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Influence of electromagnetic field parameters on the morphology of graphite in grey cast iron

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Abstract

One way to improve the unification of the casting structure may be the application of forced convection of liquid metal during the crystallization in the form or continuous casting mould. This paper presents the results describing the influence of selected parameters of rotating electromagnetic field enforcing the movement of liquid metal in the form on the morphology of graphite in grey cast iron. The results were fragmented graphite flakes in conditions of regulating the rate of cooling in the range of temperature $T_{ZAL}÷T_L$ and casting with the influence of electromagnetic field.

Keywords: electromagnetic field, graphite morphology, grey cast iron

1. Introduction

Forced convection of liquid metal in the form or the continuous casting mould has a significant influence on the crystallization process of castings. For many years, the device whose main purpose is to generate movement of the liquid metal were used. First, they were the typical mechanical or electromagnetic stirrers, used to unification the liquid metal in e.g. maintaining furnace, or faster melting of alloying additives. Developments in the field of refractory materials and electrical engineering and, above all, recognize the positive effect of forced convection on the crystallization process of casting structure has brought a wider use of the magnetohydrodynamic (MHD) devices in the seventies of the last century. In Poland, these facilities are used only in the nineties, when the steel plants installed in the continuous casting of steel lines, with inductive stirrers [1, 2].

In the case of continuous ingots of square and circular cross-section a device that forces a reversion rotary movement round the ingot axis is used (Fig.1a). Whereas for flat ingots a oscillatory movement of the liquid metal along the axis of the ingot is used (Fig.1b) [2, 3].

So far, the influence of electromagnetic fields in order to unification the structure has been successfully applied in the casting of steel [3, 4] and non-ferrous metals [5÷7]. In contrast, the paper presents the possibility of influence of the electromagnetic field on the solidifying metal to unification the structure of gray cast iron. It is anticipated that this procedure will allow to obtain more favorable properties as compared to grey cast iron without forced convection at the time of its solidification.

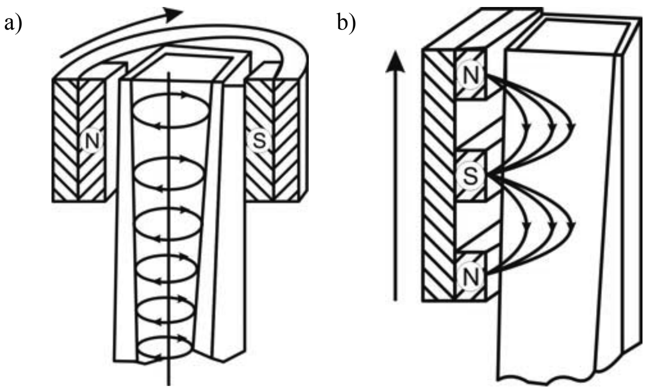

Fig. 1. The scheme of an electromagnetic stirrer enforcing (a) rotary reversion and (b) oscillatory motion of liquid metal along the axis originating ingot [2, 3]

2. Range of studies

The aim of studies was to determine a qualitative and quantitative influence of selected variable factors of grey cast iron casting in electromagnetic field on graphite morphology.

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 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.

Output parameter, representing size of flake graphite was its average length (L), which was calculated on the basis of metallographic microscopic examinations. Samples to metallographic microscopic examinations were cut at 100 mm from the base of ingot. Full experimental plan with results of examinations are shown in table 1.

3. Results of studies

Selected results of metallographic examinations of grey cast iron EN-GJL-200 after cast without and with influence of electromagnetic field are presented on Fig.2÷7.

Statistical analysis with using stepwise regression of this results was selected to determine relations between variable factors of casting and parameter of graphite morphology. Statistical analysis resulted in function shown below:

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

where:
L – average length of flake graphite, μm,
f – pulse frequency of electromagnetic field, Hz,
V – cooling rate in temperature range T_{ZAL}÷T_L, °C/s,
B – magnetic induction, mT.
Statistical parameters of correlation:

- correlation coefficient R = 0,98,
- R^2 = 0,89,
- Fisher test F = 22,4,
- standard deviation s = 6,3,
- standard error of estimation b = 8,8,
- significance level α = 0,05.

