Magnetic Properties of Spheroidal Graphite Cast Iron

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Synopsis

The magnetic properties of spheroidal and flake graphite cast irons of similar composition cast into sand moulds of various diameters were measured, and the results obtained were as follows: Under the same degree of graphitization, the maximum induction, the coercive force and the hysteresis loss of spheroidal graphite cast iron were lower than those of flake graphite cast iron, and so the maximum permeability and the residual induction were higher. With increasing degree of graphitization, the maximum permeability increased, whereas the other four quantities decreased.

I. Introduction

According to the qualitative study by Schönchen[1], magnetic properties of ordinary cast iron increase as the ratio of the amount of graphite carbon to the total amount of carbon becomes large. Since then, only a few papers have been reported on this problem. Recently, spheroidal graphite cast iron having superior mechanical properties was produced, the magnetic properties of which, however, were not thoroughly examined. Hence, the present work was carried out comparing them with those of the ordinary cast iron. At that time, two papers on the same problem were reported; one is by Everest and the other by Stauss. According to Everest[2], the initial permeability of the spheroidal graphite cast iron is lower, the residual induction is about twice higher, the coercive force is more than twice higher and the hysteresis loss is about three times higher than those of the flake graphite cast iron. According to Stauss'[3] explanation the above differences in the magnetic properties depend upon the difference in the forms of graphite carbon. In the present experiment the magnetic properties of the spheroidal graphite cast iron were measured comparing them with those of the flake graphite cast iron mainly on the amount of graphite carbon.

II. Specimens and the method of measurement

The process of obtaining the specimens was as follows: First, 3 kg of Honkeiko pig iron was melted in a high frequency induction furnace, and taken out of the furnace, after inoculation with 0.3 per cent Si. Then, 60 g of 50 per cent Fe-30 per cent Si-Mg alloy was added to it, and the melt was cast into sand

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* The 919th report of the Research Institute for Iron, Steel and Other Metals. Published in the Journal of the Japan Institute of Metals, **21** (1957), 22.

(1) E. Schönchen, Arch. Eisenhüttenw., **29** (1950), 29.
(2) A. B. Everest, Foundry Trade J., **89** (1950), 57; 59.
(3) H. E. Stauss, Foundry Trade J., **90** (1951), 553.

moulds of different sizes. In this way two groups of specimens consisting of spheroidal graphite structure were obtained. In this paper, the specimen of spheroidal graphite structures will be called specimen N, and all its properties are respectively the mean values of the two groups of specimens. Magnesium was added to them at the rate of 0.6 per cent. Diameters of specimens were 10, 15, 20, 25 and 30 mm, respectively. Then, for the comparison, another sort of specimens consisting of flake graphite structure, specimens F, were prepared not adding magnesium, but 1.3 per cent Si was added. The amounts of silicon were nearly the same both in specimens N and F. The results of the chemical analyses of the specimens are shown in Table 1. Specimens were lathed into 4~6 mm in diameters and 80~100 mm in length, and the dimension ratio of each specimen was 20.

Table 1. Chemical analysis of pig iron used and the specimens.

Materials	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Mg (%)
Pig iron (Honkeiko)	3.5	1.4	0.6	0.02	0.02	
Spheroidal graphite Cast iron	3.3~3.4	2.9~3.0	0.6	0.02	0.02	0.06
Flake graphite Cast iron	3.4~3.5	3.0~3.2	0.6	0.02	0.02	

Magnetization was measured with a ballistic galvanometer and magnetization curves and hysteresis loops were drawn at the demagnetizing factor of 0.069. The microstructures of specimens N and F cast in 25 mm diameter are shown in Photos. 1 and 2, in which the spheroidal and the flake graphite structure can be seen clearly. Further, it was ascertained that these structures at the both ends of the specimens were almost the same as each other.

III. Results of measurement

1. Graphitization (G.C./T.C.)

First, the amount of graphitized carbon (G.C.) was determined by the chemical analysis of the specimen, and the ratio of the graphitized carbon to the total

Table 2. Diameter (d) as cast, graphitized carbon (G.C.) and total carbon (T.C.) of nodular (N) and flake (F) cast iron.

