Archives of Materials Science and Engineering

Volume 42
Issue 1
March 2010
Pages 45-52

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Influence of continuous casting conditions on grey cast iron structure

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Received 15.01.2010; published in revised form 01.03.2010

ABSTRACT

Purpose: The main aim of investigations was the unification of flake graphite morphology in cast iron ingots in conditions of forced convection of liquid metal in the continuous casting mould, which contains electromagnetic stirrer.

Design/methodology/approach: To investigations of grey cast iron ingots were used laboratory stand of continuous casting, which contains continuous casting mould with inductor of rotate electromagnetic field. To investigations were made metallographic researches on scanning electron microscope and investigations of usable properties i.e. measurements of hardness and machinability.

Findings: The results of investigations and their analysis show possibility of unification of flake graphite morphology in cast iron structure, and distribution of hardness on cross-section of ingot and its machinability.

Research limitations/implications: In further research, authors of this paper are going to application of introduced method of continuous casting with use of electromagnetic field in industrial tests.

Practical implications: The work presents method of unification of structure and properties, which are particularly important in continuous casting. Uniform morphology of flake graphite in structure of cast iron ingots for automobile industry is very important in viewpoint of machinability.

Originality/value: Contributes to improvement in quality of grey cast iron continuous casted ingots.

Keywords: Casting; Cast iron; Graphite; Electromagnetic field

Reference to this paper should be given in the following way:

J. Szajnar, M. Stawarz, T. Wróbel, W. Sebzda, B. Grzesik, M. Stępień, Influence of continuous casting conditions on grey cast iron structure, Archives of Materials Science and Engineering 42/1 (2010) 45-52.

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Forced convection of liquid metal in the traditional mould or in 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 [1, 2]. 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 lines, which contain inductive stirrers [3-5].

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) [5, 6].

So far, the influence of electromagnetic fields in order to unification the structure has been successfully applied in the casting of steel [4, 5, 7-10] and non-ferrous metals [3, 11-13]. For example in Fig. 2 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.

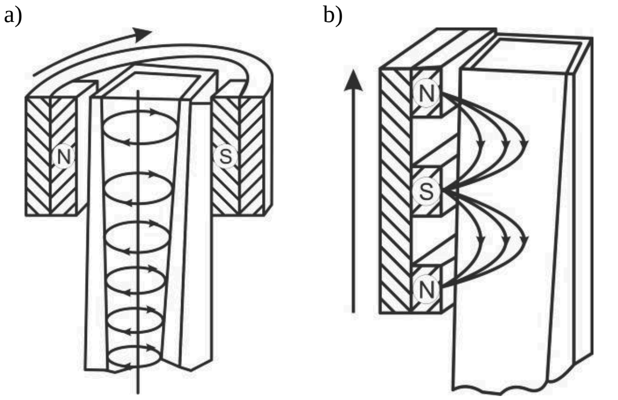


Fig. 1. The scheme of an electromagnetic stirrer enforcing (a) rotary reversion, and (b) oscillatory motion of liquid metal along the axis originating ingot [5]

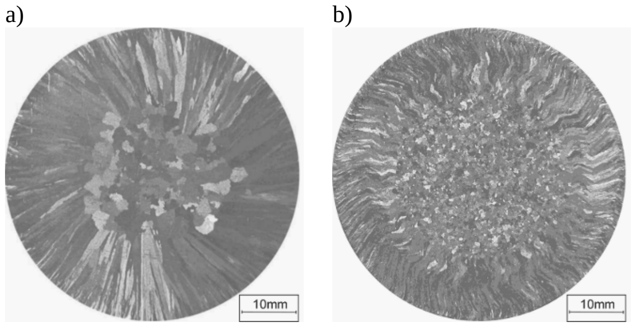


Fig. 2. Macrostructure of pure aluminium of type EN AW-Al99,5 ingot in initial state (a), and after casting with influence of rotate electromagnetic field (b) [11]

In contrast, the papers [14, 15] present 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 in continuous casting mould.

2. Range of studies

The main aim of studies was to determine the influence of rotate electromagnetic field on graphite morphology in structure of grey cast iron of type EN GJL-200 (Table 1) in continuous casting method.