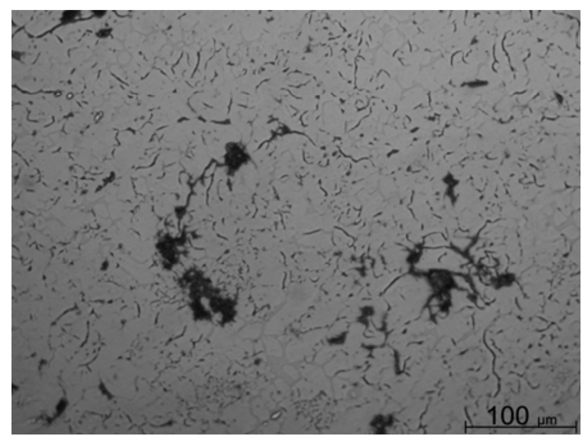

Fig.2. Microstructure of grey cast iron EN-GJL-200 after cast to graphite mould

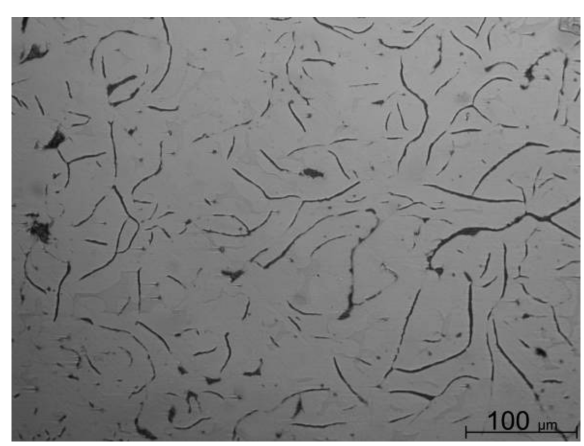

Fig.3. Microstructure of grey cast iron EN-GJL-200 after cast to shell mould

Table 1.
Full experimental plan with results

Sample number	Electromagnetic field				V [°C/s]	Mould material	L [μm]
	WPM*		IRPM*				
	f [Hz]	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;

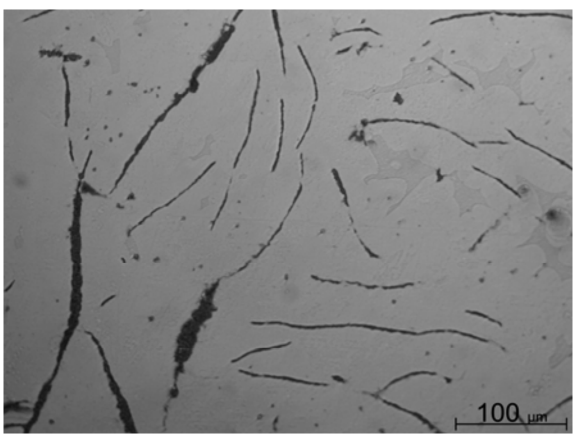

Fig.4. Microstructure of grey cast iron EN-GJL-200 after cast to Sibral mould

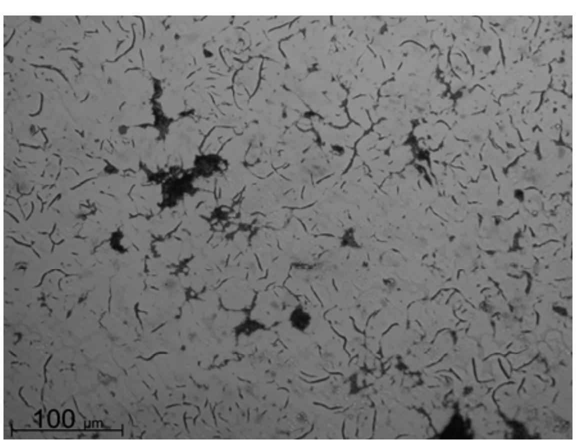

Fig.5. Microstructure of grey cast iron EN-GJL-200 after cast to graphite mould with influence of rotate electromagnetic field

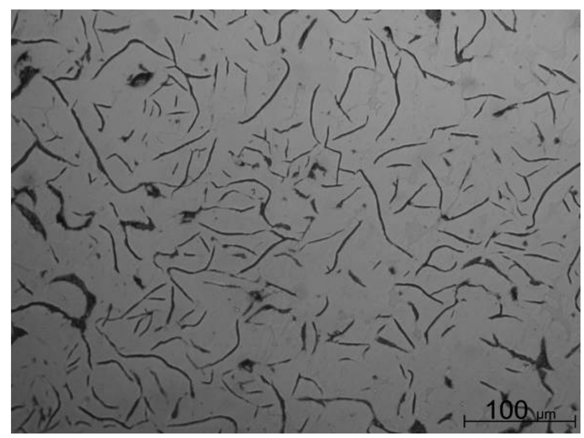

Fig.6. Microstructure of grey cast iron EN-GJL-200 after cast to shell mould with influence of rotate electromagnetic field