Specimen No.	d (mm)	G.C. (%)	T.C. (%)	G.C./T.C. ×100
N-1	30	3.12	3.35	93
N-2	25	3.08	3.31	93
N-3	20	2.95	3.31	89
N-4	15	2.50	3.38	74
N-5	10	1.70	3.28	52
F-1	30	2.94	3.43	86
F-2	25	2.96	3.45	86
F-3	20	2.90	3.38	86
F-4	15	2.83	3.50	81
F-5	10	2.57	3.47	74

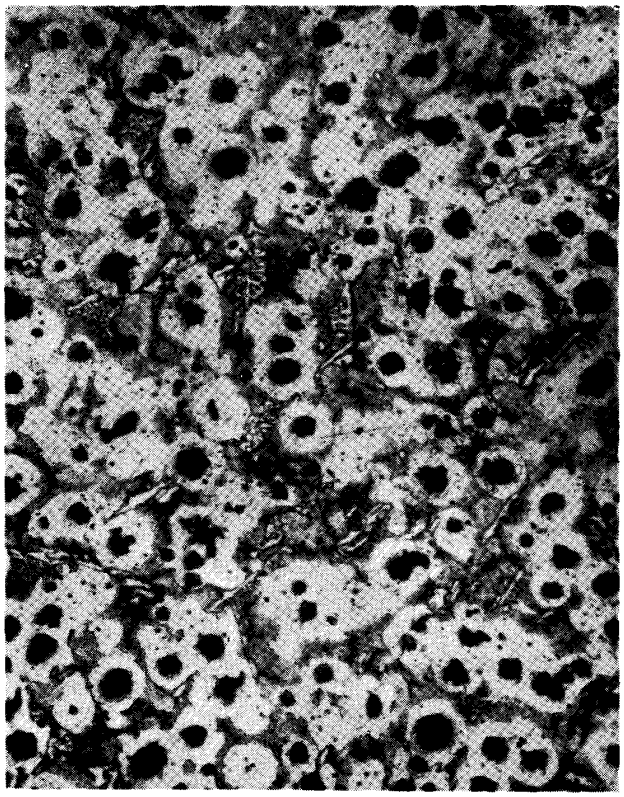

Photo. 1. Spheroidal graphite cast iron. (×100)

Photo. 2. Flake graphite cast iron. (×100)

amount of carbon was obtained(G.C./T.C.). The relation between the graphitization and the diameter of specimen is shown in Fig. 1, and the results of the determination of carbon are given in Table 2. It can be seen from Fig. 1 that the graphitization is very sensitive to the diameter of the specimen as cast, that is, it immediately increases as the diameter becomes large, but becomes nearly constant when the diameter exceeds 20 mm. The graphitization was 90~95 per cent in the case of spheroidal graphite specimen and about 85 per cent in the case of flake graphite specimen. These results are almost similar to those by the previous investigators. Moreover, in the present case, the time required to anneal the white pig iron containing the same amount of silicon was 30 min at 950°C for 90 per cent graphitization, and was about 90 min for 95 per cent graphitization.

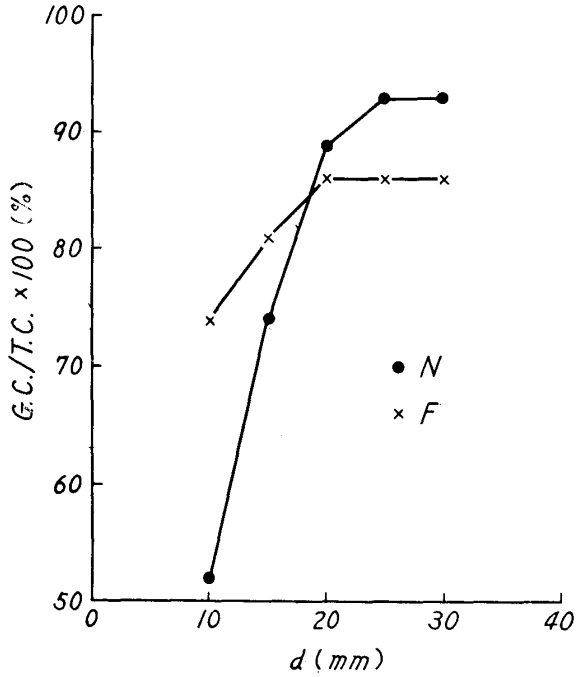

Fig. 1. Relation between graphitization(G.C·/T.C.) and diameter (d) of specimen as cast.
N : Nodular graphite cast iron.
F : Flake graphite cast iron.

