Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 54
ISSUE 1
September
2012

Electromagnetic field impact on the structure of continuous casting of grey cast iron

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Received 02.07.2012; published in revised form 01.09.2012

Manufacturing and processing

ABSTRACT

Purpose: The main aim of investigations was to describe the influence of the electromagnetic on the structure of grey cast iron obtained in the continuous casting process.
Design/methodology/approach: To investigations the grey cast iron ingots a continuous casting laboratory stand was used. The stand contains continuous casting mould with inductor of rotate electromagnetic field. The research includes also the 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, W. Sebzda, M. Stawarz, T. Wróbel, Electromagnetic field impact on the structure of continuous casting of grey cast iron, Journal of Achievements in Materials and Manufacturing Engineering 54/1 (2012) 120-127.

1. Introduction

Increasing demands of modern industry requirements for the quality of the produced castings, force the foundry equipment manufacturers, technologists, and foundry metallurgists to constantly seek ways to optimize the parameters of the production process.

One such process - constantly improving is the process of continuous casting, in which a number of factors (to a greater extent compared to other technologies for implementation) decide on the correct end result. Standard continuous casting lines are equipped with control and command systems, capable of producing continuous casting of different grades of steel, iron or non-ferrous metal alloys.

The Foundry Department of the Silesian University of Technology in Gliwice carried out the work on the use of forced convection of liquid metal in the crystallizer installed on a continuous casting line. Effect of external factors (in particular the electromagnetic field) in the solidifying cast are presented among others in the work [1-11].

For the purposes of the research a laboratory stand (shown in Figure 1) for the continuous casting of cast iron ingots of a 20 mm diameter was designed and built, the stand consists of three components:

- melting part (Fig. 1) consisting of a crucible induction furnace with the following parameters: maximum capacity of the furnace. 80 kg, water inductor cooling in a closed circuit, continuously adjustable power,
- casting part (Figs. 1, 2) consisting of a 20 mm diameter graphite crystallizer and water cooling radiator operating in a closed circuit, equipped with water flow controls and temperature measurement system and a electromagnetic field inducer of the induction up to 100MT placed in the chamber of crystallizer water cooling. The radiator is made of stainless 1H18H9T.
- manual and automatic pulling of continuous ingot part (Fig. 1) with the following technical parameters: the average speed of pulling the ingot 150-1500 mm/min, the possibility of regulating the speed of pulling in a series of manual and automatic traffic characteristics of the ingot pulling algorithm in automatic cycle: forward movement 5-15 sec, stop, backward movement 0.5-2 s, the ingot pulling roller drive with a double set - pulling roll and an overdraft roller moved to and from the ingot by a pneumatic or hydraulic actuator (Figure 1 pos. 4).

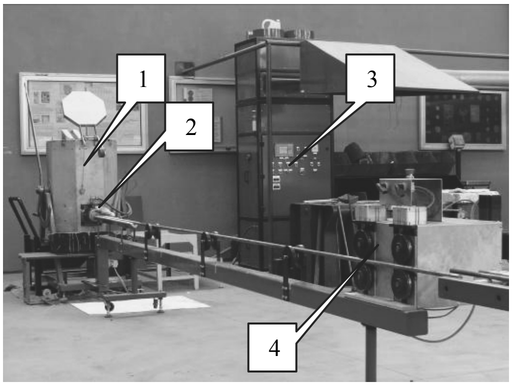


Fig. 1. The continuous casting of cast iron stand in the Foundry Department of Silesian University of Technology: 1 - induction furnace, 2 - crystallizer, 3 - control system, 4 - ingot extraction system

The proper conduct of the continuous casting process is affected by a number of factors such as temperature of metal in the furnace, the temperature of crystallizer water cooling, ingot pulling speed and specification (depending on the pulling algorithm), the temperature at the outlet of the continuous casting crystallizer, the chemical composition of metal furnace, etc.

The above-mentioned parameters can be classified into a group of necessary variables, but insufficient to obtain a grey cast iron ingot with a uniform microstructure of the cross-section. For this reason, the process of continuous casting of cast iron has been "enriched" with another group of parameters controlling the work of the inducer, which is an integral part of the casting part (with the crystallizer and the cooling system).

