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Influence of electromagnetic field on the morphology of graphite in structure of 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 mould or continuous casting mould. This paper presents the results describing the influence of selected parameters of rotate electromagnetic field enforcing the movement of liquid metal in the mould on the morphology of graphite in grey cast iron. Different form of flake graphite was obtained in conditions of changes in the rate of liquid metal solidification in the range of pouring and liquidus temperature $T_{ZAL} \div T_L$ and casting with the influence of electromagnetic field.

Keywords: Cast iron, Graphite, Electromagnetic field

1. Introduction

Forced convection of liquid metal in the mould 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].

So far, the influence of electromagnetic fields in order to unification the structure has been successfully applied in the casting of steel [3÷5] and non-ferrous metals [6÷9]. For example on figure 1 is presented influence of casting in rotate electromagnetic field on unification and reduction of grain size in macrostructure of pure aluminium of type EN AW-Al99,5 ingots.

In contrast, the paper presents the possibility of influence of the electromagnetic field on the solidifying metal to unification the structure of grey 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.

a) b)

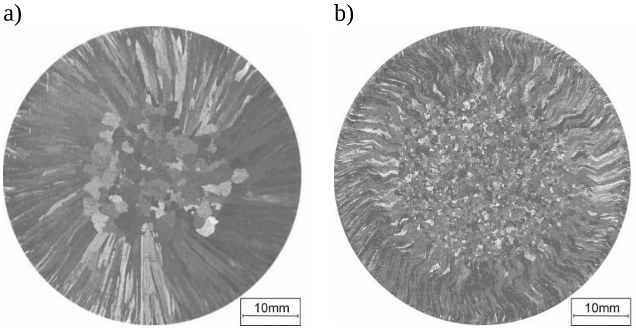


Fig. 1. Macrostructure of pure aluminium of type EN AW-Al99,5 ingot in initial state (a) and after casting with influence of electromagnetic field (b) [9]

Moreover correlations between parameters of casting process and morphology of graphite, which was steady in statical conditions, will be applied to realization of production of grey cast iron continuous ingots with unified structure on all section at use of continuous casting mould, which has electromagnetic stirrer (fig.2).

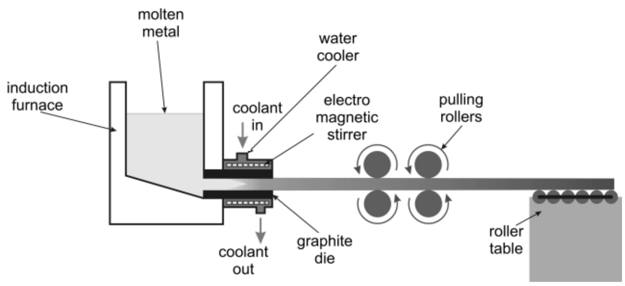


Fig. 2. Scheme of stand to continuous casting of grey cast iron ingots with circular section

2. Range of studies

The aim of studies was to determine a qualitative influence of selected parameters of hypereutectic grey cast iron casting in electromagnetic field on flake graphite morphology.

On figure 3 is presented scheme of test stand to grey cast iron EN-GJL-200 casting with influence of rotate electromagnetic field. Constant value of current intensity 10A feeding inductor, responds value of magnetic induction 65mT.

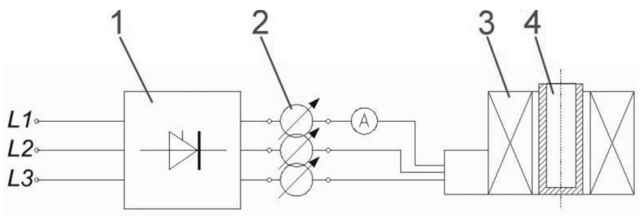


Fig. 3. Scheme of test stand: 1 – inverter, 2 – autotransformer, 3 – inductor, 4 – mould containing liquid metal, A – ammeter

By application of inverter was realized changes of frequency of supply voltage, which at constant value of current intensity makes possible regulation of inductor power and force, which generating the movement of liquid metal (fig.4) and in result of this the velocity of liquid metal movement in mould (fig.6).