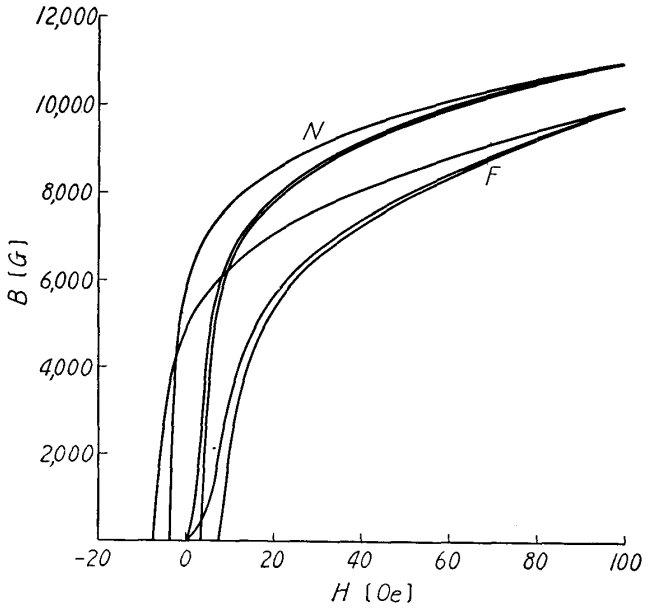

Fig. 2. Magnetization curves and hysteresis loops of spheroidal [N] and flake [F] graphite cast iron.

2. Magnetization curves

Next, the magnetization curves were examined. For example, the magnetization curves of specimens N-1 and F-1, 30 mm in diameter, are shown in Fig. 2. As it is clear from the figure, the magnetic induction of specimen N is higher than that of specimen F, and the curve of the former is steeper than that of the latter. The maximum permeability was obtained from the curves in Fig. 2, and the magnetic induction at the effective field of 100 Oe was drawn according to the degree ofgraphitization. As shown in Fig. 3, the maximum induction becomes slightly low with the increase in graphitization. In the case of cast irons of similar composition the saturation magnetization increases with the increase in

graphitization by heat-treatment. In the present case, however, different results were obtained because specimens as cast were used: the maximum permeability increased with the increase in graphitization. When specimens of the same degree of graphitization were compared, both maximum induction and maximum permeability of specimen N were higher than those of specimen F.

3. Hysteresis loops

Hysteresis loops were measured at the maximum magnetic field of 100 Oe, from which the resisual induction and the coercive force were obtained. The relations of the graphitization to the residual induction and to the coercive force are shown in Fig. 4. The residual induction as well as the maximum induction slightly decreased with the increase in graphitization. As mentioned above, Everest[2] reported that the residual induction of specimen F was about a half of that of specimen N; in the present results, however, it was five-sixths, that is, the residual induction of specimen F was about 1000 gausses lower than that of specimen N.

In opposition to the case of the maximum permeability, coercive forces decreased linearly with the increase in graphitization. When specimens contained the same amount of graphite carbon, coercive forces of specimens N were always lower than those of specimens F. The difference between them became small as the graphitization increased, and seemed to disappear when the graphitization reached 100 per cent. Let $\Delta_{N-F}[H_c]$ be the difference between the coercive force of specimen N and that of specimen F, then

$$\Delta_{N-F}[H_c] = 0.216(G - 100) .$$

Everest[2] suggested that the coercive force of specimen N was lower than that of specimen F, but the present results were not coincident with it unless graphitization was out of consideration.

