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Structure and properties of gray iron casted in the electromagnetic field

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Abstract

In the national [1] and foreign [2] literature the methods of improving the homogeneity of the structure of castings using forced convection of the solidifying metal in the casting mould or the crystallizer are presented. This article presents the influence of chosen parameters of the rotating electromagnetic filed that is forcing the movement of melted metal in the mould on the morphology of graphite and the abrasive wear of the grey cast iron. The effect of this examination is the obtained modification of the flake graphite divisions morphology and a alteration of the abrasive wear resistance of the castings manufactured this way.

Keywords: Electromagnetic field, Grey cast iron, Abrasive wear

1. Introduction

The high requirements of modern industry regarding the quality of castings, create conditions for the continuous search for methods to optimize the parameters of the manufacturing process. To a large extent the abrasive wear of cast iron is affected by the wearing conditions and the microstructure exerts a essential influence on its intensity. It is therefore an important parameter describing the quality of cast iron casting, working under conditions of abrasive wear is graphite divisions morphology.

The abrasive wear in dry friction in the (wear occurs during the rolling or sliding cooperating parts - such as clutch, cylinders, brake drums, and shoe breaks) and wear by friction with lubrication (piston rings, cylinders, shafts, valves levers, timing and cam rollers) a significant impact on the process conditions in both cases is primarily the form of graphite divisions.

Casting, that works in such conditions should have: low coefficient of friction, good ability to grind in, the ability to maintain a continuous layer of grease on the surface (friction with lubrication), and must maintain high strength properties at high temperature. All of the above requirements are fulfilled by the cast iron, which heterogeneous structure is composed of phases with a significant difference in hardness: soft phase (graphite) is more vulnerable to abrasive wear then the carcass of the casting - acting at the same time as a source of "natural lubricant tanks".

Significant influence on the resistance while friction with lubrication cause: the contribution, the form and arrangement of graphite divisions. The most favorable are the divisions of the average size of graphite flakes. Fragmentation of graphite, irrespective of form, reduces the resistance to abrasive wear, as in the dry friction [3]. Also, the presence of irregular graphite, such as local clusters of large flakes and interdendritic graphite considerably worsen its resistance to abrasion wear [4].

Therefore, the modern foundries have the problem of obtaining the gray cast iron in which graphite flakes division will be evenly distributed "A" - Figure 1, while maintaining the desired shape "I" (Figure 2) and the size of divisions. A detailed description of the graphite divisions shape and distribution can be found in the Polish standard [5].

From a theoretical point of view of the receipt of such a cast in which the graphite morphology is characterized by certain features, designed specifically for the working conditions of a particular casting seems simple. Unfortunately, practice shows that the receipt of such a cast is difficult. This happens for example in the case of castings produced on continuous casting lines, where the conditions of heat transfer from the casting differ widely depending on the distance between the point under consideration on the cross section of the casting and a point on the crystallizer wall [7].

Application of the forced convection of liquid metal during the crystallization of grey cast iron allows to achieve the intended property use of the casting as compared to casting produced without forced movement at the time of its solidification.

Fig. 1. Standard graphite divisions even distribution "A" [6]

Fig. 2. Standard graphite divisions shape "I" [6]

2. Range of studies

The aim of studies was to determine the influence of chosen variable parameters of the grey iron casting in electromagnetic field process on the morphology of graphite divisions and the resistance to abrasive wear of the casting.

The researches were carried out on the test stand which scheme and description is presented in the works [8÷9].

In range of studies of grey cast iron EN-GJL-200 were cast standard ingots of 200mm length without influence of electromagnetic field and ingots with influence of rotate electromagnetic field i.e. without reversion (WPM) and with reversion and with a pause between following changes of electromagnetic field direction (IRPM – impulse reverse electromagnetic field). Moreover, in studies (full experimental plan with results of examinations are shown in table 1.) was used different rate of liquid metal solidification by application of mould material, which have different thermal conductivity λ_c i.e.:

- graphite, λ_c=90 W/(m·K) – cooling rate 20°C/s in temperature range $T_{ZAL}÷T_L$ (pouring temperature was set to T_{ZAL} = 1450°C, T_L = 1225°C), which describes over-cooling before crystallization front, on the basis of [8],
- sand with phenolic-formaldehyde resin (shell mould) λ_c=1,5 W/(m·K) – cooling rate 10°C/s in temperature range $T_{ZAL}÷T_L$,
- aluminosilicate insulating material Sibral SI-R30 λ_c=0,35 W/(m·K) – cooling rate 2°C/s in temperature range $T_{ZAL}÷T_L$,

The experimental plan was set on three levels for following variable factors:

- pulse frequency of electromagnetic field for levels 0; 1 and 1,5 Hz, with simultaneous value of magnetic induction B = 60 mT,
- rate of liquid metal solidification in temperature range $T_{ZAL}÷T_L$ (regulated by selection of mould material) for levels 2; 10 and 20°C/s [10].

