Riserless casting of spheroidal graphite cast iron in rigid moulds

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Abstract

The influence of chemical composition, pouring temperature, nodule count, residual magnesium content, mould strength and section size changes on the soundness of spheroidal graphite cast iron, poured in chemically bonded sand moulds in the absence of external risers, has been investigated. The major effect originates from the casting geometry. As opposed to chunky shapes, a sound plate casting could not be obtained. The presence of section size changes results in casting defects. The amount of porosities becomes minimal for eutectic compositions. It decreases when lowering the pouring temperature or the residual Magnesium content. Nodule count has no influence on the soundness of unisectional castings. Mechanical properties of unsound spheroidal graphite cast iron are considerably less than in sound material.

Riassunto

Gli autori hanno analizzato l'influenza della composizione chimica, della temperatura di colata, del numero di noduli, del contenuto di magnesio residuo, della durezza della forma e della variazione delle sezioni, sull'integrità del getto in ghisa sferoidale, colato in forme in sabbia legate chimicamente, in assenza di materozze esterne. L'effetto principale è provocato dalla geometria del getto. A differenza dei getti di grosso spessore, non è possibile ottenere un getto a forma di piastra sottile e sano. La presenza di modifiche nella dimensione della sezione dà origine a difetti nel getto.

Per una ghisa a composizione eutettica, la quantità di porosità risulta essere minima e diminuisce con l'abbassamento della temperatura di colata o del contenuto di magnesio residuo. Il numero di noduli non esercita alcuna influenza sulla sanità dei getti a sezione costante. Le proprietà meccaniche dei getti in ghisa sferoidale non sani sono significativamente inferiori alle proprietà riscontrate nel materiale sano.

Introduction

The solidification of cast iron with eutectic composition is accompanied with a net volume expansion. It results from the expansion during the precipitation of graphite which is more pronounced than the austenitic contraction. The phenomenon is known for quite long (1) and has been studied frequently by dilatation experiments, e.g. (2), (3). The favourable solidification behaviour is taken advantage of to reduce or eliminate the external risering of flake graphite iron castings. It is surprising that the same beneficial effect does not occur when casting eutectic spheroidal graphite cast iron. Despite the similar quantities of the eutectic phases austenite and graphite in flake and spheroidal graphite cast iron, the latter often shrinks to the same extent as steel. Experiments show however, that for a constant mould cavity, the volume change during solidification is independent of the graphite shape (4), (5).

Several causes have been put forward to explain the difference in feeding demands of both cast iron types. As opposed to lamellar graphite cast iron, no solid skin is formed during the solidification of spheroidal graphite cast iron. The solidification morphology of the eutectic composition may be classified as mushy (6), (7). The spheroidal graphite precipitation rate differs essentially from the lamellar one since a considerable amount of all graphite precipitates during the initial solidification stages (8). On the contrary, lamellar graphite precipitates progressively during the eutectic solidification. The accompanying volume expansion will be far more intense for the spheroidal graphite spheroidal iron than for the lamellar one which results in an increased pressure on the mould wall during solidification and enlarges the mould cavity (2), (8), (9).

The practical consequence of the solidification behaviour of spheroidal graphite cast iron is that without the aid of external risers, sound castings may only be obtained using firmly rigid moulds. The present investigation aims to study some important process variables which might influence the soundness of spheroidal graphite iron castings, poured in chemically bonded sand in the absence of external risers.

