test shall be carried out to confirm the material, at a frequency to be agreed between the manufacturer and the purchaser.

8.3.2 Samples and test pieces

The samples from which the test pieces for tensile testing are taken shall be cast on to the castings or to the running system. Cast-on samples may be used for any mass or section of the casting, at the discretion of the manufacturer.

When the mass of the casting exceeds 2 000 kg and its wall thickness exceeds 200 mm, the dimensions of the cast-on sample shall be agreed between the manufacturer and the purchaser.

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 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.

The tensile test pieces shall be in accordance with Figure 5.

8.4 Samples cut from a casting

8.4.1 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 have a diameter equal to or smaller than 1/3 of the casting wall thickness, and should be larger than 1/5 of the casting wall thickness. Consideration must be given in the interpretation of results obtained from any test pieces that are smaller than that shown in Figure 5.

8.4.2 Other conditions

The location from which the sample is taken shall be in an area where the casting wall thickness is representative of its average 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 diameter of the test piece.

8.5 Formation of test units and number of tests

8.5.1 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, the test unit shall be the number of castings produced from that quantity of treated metal.

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

8.5.2 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. 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 different diameter (see Figure 5). In either case, the original gauge length of the test piece shall conform to the formula:

$$L_0 = 5{,}65 \times \sqrt{S_0} = 5 \times d$$

where

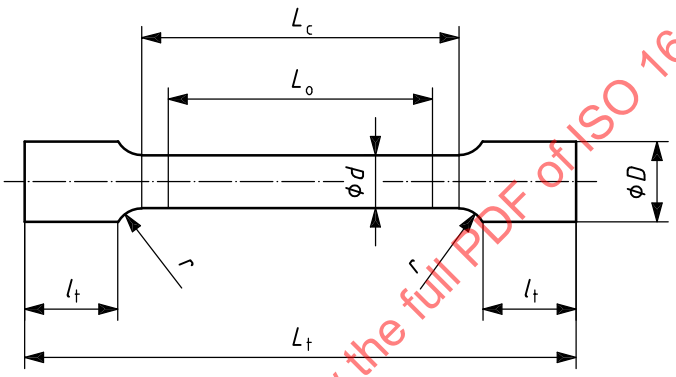
L_0 is the original gauge length;

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_0	L_c min.
5	25	30
7	35	42
10	50	60
14 [a]	70	84
20	100	120

[a] Preferred dimension.

where

L_0 is the original gauge length, i.e. $L_0 = 5 \times d$;

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

L_c is the parallel length; $L_c > L_0$ (in principle, $L_c - L_0 > d$);

L_t is the total length of the test piece, which depends on L_c.

NOTE The method of gripping the ends of the test piece, together with their length l_t, may 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.

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 International Standard.

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

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 International Standard, 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 International Standard.

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]	N/mm^2	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]	N/mm^2	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	%	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 [b]	kN/mm^2	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
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
		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 15 mm, modulus M = 0,75.

[b] Secant modulus (200 N/mm^2 to 300 N/mm^2).

Annex B
(informative)

Compacted (vermicular) graphite cast iron nodularity evaluation

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

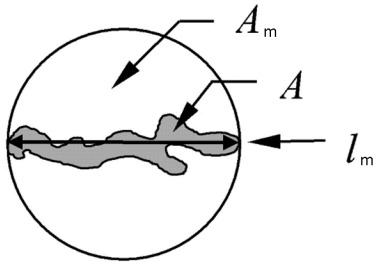
B.2 The level of nodularity depends not only on how the cast iron is prepared (nature of the basic cast iron, residual magnesium content, inoculation level, etc.), but also on the cooling modulus of the section in question. Moreover, some degeneration of the graphite in contact with the mould is usually 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 manual point count, chart comparison techniques, or semiautomatic 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 may 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 equation and accompanying illustration, Figure B.1.

$$\text{Roundness} = \frac{A}{A_m} = \frac{4 \times A}{\pi \times l_m^{\,2}}$$



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 larger than 10 µm are classified by roundness-shape factor as either spheroidal (nodular) graphite (form VI according to ISO 945), intermediate forms (form V and form IV according to ISO 945) or compacted (vermicular) graphite (form III according to ISO 945), 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, as they are not permitted in the compacted (vermicular) graphite iron structure (see 7.5).

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

Roundness-shape factor	Graphite form
0,625 to 1	Nodular (ISO form VI)
0,525 to 0,625	Intermediate (ISO forms IV and V)
< 0,525	Compacted (ISO form III)
Flake graphite particles and graphite particles with maximum axis length less than 10 µm are not included in the analysis.	

B.7 Percent nodularity is calculated on an area basis as follows:

$$\text{Percent nodularity} = \frac{\sum A_{\text{nodules}} + 0{,}5 \times \sum A_{\text{intermediates}}}{\sum A_{\text{all particles}}} \times 100$$