To investigations of grey cast iron ingots ϕ20 mm were used laboratory stand of continuous casting, which is placed in Foundry Department of Silesian University of Technology.

The most essential element of continuous casting stand (Fig. 3) is water-cooled continuous casting mould, which contains inductor of rotate electromagnetic field (Fig. 1a). Application of this type of electromagnetic field makes possible obtainment of forced convection of liquid metal in perpendicular plane to ingot axis.

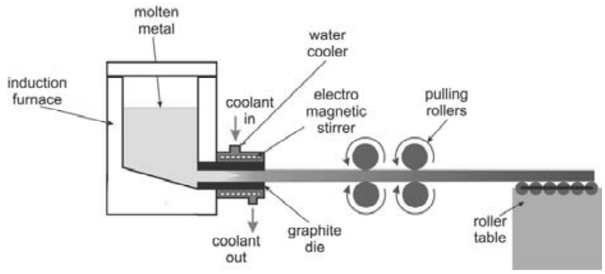


Fig. 3. Scheme of stand to continuous casting of grey cast iron ingots with circular section

To fundamental steering parameters of inductor work belong:

- current intensity feeding the inductor I [A], which increase result in increase in value of magnetic induction inside of continuous casting mould (Fig. 4),

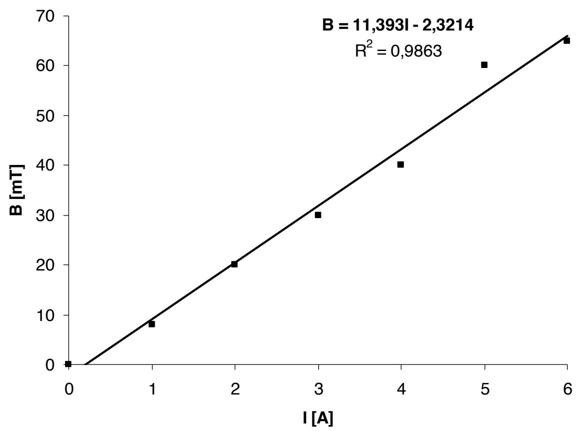


Fig. 4. Influence of current intensity I on magnetic induction B

- frequency of supply voltage f [Hz], which at constant value of current intensity makes possible regulation of inductor power and force F (Fig. 5), which generating the movement of liquid metal and in result of this the velocity of liquid metal movement in continuous casting mould V_{cm} (Fig. 6).

Table 1.
Chemical composition of grey cast iron EN GJL-200 (mass. %)

C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Al	Ti	Fe
3.870	2.090	0.300	0.033	0.034	0.413	0.002	0.014	1.023	0.008	0.025	92.208

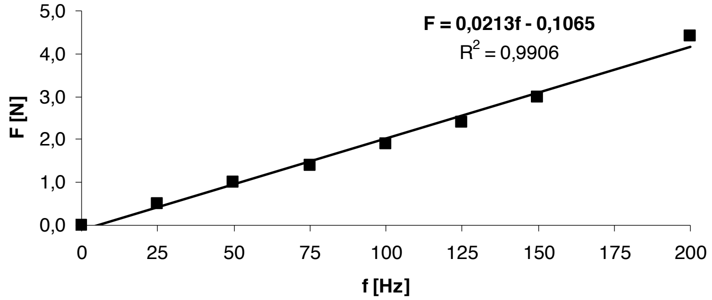


Fig. 5. Influence of frequency of supply voltage f on force F, which generates liquid metal movement at radius of ingot 10 mm