Experimental Procedure

The effect of various factors which might affect the soundness of riserless castings has been studied by pouring two prismatic geometries having the same modulus of 1.5 cm: a plate-like type (400 × 400 × 39 mm) and a chunky one (120 × 120 × 60 mm). Both shapes were poured using one mould composed of two moulding boxes dimensioning each 615 × 615 × 125 mm. All moulds have been produced in furan resin bonded sand having a compression strength of 800 N/cm^2. In a second series of experiments, test castings composed of different sections have been examined (Table 3). All cast iron heats have been melted in a medium frequency induction furnace. Charges have been composed with pig iron, steel scrap and ferro-alloys. The chemical composition of all heats is listed in Table 1. Carbon equivalent values are calculated as:

$$CE = C\% + \frac{Si\% + P\%}{3}$$

Magnesium treatment and inoculation conditions are

TABLE I - Chemical composition of all heats (weight percent)

NO	C	Si	Ni	Mg	CE
1	3.59	2.02	0.85	0.089	4.27
2	3.83	2.16	0.94	0.078	4.56
3	3.72	2.21	0.88	0.057	4.47
4	3.59	2.23	0.81	0.055	4.34
5	3.68	2.25	0.88	0.067	4.44
6	3.31	2.19	0.93	0.078	4.05
7	3.48	2.12	0.87	0.067	4.20
8	3.98	2.32	0.94	0.079	4.76
9	3.79	2.82	0.91	0.064	4.74
10	3.79	2.30	0.89	0.067	4.57
11	3.64	2.16	0.88	0.065	4.37
12	3.79	2.20	0.91	0.058	4.53
13	3.82	2.23	0.86	0.076	4.57
14	3.75	2.08	0.93	0.066	4.45
15	3.79	2.19	0.86	0.051	4.53
16	3.73	2.04	0.87	0.063	4.42
17	3.65	2.23	0.90	0.067	4.40
18	3.71	2.12	0.89	0.085	4.42
19	3.76	2.21	0.85	0.066	4.50
20	3.71	2.29	0.87	0.068	4.48
21	3.84	2.13	1.68	0.165	4.56
22	3.74	2.28	0.90	0.073	4.51
23	3.56	2.01	0.84	0.069	4.23
24	3.74	2.12	0.92	0.072	4.45
25	3.69	2.02	0.85	0.062	4.37
26	3.79	2.17	0.84	0.065	4.52
27	3.90	1.99	1.06	0.080	4.57

Mn = 0.07% max
P = 0.020 - 0.30%
S = 0.011% max

TABLE 2 - Magnesium treatment and inoculation conditions

No	Mg-treatment	Inoculation
Normal conditions	1%	0.5% A
Exceptions		
3	1%	0.5% B
4	1%	0.3% A
9	1%	1.0% B
10	1%	0.3% A
11	1%	1.0% B
16	1%	1.0% A
20	1%	1.0% B
21	2%	0.5% A

Inoculant A = Fe Si (70%) Ca (1%) Al (4%) (trade mark VP216)
Inoculant B = Fe Si (70%) Ca,Bi,Rare Earth metals (trade mark SPHERIX)

listed in Table 2. All castings were top-poured. The soundess has been examined radiographically as well as by density measurement. The last technique has been described by Sinha and Kondic (11). It enables to calculate the amount of porosities by sectioning each casting into 6 (chunky casting) or 12 (plate casting) pieces. The highest density is taken as a reference for porosity calculation of the particular casting. As opposed to the density measurements, radiographic examination only gives a qualitative result.

For this reason porosity measurements are most appropriate to quantify the soundness of the experimental castings.

Radiographic examination has been used to classify castings as being sound or unsound.

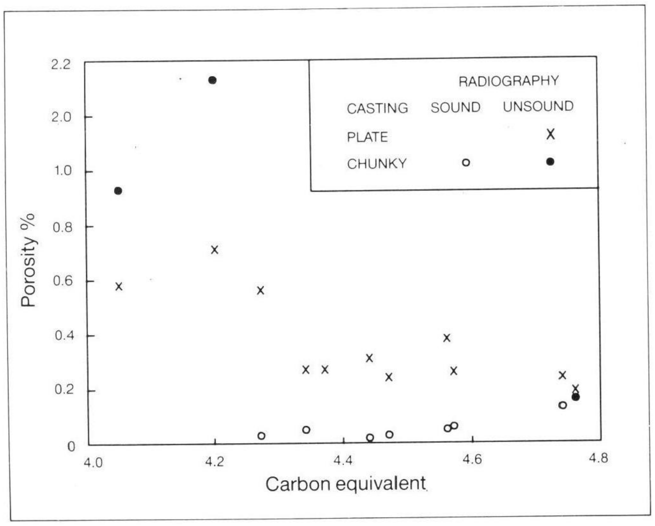
Results and discussion

Influence of the carbon equivalent

The effect of the Carbon Equivalent on the amount of porosities is shown in Figure 1. Variations in Carbon Equivalent are achieved by changing the Carbon content only.

