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Inoculation of pure aluminium structure with Ti+B addition in impulse magnetic field

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Properties

ABSTRACT

Purpose: The main aim of investigations was the reduction of grain size and unification of structure for clean metal casting by introduction of small amount of inoculant with impulse magnetic field.
Design/methodology/approach: Experimental plan was planed on the basis of statistical factor design on two levels for three variables (pouring parameters). The equiaxed crystals zone content was calculated by computer program to processing and image analysis after metallographic research.
Findings: The results of study show relationship between area of equiaxial zone and pouring parameters.
Research limitations/implications: Towards lack of resolute relations between casting parameters and structure was selected statistical analysis to determine these relations using stepwise regression.
Practical implications: The work presents refinement of structure methods which are particularly important in continuous and semi-continuous casting where products are used for plastic forming. Large columnar crystals zone result in forces extrusion rate reduction and during the ingot rolling delamination of external layers can occur.
Originality/value: The value of this paper resides in coupling of two refinement of structure methods. The first method is internal factor - inoculation with Ti+B and the second method is external factor - influence of electromagnetic field on crystallization process.
Keywords: Magnetic field; Inoculation; Aluminium; Titanium; Boron

1. Introduction

The most important parameter influencing casting quality is its primary structure obtained in casting solidification and crystallization process. Different solidification conditions and chemical composition cause changes in casting structure. Three zones can be distinguished in casting structure:

- chilled crystals,
- columnar crystals,
- equiaxed crystals.

Columnar crystals zone results from directional solidification, which proceeds when thermal gradient on solidification front has a positive value. Volumetric solidification progressing with negative thermal gradient in liquid phase results in equiaxed crystals zone. Dimensions of both zones determine the casting homogeneity. The bigger the equiaxed zone with small grain the better the casting quality. By selecting solidification parameters (thermal gradient G, solidification velocity V, initial concentration C_o) there is a possibility to quick transition from directional to volumetric solidification. As an effect the bigger equiaxed zone can be obtained with concurrent decrease of columnar zone or its disposal.

Columnar crystals zone is particularly undesirable in continuous and semi – continuous casting where products are used for plastic forming. It forces extrusion rate reduction and during the ingot rolling delamination of external layers can occur. Thus, in some cases ingot skinning is needed, which rises the production costs.

Columnar crystals zone can be eliminated by use of inoculants or magnetic stirring in crystallizer. Inoculants cannot applied for pure metal casting such as: Al99,99; Cu99,99 etc. because they decrease the purity specified in EN-PN standards.

