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Spheroidal graphite cast irons — Classification

Fontes à graphite sphéroïdal — Classification

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Contents

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 voluntary nature of standards, 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 fourth edition cancels and replaces the third edition (ISO 1083:2004), which has been technically revised with the following changes:

— solid-solution strengthened ferritic spheroidal graphite cast irons grades have been added;

— side-by-side cast samples have been added;

— several definitions have been added;

— the relation between mechanical properties and wall thickness has been added;

— figures for separately cast or side-by-side cast samples have been updated;

— the tensile test piece figure has been updated and the Charpy V-notched impact test piece figure has been removed;

— Annex A has been partially reworded;

— Annex C has been entirely reworded;

— Annex D has been developed;

— Annex E has become informative;

— Annex G has been developed;

— Annex H has been added.

Introduction

The properties of spheroidal graphite cast irons depend on their structure.

Spheroidal graphite cast irons covered by this document are divided into two groups:

a) ferritic to pearlitic spheroidal graphite cast irons;

b) solid-solution strengthened ferritic spheroidal graphite cast irons.

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

— separately cast samples;

— side-by-side cast samples;

— cast-on samples;

— samples cut from a casting.

The material grade is defined by mechanical properties measured on machined test pieces prepared from cast samples.

If hardness is a requirement of the purchaser as being important for the application, then Annex E provides means for its determination.

It is well known that tensile properties and hardness of spheroidal graphite cast irons are interrelated. When considered by the purchaser as being important for the application, both tensile and hardness properties may be specified.

Some material grades can be suitable for pressure applications.

Further technical data on spheroidal graphite cast irons is given in Annexes C and G.

Spheroidal graphite cast irons — Classification

1 Scope

This document defines the grades and the corresponding requirements for spheroidal graphite cast irons.

This document specifies two groups of spheroidal graphite cast iron grades by a classification based on mechanical properties measured on machined test pieces prepared from cast samples. The first group deals mainly with ferritic to pearlitic grades. The second group deals with solid-solution strengthened ferritic grades.

This document also gives an informative classification as a function of hardness.

This document does not apply to the following:

— spheroidal graphite cast irons used for pipes, fittings and accessories which are specified in accordance with ISO 2531 and ISO 7186;

— highly alloyed (austenitic) spheroidal cast irons which are specified in accordance with ISO 2892;

— ausferritic cast irons which are specified in accordance with ISO 17804.

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 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

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
spheroidal graphite cast iron
cast material, iron, carbon and silicon-based, the carbon being present mainly in the form of spheroidal graphite particles

Note 1 to entry: Spheroidal graphite cast iron is also known as ductile iron, and less commonly as nodular iron.

3.2
ferritic to pearlitic spheroidal graphite cast iron
spheroidal graphite cast iron (3.1) with a matrix containing ferrite or pearlite or a combination of both

Note 1 to entry: Pearlite can be partially or totally replaced by quenched microstructures in grades having higher strength.

3.3
solid-solution strengthened ferritic spheroidal graphite cast iron
spheroidal graphite cast iron (3.1) with a matrix mainly consisting of ferrite, solution strengthened by increasing the amount of silicon compared to *ferritic to pearlitic spheroidal graphite cast iron* (3.2)

3.4
graphite spheroidizing treatment
process that brings the liquid iron into contact with a substance to produce graphite in the predominantly spheroidal (nodular) form during solidification

Note 1 to entry: This process is often followed by a second process called inoculation.

3.5
cast sample
quantity of material cast to represent the cast material, including *separately cast sample* (3.6), *side-by-side cast sample* (3.7) and *cast-on sample* (3.8)

3.6
separately cast sample
sample cast in a separate sand mould under representative manufacturing conditions and material grade

3.7
side-by-side cast sample
sample cast in the mould alongside the casting, with a joint running system

3.8
cast-on sample
sample attached directly to the casting

3.9
sample cut from a casting
sample obtained directly from the casting

3.10
relevant wall thickness
section of the casting, agreed between the manufacturer and the purchaser, to which the determined mechanical properties shall apply

3.11
test unit
number of pieces or the tonnage of castings to be accepted or rejected together, on the basis of the tests carried out on test pieces in accordance with the requirements of the relevant specification, material standard or order

Note 1 to entry: This term is sometimes referred to as “inspection lot” or “test batch”.

[SOURCE: EN 1559-1:2011, 3.12]

4 Designation

The material shall be designated in accordance with ISO/TR 15931. The relevant designations are given in Tables 1 to 3.

NOTE Further information on designation is given in Annex I.

5 Order information

The following information shall be supplied by the purchaser:

a) the complete designation of the material;

b) any special requirements (including the relevant wall thickness, where necessary) that shall be agreed upon between the manufacturer and the purchaser by the time of acceptance of the order;

c) the number of this document, i.e. ISO 1083.

6 Manufacture

The method of producing spheroidal graphite cast irons and their 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.

For ferritic to pearlitic cast iron grades, the level of the mechanical properties is determined by the ferrite to pearlite ratio. The ferrite to pearlite ratio is normally adjusted by alloying or, less commonly, by heat treatment.

For solid-solution strengthened cast iron grades, the level of the mechanical properties is determined by the extent of solid solution strengthening of the ferritic matrix. Solid-solution strengthening is normally governed by the silicon content.

For spheroidal graphite cast irons to be used in special applications, the chemical composition and heat treatment may be the subject of an agreement between the manufacturer and the purchaser.

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

7 Requirements

7.1 General

The property values apply to spheroidal graphite cast irons cast in sand moulds or moulds of comparable thermal behaviour. Subject to amendments to be agreed upon in the order, they can apply to castings obtained by alternative methods.

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

Mechanical properties are wall thickness dependant as shown in Tables 1, 2 and 3.

For relevant wall thicknesses greater than 200 mm, the manufacturer and the purchaser shall agree on the minimum mechanical properties, the type and size of the cast sample, and microstructure requirements.

NOTE Tensile testing requires sound test pieces in order to guarantee pure uni-axial stress during the test.

7.2 Ferritic to pearlitic spheroidal graphite cast irons

7.2.1 Test pieces machined from cast samples

7.2.1.1 Tensile properties

The mechanical properties of ferritic to pearlitic spheroidal graphite cast iron test pieces shall be as specified in Table 1.