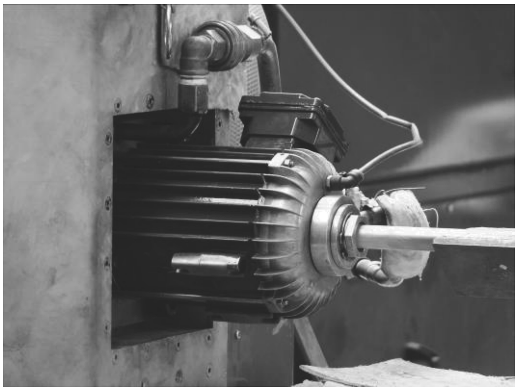


Fig. 2. View the casting crystallizer with the visible electromagnetic field generating inductor

The basic parameters include the intensity of the supply current I. The increase in the value of inductor current causes an increases in the value of the magnetic induction B inside the crystallizer, which intensifies the mixing of the liquid metal in a crystallizer. Another parameter is the inducer voltage frequency f, which allows maintaining a constant value of electrical current while regulating its power and force that enforces the movement of liquid metal F (Fig. 3) and consequently the speed of its rotation in the crystallizer.

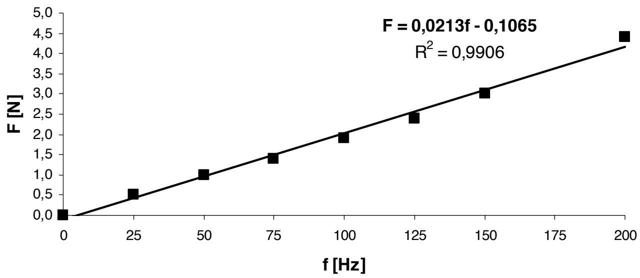


Fig. 3. Effect of power supply frequency f inducer on the force F which enforces the movement of liquid iron in a graphite mould of 20 mm diameter

However it should be noticed that with increasing force that enforces the movement of liquid metal (by increasing the frequency of voltage inducer) adverse events occur. These phenomena are illustrated in Figure 4, where the current density distributions are presented. It may be noted that despite the summary increase in the mixing strength of liquid metal with increasing the frequency, while too large values of frequency intensifies the skin phenomenon effect, which reduces the surface impact of current, and current distributions go asymmetric as a result of excessive speed of rotation of the magnetic field.

These effects also limit the scope of the beneficial changes to the frequency of the electromagnetic stirring, to about 500 Hz.

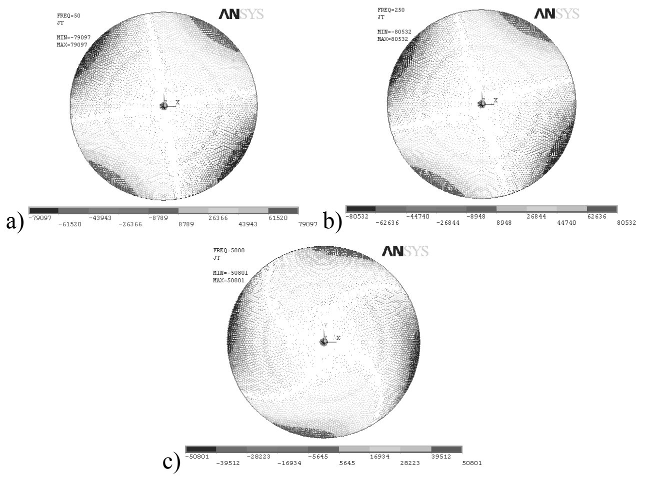


Fig. 4. The distribution of current density in the area of cast metal: a) - 50 Hz, b - 250 Hz, c - 5 kHz

2. Range of studies

The main objective of this study was to determine the effect of electromagnetic field on the structure of gray cast iron EN GJL-250 cast continuously. In order to determine the control parameters of continuous casting process, a series of computer simulations in ANSYS FLUENT program was carried out. Simulations were carried out on a simple two-dimensional model of the ingot-crystallizer shown in Figure 5.

To set up the simulation of the process the most realistic simulation environment conditions were selected [12-16].

Solver
- segregated, implicite, two-dimensional, unsteady, and absolute velocity formulation,

Viscosity model
- turbulent k-ε,

Materials
- grey cast iron GJL-250, 1H18N9T steel, graphite,

Initial conditions
- inlet ingot temperature = 1450°C,
- instantaneous speed of ingot pulling = 0.02 m/s.

