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	Flake graphite cast iron (grey cast iron) General information on the selection of material and design Guide values of mechanical and physical properties	Supplement 1 to DIN 1691

Gußeisen mit Lamellengraphit (Grauguß); allgemeine Hinweise für die Werkstoffwahl und die Konstruktion; Anhaltswerte der mechanischen und physikalischen Eigenschaften

Supersedes Supplement to DIN 1691, August 1964 edition.

In keeping with current practice in standards published by the International Organization for Standardization (ISO), a comma has been used throughout as the decimal marker.

This supplement contains information additional to that given in DIN 1691, but no additional standard specifications.

1 Introduction

Flake graphite cast iron is a material used in many technical fields. For this reason, the requirements regarding the design of castings and their properties are extensive; the masses of such castings varying from a few grammes to more than 100 tonnes and the wall thicknesses also covering wide ranges.

The properties of the castings must meet the technical requirements of a wide range of applications. Examples of these properties are:

- strength properties;
- machineability;
- damping capacity;
- resistance to wear;
- resistance to high temperatures and to thermal shock;
- resistance to chemical exposure;
- thermal conductivity;
- density;
- electrical and magnetic properties.

2 Notes on the selection of material

The properties of flake graphite cast iron are determined by the quantity of precipitated graphite, the graphite form and the structure of the metallic matrix. These are dependent on the manufacturing conditions, the chemical composition, the solidification time and the rate of cooling in the mould. The wall thickness, mass and shape of the casting have a significant effect on these.

For lightweight castings with a mass of up to 200 kg, the tensile strength in the separately cast 30 mm diameter sample may be used for quality control and as a guide to the properties in the casting. Smaller sample diameters may be agreed in the case of wall thicknesses of less than 10 mm. For heavy castings with a mass exceeding 1000 kg, normally cast-on samples shall be used for assessing the properties of the casting. Castings falling in the intermediate range shall be treated as lightweight castings, except in cases where cast-on samples have been specified.

For heavy individual castings, instead of giving the tensile strength for certain parts of the casting, e.g for sliding tracks of machine tools, minimum values of Brinell hardness may be specified as a guarantee against premature wear. To comply with such a requirement, alloying elements, such as chromium, molybdenum, nickel, copper, tin, may be added and/or locally mould materials with a higher thermal diffusivity than sand (chills) may be used.

For a lot of castings, the requirements set chiefly relate to hardness, e.g.:

- in the case of machining at high cutting speeds (transfer lines), maximum values shall not be exceeded;
- if a certain resistance to wear is to be given, the values shall not go below the minimum required values. Requirements regarding hardness in a particular area of the casting shall be agreed on the basis of maximum or minimum values. If narrower ranges of hardness than those specified are necessary, these should cover at least 40 units of Brinell hardness.

3 Notes on the design

Cast iron is a material with almost unlimited design potential, the main reasons for this being:

- a good fluidity and cavity filling capacity of the liquid iron;
- no change or very little change of volume during solidification (± 0,5 % by volume), which means that the necessity for placing gates and risers is minimized and that large feeding lengths are possible.

The properties of the material are significantly influenced by the crystallization period and thus by the mass and wall thickness of the castings. The solidification modulus, i.e. the quotient of the volume and the surface area of the casting is used as the geometrical measure for this. The relationship between the solidification modulus and the solidification time is approximately as follows:

$$\text{solidification time [min]} \approx K\left[\frac{\text{min}}{\text{cm}^2}\right] \times \left(\frac{\text{volume [cm}^3\text{]}}{\text{surface [cm}^2\text{]}}\right)^2 = K \times (\text{solidification modulus [cm]})^2$$

The factor K takes into account the casting temperature and the thermal properties of the metal and the mould material.

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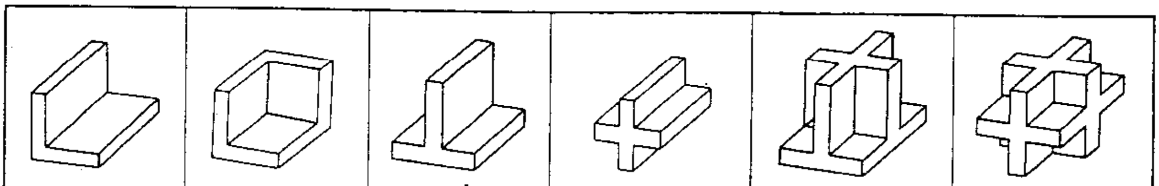

Edge	Corner	T shape	Cross shape	Cross shape backed by a vertical plate	Cross shape penetrated by a vertical plate
1,15	1,25	1,25	1,45	1,5	1,7

Figure 1. Multiplication factor for the modulus in the case of junctions of plates of equal thickness

The heat content is proportional to the volume and the heat exchange area is proportional to the casting surface area [1]).