Table 1 — Mechanical properties measured on test pieces machined from cast samples for ferritic to pearlitic grades

Material designation	Relevant wall thickness t mm	0,2 % proof strength $R_{p0,2}$ MPa min.	Tensile strength R_m MPa min.	Elongation after fracture A % min.
ISO1083/JS/350-22-LT[a]	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	220 210 200	350 330 320	22 18 15
ISO1083/JS/350-22-RT[b]	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	220 220 210	350 330 320	22 18 15
ISO1083/JS/350-22	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	220 220 210	350 330 320	22 18 15
ISO1083/JS/400-18-LT[a]	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	240 230 220	400 380 360	18 15 12
ISO1083/JS/400-18-RT[b]	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	250 250 240	400 390 370	18 15 12
ISO1083/JS/400-18	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	250 250 240	400 390 370	18 15 12
ISO1083/JS/400-15	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	250 250 240	400 390 370	15 14 11
ISO1083/JS/450-10	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	310 to be agreed upon between the manufacturer and the purchaser	450	10
ISO1083/JS/500-7	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	320 300 290	500 450 420	7 7 5
ISO1083/JS/550-5	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	350 330 320	550 520 500	5 4 3
ISO1083/JS/600-3	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	370 360 340	600 600 550	3 2 1
ISO1083/JS/700-2	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	420 400 380	700 700 650	2 2 1
ISO1083/JS/800-2	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	480 to be agreed upon between the manufacturer and the purchaser	800	2
ISO1083/JS/900-2	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	600 to be agreed upon between the manufacturer and the purchaser	900	2

NOTE 1 Elongation values are determined from $L_0 = 5\ d$. For other gauge lengths, see 9.1 and Annex B.

NOTE 2 The mechanical properties of test pieces machined from cast samples do not necessary reflect exactly the properties of the casting itself. Values for tensile properties of the casting are given in Annex D for guidance.

NOTE 3 The data apply to separately cast samples, cast on samples and side-by-side cast samples; therefore the suffix “S” is not included.

[a] LT for low temperature. [b] RT for room temperature.

7.2.1.2 Impact energy

The impact energy values given in Table 2 for room temperature (RT) and low temperature (LT) applications, if applicable, shall only be determined if specified by the purchaser by the time of acceptance of the order.

The mean value of the three Charpy impact tests and the individual values shall meet the specified requirements in Table 2.

NOTE The relevance of the use of impact energy as a measure of resistance to brittle fracture in castings, subjected to application loads, is currently being reassessed. Annex C gives information about a fracture mechanical approach to spheroidal graphite cast irons.

Table 2 — Minimum impact energy values measured on V-notched test pieces machined from cast samples for ferritic grades of the ferritic to pearlitic group

Material designation	Relevant wall thickness T mm	Minimum impact energy values J Room temperature (23 ± 5) °C Mean value (3 tests)	Room temperature (23 ± 5) °C Individual value	Low temperature (−20 ± 2) °C Mean value (3 tests)	Low temperature (−20 ± 2) °C Individual value	Low temperature (−40 ± 2) °C Mean value (3 tests)	Low temperature (−40 ± 2) °C Individual value
ISO1083/JS/350-22-LT[a]	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	— — —	— — —	— — —	— — —	12 12 10	9 9 7
ISO1083/JS/350-22-RT[b]	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	17 17 15	14 14 12	— — —	— — —	— — —	— — —
ISO1083/JS/400-18-LT[a]	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	— — —	— — —	12 12 10	9 9 7	— — —	— — —
ISO1083/JS/400-18-RT[b]	$t \leq 30$ $30 < t \leq 60$ $60 < t \leq 200$	14 14 12	11 11 9	— — —	— — —	— — —	— — —

NOTE 1 These material grades can be suitable for some pressure vessel applications. (For fracture toughness, see Annex C.)

NOTE 2 The mechanical properties of test pieces machined from cast samples do not necessarily reflect exactly the properties of the casting itself.

NOTE 3 The data apply to separately cast samples, cast on samples and side-by-side cast samples; therefore the suffix "S" is not included.

a LT for low temperature.

b RT for room temperature.

7.2.2 Test pieces machined from samples cut from a casting

If applicable, the manufacturer and the purchaser shall agree on the following:

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

— the mechanical properties that shall be measured;

— the minimum values or allowable range of values, for these mechanical properties (for information, see Annex D).

NOTE 1 The properties of castings are often not uniform, because casting properties depend on the complexity of the casting and variation in section thickness.

NOTE 2 Mechanical properties for test pieces cut from a casting are affected not only by material properties (covered by this document) but also by the local casting soundness (not covered by this document).

7.2.3 Classification by hardness

The classification by Brinell hardness shall only be specified when agreed between the manufacturer and the purchaser (see Annex E).

7.2.4 Graphite structure

The graphite structure shall be mainly of form VI and form V in accordance with ISO 945-1. A more precise definition of graphite structure may be agreed between the manufacturer and the purchaser.

This 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.

NOTE Annex F gives more information on nodularity.

7.2.5 Matrix structure

Information on matrix structure is given in Table G.1 and ISO/TR 945-3.

7.3 Solid solution strengthened ferritic spheroidal graphite cast irons

7.3.1 Test pieces machined from cast samples

The mechanical properties of solid solution strengthened ferritic spheroidal graphite cast iron test pieces shall be as specified in Table 3.

Table 3 — Mechanical properties measured on test pieces machined from cast samples for solid solution strengthened ferritic grades

Material designation	Relevant wall thickness t mm	0,2 % proof strength $R_{p0,2}$ MPa min.	Tensile strength R_m MPa min.	Elongation after fracture A % min.
ISO1083/JS/450-18	$t \leq 30$	350	450	18
	$30 \leq t \leq 60$	340	430	14
	$t > 60$	to be agreed upon between the manufacturer and the purchaser		
ISO1083/JS/500-14	$t \leq 30$	400	500	14
	$30 \leq t \leq 60$	390	480	12
	$t > 60$	to be agreed upon between the manufacturer and the purchaser		
ISO1083/JS/600-10	$t \leq 30$	470	600	10
	$30 \leq t \leq 60$	450	580	8
	$t > 60$	to be agreed upon between the manufacturer and the purchaser		

NOTE 1 The mechanical properties of test pieces machined from cast samples do not necessarily reflect exactly the properties of the casting itself. Values for tensile properties of the casting are given in Annex D for guidance.

NOTE 2 The data apply to separately cast samples, cast on samples and side-by-side cast samples; therefore the suffix “S” is not included.

7.3.2 Test pieces machined from samples cut from a casting

If applicable, the manufacturer and the purchaser shall agree on the following:

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

— the mechanical properties that shall be measured;

— the minimum values or allowable range of values, for these mechanical properties (for information, see Annex D).

NOTE 1 The properties of castings are often not uniform, because casting properties depend on the complexity of the casting and variation in their section thickness.

NOTE 2 Mechanical properties for test pieces cut from a casting are affected not only by material properties (covered by this document) but also by the local casting soundness (not covered by this document).

7.3.3 Classification by hardness

The classification by Brinell hardness shall only be specified when agreed between the manufacturer and the purchaser (see Annex E).