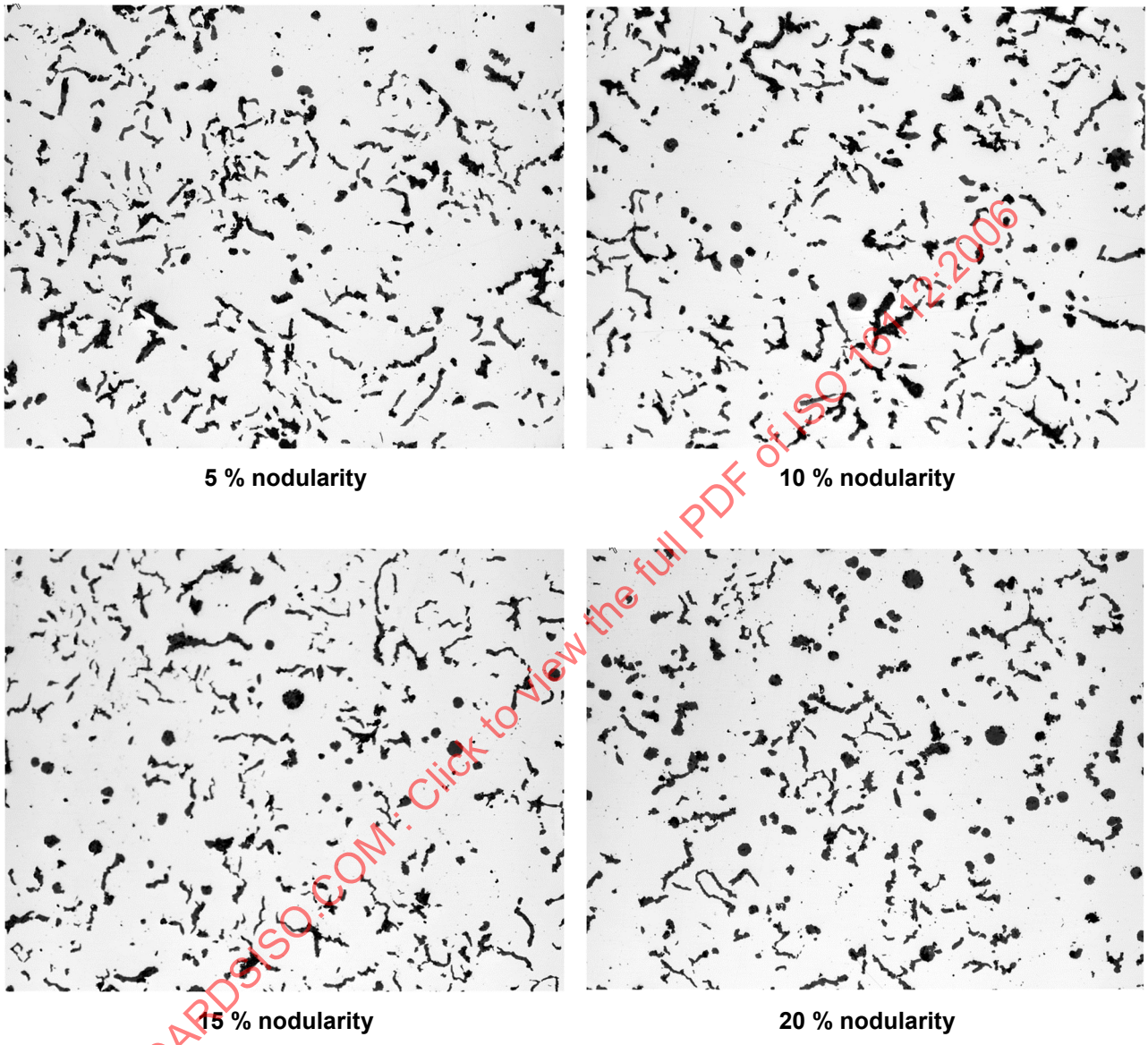
where

A_{nodules} is the area of particles classified as spheroidal (nodular) graphite;

$A_{\text{intermediates}}$ is the area of particles classified as intermediate forms of graphite;

$A_{\text{all particles}}$ is the area of all graphite particles greater than 10 µm.

B.8 Typical compacted (vermicular) graphite cast iron microstructures (containing 5 %, 10 %, 15 % and 20 % nodularity) are shown at ×100 magnification in Figure B.2.

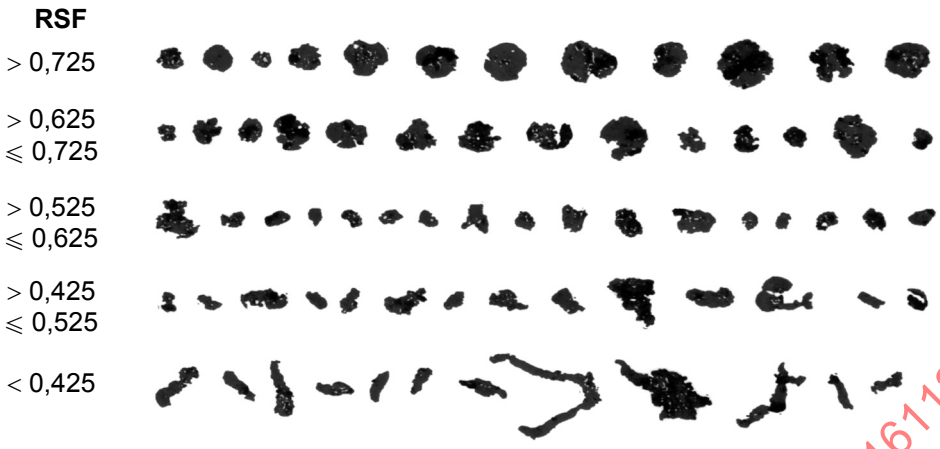


5 % nodularity **10 % nodularity**

15 % nodularity **20 % nodularity**

Figure B.2 — Typical compacted (vermicular) graphite cast iron microstructures (×100 magnification)

B.9 Graphite particles with different roundness-shape factors are shown in Figure B.3.



Key
RSF roundness-shape factor

Figure B.3 — Visual representation of graphite particles categorized by roundness-shape factor

B.10 The location of the nodularity test shall be agreed between the manufacturer and the purchaser.