In order to determine the solidification moduli of the castings the castings proper have to be divided up into separate areas:

- in the case of flat areas of the casting, e.g. plates, the modulus shall be taken as half the wall thickness (in cm);
- in the case of bar-shaped areas of the casting, the modulus can be determined from the ratio of the cross-sectional area to the circumference;
- if plates of equal thickness are joined or interpenetrate, the modulus can be estimated by multiplying the plate modulus by the factors given in figure 1.

In the case of junctions of plates of unequal thickness, the following can be expected:

if plates of smaller thickness branch off, the modulus becomes reduced and can even fall below 1,0 if the branches act as cooling surfaces.

The following notes should be observed for the design of castings:

a) A right angle shall be used as far as possible for branches and junctions.

b) In the case of sudden changes in wall thickness (resulting in changes in the modulus) and internal edges, the use of a fillet is advisable.

c) Differences in wall thickness exceeding a ratio of 5 : 1 shall be avoided. In the case of GG-30 cast iron, the ratio should be less than 4 : 1 and in the case of GG-35 cast iron less than 3 : 1.

d) Concentrations of material, e.g. as in the case of cross shapes, should be avoided as far as possible or resolved into staggered T shapes.

4 Relationship between tensile strength and Brinell hardness

Hardness, tensile strength, and also the modulus of elasticity and the shear modulus are determined by the quantity of the graphite flakes, their form and size and by the chemical composition and the structure of the metallic matrix. An increase in one of these parameters generally results in an increase in the measured value of one of the other parameters [2]).

Because of the large number of influencing factors, however, the relationship between tensile strength and hardness is not close enough to allow conversion from one parameter into the other, as with non-alloy and low alloy steels, without considerable dispersion.

There is an empirically determined relationship:

$$\text{Brinell hardness} = C\,(100 + 0{,}44 \times \text{tensile strength})$$

The constant of proportionality C [3]) can however exhibit a dispersion of more than ± 15 %, see figure 2.

Within a foundry it is however generally possible to maintain the relationship between tensile strength and Brinell hardness within narrow limits, for example in the case of lightweight castings. In the case of heavy castings, deviations from this relationship can occur (when chills on sliding tracks are used, for example) if minimum values of Brinell hardness are to be specified.

5 Dependence of tensile strength and Brinell hardness on wall thickness

The wall thicknesses (moduli) influence the tensile strength and Brinell hardness in the casting, via the solidification and cooling rates. The anticipated values of tensile strength and Brinell hardness are shown in figures 3 and 4 for casting wall thicknesses of 2,5 to 300 mm.

These diagrams do not necessarily provide a basis of agreements but they give a rundown of the relationships. Tensile strength and Brinell hardness are higher in the outer zones of the casting cross section than in the mid zone. The reason for this is the difference in the rate of crystallization in the outer zone and in the mid zone of a casting during solidification of liquid iron in the mould.

6 Guide values of mechanical and physical properties

Guide values of mechanical and physical properties in separately cast samples are given in tables 1 and 2.

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1) For the principles, see Wlodawer, R. *Gelenkte Erstarrung von Stahlguß* (Controlled solidification of cast steel), *Giesserei-Verlag* 1961.

2) A. Collaud. *Giess.-Forsch.* 14 (1954), pp. 709/26 and 15 (1955), pp. 767/99.

3) W. Patterson. *GIESSEREI* 45 (1958), pp. 385/87.