7.3.4 Graphite structure

The graphite structure shall be mainly of form VI and form V in accordance with ISO 945-1. A more precise definition of graphite structure may be agreed between the manufacturer and the purchaser.

This 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.

NOTE 1 A.2.3 gives more information on graphite structure.

NOTE 2 Annex F gives more information on nodularity.

7.3.5 Matrix structure

Information on matrix structure is given in A.2.2, Table G.1 and ISO/TR 945-3.

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 sample (separately cast samples, cast-on samples, side-by-side cast samples, samples cut from a casting) can be used, depending on the mass and wall thickness of the casting.

When appropriate the type of sample should be agreed between the manufacturer and the purchaser. Unless otherwise agreed the choice of the option is left to the discretion of the manufacturer.

When the mass of the casting exceeds 2 000 kg and its relevant wall thickness exceeds 60 mm, cast-on samples or side-by-side cast samples should be preferably used; representative dimensions and the location of the sample shall be agreed between the manufacturer and the purchaser by the time of acceptance of the order.

If the spheroidizing treatment is carried out in the mould (in-mould process), the separately cast sample should be avoided.

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.

Tensile and impact test pieces shall be finally machined from the samples after the heat treatment.

8.2 Cast samples

8.2.1 Size of cast samples

The size of the sample shall be in correspondence with the relevant wall thickness of the casting as shown in Table 4.

If other sizes are used, this shall be agreed between the manufacturer and purchaser.

Table 4 — Types and sizes of cast samples and sizes of tensile test pieces in relation to relevant wall thickness of the casting

Relevant wall thickness *t* mm	Type of sample				Preferred diameter of tensile test piece[a] *d* mm
	Option 1 U-shaped (see Figure 1)	Option 2 Y-shaped (see Figure 2)	Option 3 Round bar (see Figure 3)	Cast-on sample (see Figure 4)	
$t \leq 12,5$	—	I	Types b, c	*A*	7 (Option 3: 14 mm)
$12,5 < t \leq 30$	—	II	Types a, b, c	*B*	14
$30 < t \leq 60$	[b]	III	—	*C*	14
$60 < t \leq 200$	—	IV	—	*D*	14

[a] Other diameters, in accordance with Figure 5, may be agreed between the manufacturer and the purchaser.

[b] The cooling rate of this cast sample corresponds to that of a 40 mm wall thickness.

8.2.2 Frequency and number of tests

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

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

When impact tests are required, samples shall be produced at a frequency to be agreed between the manufacturer and the purchaser.

8.2.3 Separately cast samples

The samples shall be cast separately in sand moulds at the same time as the castings and under representative manufacturing conditions. The moulds used to cast the separately cast samples shall have comparable thermal behaviour to the moulding material used to cast the castings.

It is an option of the manufacturer to use an adequate running system which reproduces conditions similar to those of the castings.

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

The samples shall be removed from the mould at a temperature similar to that of the castings.

If the graphite spheroidizing treatment is carried out in the mould (in-mould method), the samples shall 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.

8.2.4 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 test unit.

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 in the last moulds poured.

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

8.2.5 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 test unit.

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

The location of cast-on samples shall be agreed between the manufacturer and the purchaser by the time of acceptance of the order, 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.

Unless otherwise 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 the heat treatment.

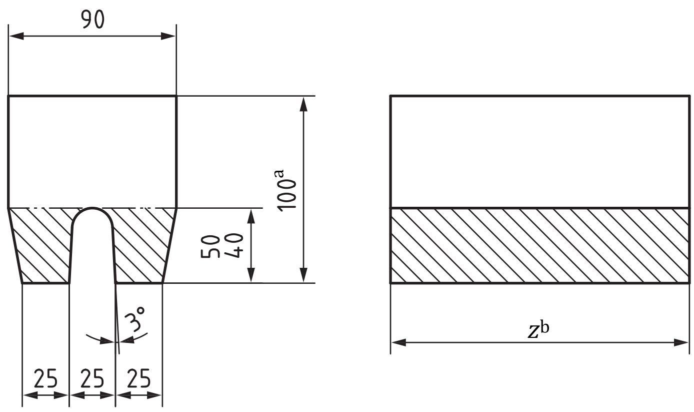
8.2.6 Test pieces machined from cast samples

The tensile test piece shown in Figure 5 and, if applicable, the test piece for the impact test shall be machined from a sample shown in Figure 3 or from the hatched part of Figures 1, 2 or 4.

The sectioning procedure for cast samples should be in accordance with Annex H.

Unless otherwise agreed, the preferred diameter (see Figure 5) for the test piece shall be used.

Dimensions in millimetres



Key

a For information only.

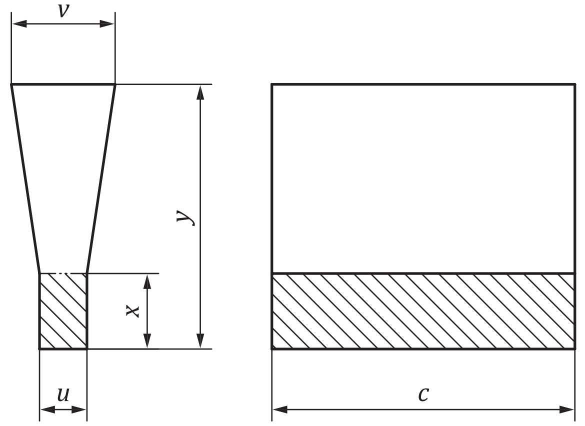
b The length z shall be chosen to allow a test piece of dimensions shown in Figure 5 to be machined from the sample.

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

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, less than 12,5 mm.

Figure 1 — Separately cast or side-by-side cast samples — Option 1: U-shaped sample

Dimensions in millimetres



Key

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 dimensions shown in Figure 5 to be machined from the sample.