Value of force, which generating the movement of liquid metal and distribution of the velocity on radius of ϕ20mm casting, were calculated with use of ANSYS software, according to model, which is presented on figure 5. This model contains 230 thousands finite elements in which 180 thousands contains field of cast iron ingot.

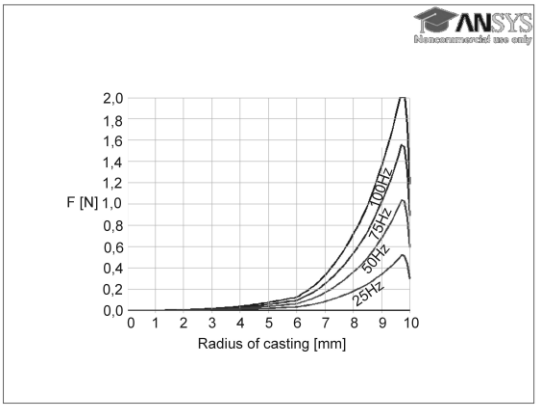


Fig. 4. Influence of frequency of supply voltage f on value of force F, which generates liquid metal movement

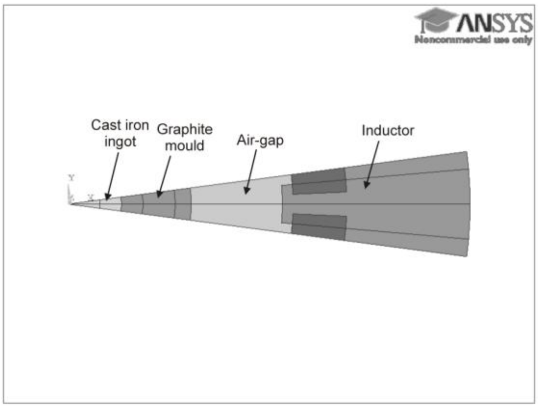


Fig. 5. Part of model to force and velocity of liquid metal movement calculations

In range of studies of grey cast iron EN-GJL-200 were cast standard ingots of 200mm length and diameter ϕ20mm, without influence of electromagnetic field and ingots with influence of rotate electromagnetic field. Full experimental plan is presented in table 1.

In studies was used different rate of liquid metal solidification by application of mould materials, which have different thermal conductivity λ_c. In first case was used mould from sand with phenolic-formaldehyde resin (shell mould) - λ_c=1,5 W/(m·K) with rate of liquid metal solidification 10°C/s in range of pouring

T_{ZAL} = 1450°C and liquidus temperature T_L = 1225°C. In second case was used aluminosilicate insulating material Sibral SI-R30 - λ_c=0,35 W/(m·K) with rate of liquid metal solidification 2°C/s in temperature range $T_{ZAL} \div T_L$.

Table 1.
Full experimental plan

Sample number	Supply and work parameters of inductor					Parameters of movement and solidification of liquid metal in mould		
	Frequency of supply voltage f [Hz]	Voltage U [V]	Current intensity I [A]	Power P* [kW]	Velocity of rotating field n [rot/min]	Force of liquid metal movement F [N]	Velocity of liquid metal movement V** [m/s]	Rate of liquid metal solidification in range $T_{ZAL} \div T_L$ V_{ch} [°C/s]
1	-	-	-	-	-	-	-	10
2	25	70	10	0,602	750	0,5	0,11	
3	50	50		0,430	1500	1,0	0,22	
4	75	70		0,602	2250	1,4	0,32	
5	100	80		0,688	3000	1,9	0,43	
6	-	-	-	-	-	-	-	2
7	25	70	10	0,602	750	0,5	0,11	
8	50	50		0,430	1500	1,0	0,22	
9	75	70		0,602	2250	1,4	0,32	
10	100	80		0,688	3000	1,9	0,43	