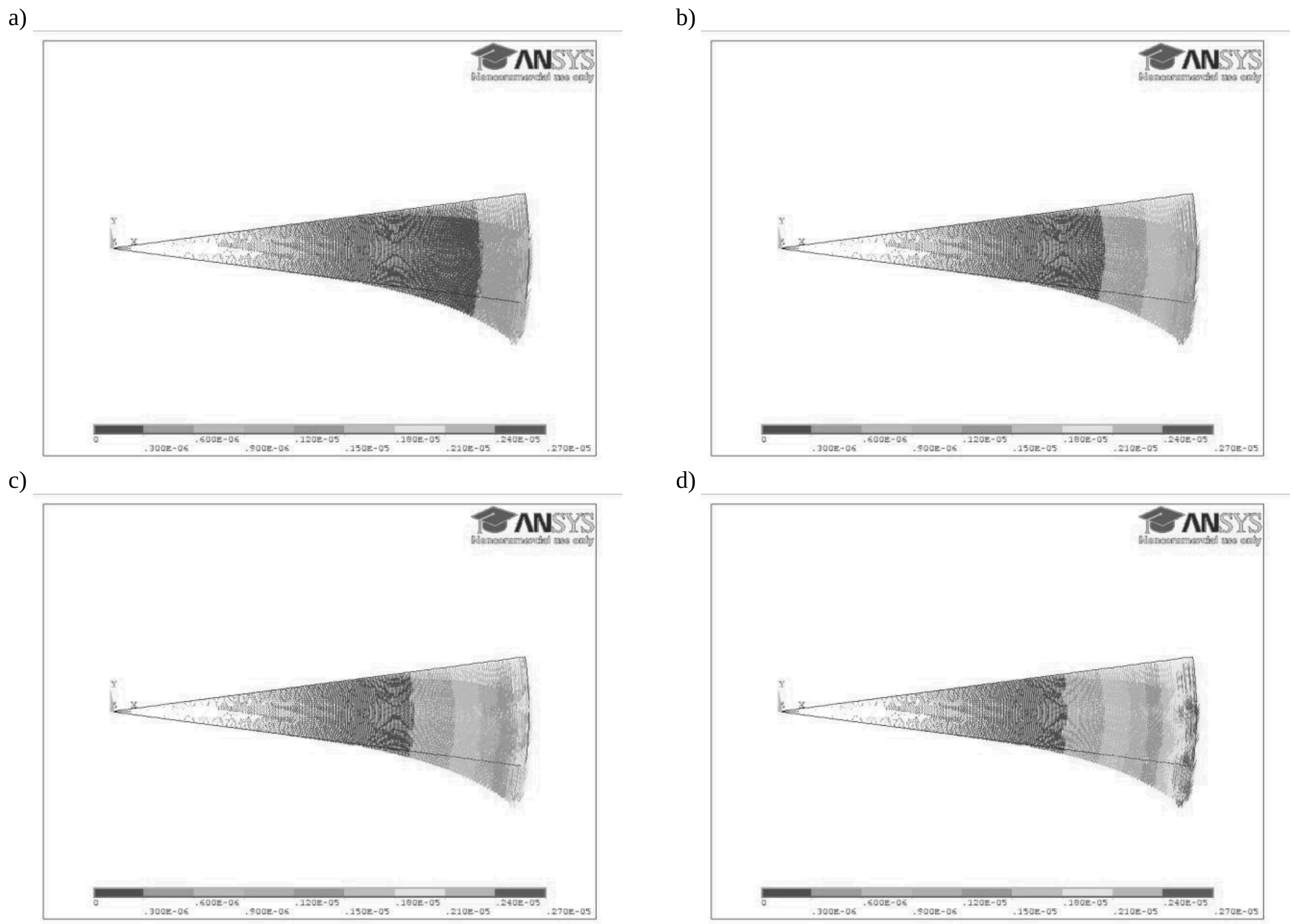


Fig. 6. Influence of frequency f of supply voltage on distribution of velocity V_{cm} of liquid metal movement at radius of ingot 10 mm: a) 25 Hz, b) 50 Hz, c) 75 Hz and d) 100 Hz

To residual parameters of investigated continuous casting belong:

- overheating temperature of liquid metal in furnace T [°C],
- temperature of cooling water in continuous casting mould T_w [°C], which value depend on set flow rate Q_w [l/min],
- velocity of ingot pulling V [mm/min],
- temperature of ingot after leaving the continuous casting mould T_0 [°C], which value depend on all presented parameters. This temperature is measured directly in casting process with use of pyrometer PZ20 AF1/D KELLER.