The thickness of the sand mould surrounding the samples shall be:

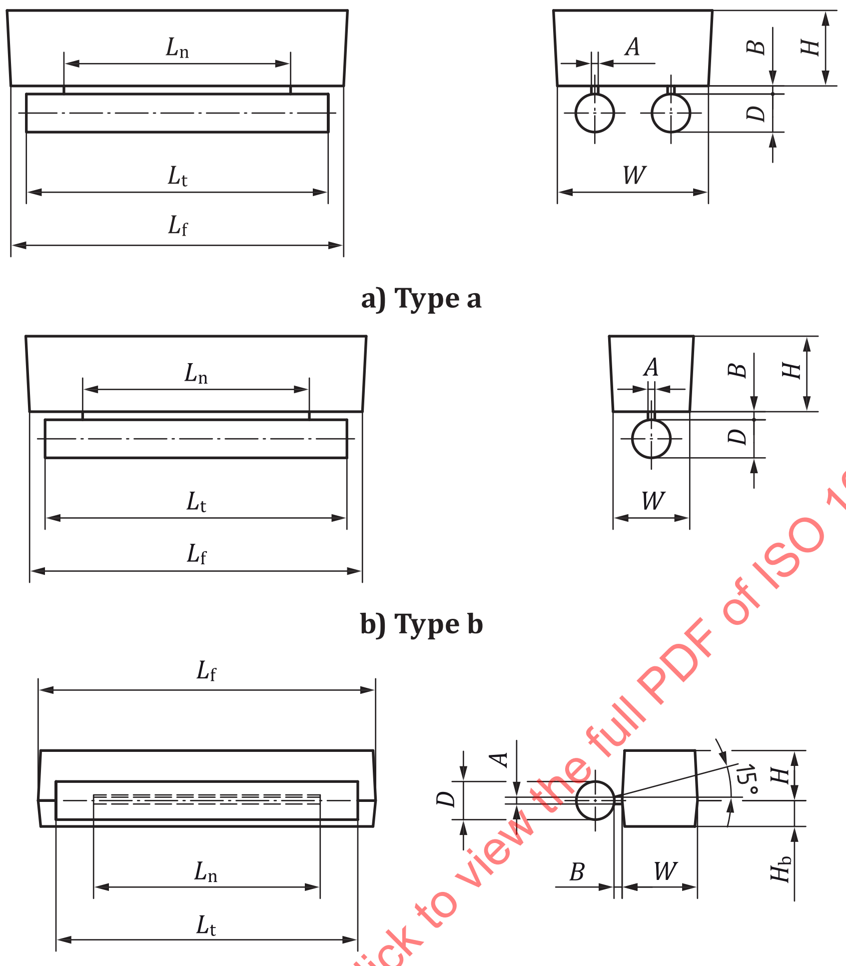
— 40 mm minimum for types I and II;

— 80 mm minimum for types III and IV.

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, less than 12,5 mm.

Figure 2 — Separately cast or side-by-side cast samples — Option 2: Y-shaped sample

Dimensions in millimetres



a) Type a

b) Type b

c) Type c

Key

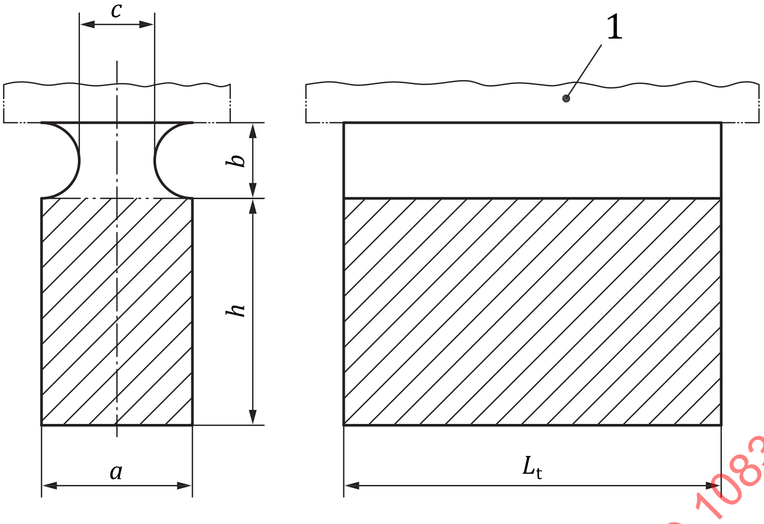
Type	A	B	D	H	H_b	L_f	L_n	L_t	W
a	4,5	5,5	25	50	—	$L_t + 20$	$L_t - 50$	a	100
b	4,5	5,5	25	50	—	$L_t + 20$	$L_t - 50$		50
c	4,0	5,0	25	35	15	$L_t + 20$	$L_t - 50$		50

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

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

Figure 3 — Separately cast or side-by-side cast samples — Option 3: Round bar-shaped sample

Dimensions in millimetres



Key

1 casting

Type	Relevant wall thickness of the casting *t*	*a*	*b* max.	*c* min.	*h*	L_t
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	
C	$30 < t \leq 60$	40	30	20	40 to 65	
D	$60 < t \leq 200$	70	52,5	35	65 to 105	

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

The thickness of the sand mould surrounding the samples shall be at least:

— 40 mm for types A and B;

— 80 mm for types C and D.

If smaller dimensions are agreed upon between the manufacturer and the purchaser, the following relationships apply:

$b = 0,75 \times a$

$c = 0,5 \times a$

Figure 4 — Cast-on sample

8.3 Samples cut from a casting

In addition to the requirements of the material, the manufacturer and the purchaser may agree on the properties required (for information see Annex D) 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 manufacturer and the purchaser shall agree on the dimensions of these test pieces.

In the absence of any direction by the purchaser, the manufacturer may select locations from which to cut the samples and the dimensions of the test pieces.

The centreline of the test piece should be located at a point half way between the surface and the centre.

NOTE When the zone of last solidification of the casting is included in the test piece diameter, the minimum elongation after fracture guidance value is not necessarily obtained.

For cases of large individual castings, trepanned samples may be taken at agreed positions in the casting which shall be stated.

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;

— for continuous pouring of large tonnages of spheroidal graphite cast iron, the maximum size of test unit shall be restricted to the castings produced in a two hour period of pouring;

— when the graphite spheroidizing treatment is carried out on less than 2 000 kg, the test unit to be taken shall be the number of castings produced from that quantity of treated metal.

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 lots. When the graphite spheroidizing 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 by the time of acceptance of the order.

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, either for technical reasons or for test pieces machined from samples cut from the casting, it is permitted to use a test piece of different diameter (see Figure 5). For either of these exceptions the original gauge length of the test piece shall conform to Formula (1):

$$L_o = 5{,}65 \times \sqrt{S_o} = 5 \times d \qquad (1)$$

where

L_o is the original gauge length;

S_o is the original cross-section area of the test piece;

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

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

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

For tensile test pieces with a gauge length $L_o = 4 \times d$, Table B.1 shall be used to convert the elongation value to that for $L_o = 5 \times d$.

9.2 Impact test

The impact test shall be carried out on three standard Charpy V-notched impact test pieces in accordance with ISO 148-1.

Test equipment with an appropriate energy shall be used to determine the properties correctly.

The 2 mm radius striker shall be used.