* - at power factor cosφ = 0,86, **- lineal velocity for radius of ingot r = 10mm

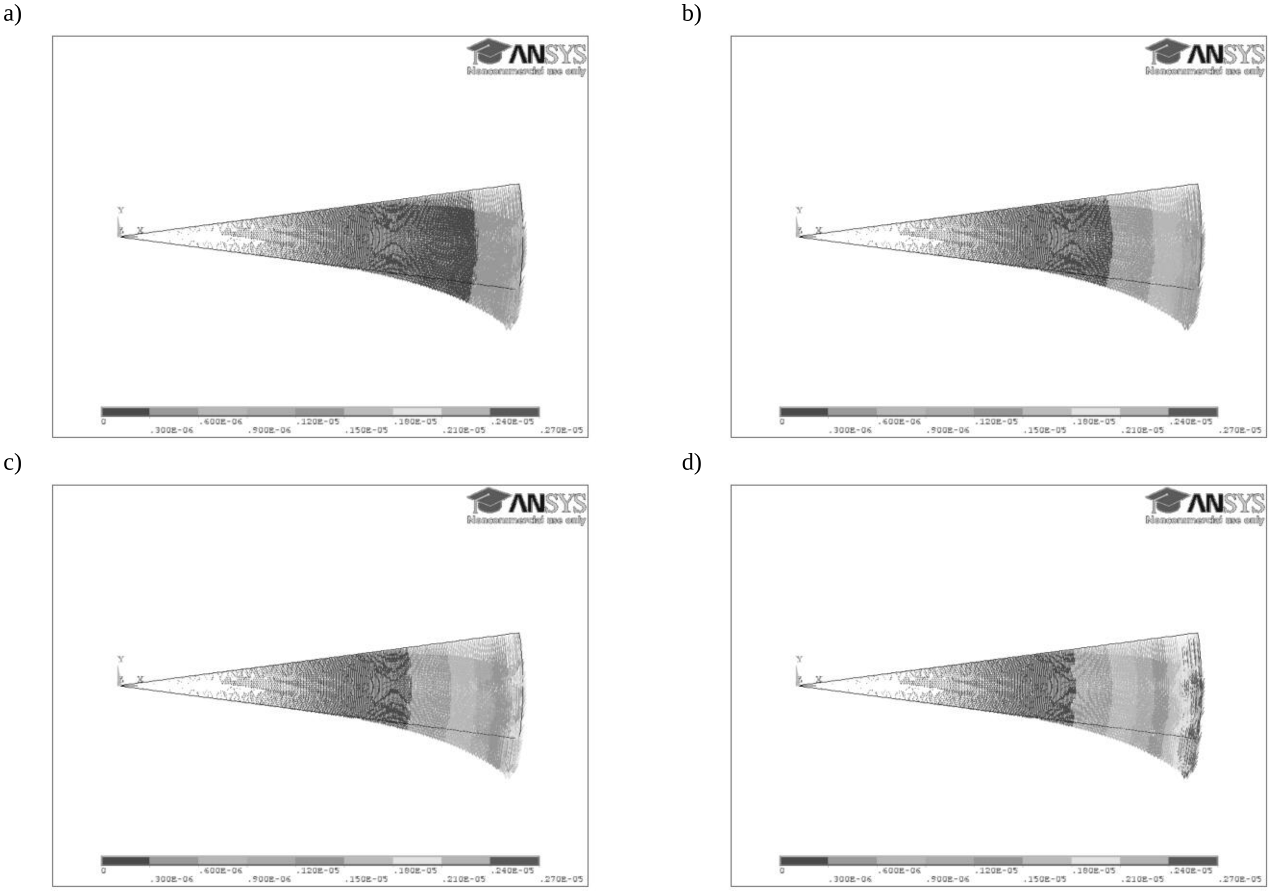


Fig. 6. Influence of frequency of supply voltage f on distribution of velocity V on radius of liquid metal movement in cylindrical mould ϕ20mm: a) 25Hz, b) 50Hz, c) 75Hz and d) 100Hz

Table 2.
Microstructures of grey cast iron EN GJL-200 after cast to shell mould without and with influence of rotate electromagnetic field at parameters from table 1 – non-etch microsection, magnification 200x.