Process of continuous casting of grey cast iron ingots with 20 mm diameter was realized with following assumptions: T = 1450°C, T_w = 70°C at flow rate Q_w = 2,5-5 l/min in dependence of velocity of ingot pulling V = 200÷700 mm/min. Temperature of ingot after leaving the continuous casting mould, in dependence of velocity of ingot pulling, was T_0 = 300÷1000°C. Value of magnetic induction inside the continuous casting mould was 60 mT.

Simulation of solidification process of grey cast iron ingot in continuous casting mould was made with use of ANSYS software, according to model contains 230 thousands finite elements in which 180 thousands contains field of cast iron ingot.

Morphology of flake graphite in structure of investigated grey cast iron was evaluated in bases of metallographic microscopic examinations on scanning electron microscope InspectF with EDS. Observation of microstructure was made on non-etch microsections in fields: on periphery, half of radius and in axis of ingot.

In range of studies of usable properties were made measurements of hardness on cross-section of ingots with use of Brinell method and designation of machinability with use of Keep-Bauer method. To machinability studies was used cutting tools (borer ϕ5 mm) with identical contour and angles, which were burdened of force 350 N. Rotational speed of tools was 360 turns on minute and height of samples was 20 mm. In each investigated ingots were bored 3 test-hole and time of boring was measured.

3. Results of studies

In Fig. 7 the influence of velocity of ingot pulling on the quantity of hard spots in structure of cast iron is shown. It was found that with an increase in velocity of ingot pulling the amount of cementite in the structure of cast iron is decreasing, assuming the other casting parameters remain unchanged. The most advantageous velocity of ingot pulling V = 700 mm/min provides low cooling rate of cast iron, because of its short stay time in area of the water-cooled continuous casting mould. Then the temperature of ingot after leaving the continuous casting mould is about 1000 °C, and a large part of the process of shaping the final structure of the cast iron takes place during cooling in air.

The maximum velocity of ingot pulling depends on the position of the crystallization front (Fig. 8). An increase of velocity of ingot pulling over the 700 mm/min results in shifting of the crystallization front outside the continuous casting mould. Then liquid metal pours on the outside of continuous casting mould.

In Table 2 are presented the results of metallographic microscopic examinations of ingots, which were cast at velocity of pulling V = 700 mm/min. As a result of obtaining a small amount of cementite and the irregular shape and distribution of graphite in the microstructure there is a gradient of hardness in cross-section of the ingot (Fig. 9), which consequently caused a deterioration in machinability (Fig. 10). By contrast, the use of electromagnetic field forced convection of the solidifying metal result in increases of the unification of flake graphite morphology. This phenomenon has been advanced especially by the influence of the electromagnetic field created in the inductor powered with a frequency of 50 Hz. Whereas the influence of the application of rotate electromagnetic field powered with the frequency different from the power network, i.e. 25, 75 and 100 Hz promotes partial unification of the graphite morphology, only in fields from about half of radius of ingot to its center. On the periphery of the ingot, occur undesirable in the point of view of usable properties i.e. machinability (Fig. 9) short and compact graphite, often with a different shape then the flake graphite.