9.3 Hardness test

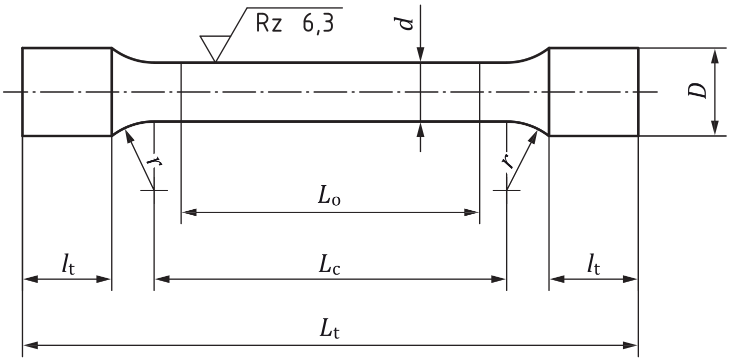
If agreed between the manufacturer and the purchaser, the hardness shall be determined as Brinell hardness in accordance with ISO 6506-1. Alternative hardness tests may also be agreed upon.

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

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

Further information on hardness is given in Annex E.

Dimensions in millimetres



Key

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 surface roughness condition, expressed in µm.

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

Figure 5 — Tensile test piece

9.4 Graphite structure examination

The graphite structure shall be confirmed by metallographic examination in accordance with ISO 945-1.

Non-destructive methods can also give information.

In case of dispute, the results of the microscopic examination shall prevail.

10 Retests

10.1 Need for retests

Retests shall be carried out if a test is not valid.

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

10.2 Test validity

A test is not valid if there is the following:

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 tensile 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 to replace those invalid test results.

10.3 Non-conforming 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 test pieces for the tensile test and two sets of three test pieces for the impact test shall be tested for each failed test.

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

If one or both retests give results that 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, for castings in the as-cast condition with mechanical properties not in conformance with this document, a heat treatment may be carried out.

For castings that have undergone a heat treatment and for which the test results are not valid or 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 specified requirements of this document.

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

Annex A
(informative)

Additional information on solid solution strengthened ferritic spheroidal graphite cast irons

A.1 General

This annex applies to solid solution strengthened ferritic spheroidal graphite cast iron grades as specified in Table 3.

A.2 Material constitution

A.2.1 Chemical composition

In order to fulfil the requirements for the mechanical properties, a ferritic structure solid solution strengthened by silicon is recommended (see Table A.1).

Table A.1 — Guidance values for silicon content

Designation	Silicon % approx.[a,b]
ISO1083/JS/450-18	3,20
ISO1083/JS/500-14	3,80
ISO1083/JS/600-10	4,20

a Silicon content may be lower due to other alloying elements or for thick sections.

b With increasing silicon content, the carbon content should be decreased correspondingly.

NOTE Sampling technique and method of chemical analysis for high-silicon can have significant effects on the reported silicon content. It is therefore important to establish sampling parameters, in order to obtain a white structure, and to select chemical analysis methods which can be confirmed as giving accurate results.

A.2.2 Matrix structure

The matrix should be predominantly ferrite with a maximum pearlite content of 5 %. The amount of free cementite/carbides should not exceed 1 %.

A.2.3 Graphite structure

The graphite structure should be mainly of form VI and form V in accordance with ISO 945-1.

Due to the increased silicon content, these solid solution strengthened ferritic spheroidal graphite cast irons can show graphite deviations in thick sections. However ferritic matrices are, also for higher levels of solution strengthening by silicon, much less sensitive to reduced nodularity than cast irons strengthened by substantial amounts of pearlite.

A proportion of form lll graphite can be accepted, provided the remainder is mainly of form VI and form V, to fulfil the minimum tensile properties specified in this document.

A.3 Supplementary information

A.3.1 Application

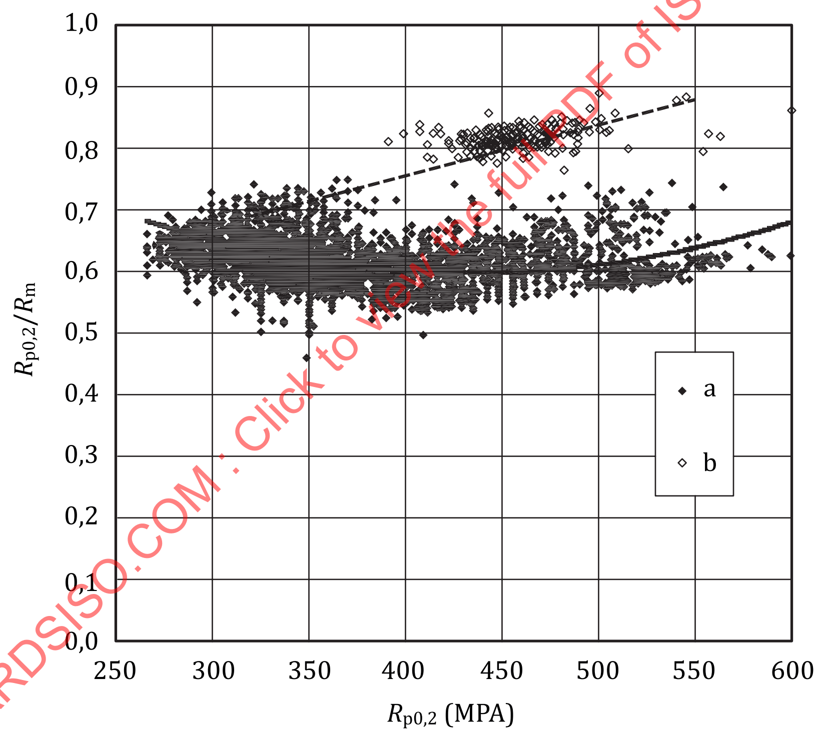
These solid solution strengthened ferritic spheroidal graphite cast iron grades are used for applications where concurrently high ductility, high proof strength and good machinability are required.

A.3.2 Mechanical properties

A.3.2.1 0,2 % proof strength

One of the characteristic properties of these solution strengthened ferritic spheroidal graphite cast irons is the high ratio “0,2 % proof strength/tensile strength” being 75 % to 85 % as compared to the lower ratio being 55 % to 65 % for ferritic to pearlitic spheroidal graphite cast irons (see Figure A.1).

Despite this higher ratio, ductility determined as percentage elongation after fracture values are concurrently considerably higher for solid solution strengthened ferritic spheroidal graphite cast irons (compare Table 1 and Table 3).



Key

a ferritic, ferritic-pearlitic and pearlitic spheroidal graphite cast irons

b solution strengthened ferritic spheroidal graphite cast irons

R_m tensile strength

$R_{p0,2}$ 0,2 % proof strength

Figure A.1 — Spheroidal graphite cast irons — 25 mm cast samples — Ratio “0,2 % proof strength/tensile strength”, determined at room temperature and quasi static loading

Another characteristic property of these solid solution strengthened ferritic spheroidal graphite cast irons is that for an equal value in hardness, proof strength is significantly higher (compare the values for these properties in Table 1, Table 3 and Table E.1).