When lowering the Carbon Equivalent below the eutectic value, the amount of porosities in both casting shapes drastically increases. Since lower Carbon Equivalents result in decreasing amounts of graphite which precipitate during solidification, the accompanying volume expansion drops, giving a smaller self-feeding capacity of the iron.

Fig. 1 - Variation of the casting porosity as a function of the Carbon Equivalent (pouring temperature 1350C; heats 1 - 11).



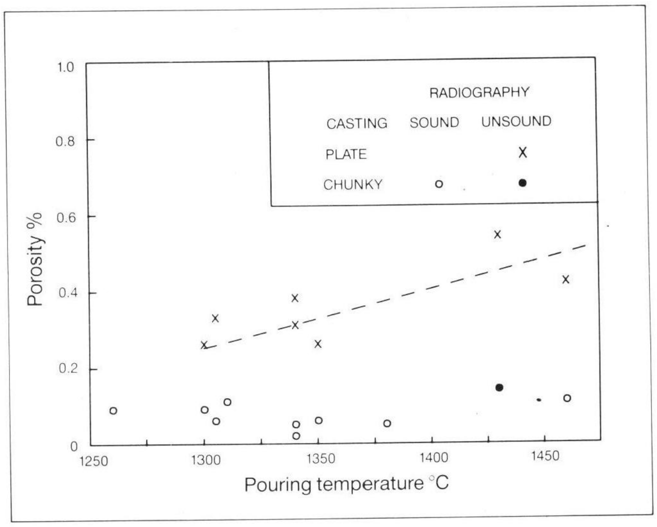


Fig. 2 - Effect of the pouring temperature upon the casting porosity. (CE 4.4 - 4.57; heats 2, 5, 10, 12 - 15, 17 - 19).

Augmentation of the Carbon Equivalent from eutectic to hyper-eutectic compositions slightly raises the porosity percentage of the chunky casting.

Influence of the pouring temperature

Examination of Figure 2 which represents the casting porosity as a function of the pouring temperature reveals that a raise in pouring temperature moderately increases the amount of porosities in both test castings. It results from a higher liquid contraction while the eutectic expansion remains the same at constant Carbon Equivalent.

Influence of nodule count

Changes in nodule count have been realized by varying the amount and the type of inoculant as well as by enlarging the time between the inoculation treatment and the pouring.

The presence of carbides has been avoided carefully in all test castings. Within the range of nodule counts realized in the actual experiments, no single correlation with the amount of porosities could be detected for either test castings (Figure 3).

Fig. 3 - Amount of porosities as a function of the nodule count (pouring temperature 1350C; CE 4.34 - 4.57; heats 2 - 5, 10, 11, 17, 20).