Next, to simulate the prepared model (Fig. 5) ingot extraction algorithms have been proposed in Table 1, which summarizes the different times of the ingot movement forward, backward and stops.

Table 1.
Ingot extraction algorithms

Movement type	Movement time [s]		
	A	B	C
forward	Forward movement only	10	5
pause		0.5	0.5
backward		1	1
pause		0.5	0.5

The simulations allowed us to define the initial parameters of the actual process of continuous casting of cast iron. The Data was then used in the real process. Ingot samples obtained by continuous casting, were analysed on microscopic metallographic. Hardness and the machinability tests of samples were also conducted.

3. Results of studies

18 simulations were preformed, which aimed to determine the temperature field as well as the shape and position of the front of crystallization. The paper presents the simulation results for algorithms B and C, recognized as the most optimal due to the location of the crystallization front and the temperature at the outlet of the crystallizer.

In Figures 6 and 7 simulation results are presented in the form of temperature field and the liquid phase amount corresponding to the algorithms B and C. The algorithm A results were omitted because they were not suitable for use in the real process of continuous casting, resulting in pouring liquid metal from the crystallizer. Simulations allow us to conclude that shortening the forward movement causes a displacement of the solid / liquid interface into the mould (i.e. in the direction of the furnace.) As a result of the crystallization front shifting, the temperature at the outlet of the mould was also lowered.

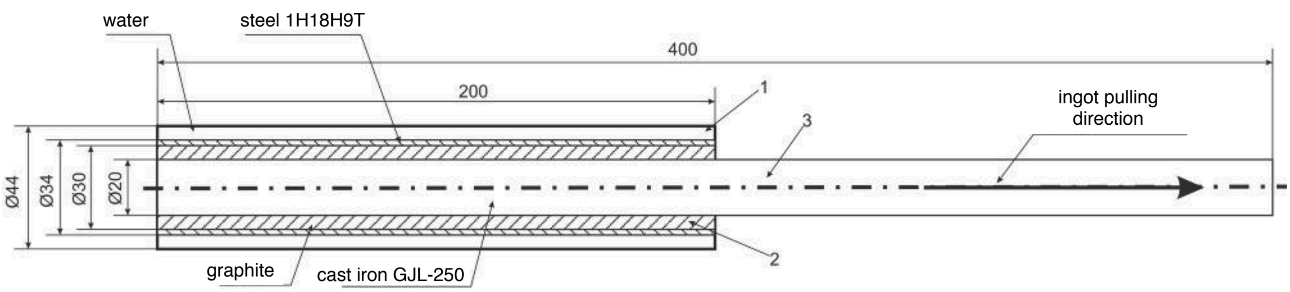


Fig. 5. Model of ingot-cooler-crystallizer used in the program. ANSYS FLUENT 12: 1 - cooler, 2 - crystallizer, 3 - ingot