A.3.2.2 Other mechanical and physical properties

For information see Annex G.

A.3.3 Machinability

Compared to the corresponding ferritic/pearlitic grades, the solid solution strengthened ferritic spheroidal graphite cast iron grades exhibit considerably less hardness variation due to their single-phase matrix structure. For a same level of hardness, this reduction in hardness variation (see Table E.1), combined with a negligible amount of pearlite, results in improved machinability and dimensional accuracy.

Annex B
(normative)

Relationship between the elongation values obtained when using test pieces with $L_0 = 5 \times d$ and $L_0 = 4 \times d$

The choice of a test piece with a gauge length of $L_0 = 4 \times d$ instead of $5 \times d$ shall be agreed upon between the manufacturer and the purchaser.

If a test piece with a gauge length of $L_0 = 4 \times d$ is used, the dimensions of the test piece shown in Figure B.1 shall be used.

Table B.1 gives the relationship between the values for elongation to fracture for both test pieces.

Table B.1 — Relationship between elongation values for $L_0 = 5 \times d$ and $L_0 = 4 \times d$ test pieces

Elongation ($L_0 = 5 \times d$) %	**Elongation** ($L_0 = 4 \times d$) %
22	23
18	19
15	16
10	11
7	8
5	6
3	3,5
2	2,5

The values for elongation using a gauge length of $L_0 = 4 \times d$ are calculated according to Formula (B.1):

$$A(L_0 = 4 \times d) = A(L_0 = 5 \times d) \times 1{,}047 + 0{,}39 \quad \text{(B.1)}$$

NOTE Values given in Table B.1 have been calculated from a statistically determined regression using values from separately cast test pieces.[12]

Dimensions in millimetres

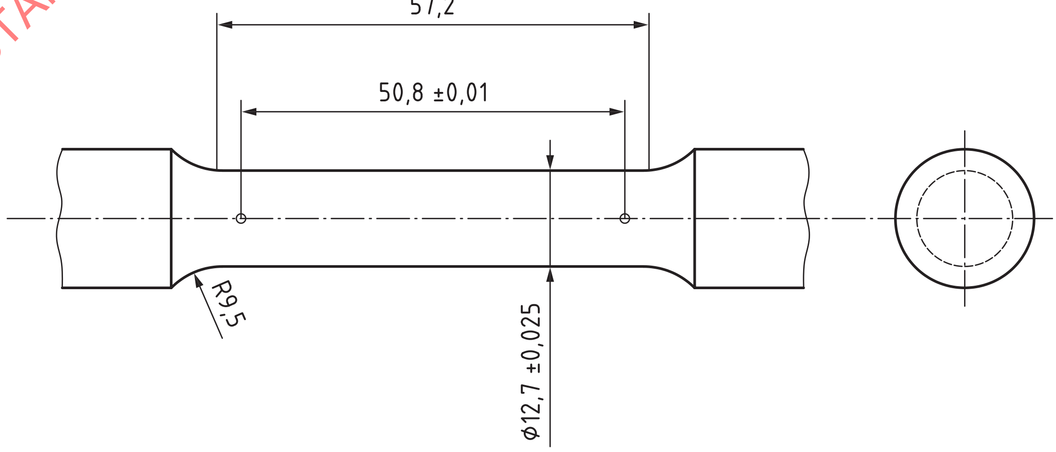


Figure B.1 — Tensile test piece with a gauge length $L_0 = 4 \times d$

Annex C
(informative)

Fracture mechanical approach to spheroidal graphite cast irons

C.1 General

By applying fracture mechanical criteria to the selection of materials and the safety evaluation of a component, the conventional criteria based on uniaxial tensile testing are supplemented and expanded. This enables inclusion of fracture mechanical properties (which are defined as material resistance to crack initiation or crack propagation) into the evaluation of the resistance to fracture. The designers are now in a position to make a material selection which corresponds far better with the specific loading situation in castings than a selection made on the basis of the notched bar impact energy.[18]

The notched bar impact energy is not suitable for component design and evaluation. The notched bar impact energy only gives information on the susceptibility to brittle fracture for a material under Charpy test conditions (impact loading, notched specimen, temperature).

Ductility determined as percentage elongation after fracture of test pieces in uniaxial tensile tests is erroneously used as synonym to the term material toughness. Percentage elongation after fracture, however, can only give information regarding elasto-plastic constitutive models for design.[19]

C.2 Fracture mechanics concept

Fracture mechanical concepts cover quantitative relations between the load acting on the component, the size of present or hypothetically assumed cracks or crack-like stress concentration spots (e.g. casting imperfections), subcritical cracks grown under fatigue conditions and the material's fracture mechanical properties.[20][21]

One basic pre-requisite for the fracture mechanical evaluation of the material and the component is that both applied loading and loading resistance, i.e. the material's resistance to crack initiation and propagation, are available on the basis of the same fracture mechanical concept and under the same loading conditions.

C.3 Determination of fracture mechanical properties

For the experimental determination of the fracture mechanical material properties of spheroidal graphite cast irons under quasi-static loading mainly test standards such as ISO 12135[22], ASTM E 1820[23] or ASTM E 399[24] are used. These standards are also called on for the purposes of testing under dynamic loading conditions since specific standards for dynamic fracture mechanics testing have not yet been finalized.[25] to [32]

With regard to the initiation of instable crack propagation under linear-elastic conditions, fracture toughness values K_{Ic} in accordance with References [22], [23] and [24] are considered as transferable to the component (denoted K_{Id} under dynamic loading).

The only characteristic material values to be considered as transferable to the component with regard to the initiation of stable crack propagation under elastic-plastic conditions are physical crack initiation toughness values (e.g. J_i in accordance with ISO 12135) excluding any crack growth. The characteristic crack initiation toughness value J_{Ic} according to ASTM E 1820 contains considerable amounts of ductile tearing and does not fulfil the above condition unless additional validity requirements are met.[23][32]

For the experimental determination of fracture mechanical characteristic values of spheroidal graphite cast irons under fatigue conditions, mainly the standards ASTM E 647[33] or ISO 12108[34] are used. Threshold value for the stress intensity factor ΔK_{th} is the most common parameter used by designers for the assessment of fatigue life when imperfections and sharp notches are considered.

Due to the variety of possible definitions of characteristic values, the user of fracture mechanical characteristic material values shall be particularly careful. Usually, fracture mechanical tests are carried out on relatively small test pieces taken from a casting or a semi-finished product. In order to avoid errors in the evaluation of safety or unintentional non-conservatives, the transferability of the determined characteristic values to the component shall be ensured on the basis of the validity requirements formulated in the test standards.