Output parameter, representing size of flake graphite was its average length (L), which was calculated on the basis of metallographic microscopic examinations carried out on the picture analyzer Multiscan Base 13.01® on the samples to cut at 100 mm from the base of ingot.

Table 1.
Full experimental plan with results

Sample number	Electromagnetic field			V [°C/s]	Mould material	L [µm]
	WPM*	IRPM*				
	B [mT]	f** [Hz]	B [mT]			
01	-	-	-	2,0	Sibral	106, 083
02	-	-	-	10,0	Shell mould	63,248
03	-	-	-	20,0	Graphite	40,731
1	60	-	-	2,0	Sibral	94,286
2	60	-	-	10,0	Shell mould	68,673
3	60	-	-	20,0	Graphite	36,257
4	-	0,5	60	2,0	Sibral	80,210
5	-	0,5	60	10,0	Shell mould	75,889
6	-	0,5	60	20,0	Graphite	48,924
7	-	1	60	2,0	Sibral	105,272
8	-	1	60	10,0	Shell mould	83,665
9	-	1	60	20,0	Graphite	63,547

* - WPM - rotate electromagnetic field, IRPM - impulse reverse electromagnetic field;
** - f – electromagnetic field pulsation frequency
*** - L – the average length of graphite divisions analyzed along the cross-section diameter of the casting

3. Results of studies

Selected results of metallographic examinations of grey cast iron are presented on Fig. 3÷8.

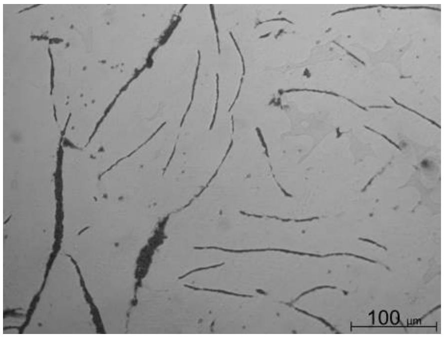

Fig. 3. Microstructure of grey cast iron EN-GJL-200 casted in the Sibral mould – model cast (sample 01)

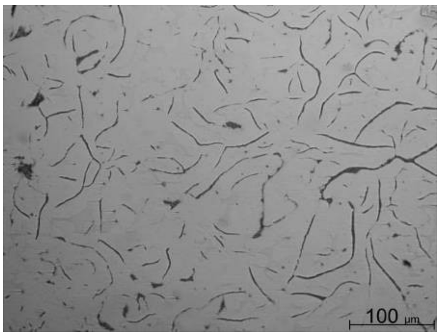

Fig. 4. Microstructure of grey cast iron EN-GJL-200 casted in the shell mould – model cast (sample 02)

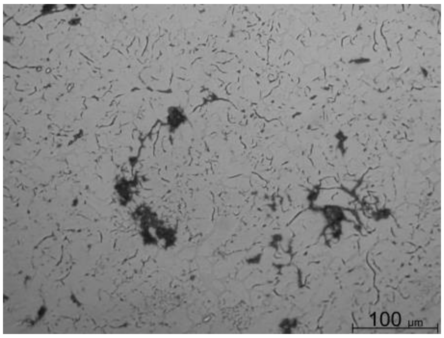

Fig. 5. Microstructure of grey cast iron EN-GJL-200 casted in the graphite mould – model cast (sample 03)

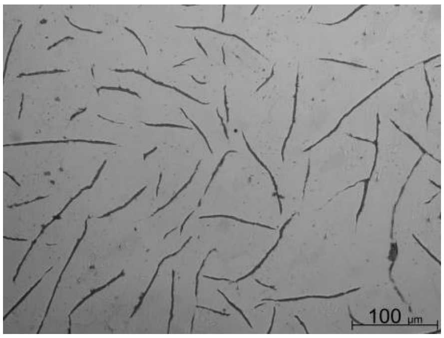

Fig. 6. Microstructure of grey cast iron EN-GJL-200 casted in the Sibral mould under rotating electromagnetic field –sampel 1