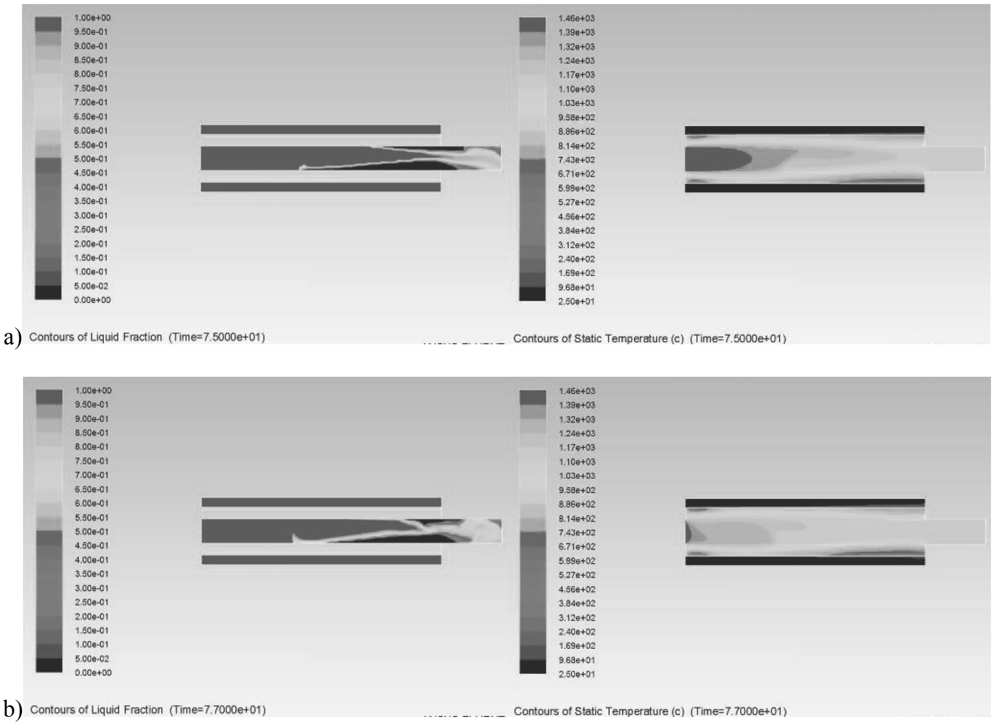


Fig. 6. Algorithm B simulation – model I (respectivly liquid phase amount and temperature field): a) forward movement after 75 s, b)backward movement after 77 s

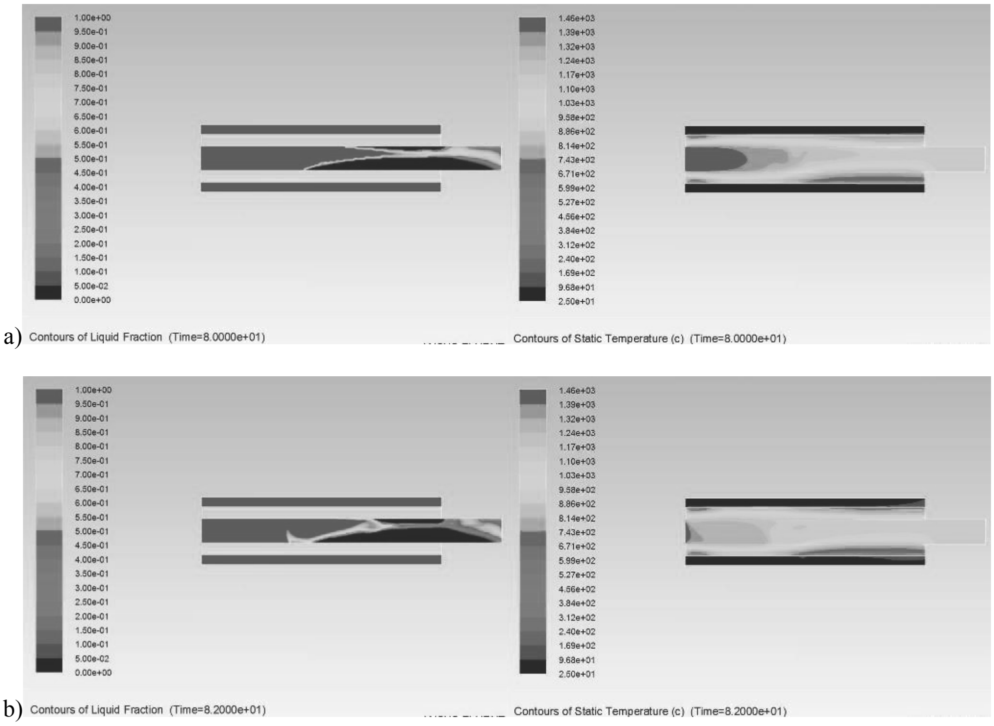


Fig. 7. Algorithm C simulation - model I (respectivly liquid phase amount and temperature field): a) forward movement after 80 s, b) backward movement after 82 s

In Figure 8 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.

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.