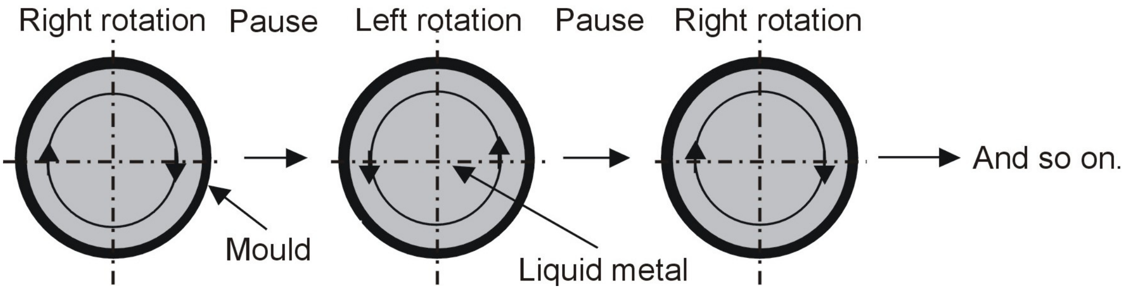

Fig. 1. Scheme of impulse reverse magnetic field influence on liquid metal

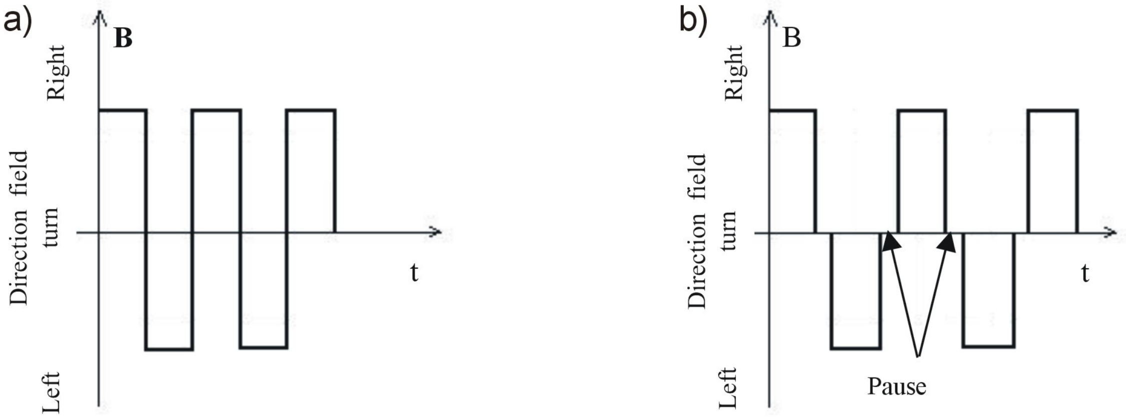

Fig. 2. Scheme of work cycles for reverse magnetic field (a) and impulse reverse magnetic field (b)

Creation of primary structure is determined by physical and chemical properties of cast metal and mould, by technological parameters and by external factors influence such as rotating reversing magnetic field causing liquid metal stirring during solidification [1÷3]. This method is one of the ways to obtain high quality casting. Rotating reversing magnetic field causes changes in crystallization process. One of the effects is grain refinement and its homogeneity improvement. Use of rotating reversing magnetic field to force liquid metal movement is a modification of metal casting in rotating magnetic field casting technique [4,5]. The main difference is that rotational movement of magnetic field was changed into rotational – reversing movement. As was mentioned before, better casting quality can be obtained by changing its structure to equiaxed. Proper selection of solidification parameters and rotating reversing magnetic field parameters can be very effective in changing columnar structure to more desirable equiaxed structure. Studies on magnetic field influence on solidification process, including rotating and rotating reversing magnetic field are conducted from many years in Foundry Department of Silesian University of Technology in Gliwice, Poland.

Use of inductive stirring for liquid metal is not always effective in columnar zone reduction, mainly because coils with sufficient power cannot be used [6÷11] or when magnetic field affects metal with very high purity [6].

Thus, a need of different magnetic field application has occurred with higher power coils. New cycle of rotating reversing magnetic field was developed with use of pause between following changes of magnetic field direction (Fig. 1) what enabled occurrence of considerably higher electro dynamical forces in liquid metal.

Difference between rotating reversing magnetic field and impulse reversing magnetic field is shown on Fig. 2.

2. Aim and range of studies

Main aim of studies was to determine influence of impulse magnetic field and different Ti+B inoculant content on grain refinement of pure aluminum casting. Inoculant content did not exceeded values specified in EN-PN standards. Experiment was conducted on test stand created in Foundry Department of Silesian University of Technology in Gliwice.

In the studies the cylindrical castings of Al99,98 were poured in impulse reversing magnetic field with variable impulse frequency, magnetic field power and inoculant content. Full experimental plan is shown in Table 1.

Experimental plan enclosed also metalographic analysis conducted to observe the changes in structure produced by magnetic field and inoculant addition.

Test stand is shown in Fig. 3. It is composed of:

- asynchronous motor stator *1* – which performs as an electric primer, rotor is replaced with mould containing liquid metal 2,

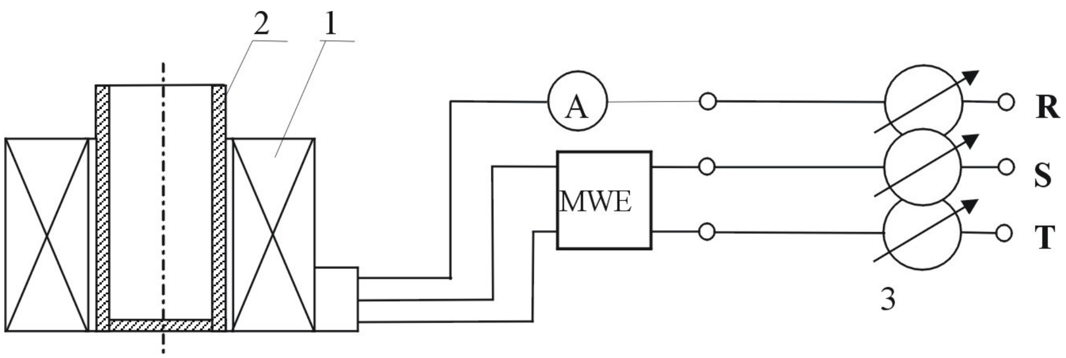

Fig. 3 Test stand scheme: 1- magnetic field coil, 2- mould, 3- three-phase transformer, A- ammeter, MWE- multivibrator

- autotransformer *3* – which regulates three – phase voltage feeding the electric primer and changes the induction value,
- ammeter – which measures the current feeding the electric primer,
- multivibrator MWE – which changes the direction of magnetic field. Based on two integrated circuits ensures generation of stable impulses [12].

