2 Ductile cast iron as a material

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In contrast to grey cast iron, where the free graphite is present in lamellar form, the free graphite in ductile (malleable) cast iron is spherical in shape (spheroidal graphite). This form of graphite favours the elasticity of the cast iron and increases its inherent strength. It was only in the 1950's that the industrial production of cast iron pipes with spheroidal graphite (ductile iron pipes) began.

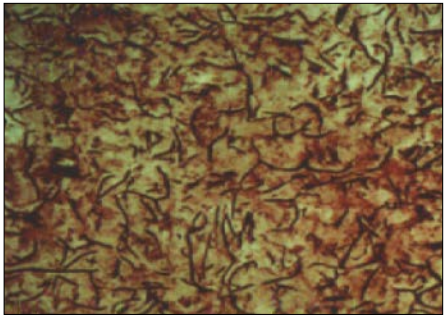

Fig. 2.1:
Cast iron with lamellar graphite (grey cast iron)

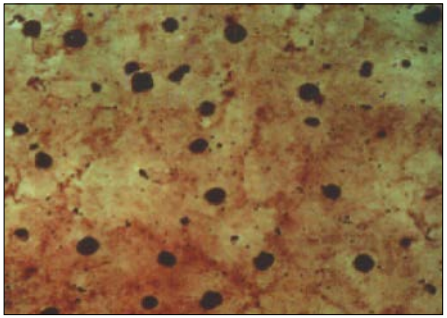

Fig. 2.2:
Cast iron with spheroidal graphite (ductile cast iron)

2.1 General

Ductile cast iron is a plastically malleable, tough iron-carbon material in which the carbon fraction is predominantly present as elementary spheroidal graphite. The main way in which it differs from grey cast iron is in the shape of the graphite particles. The word ductile comes from the Latin "ducere" = pliable (from ductus = to lead) and means malleable. In static calculations, pipes in ductile cast iron are therefore considered as having pliable properties or being flexible pipes.

When it is used for pipes, fittings and accessories, the material is referred to as ductile cast iron. Its mechanical and technological properties are described in standard EN 545 [2.1]. When used in bodies for valves it is called spheroidal graphite cast iron, as is usual in mechanical engineering generally, and its properties are determined in standard EN 1563 [2.2]. The two standards are the work of different technical standardisation committees.

With grey cast iron **(Fig. 2.1)**, because of their notching effect the graphite lamellae reduce the relatively high stability of the basic structure, whereby they cause its elongation after fracture to fall below 1 %.

In ductile cast iron or spheroidal graphite cast iron the graphite is formed spherically **(Fig. 2.2)**. Spheroids (spherical mineral structures) affect the properties of the basic metallic structure to a considerably lesser extent than lamellae. While with cast iron with lamellar graphite **(Fig. 2.3)** the lines of tension are highly concentrated at the tips of the graphite lamellae, they flow around the graphite precipitated in spheroidal form almost undisturbed **(Fig. 2.4)**. For this reason, ductile cast iron is able to deform under load.

So that, during the solidification phase, the carbon crystallises in a broadly spheroidal shape, the molten iron has to be treated with magnesium. The result is a considerable increase in strength and malleability as compared with grey cast iron.