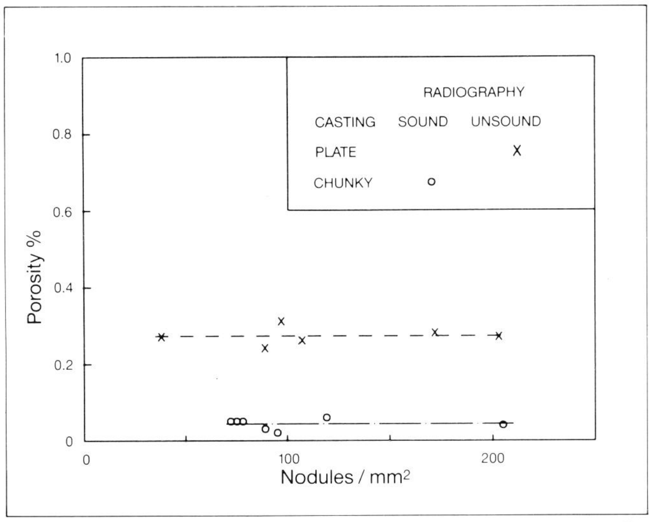
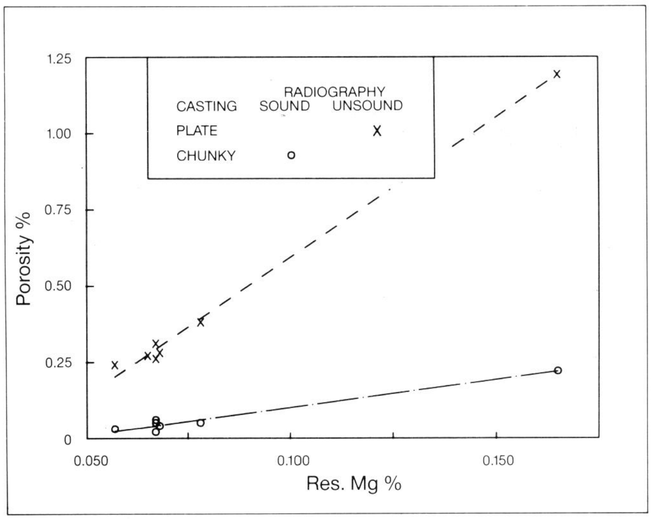


Fig. 4 - Variation of the casting porosity as a function of the residual magnesium content. (pouring temperature 1350C; CE 4.4 - 4.6; heats 2 - 3, 5, 10 - 11, 17, 21).



Influence of residual magnesium content

Increasing residual magnesium content gradually raises the amount of porosities in both test castings (Figure 4).

The effect becomes very pronounced for extremely high residual magnesium percentages.

Influence of mould strength

Spheroidal graphite iron castings which are produced in the absence of external risering often present internal defects. Experience shows that a reinforcement of the mould may result in better quality castings. In order to evaluate the influence of the mould strength on the amount of porosities of the test castings, a two dimensional finite element analysis has been carried out. This technique enables to calculate the internal stresses within the mould resulting from the volume expansion occuring during solidification of the casting.

In the present analysis the thermal influence of the casting on the moulding sand has been neglected.

Calculation of σ von Mises offers a good method to represent the internal stress distribution within the mould. The maximal value of σ von Mises is taken as a measure to compare the mechanical loading of the mould configurations studied. Each of the plate and chunky casting has been moulded with low (125 mm) and high (205 mm) moulding boxes. The amount of internal porosities within each casting is plotted as a function of the maximal value of σ von Mises obtained

TABLE 3 - Influence of section size changes (pouring temperature 1350C; inoculated 1% A)

Heat No	Casting geometry (Figure 6)	Radiography	Porosity % (⋆)	σ Von Mises max MPa
average	A	sound	0.02 - 0.05	3.93
22	B0	unsound (pronounced)	0.22	6.14
23	B1	unsound (slightly)	0.17	6.14
24	B2	sound	0.12	6.14
26	C0	unsound (pronounced)	0.97	5.96
27	C1	sound	0.17	5.96

(⋆) amount of porosities in the massive casting part measuring 120 × 120 × 60 mm.