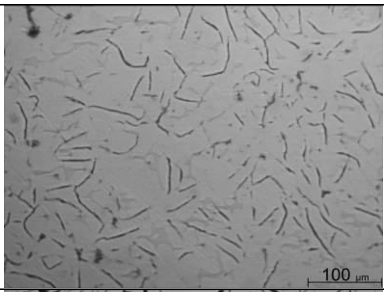
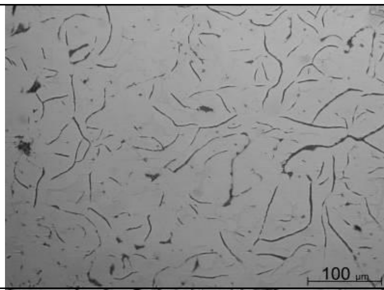
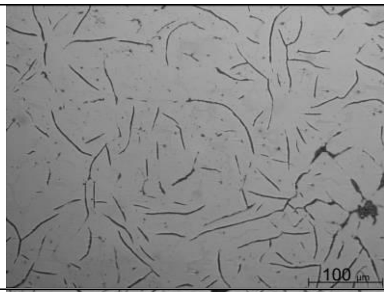
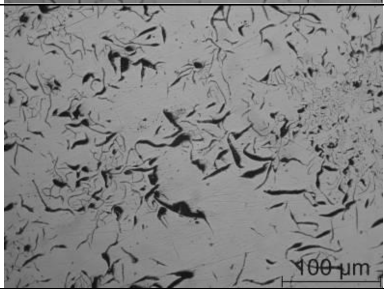
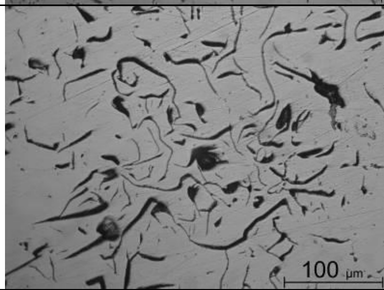
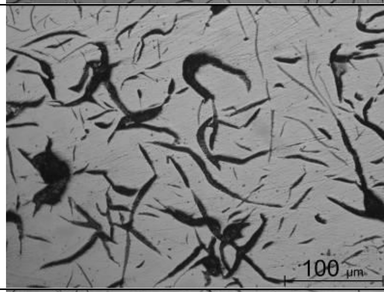
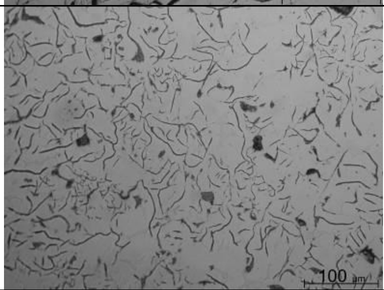
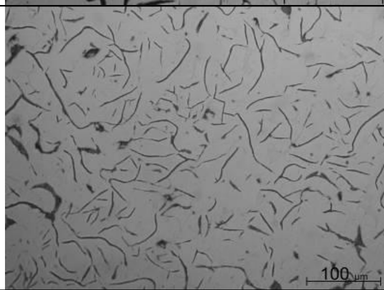
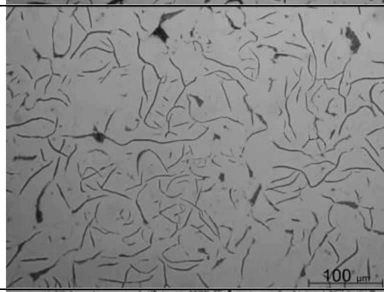
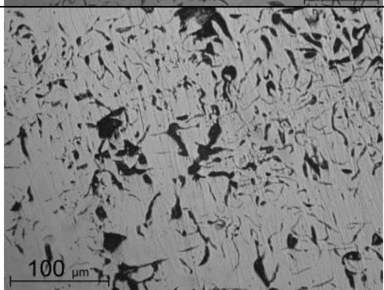
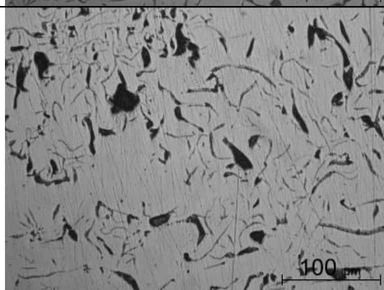
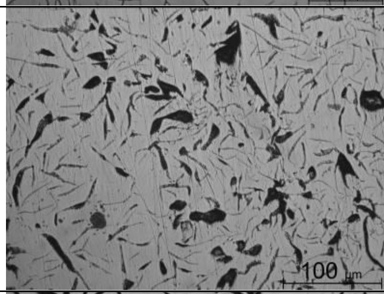
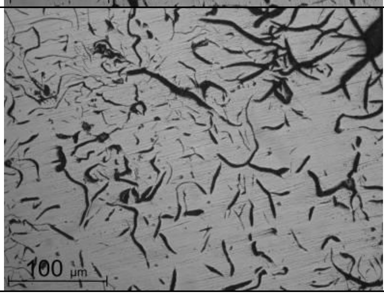
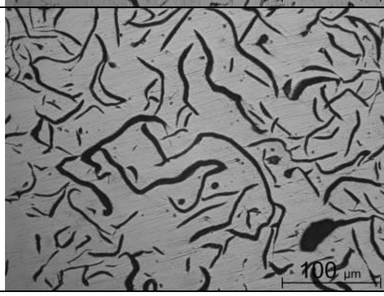
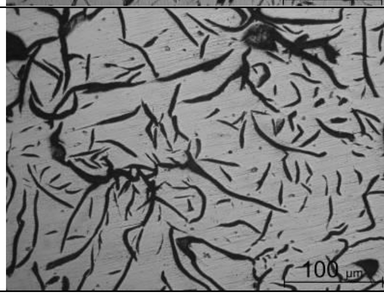
Sample number	Number of measurement fields from fig.7		
	1	2	3
1			
2			
3			
4			
5			