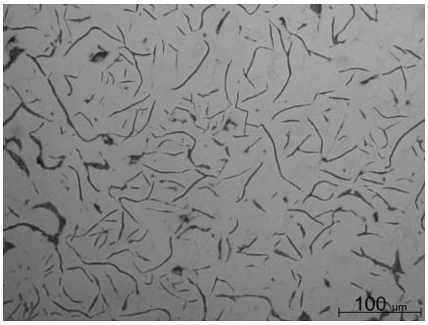

Fig. 7. Microstructure of grey cast iron EN-GJL-200 casted in the shell mould under rotating electromagnetic field – sample 2

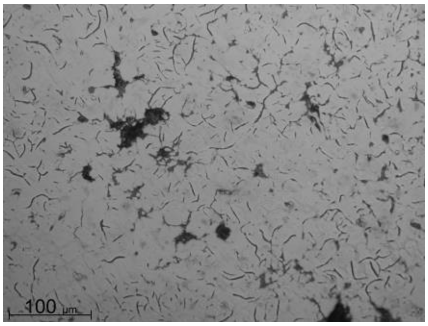

Fig. 8. Microstructure of grey cast iron EN-GJL-200 casted in the graphite mould under rotating electromagnetic field – sample 3

3.1. Metallographic analysis - statistical treatment of results

The use of step regression method in the statistical analysis, allowed to find the statistical equation linking the length of the flake graphite divisions with the various factors in the process of casting:

$$L = 17{,}7f – 2{,}7V – 0{,}1B + 98{,}9 \quad (1)$$

where:
L – average length of flake graphite, μm,
f – electromagnetic field pulsation frequency, Hz,
V – cooling rate in the range of $T_{ZAL} \div T_L$,
B – magnetic induction, mT.

The statistical parameters relationships (1):
- multi-dimensional correlation coefficient R = 0,98;
- $R^2 = 0{,}89$;
- test F (Fishera) F= 22,4;
- standard deviation s = 6,3;
- standard error of estimation b = 8,8;
- significance level $\alpha = 0{,}05$.

Graphic interpretation of equation (1) for grey cast iron casted under the above conditions are shown in fig.9 and 10.

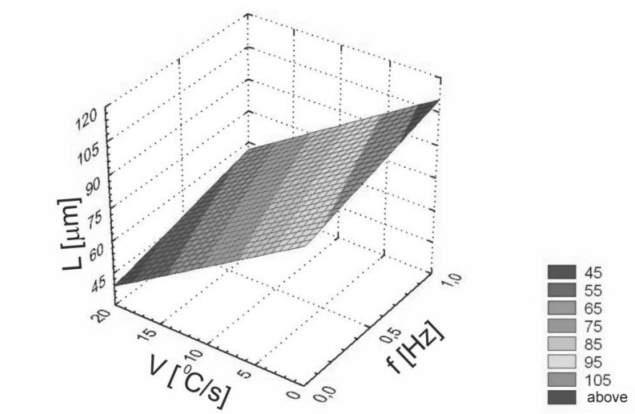

Fig. 9. Average length of flake graphite (L) in structure of grey cast iron EN-GJL-200 in function of pulse frequency of electromagnetic field (f) and cooling rate (V) – for casting with influence of electromagnetic field about value of magnetic induction B = 60mT

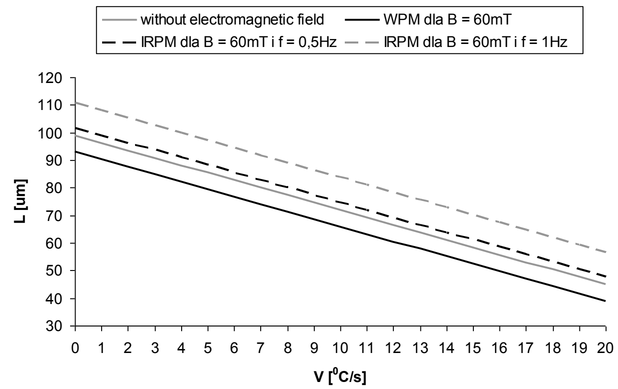

Fig. 10. Influence of cooling rate in temperature range $T_{ZAL} \div T_L$ (V) on average length of flake graphite (L) in structure of grey cast iron EN-GJL-200 for casting without and with influence of electromagnetic field

4. Evaluation of the exploit properties of the castings

Due to the required resistance to abrasive wear of gray perlitic iron, the crystallization conditions were chosen so as to ensure the obtaining of flake graphite divisions of the distribution "A", shape "I" and the size of 5 according to [5] on the whole cross-section of the casting.