Hysteresis loss was then calculated and the relation between the hysteresis loss and the graphitization is shown in Fig. 5. As seen in the figure, the hysteresis loss of specimen N was

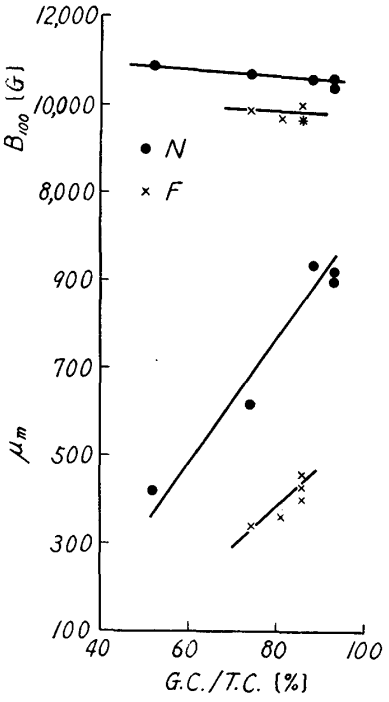

Fig. 3. Relation between induction at 100 Oe B_{100}, maximum permeability and graphitization G.C./T.C.

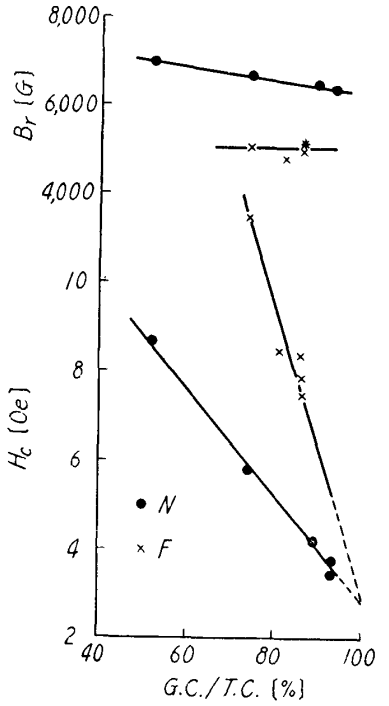

Fig. 4. Relation between residual induction Br, coercive force H_c and graphitization G.C./T.C.

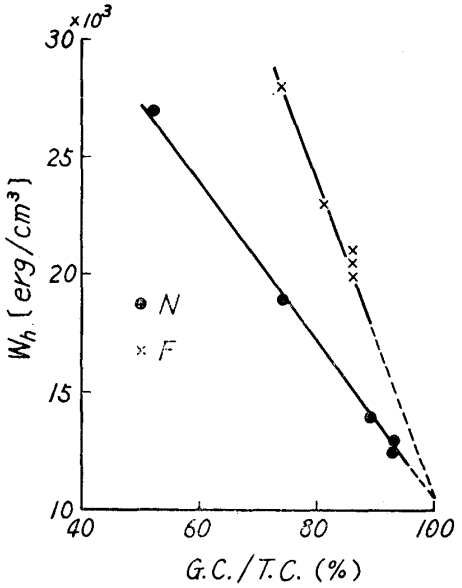

Fig. 5. Relation between hysteresis loss W_h and graphitization G.C./T.C.

always smaller than that of specimen F provided the degree of graphitization was the same. Hysteresis losses of both specimens had the same tendency as the coercive forces, that is, they decreased with increasing graphitization, finally coinciding with each other at 100 per cent graphitization.

According to Everest[2], the hysteresis loss of specimen N was larger than that of specimen F; when, however, the hysteresis loss of specimen N was compared with that of specimen F under the same degree of graphitization, the former was smaller than the latter, similar to the case of coercive force. Moreover, the hysteresis loss of specimen N decreased with the increase in graphitization, which can be expressed as follows:

$$[W_h]_N = -0.34G + 45$$

Further, the relation between the hysteresis loss of specimen N and that of specimen F can be expressed as follows:

$$[W_h]_N = 0.5[W_h]_F + 5$$

From Figs. 4 and 5 it will be seen that at 100 per cent graphitization the coercive forces and the hysteresis losses of both specimen N and F show respectively the same value. This, however, can not be explained theoretically.

Summary

The magnetic properties of spheroidal and flake graphite cast irons of similar compositions cast into sand moulds of various diameters were measured and the following results were obtained.

(1) Under the same degree of graphitization the coercive force and the hysteresis loss of the spheroidal graphite cast iron were lower than those of the flake graphite cast iron, while the maximum induction at 100 Oe field, the residual induction and the maximum permeability were higher.

(2) With the increase in graphitization maximum permeabilities of both specimens linearly increased, but maximum inductions at 100 Oe, residual inductions, coercive forces and the hysteresis losses decreased.

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