Table 3.
Microstructures of grey cast iron EN GJL-200 after cast to sibral mould without and with influence of rotate electromagnetic field at parameters from table 1 – non-etch microsection, magnification 200x.

Sample number	Number of measurement fields from fig.7		
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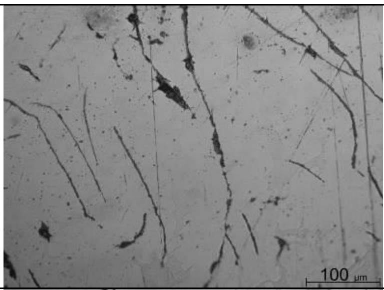
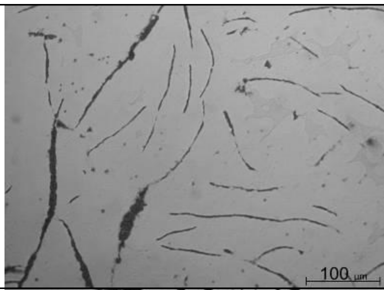
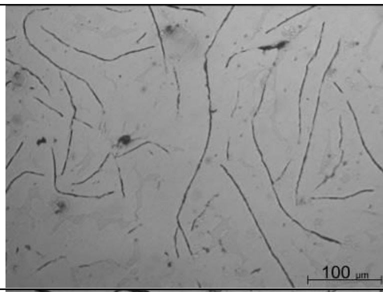
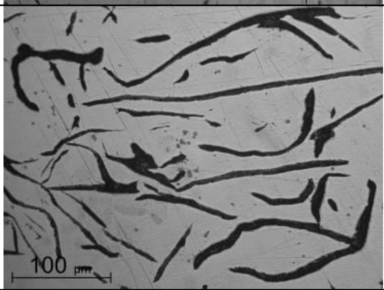