C.4 Influences on fracture mechanical properties

The fracture mechanical properties of spheroidal graphite cast irons under quasi-static, dynamic and cyclic mechanical loading are determined by the microstructure and the chemical composition as well as by loading factors such as temperature and loading rate. With regard to the microstructure, both the metallic matrix and the distribution and morphology of the graphite particles should be considered.

In addition to the size of the used fracture mechanics samples, the mentioned influences determine whether the material behaviour is linear-elastic or elastic-plastic and, based on this behaviour, which fracture mechanics concept can be applied for the description of the material toughness.

C.5 Publications

C.5.1 Testing

In the course of the increasing use of spheroidal graphite cast irons, investigations regarding the fracture behaviour as well as the load- and microstructure-dependent fracture mechanical material characterization have been performed, particularly over the past 25 years, as it can be seen in References [25] to [32] and [35] to [47].

Based on the proceeding development of the fracture mechanical test methods, the focus of afore-mentioned investigations has been on the determination of the quasi-static and the dynamic fracture toughness[25] to [32], [35] to [42] and the cyclic fracture-mechanical properties[42][43][44], respectively.

NOTE In Reference [42], the thick walled castings have low nodularity, influencing fracture toughness and fatigue negatively.

Furthermore, the examinations have focused on aspects of the establishment of correlations between microstructural parameters and fracture mechanical properties[39][40] as well as the welding-related processing of spheroidal graphite cast irons.[45]

C.5.2 Component assessment

As far as performing fracture mechanical assessments on spheroidal graphite cast iron components is concerned, compilations of engineering rules and regulations such as the British Standard BS 7910[48] or the European FITNET procedure[49] are available. Furthermore, subject-specific provisions for fields of application having higher safety or reliability requirements, such as nuclear technology[50][51], generation of wind energy[52], mechanical engineering[53] or welding technology[54] can be used.

References [46], [47] and [55] give a selection of examples of the application of fracture mechanical design procedures for components made of spheroidal graphite cast irons or of metallic materials in general.[56]

Annex D
(informative)

Guidance values for mechanical properties measured on test pieces machined from samples cut from the castings

Tables D.1 and D.2 give guidance values for mechanical properties measured on test pieces machined from samples cut from the castings.

Table D.1 — Guidance values for mechanical properties measured on test pieces machined from samples cut from the castings for ferritic to pearlitic grades

Material designation	Relevant wall thickness t mm	0,2 % proof strength $R_{p0,2}$ MPa min.	Tensile strength R_m MPa min.	Elongation after fracture A % min.
ISO1083/JS/350-22C-LT/C	$t \leq 30$	220	340	20
	$30 < t \leq 60$	210	320	15
	$60 < t \leq 200$	200	310	12
ISO1083/JS/350-22C-RT/C	$t \leq 30$	220	340	20
	$30 < t \leq 60$	210	320	15
	$60 < t \leq 200$	200	310	12
ISO1083/JS/350-22/C	$t \leq 30$	220	340	20
	$30 < t \leq 60$	210	320	15
	$60 < t \leq 200$	200	310	12
ISO1083/JS/400-18-LT/C	$t \leq 30$	240	390	15
	$30 < t \leq 60$	230	370	12
	$60 < t \leq 200$	220	340	10
ISO1083/JS/400-18-RT/C	$t \leq 30$	250	390	15
	$30 < t \leq 60$	240	370	12
	$60 < t \leq 200$	230	350	10
ISO1083/JS/400-18/C	$t \leq 30$	250	390	15
	$30 < t \leq 60$	240	370	12
	$60 < t \leq 200$	230	350	10
ISO1083/JS/400-15/C	$t \leq 30$	250	390	12
	$30 < t \leq 60$	240	370	11
	$60 < t \leq 200$	230	350	8
ISO1083/JS/450-10/C	$t \leq 30$	300	440	8
	$30 < t \leq 60$	Guidance values to be provided by the manufacturer		
	$60 < t \leq 200$			
ISO1083/JS/500-7/C	$t \leq 30$	300	480	6
	$30 < t \leq 60$	280	450	5
	$60 < t \leq 200$	260	400	3
In cases where the purchaser requires minimum mechanical property values to be obtained in a stated location of the casting, these values shall be agreed with the manufacturer.				

Table D.1 *(continued)*

Material designation	Relevant wall thickness t mm	0,2 % proof strength $R_{p0,2}$ MPa min.	Tensile strength R_m MPa min.	Elongation after fracture A % min.
ISO1083/JS/550-5/C	$t \leq 30$	330	530	4
	$30 < t \leq 60$	310	500	3
	$60 < t \leq 200$	290	450	2
ISO1083/JS/600-3/C	$t \leq 30$	360	580	3
	$30 < t \leq 60$	340	550	2
	$60 < t \leq 200$	320	500	1
ISO1083/JS/700-2/C	$t \leq 30$	410	680	2
	$30 < t \leq 60$	390	650	1
	$60 < t \leq 200$	370	600	1
ISO1083/JS/800-2/C	$t \leq 30$	460	780	2
	$30 < t \leq 60$	Guidance values to be provided by the manufacturer		
	$60 < t \leq 200$			
In cases where the purchaser requires minimum mechanical property values to be obtained in a stated location of the casting, these values shall be agreed with the manufacturer.				

Table D.2 — Guidance values for mechanical properties measured on test pieces machined from samples cut from the castings for solid solution strengthened ferritic grades

Material designation	Relevant wall thickness t mm	0,2 % proof strength $R_{p0,2}$ MPa min.	Tensile strength R_m MPa min.	Elongation after fracture A % min.
ISO1083/JS/450-18/C	$t \leq 30$	350	440	16
	$30 < t \leq 60$	340	420	12
	$60 < t \leq 200$	Guidance values to be provided by the manufacturer		
ISO1083/JS/500-14/C	$t \leq 30$	400	480	12
	$30 < t \leq 60$	390	460	10
	$60 < t \leq 200$	Guidance values to be provided by the manufacturer		
ISO1083/JS/600-10/C	$t \leq 30$	450	580	8
	$30 < t \leq 60$	430	560	6
	$60 < t \leq 200$	Guidance values to be provided by the manufacturer		
In cases where the purchaser requires minimum mechanical property values to be obtained in a stated location of the casting, these values shall be agreed with the manufacturer.				

Annex E
(informative)

Classification as a function of hardness

NOTE This annex is only applicable when its requirements have been agreed upon between the manufacturer and the purchaser at the time of acceptance of the order.

E.1 General

When only hardness is required, the Brinell hardness values shall be as specified in Table E.1.