Table 1. Mechanical properties in a separately cast sample with a raw casting diameter of 30 mm

Material grade 1)			GG-15	GG-20	GG-25	GG-30	GG-35	Literature
Basic structure			Ferritic/ pearlitic	Pearlitic				-
Tensile strength	R_m	N/mm²	150–250	200–300	250–350	300–400	350–450	DIN 1691
0,1 % proof stress	$R_{p0,1}$	N/mm²	98–165	130–195	165–228	195–260	228–285	[1]
Elongation after fracture	A	%	0,8–0,3	0,8–0,3	0,8–0,3	0,8–0,3	0,8–0,3	[2]
Compressive strength	σ_{dB}	N/mm²	600	720	840	960	1080	[1]
0,1% compressive yield strength	$\sigma_{d0,1}$	N/mm²	195	260	325	390	455	[1]
Bending strength	σ_{bB}	N/mm²	250	290	340	390	490	[1]
Shear strength	σ_{aB}	N/mm²	170	230	290	345	400	[1]
Torsional strength	τ_{tB}	N/mm²	170	230	290	345	400	[1]
Modulus of elasticity 2)	E	kN/mm²	78–103	88–113	103–118	108–137	123–143	[1]
Poisson's ratio	ν	-	0,26	0,26	0,26	0,26	0,26	[2]
Brinell hardness	HB 30	-	125–205	150–230	180–250	200–275	220–290	DIN 1691
Fatigue strength under reversed bending stresses 3)	σ_{bW}	N/mm²	70	90	120	140	145	[3]
Fatigue strength under reversed tension-compression stresses 4)	σ_{zdW}	N/mm²	40	50	60	75	85	[3]
Fracture toughness	K_{1c}	N/mm$^{3/2}$	320	400	480	560	650	[4]

1) Grade GG-10 is obtained in some cases by heat treatment to alter the structure, when there are particular requirements with regard to machineability or magnetic properties, and is not included here.
2) Dependent on the quantity of graphite and the form in which it is present and the mechanical loading.
3) $\sigma_{bW} \approx 0,35$ to $0,50 \times R_m$ [3] applies approximately.
4) $\sigma_{zdW} \approx 0,53 \times \sigma_{bW} \approx 0,26 \times R_m$ [3] applies approximately.
Torsional fatigue strength at alternating load $\tau_{tW} \approx 0,42 \times \tau_{tB}$ [3].

[1] Engineering data on grey cast irons. BCIRA Alv. Birm. 1977.
[2] Nechtelberger, E. *Österr. Gießerei-Institut* (Austrian Foundry Institute). Report A No. 18.670. Leoben 1973.
[3] Hänchen, R. *Dauerfestigkeitsbilder für Stahl und Gußeisen* (Fatigue strength diagrams for steel and cast iron). *Carl Hanser Verlag*, München, 1963.
[4] Speidel, M. O. *Bruchzähigkeit und Ermüdungsrißwachstum von Gußeisen* (Fracture toughness and fatigue crack growth in cast iron), *Z. Werkstofftech.* 12 (1981), pp. 387–402.

Table 2. Physical properties in a separately cast sample with a raw casting diameter of 30 mm

Material grade 1)			GG-15	GG-20	GG-25	GG-30	GG-35	Literature
Density	ϱ	g/cm³	7,10	7,15	7,20	7,25	7,30	DIN 1691
Specific heat capacity At 20 to 200 °C At 20 to 600 °C	c	J/(kg · K)	 460 535					[1]
Coefficient of thermal expansion At −100 to + 20 °C At 20 to 200 °C At 20 to 400 °C	α	l/(106 · K)	 10,0 11,7 13,0					[1]
Thermal conductivity At 100 °C At 200 °C At 300 °C At 400 °C At 500 °C	λ	W/(m · K)	 52,5 51,0 50,0 49,0 48,5	 50,0 49,0 48,0 47,0 46,0	 48,5 47,5 46,5 45,0 44,5	 47,5 46,0 45,0 44,0 43,0	 45,5 44,5 43,5 42,0 41,5	[1]
Electrical conductivity	ϱ	Ω · mm²/m	0,80	0,77	0,73	0,70	0,67	[1]
Coercive force	H_c	A/m	560 to 720					[1], [2]
Maximum permeability	μ	µH/m	220 to 330					[1], [2]
Hysteresis losses at $B = 1\,T$		J/m³	2500 to 3000					[1], [2]

1) Grade GG-10 is obtained in some cases by heat treatment to alter the structure when there are particular requirements with regard to machineability or magnetic properties and is not included here.

[1] Angus, H. T. Cast Iron: Physical and Engineering Properties. Publ. Butterworths, London 1976.
[2] Dietrich, H. *Giesserei Techn.-wiss. Beih.* **14** (1962) No. 2, pp. 79/91.