Table 1.
Experimental plan

Sample number	Superheating temperature [°C]	Pulse frequency f_p [Hz]	Current intensity I [A]	Quantity of inoculant M [ppm (Ti+B)]
1	780	-	-	-
4	775	-	-	50+10
5	670	1	3,75	50+10
8	852	1	5	75+15
9	670	1	8,25	75+15
10	672	-	-	-
11	672	1	8,25	100+20
12	770	0,5	8,25	100+20
13	702	0,5	8,25	125+25
14	760	0,5	8,25	150+30
15	670	0,5	8,25	200+40
16	670	-	-	200+40
17	665	1	8,25	200+40
18	665	0,5	6	200+40
19	670	1	3,75	-

3. Studies

During the studies cylindrical Al99,98 ingots with dimensions of 45 mm diameter and 180 mm length were poured into graphite mould with wall thickness 6 mm. Metal was melted in inductive furnace and temperature was measured wit use of NiCr-NiAl thermocouple. Metal was poured into the mould placed inside the electric primer with engaged impulse reversing magnetic field. Pouring temperature was set to 740 °C and time of magnetic field action was 30 s counted from the end of pouring.

Cast ingot was then cut at 55 mm from the base and prepared for macrostructure analysis. Analized surface was etched with use of solution of: 50g Cu, 400ml HCl, 300ml HNO_3 and 300 ml H_2O. With use of computer programme Multi Scan Base following characteristics were measured:

- area of equiaxed crystals zone PSKR [mm^2],
- average area of equiaxed crystal PKR [mm^2],
- average area of columnar crystal PKK [mm^2],
- zone width of columnar crystals SKK [mm^2],
- equiaxed crystals zone content SKR [%].

4. Results and analysis

Selected results [13] are presented on Fig. 4 – 9 and in Table 2.

In Fig. 10 relation between impulse frequency of magnetic field and equiaxed crystals zone content on transverse section of ingot.

Table 2.
Results of investigations

Sample number	PSKR [mm^2]	PKR [mm^2]	PKK [mm^2]	SKK [mm]	SKR [%]
1	36,5	1,7	17,7	19,8	2,4
4	49,7	1,5	21,3	17,9	3,3
5	16,6	0,5	12,7	19,8	0,5
8	76,5	0,8	14,6	18,0	5,0
9	88,6	1,3	16,4	16,7	5,8
10	73,4	1,2	12,7	18,5	4,8
11	183,8	1,4	9,1	14,4	12,1
12	392,6	0,7	6,6	10,2	25,8
13	478,4	0,7	7,7	10,0	31,5
14	583,5	0,5	5,4	8,7	38,4
15	538,0	0,4	6,9	8,8	35,4
16	44,7	0,6	3,8	18,4	2,9
17	449,2	0,4	4,5	10,2	29,5
18	521,1	0,6	6,1	10,6	34,3
19	47,4	1,2	9,3	18,2	3,1

Fig. 4. Macrostructure of sample number 10 f_p=0 Hz, I=0A, M=0ppm Ti+B

Fig. 5. Macrostructure of sample number 16 f_p= 0 Hz, I= 0 A, M=200 ppmTi+40ppmB

Fig. 6. Macrostructure of sample number 8 f_p= 1 Hz, I= 5 A, M=75 ppmTi+15ppmB

Fig. 7. Macrostructure of sample number 15 f_p= 0.5 Hz, I= 8.25 A, M=200 ppmTi+40ppmB

Fig. 8. Macrostructure of sample number 12 f_p= 0.5 Hz, I= 8.25 A, M=100 ppmTi+20ppmB

Fig. 9. Macrostructure of sample number 18 f_p= 0.5 Hz, I= 6 A, M=200 ppmTi+40ppmB