It was found that the required criteria on the morphology of graphite flake has been met for the rate of cooling in terms of temperature TZAL ÷ TL of about 10 [°C/s] while applying forced unidirectional rotating electromagnetic field (wpm) convection of liquid metal in the form. Castings obtained in such circumstances characterize by the highest hardness of all affected by the plan of the experiment (see Table 1). Graphic interpretation of results is shown on Figure 11.

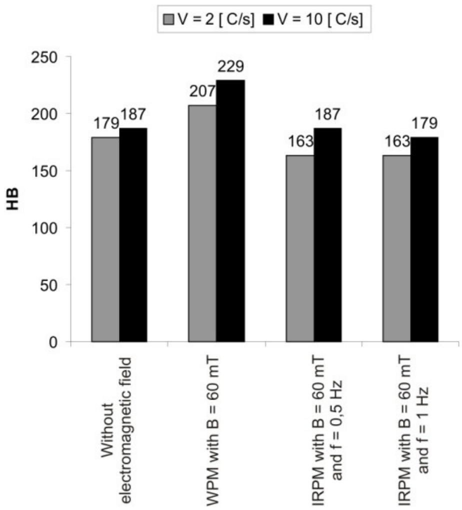

Figure 11. Effects of various casting parameters on the hardness of the test cast

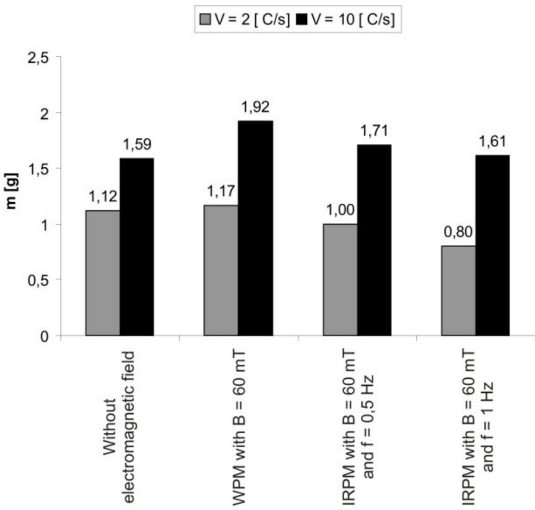

Figure 13. Effects of various casting parameters on the abrasive wear resistance of the test cast

Simultaneously with the increases the hardness, the resistance to abrasive wear in combination with friction-type metal-metal in dry conditions is decreasing. This means simultaneously an increase in the grey iron machnability properties, which is the result of the fragmentation of graphite obtained by means of rotating electromagnetic field, because the smaller divisions of graphite are not a source of effective natural lubricant tanks during abrasive wear, in contrast to the divisions of large graphite flakes.

Studies of resistance to abrasive wear were performed for the following conditions: F = 700N load, grinding-in of the associations time 30s, proper test time 300s. As the material for the counter-sample (2) high-chromium iron was used. Sample (1) rotating speed was 200 rpm. Diagram of research idea is presented in Figure 12.

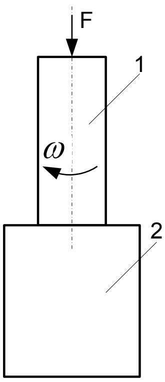

Figure 12. The principle of measuring the resistance to abrasive wear, where: 1 - test sample, 2 - counter-sample, F - clamping force, ω - the rotational speed

Graphic interpretation of the results obtained in the analysis of resistance to abrasive wear is shown in Figure 13.

5. Summary

On the basis of the results of research and analysis, it was found that the use of electromagnetic field forced convection of liquid metal in the mould, at a cooling rate in the range of T_{ZAL} - T_L of about 10°C/s, it is possible to obtain the proposed morphology of graphite in the casting.

For the established parameters for the sample casting in the electromagnetic field the improvement of hardness was obtained (sample No. 2). Simultaneously it is assumed that the machining properties of the casting will also improve, which should be related to a positively balanced distribution of graphite divisions on the cross-section of the ingot. To confirm this hypothesis further studies should be performed.

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