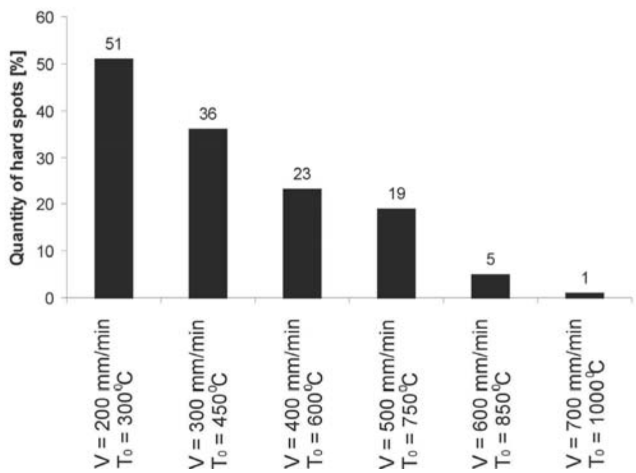
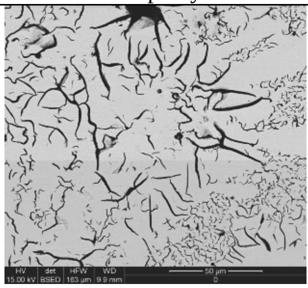
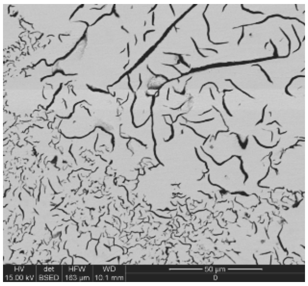
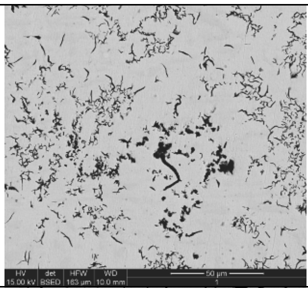
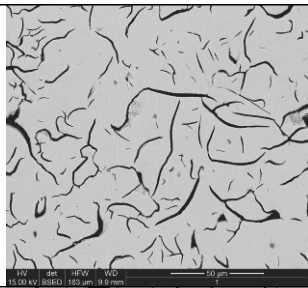
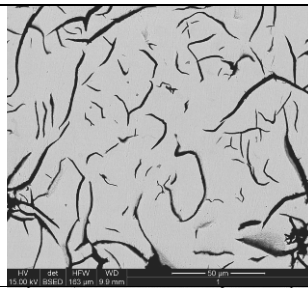
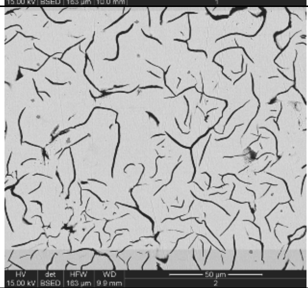
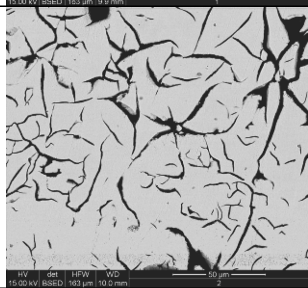
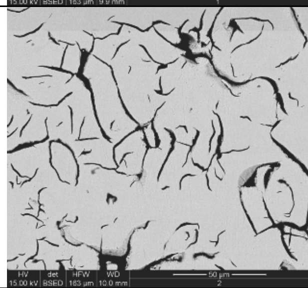
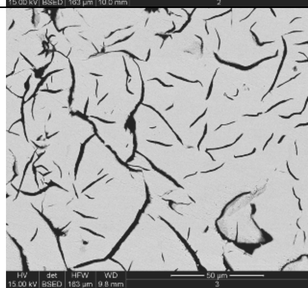
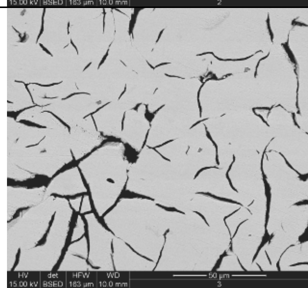
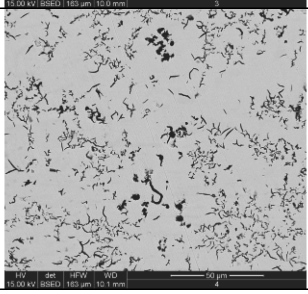
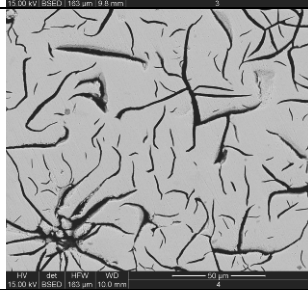


Fig. 7. Influence of the velocity of ingot pulling V on percentage quantity of hard spots in structure of grey cast iron (at definite value of the temperature of ingot after leaving the continuous casting mould T_0)

Table 2.
Microstructures of grey cast iron EN GJL-200 ingot after cast in continuous casting mould, which contains inductor of rotate electromagnetic field - non-etch microsection