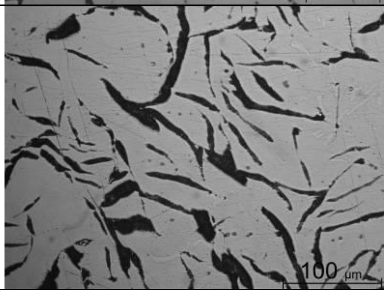
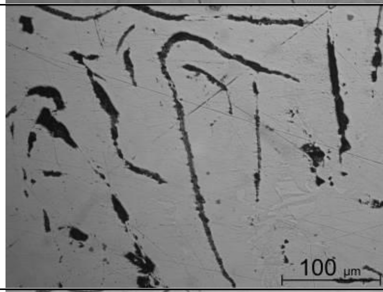
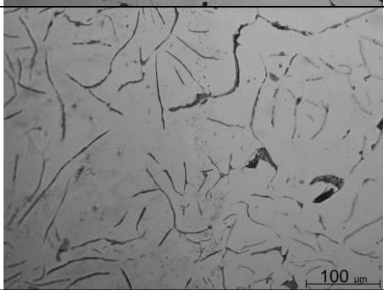
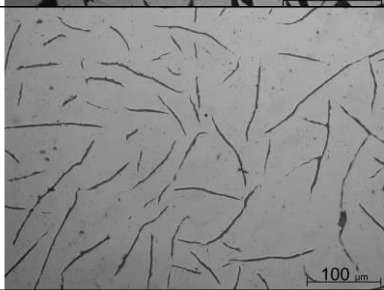
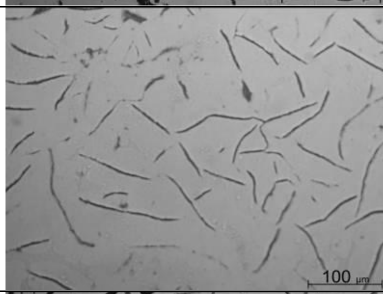
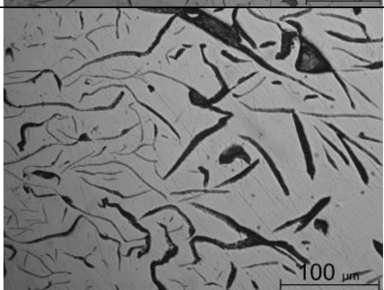
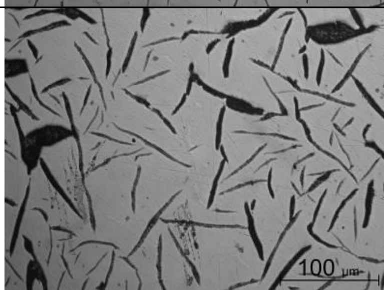
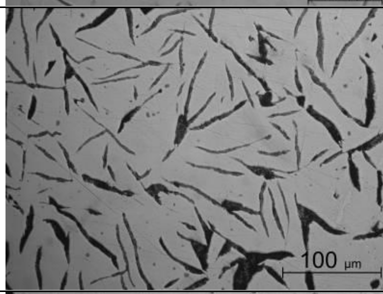
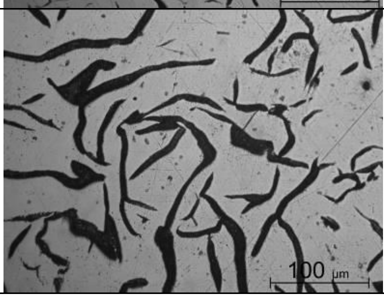
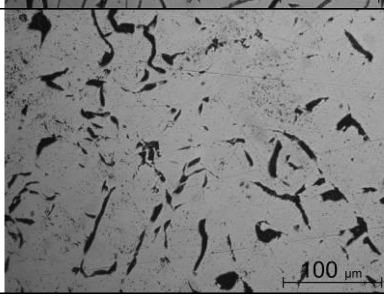
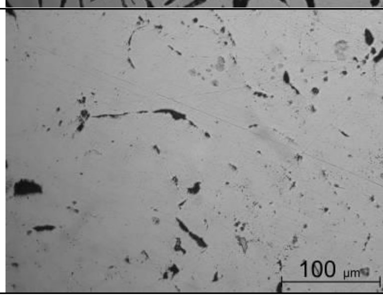
6			
7			
8			
9			
10			