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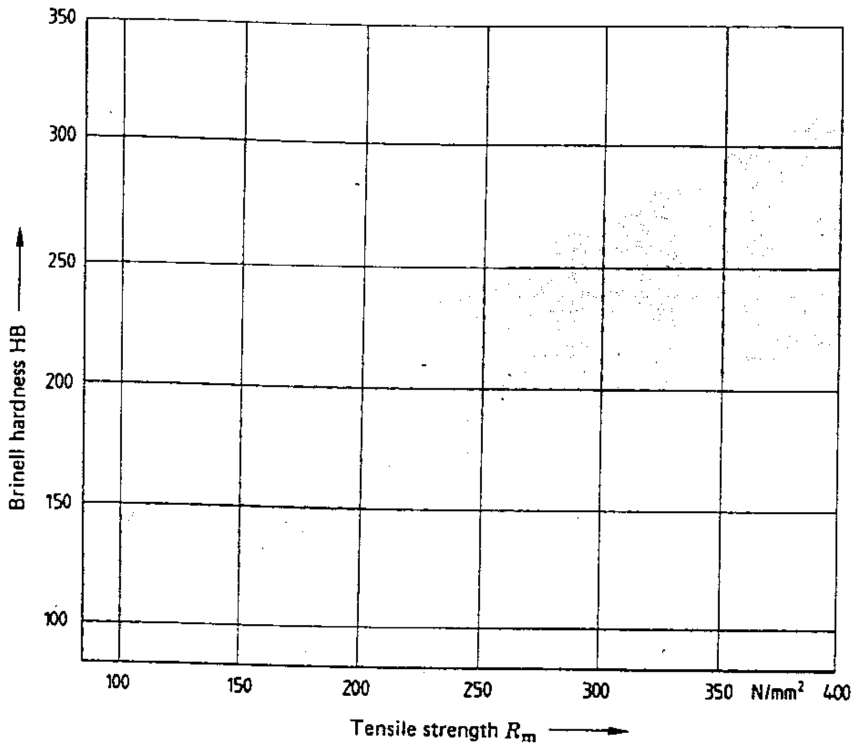

Figure 2. Relationship between tensile strength and Brinell hardness of flake graphite cast iron

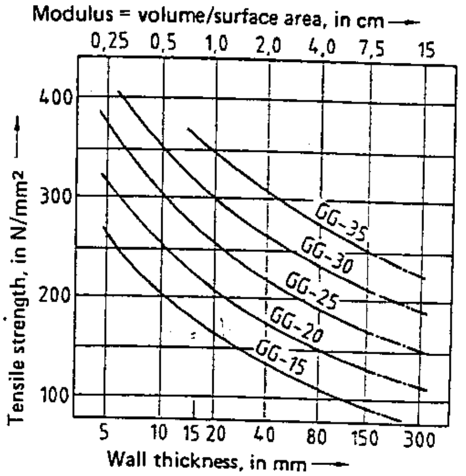

Figure 3. Expected mean values of tensile strength as a function of the wall thickness of castings

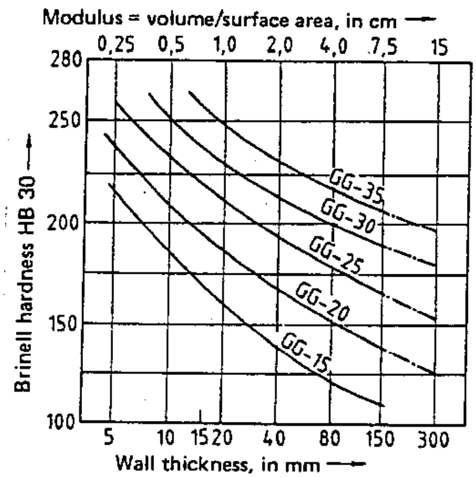

Figure 4. Expected mean values of Brinell hardness as a function of the wall thickness of castings

Previous editions

Supplement to DIN 1691: 08.64

Amendments

The following amendments have been made in comparison with the Supplement to DIN 1691, August 1964 edition:

a) Notes on design and selection of materials have been included.

b) A summary of the mechanical properties in separately cast samples has been included.

c) A summary of the physical properties in separately cast samples has been included.

d) Whilst revising DIN 1691, the contents of this Supplement have been editorially and factually modified to bring it into line with DIN 1691, May 1985 edition.

International Patent Classification

C 22 C 37/00 C 21 D 5/00 G 01 N 33/20