Sample specification	Field of observation		
	Periphery	Half of radius	In axis
Electromagnetic field: lack			
Electromagnetic field: present B = 60 mT, f = 25 Hz			
Electromagnetic field: present B = 60 mT, f = 50 Hz			
Electromagnetic field: present B = 60 mT, f = 75 Hz			
Electromagnetic field: present B = 60 mT, f = 100 Hz			

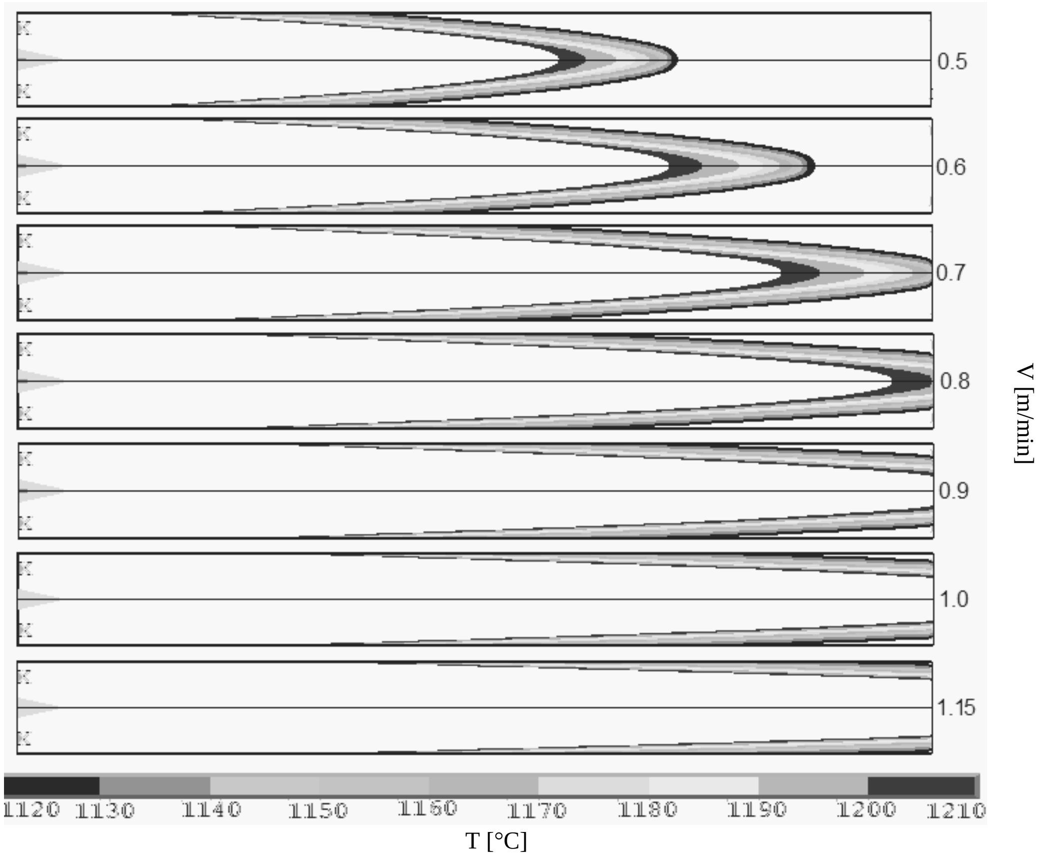


Fig. 8. Influence of the velocity of ingot pulling V on position of crystallization front in continuous casting mould