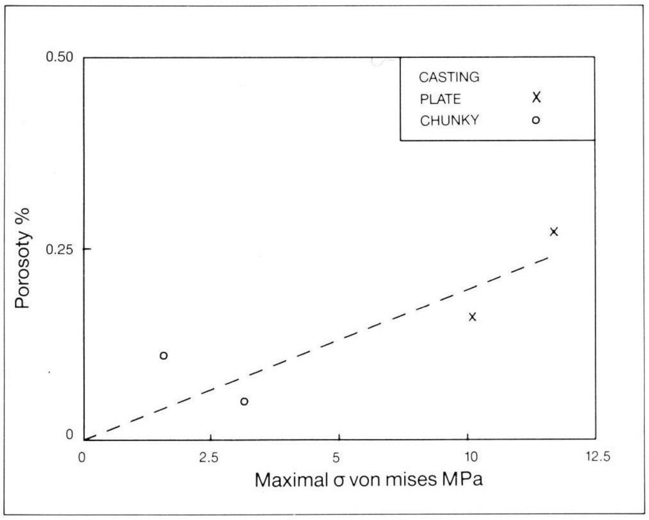


Fig. 5 - Correlation between the amount of porosities and sigma von Mises (pouring temperature 1350C; CE 4.4 - 4.6; heats 25 for high moulding boxes; average values for low moulding boxes).

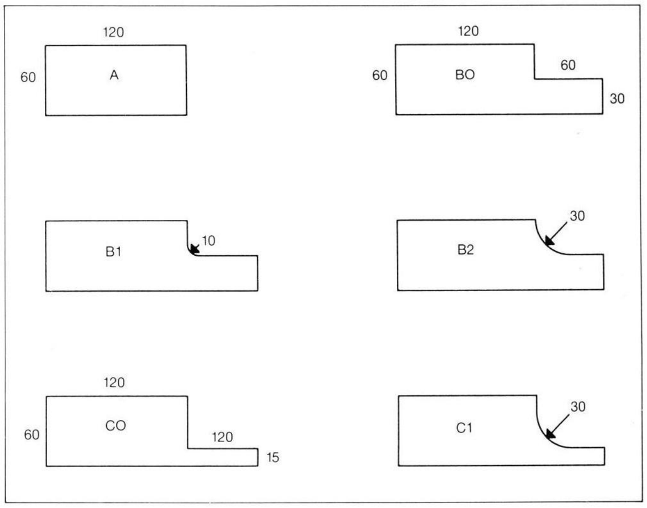


Fig. 6 - Cross section of the casting geometries studied (dimensions in mm; all castings measure 120 mm perpendicular to the cross sections shown).

using the finite element analysis of the moulding box involved (Figure 5). Calculations were executed for an internal pressure at the interface between mould and casting of 1 MPa (9). As a result of its shape, the chunky casting induces much lower stresses in the mould than the plate casting. Figure 5 shows that the amount of porosities lineary increases with the maximal stress as calculated in the mould.

Influence of section size changes

Most industrial castings are composed of different section sizes. In the present study, these cases have been simulated by adding a prismatic part with smaller section size at the chunky test casting. Dimensions and shape of this second series of test castings are shown in Figure 6, the experimental results are listed in Table 3. The introduction of a section size change increases the amount of porosities which results in radiographically detectable casting defects (BO, CO).

Smoothing the section size transition by rounding the corners, decreases the intensity of the defects although remaining higher than in the unimodal casting (A). Rounding does not lower the maximal value of σ von Mises. Consequently, the decrease of the porosities cannot be attributed to a strengthening of the mould but will probably result from changes in the solidification progress.
The preceding experimental results show that the chunky shape can be cast radiographically sound within a wide range of test conditions (pouring temperature, nodule count, residual magnesium content, carbon equivalent). By reviewing the actual experimental data as listed in Table 3, it seems that the chances to eliminate shrinkage defects in castings presenting section size changes, might be dependent from the ratio between the modulus of the adjacent casting parts.

Mechanical properties

In order to study to which extent the mechanical properties are lowered by the presence of porosities, tensile test pieces were machined from the edge (sound location) and the centre (porosity location) of each plate casting. In this way, tensile strength ratio and elongation ratio between sound and unsound material properties are plotted as a function of the porosity percentage of the casting (Figure 7, 8 resp).