When hardness is required in addition to the tensile properties, the Brinell hardness values shall be as specified in Table E.1 and the procedure given in E.3 is recommended.

E.2 Classification

The hardness classes for the ferritic to pearlitic materials shall be as specified in Table E.1 and the hardness classes for the solution strengthened materials shall be as specified in Table E.2.

Table E.1 — Classification as a function of hardness

Material designation	Brinell hardness range	Other properties[a,b]	
	HBW	R_m MPa	$R_{p0,2}$ MPa
ISO1083/JS/HBW130	less than 160	350	220
ISO1083/JS/HBW150	130 to 175	400	250
ISO1083/JS/HBW155	135 to 180	400	250
ISO1083/JS/HBW185	160 to 210	450	310
ISO1083/JS/HBW200	170 to 230	500	320
ISO1083/JS/HBW215	180 to 250	550	350
ISO1083/JS/HBW230	190 to 270	600	370
ISO1083/JS/HBW265	225 to 305	700	420
ISO1083/JS/HBW300[c]	245 to 335	800	480
ISO1083/JS/HBW330[c]	270 to 360	900	600

NOTE 1 MPa = 1 N/mm^2.

[a] When only hardness is required, these properties are for information.

[b] When hardness is required in addition to tensile properties, these properties provide an introductory step to the procedure given in E.3.

[c] ISO1083/JS/HBW300 and ISO1083/JS/HBW330 are not recommended for thick section castings.

By agreement between the manufacturer and the purchaser, a narrower hardness range may be adopted; a tolerance range of between 30 and 40 Brinell hardness units is commonly acceptable. This hardness range may be wider for grades with a ferritic-pearlitic matrix structure.

Table E.2 — Classification as a function of hardness

Material designation	Brinell hardness range HBW	Other properties[a,b] R_m MPa	 $R_{p0,2}$ MPa
ISO1083/JS/HBW175	160 to 190	450	350
ISO1083/JS/HBW195	180 to 210	500	400
ISO1083/JS/HBW210	195 to 225	600	470

NOTE 1 MPa = 1 N/mm^2.

[a] When only hardness is required, these properties are for information.

[b] When hardness is required in addition to tensile properties, these properties provide an introductory step to the procedure given in E.3.

In absence of pearlite, the hardness of fully ferritic spheroidal graphite iron grades is directly proportional to the solution strengthening effect from the silicon content, according to the formula HBW = 54 + (37 × Si %). This formula also applies to the fully ferritic grades with conventional silicon content or with reduced silicon content for minimum impact energy values, as given in Table E.1.

E.3 Determination of a hardness range capable of meeting the tensile property requirements

This procedure applies mainly to serial production of castings, where it is possible to obtain the required number of samples.

This procedure is used to determine the hardness range of a material grade specified by its tensile properties according to Table 1 or Table 3, for a grade designated in Table E.1, for a particular foundry process.

a) Select the hardness grade from Table E.1.

b) Select the corresponding grade in Table 1 or Table 3 and the type of sample using the values shown in Table E.1 for tensile strength and yield strength of the specified hardness grade.

c) Retain only those test pieces with a value within the hardness range for the selected grade, see a).

d) Determine tensile strength, yield strength, elongation and Brinell hardness values for each test piece. Round hardness values to the nearest 10 HBW. As agreed between the manufacturer and the purchaser, in order to obtain the desired statistical confidence, conduct as many tests as necessary to obtain a minimum number of values of tensile strength for each HBW value.

e) Plot histograms of tensile properties, as a function of hardness.

f) For each HBW value, take the minimum value of each tensile property as the process capability indicator.

g) Specify as the minimum HBW value the minimum hardness for which tensile strength and yield strength meet the requirements of the grade specified in Table 1 and Table 3.

h) Specify as the maximum HBW value the maximum hardness for which the elongation meets the requirements of the grade specified in Table 1 or Table 3.

The hardness range lies between the minimum and the maximum HBW values as determined by the above procedure.

E.4 Sampling

Each hardness test shall be carried out either on a casting or on a test piece at locations agreed between the manufacturer and the purchaser. In the absence of an agreement the test shall be carried out at representative locations chosen by the manufacturer.

E.5 Test method

The hardness test shall be carried out in accordance with ISO 6506-1.

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

If the test is carried out on a knob cast-on to the casting, it shall not be separated before concluding any required heat treatment.

If the test is carried out on a test piece taken from a separately cast sample, it shall first be subjected to any heat treatment required for the castings of which it is representative.

E.6 Number and frequency of hardness tests

The number and frequency of hardness tests can be the subject of an agreement between the manufacturer and the purchaser by the time of acceptance of the order.

E.7 Microstructure

The lowest hardness is achieved with a ferritic matrix. The hardness increases with the amount of pearlite.

Eutectic carbides increase hardness but they are normally undesirable and only likely to be present in minor amounts.

Annex F
(informative)

Nodularity

The nodularity of spheroidal graphite cast irons is defined as the percentage of graphite particles that are spheroidal or nodular in shape (form VI and form V of ISO 945-1). Nodularity can be determined by three methods:

— visual comparison of nodule appearance to the schematics of ISO 945-1 and estimating the fraction of forms V and VI;

— visual comparison of the graphite structure in the microscope to a comparison chart specific to spheroidal cast irons;

— automatic image analysis of the graphite structure by determining the area fraction of forms V and VI, divided by the area fraction of all graphite particles registered.

This percentage is generally determined at 100 x magnification on a polished, cut section of a sample. It may also be determined visually at other magnifications, by image analysis, or even after prior calibration, by measuring the ultrasonic velocity across the material.

The level of nodularity depends not only on the manufacturing process (charge material, residual magnesium content, inoculation mode, etc.) but also on the cooling modulus of the section in question. Moreover, some degeneration of the graphite in contact with the mould is occasionally observed.

Concerning the minimum material properties specified in this document, it is thus impossible to define a concrete nodularity value, even for a specified cooling modulus, because the level varies not only with the measuring method used but also with the grade of cast iron in question (in particular its chemical composition), the pearlite content and, to some extent, the number of graphite particles per unit area.

However, a level of nodularity of 80 % to 85 % or more generally ensures (more than enough for $R_{p0,2}$) the minimum tensile properties specified in this document. Most of the 15 % to 20 % of graphite not in form VI or form V is then in form IV and possibly in form III.

For castings subjected to severe loading, in particular under fatigue conditions, a higher nodularity (including requirements for a specific percentage of form VI and form V graphite) can be required to achieve the desired properties. Such a requirement should be evaluated by an experimental study, specific to the casting and the material grade.

Annex G
(informative)

Additional information on mechanical and physical properties

Information on mechanical and physical properties is given in Tables G.1 and G.2 (in addition to that given in Tables 1 to 3).