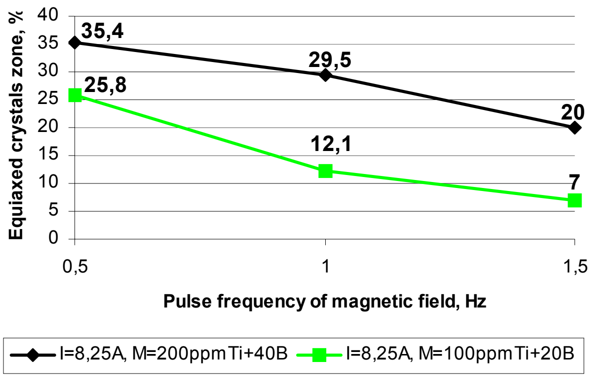

Fig. 10. Equiaxed crystals zone in function of pulse frequency of magnetic field

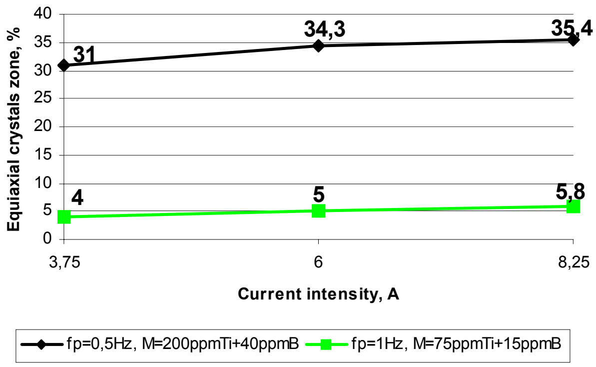

Fig. 11. Equiaxed crystals zone in function of current intensity

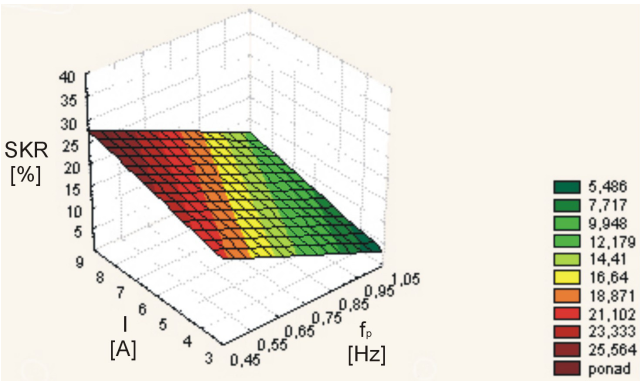

Fig. 12. Equiaxed crystals zone in function of current intensity and impulse frequency of magnetic field for identical quantity of inoculants (200ppm Ti + 40ppm B)

For both curves one can see, that with decrease in impulse frequency increase in equiaxed zone is observed. It results from high velocities that are attained in liquid metal and which lead to columnar crystals tearing occurring on crystallization front.

Diagram on Fig. 11 shows relation between current intensity and equiaxed zone content on ingot transverse section for constant inoculant addition and impulse frequency.

Magnetic field power represented indirectly by current intensity shows influence on equiaxed crystals quantity in ingot transverse section. With increase in current intensity and magnetic field induction grain refinement increases.

Towards lack of resolute relations between casting parameters and structure as a next step statistical analysis was selected to determine these relations using stepwise regression. Following function was wanted:

$$SKR = f(\text{casting parameters}) = f(f_p, I, M) \quad (1)$$

where:

- SKR – equiaxed crystals zone content on transverse section of ingot [%],
- impulse frequency of magnetic field [Hz],
- I – current intensity feeding the electric primer [A],
- M – Ti+B inoculant quantity [ppm].

Statistical analysis resulted in function shown below:

$$SKR = -26{,}9 \cdot f_p + 1{,}4 \cdot I + 0{,}13 \cdot M + 14{,}3 \quad (2)$$

statistical parameters of correlation:

- correlation coefficient R=0,978,
- R^2=0,956,
- Fisher test F=43,96,
- average value SKR =21,83,
- standard deviation SD=14,42,
- standard error of estimation B=3,6

Graphic interpretation of equiaxed crystals zone content in function of current intensity and impulse frequency of magnetic field by constant inoculant addition (200ppmTi+40ppmB) is shown in Fig. 12.

5. Summary

Based on conducted studies following conclusions have been formulated:

1. Impulse reversing magnetic field has little effect on casting structure, although liquid metal stirring is very intensive the grain remain coarse. This is in agreement with results of other studies [6] conducted in Foundry Department of Silesian University of Technology.
2. Magnetic field influence efficiency increases with growing inoculant addition introduced into liquid metal.
3. Results show that increase of impulse frequency decreses the efficiency of inoculation process. By frequency of f_p=0,5Hz grain refinement was higher than for f_p=1Hz.

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