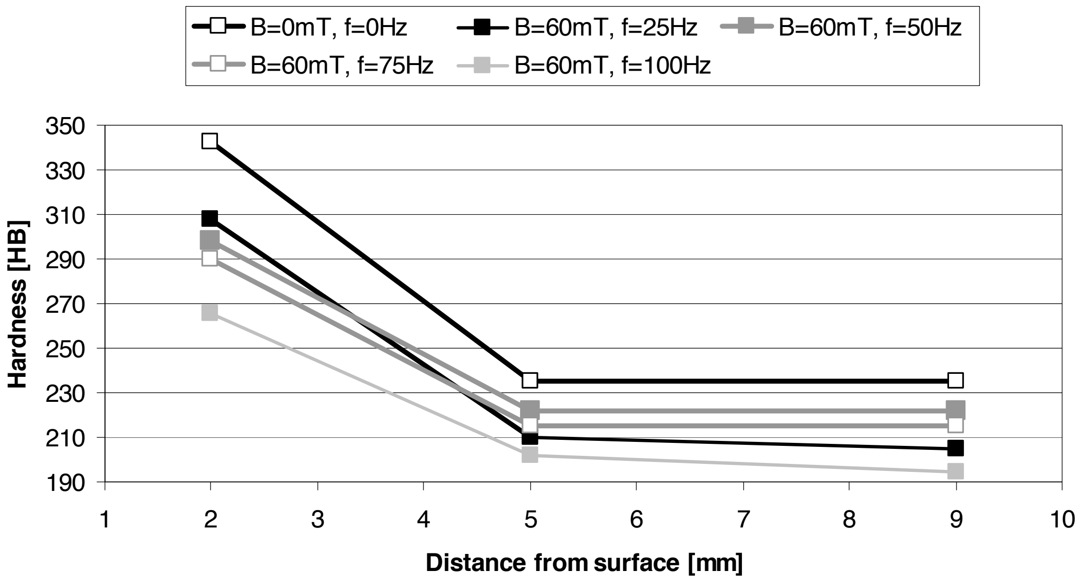


Fig. 9. Influence of the electromagnetic field on hardness distribution on cross-section of grey cast iron continuous ingot

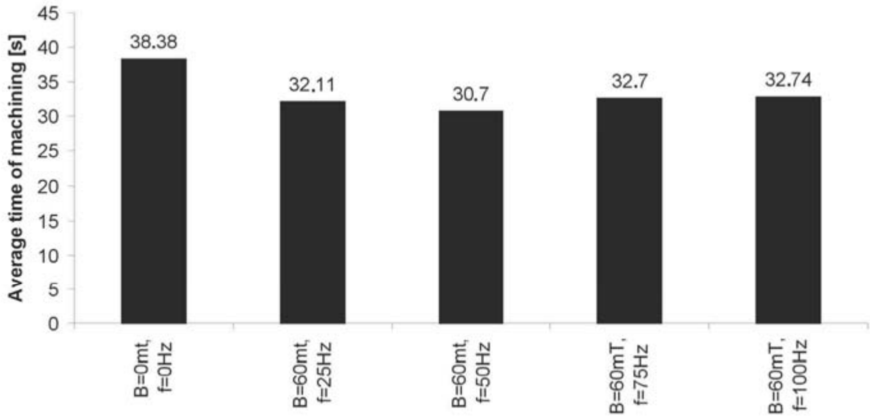


Fig. 10. Influence of the electromagnetic field on machinability of grey cast iron continuous ingot

Unification of the flake graphite morphology results from the change of thermal conditions on the crystallization front of irregular eutectic in grey cast iron, caused by the influence of electromagnetic field forced convection of the liquid alloy in continuous casting mould.

Moreover, the use of electromagnetic field forced convection of liquid metal in time of its solidification in continuous casting mould increases the quality of ingots by completely eliminating the presence of hard spots in structure of grey cast iron.

4. Conclusions

Based on conducted studies following conclusions have been formulated:

- Selection of continuous casting parameters that ensure temperature of ingot after leaving the continuous casting mould about 1000°C, allows to reduce defects in the form of fields of hard spots in structure of grey cast iron to about 1%.
- The change of thermal conditions on the crystallization front obtained as a result of the influence of electromagnetic field forced convection of the solidifying metal in continuous casting mould, ensures complete elimination of the presence of fields of hard spots and leads to unification of flake graphite morphology from consideration of its shape and distribution.
- Increasing the unification of flake graphite morphology is favored by the influence of the electromagnetic field created in the inductor powered with a frequency of supply voltage 50Hz.
- The unification of flake graphite morphology result from the influence of the electromagnetic field provides a reduction in gradient of hardness on cross-section hardness of ingots, which leads to an improvement in their machinability.

Acknowledgements

Scientific project financed from means of budget on science in years 2008-2009 as research project N R07 0002 04.

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