Morphology of flake graphite in structure of investigated grey cast iron was evaluated in bases of metallographic microscopic examinations of measurement fields on cross-section of ingots i.e. in periphery (1), half of radius (2) and centre (3) (fig.7).

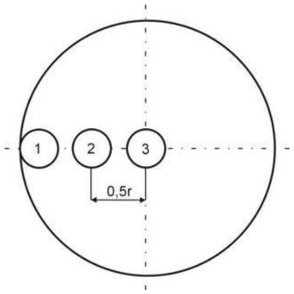


Fig.7. Scheme of measurement fields on cross-section of ingot

3. Results of studies

Table 2 and 3 compares the results of the metallographic microscopic examination of grey cast iron after casting without and with the influence of rotate electromagnetic field, adequately in the shell and sibral moulds. In both cases, the influence of electromagnetic field on the characteristics of flake graphite divisions is visible. Compared to the microstructure of the standard ingots (sample 1 and 6), the use of rotate electromagnetic field with frequency of supply voltage different from the power network, i.e. 25, 75 and 100Hz promotes the formation of graphite with a higher volume and is considerably different in the form then the flake graphite, especially at higher solidification rates in the range of $T_{ZAL} \div T_L$ (samples 2, 4 and 5).

In contrast, the use of electromagnetic field generated by powering the inductor with network frequency 50Hz, both at the rate of liquid metal solidification in range $T_{ZAL} \div T_L$ 2 and 10 °C/s (samples 3 and 8) allows to get shorter and evenly spaced divisions of graphite flakes compared to ingots, which were cast without the influence of electromagnetic field.

Moreover, it was found that by increasing the frequency of supply voltage of inductor and consequently increase the force, which generating the movement of liquid metal, and the velocity of rotation in the mould, follows a "throwing away" of the eutectic cells from the central areas of the ingot and their concentration in the outer zone (sample 10). These phenomena concerns particularly ingots, which were cast with the influence of electromagnetic field in sibral moulds in which due to their low thermal conductivity, metal is in a liquid state for a few dozen seconds longer after pouring, which lengthens the time of influence of the rotate electromagnetic field in comparison to the process of casting in shell moulds with the same supply and work conditions of the inductor.

In addition, a reduction in the solidification rate favors the achievement of much longer divisions of flake graphite, which results from the crystallization mechanism of the irregular grey cast iron eutectic, which has been described in detail in [10 and 11].

4. Summary

Based on the analysis of research results, it was found that the use of electromagnetic fields forced convection in liquid metal, can effectively influence on the size and shape of flake graphite in the structure of grey cast iron.

In order to improve the unification of flake graphite in relation to the initial state, it is recommended to use casting with the electromagnetic field produced by the inductor with a frequency of 50Hz or possibly in the case of small solidification rates in the range of $T_{ZAL} \div T_L$, the frequency of 75Hz is also acceptable.

At the moment, a research on the influence of the electromagnetic casting on the pearlitic matrix as a result of the influence on increasing the amount of austenite grains, which nucleates on graphite in the examined hypereutectic grey iron is being conducted. Simultaneously a continuous casting station is being examined.

Acknowledgements

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