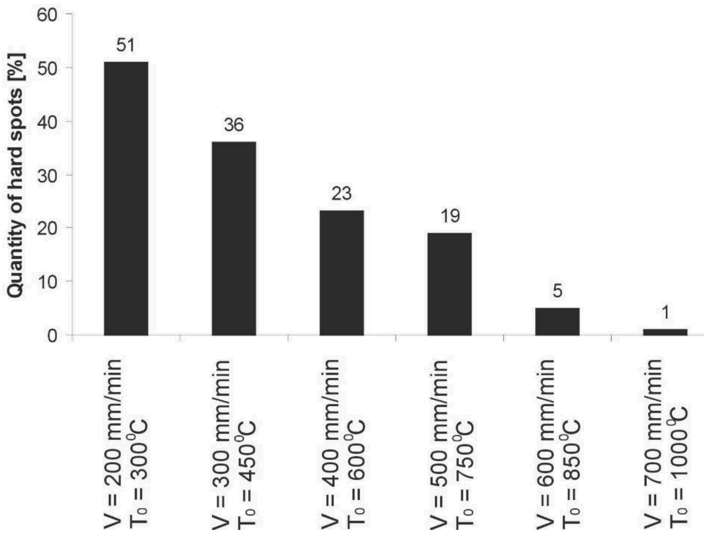


Fig. 8. Influence of the velocity of ingot pulling V on percentage quantity of hard spots in structure of grey cast iron (at definite value of the temperature of ingot after leaving the continuous casting mould T_0)

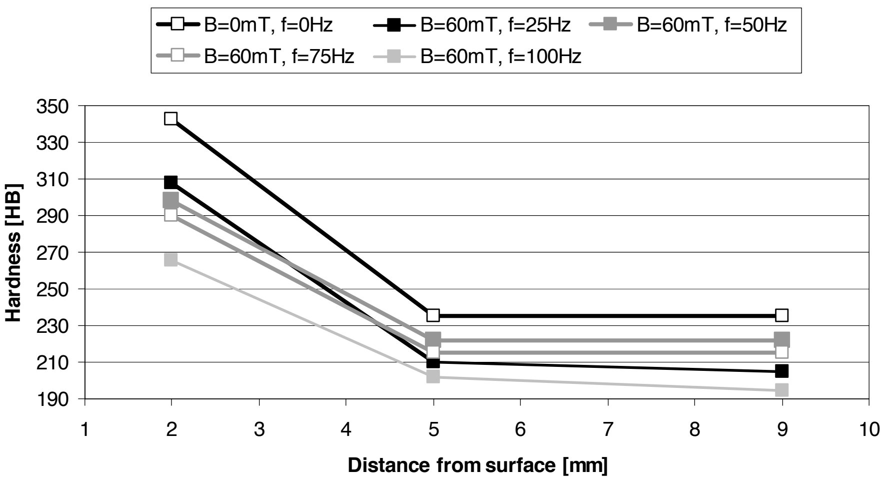
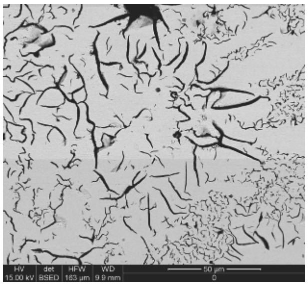
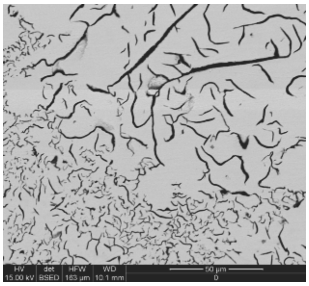
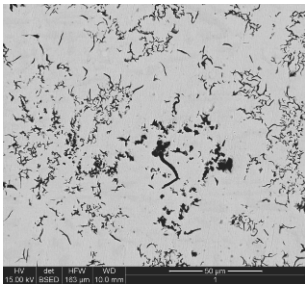
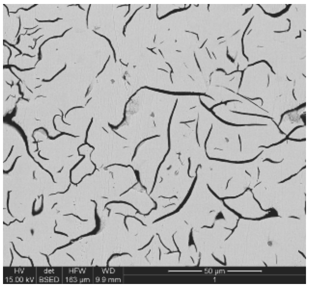
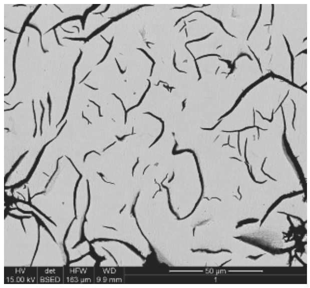
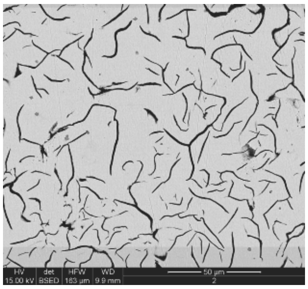
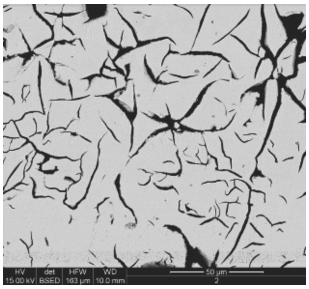
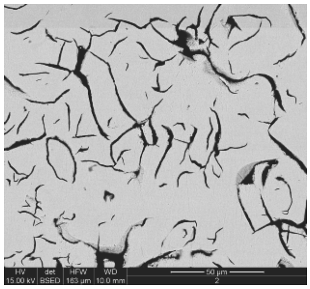
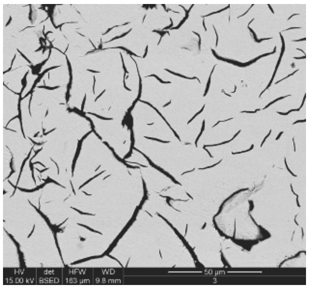
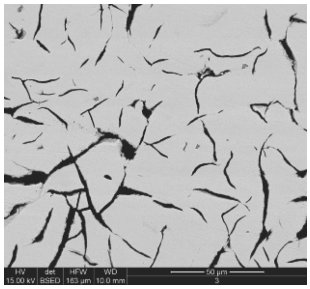
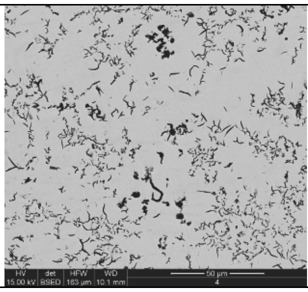
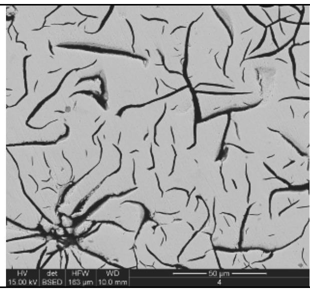