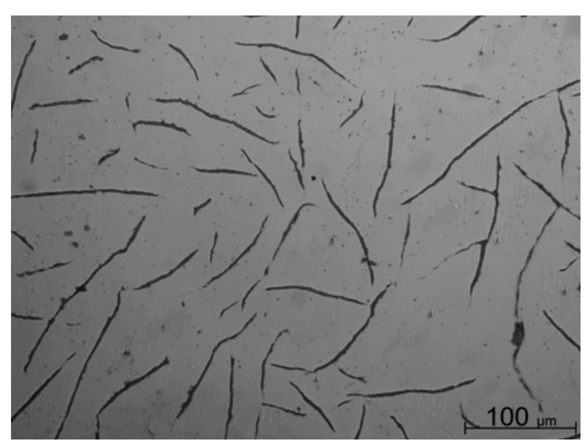

Fig.7. Microstructure of grey cast iron EN-GJL-200 after cast to Sibral mould with influence of rotate electromagnetic field

Graphic interpretation of equation (1) for grey cast iron casting with influence of electromagnetic field i.e. B = 60mT and for casting without and with influence of different types of rotate electromagnetic field are shown in fig.8 and 9.

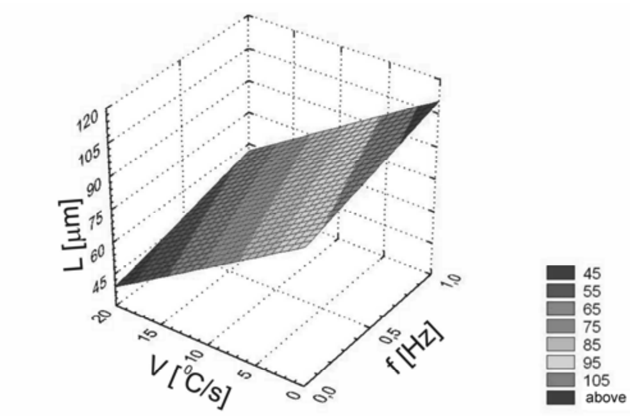

Fig. 8. Average length of flake graphite (L) in structure of grey cast iron EN-GJL-200 in function of pulse frequency of electromagnetic field (f) and cooling rate (V) – for casting with influence of electromagnetic field about value of magnetic induction B = 60mT

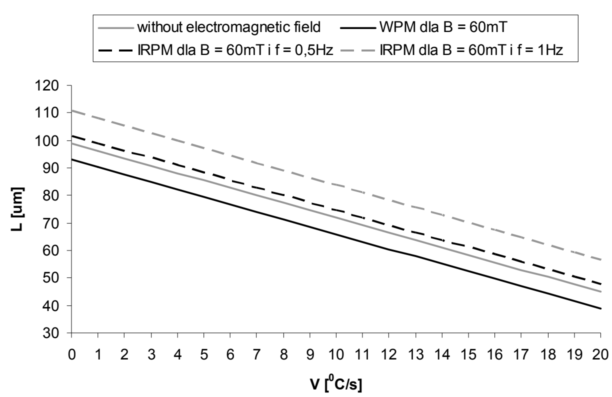

Fig.9. Influence of cooling rate in temperature range $T_{ZAL} \div T_L$ (V) on average length of flake graphite (L) in structure of grey cast iron EN-GJL-200 for casting without and with influence of electromagnetic field

4. Summary

Based on the analysis of research results, it was found that the use of electromagnetic field forced convection of liquid metal in the form, at a specified cooling rate in the range of T_{ZAL} - T_L to effectively interact with the size and shape of graphite flakes in the structure of grey cast iron. In addition, it is shown that a greater degree of fragmentation of graphite flakes is provided by a unidirectional rotating electromagnetic field (WPM) in contrast to the casting of pure metals such as Al [6, 7], for which the use of the rotate electromagnetic field with reversion and with a pause between following changes of rotation direction is advised.

Further studies will address the influence of casting in the electromagnetic field on the distribution (represented by the interfacial distance λ) of graphite flakes in the structure of grey cast iron and the influence on the pearlitic matrix as a result of the impact on austenite, which nucleates on graphite.

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