Fig. 2.3:
The flow of lines of tension in cast iron with lamellar graphite

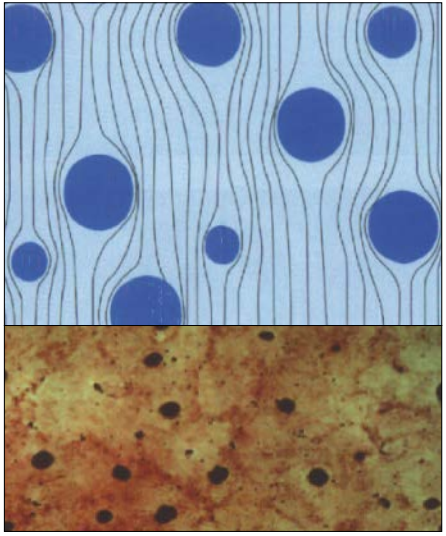

Fig. 2.4:
The flow of lines of tension in cast iron with spheroidal graphite

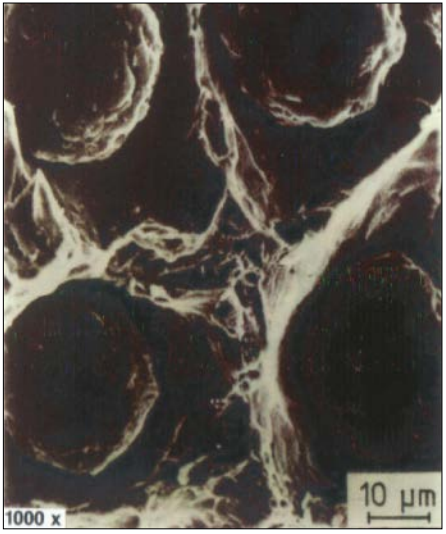

Fig. 2.5:
Scanning electron micrograph of graphite nodules

Fig. 2.5 shows spheroidal graphite nodules on the fracture surface of a ductile cast iron specimen. The size of the graphite nodules is in a range between 0.01 mm and 0.5 mm.

2.2 Structure

According to the applicable standards EN 545 [2.1] and EN 598 [2.3] the carbon fraction present as graphite must be predominantly spheroidal in form so that the workpiece has the required properties.

The matrix of the pipes should be predominantly ferritic **(Fig. 2.6)**, as ferrite produces the highest elongation values at the lowest hardness levels. Fittings, valve bodies and accessories are produced in sand moulds and have a ferritic-pearlitic structure. They do not need any additional heat treatment **(Fig. 2.7)**.

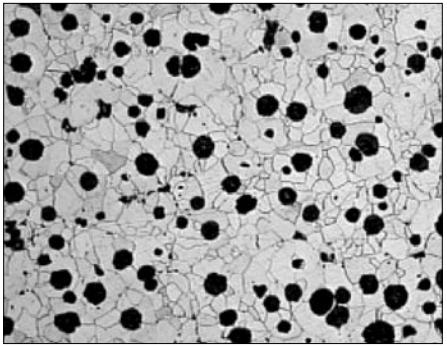

Fig. 2.6:
Ferritic structure

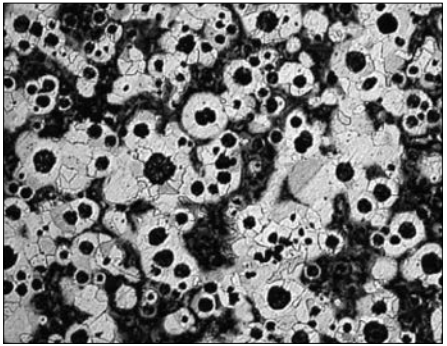

Fig. 2.7:
Ferritic-pearlitic structure

2.3 Technological properties

2.3.1 Material properties

According to standards EN 545 [2.1] and EN 598 [2.3], tensile strength and elongation after fracture are to be tested using round test bars. In addition, hardness of the material is to be determined. This is subject to an upper limit in order to enable machining, e.g. for flanges. Higher hardness levels are permissible in the area of the heat affected zone of weld seams **(Chapter 18)**.

The standardised values for the mechanical properties of ductile cast iron and spheroidal graphite cast iron are given in **Tables 2.1 a and 2.1 b**.

Table 2.1 a:
Properties of ductile cast iron

Material	Application	Standard	Minimum tensile strength R_m [MPa]	0.2 % elongation limit[1] $R_{p0,2}$ [MPa]	Minimum elongation after fracture[2] A [%]	Hardness [HB]	Notched bar impact work [J]	Structure
Ductile cast iron	Pipes DN 80 to DN 1000	EN 545 [2.1]	420	300	10	< 230	[3]	[3]
Ductile cast iron	Pipes DN >1000		420	300	7	< 230	[3]	[3]
Ductile cast iron	Non-centrifuged pipes, fittings DN 80 to DN 2000	EN 598 [2.3]	420	300	5	< 250	[3]	[3]

[1] The 0.2 % elongation limit ($R_{p0.2}$) can be determined. It should not be less than:
- 270 MPa if A ≥ 12 % for DN 80 to DN 1000 or A ≥ 10 % for DN > 1000
- 300 MPa in other cases

[2] For centrifuged pipes from DN 80 to DN 1000 and a minimum wall thickness of ≥ 10 mm the elongation after fracture must be at least 7 %