Fig. 9. Influence of the electromagnetic field on hardness distribution on cross-section of grey cast iron continuous ingot

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			

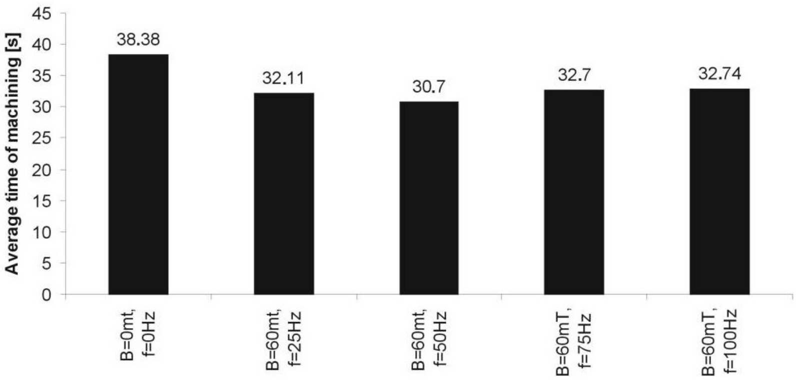


Fig. 10. Influence of the electromagnetic field on machinability of grey cast iron continuous ingot

4. Conclusions

From the simulations in Ansys Fluent 12 following conclusions can be drawn:

- the introduction of backward motion significantly affects the shape and position of the solid / liquid interface and temperature field in the ingot cross section,
- backward movement contributes to the crystallization front shifting in the direction of entry of metal into the crystallizer,
- the shifting of the crystallization front and temperature field in the direction to the crystallizer entry allows for higher pulling speeds of the ingot.
- The largest share of the liquid phase in the crystallizer, allowing the safe conduct of the casting process was obtained by extracting the ingot with the instantaneous speed of 700-1000 mm / min while maintaining the temperature at the exit of the ingot mould at about 1000°C.

Based on conducted studies following conclusions have been formulated:

1. 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%.
2. 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.
3. 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.
4. 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.

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