Examination of Figure 7 reveals that the tensile strength in unsound regions equals circa 60 percent of the value obtained for sound spheroidal graphite cast iron. The elongation however drastically drops down to circa 10 percent of its normal value (Figure 8). On the other hand both ratios do not vary with the amount of porosities. This may be explained by the fact that with increasing amounts of porosities, the volume in which the porosities are located, enlarges accordingly rather than gradually lowering the density of the restricted spot.

Fig. 7 - Ratio between tensile strength in unsound and sound material as a function of the porosity percentage of the plate casting.

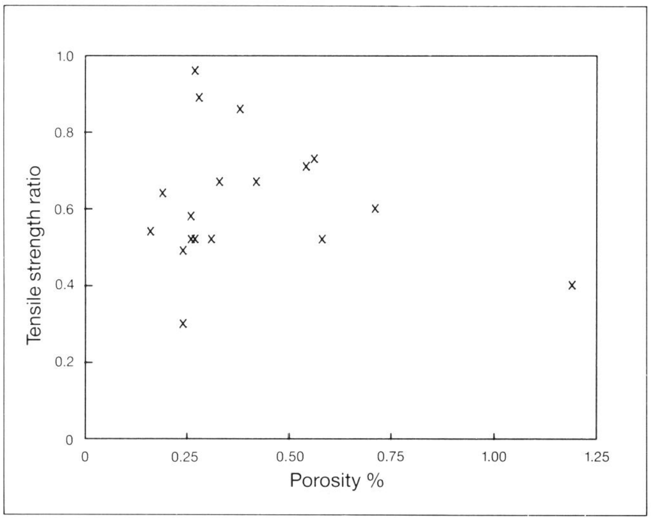
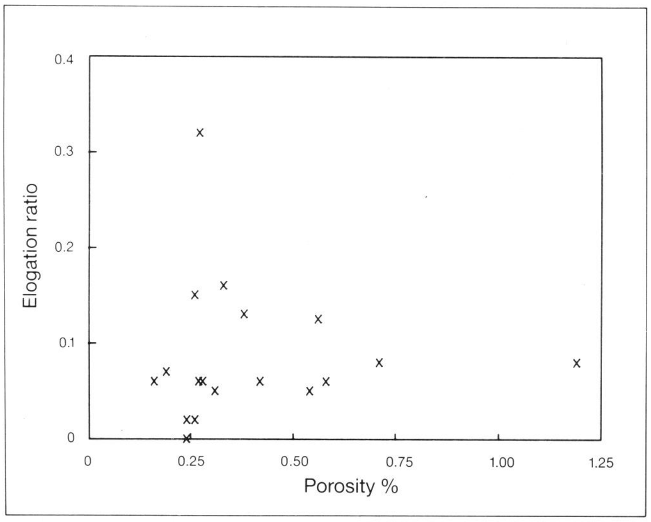


Fig. 8 - Ratio between elongation in unsound and sound material as a function of the porosity percentage of the plate casting.



Conclusions

The present study allows to formulate next conclusions:

- The geometry of a spheroidal graphite iron casting influences its soundness in a decisive way. As as result of the expansion present during the eutectic solidification of spheroidal graphite cast iron, particular geometries (in casu plate shape) give raise to stresses in the sand, which the mould cannot withstand. In this case the effect of the mould wall movement exceeds the self-feeding capacity of the spheroidal graphite cast iron. Without the aid of external risering, no sound castings can be obtained.
- The amount of porosities present in spheroidal graphite cast iron castings is influenced by all factors which change the shrinkage behaviour of the iron. Minimum porosities are obtained for low pouring temperature and eutectic compositions.
- The soundness of uniformly sectioned castings is not influenced by the nodule count or the inoculation treatment.
- Increasing the residual magnesium content raises the amount of porosities.
- The presence of section size changes results in casting defects which are difficult to avoid.
- The mechanical properties of unsound spheroidal graphite cast iron is considerably less than in sound material. Especially, nearly all elongation is lost by the presence of porosities.

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