[3] No requirement

Table 2.1 b:
Properties of spheroidal graphite ductile cast iron

Material	Application	Standard	Minimum tensile strength R_m [MPa]	0.2 % elongation limit [1] $R_{p0,2}$ [MPa]	Minimum elongation after fracture [2] A [%]	Hardness [HB]	Notched bar impact work [J]	Structure
EN-GJS-500-7 (GGG 50)	Valves and hydrants	EN 1563 [2.2]	500	320	7	180 – 220	6 – 8	perlitic-ferritic
EN-GJS-400-15 (GGG 40)			400	250	15	140 – 180	8 – 12	predominantly ferritic
EN-GJS-400-18LT (GGG 40.3)	Valves for use at low temperatures		400	250	18	140 – 150	>12	purely ferritic

With centrifugally cast pipes, in addition to the standard, routine ductility tests can also be carried out in-works with the help of ring flattening specimens or ball pressure specimens.

The strength properties mentioned so far, which are mainly to be tested on prepared specimens, relate to the material.

A summary of additional material properties of ductile cast iron and spheroidal graphite cast iron, which in some cases come from other standards and sources, is given in the following **Table 2.2**.

Other characteristic values which relate to components have been determined in the context of a DVGW study [2.4] on drinking water pipelines on the basis of tests.

Pressure pipes in ductile cast iron have strength values according to **Table 2.3**.

Because of the high bursting pressures which ductile iron pipes resist, they offer high safety margins.

Table 2.2:
Mechanical and physical values of ductile cast iron and spheroidal graphite cast iron

Property	Dimension	Value
Compression strength	MPa	550
Modulus of elasticity	MPa	160,000 – 170,000
Mean coefficient of linear thermal expansion	m/m · K	$10 \cdot 10^{-6}$
Heat conductivity	W/cm · K	0.42
Specific heat	J/g · K	0.55

Table 2.3:
Component strength of ductile iron pipes

Property	Dimension	Value
Compression strength	MPa	550
Longitudinal bending strength	MPa	420
Bursting strength	MPa	300
Stress range	MPa	135

2.3.2 Material testing

In order to test centrifugally cast pipes, specimen rings are separated from the spigot end of the pipe. With fittings, accessories and valve bodies (sand casting) separately cast specimens are tested.

The material properties
- tensile strength,
- 0.2 % proof stress and
- elongation after fracture

are determined on machined cylindrical test bars exclusively according to Equation (2.1).

$$L_o = 5 \cdot d_o \qquad (2.1)$$

L_o Length of the machined cylindrical bar in mm
d_o Diameter of the machined cylindrical bar in mm

Hardness is determined using the Brinell test as per ISO 6506-1 [2.5] and EN ISO 6506-1 [2.6] on the casting itself or on a specimen separated from the casting. To do this, the surface to be tested is prepared by means of light local grinding. After that a hardened steel ball with a defined diameter and a defined test force is pushed vertically into the specimen. The precise indentation diameter measured is inversely proportional to the Brinell hardness.

For pipes, the flattening tests on 30 mm wide rings supplement the determination of mechanical properties on a specimen bar **(Fig. 2.8)**.

Fig. 2.8:
Ring flattening test

2.4 References

[2.1] EN 545
Ductile iron pipes, fittings, accessories and their joints for water pipelines – Requirements and test methods [Rohre, Formstücke, Zubehörteile aus duktilem Gusseisen und ihre Verbindungen für Wasserleitungen – Anforderungen und Prüfverfahren]
2010

[2.2] EN 1563
Founding – Spheroidal graphite cast irons [Gießereiwesen – Gusseisen mit Kugelgraphit]
2012

[2.3] EN 598
Ductile iron pipes, fittings, accessories and their joints for sewerage applications – Requirements and test methods [Rohre, Formstücke, Zubehörteile aus duktilem Gusseisen und ihre Verbindungen für die Abwasser-Entsorgung – Anforderungen und Prüfverfahren]
2007+A1:2009

[2.4] Deutscher Verein des Gas- und Wasserfaches e. V.: „Studie über erdverlegte Trinkwasserleitungen aus verschiedenen Werkstoffen“, Bericht II, Eschborn
1971

[2.5] ISO 6506-1
Metallic materials – Brinell hardness test – Part 1: Test method [Metallische Werkstoffe – Härteprüfung nach Brinell – Teil 1: Prüfverfahren]
2005

[2.6] EN ISO 6506-1
Metallic materials – Brinell hardness test – Part 1: Test method (ISO 6506-1:2005) [Metallische Werkstoffe – Härteprüfung nach Brinell – Teil 1: Prüfverfahren (ISO 6506-1:2005)]
2005