Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 17
ISSUE 1-2
July-August
2006

# Influence of magnetic field and inoculation on columnar structure transformation

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Received 15.03.2006; accepted in revised form 30.04.2006

## 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 rotate and impulse reverse magnetic field.
**Design/methodology/approach:** Experimental plan was planed on the basis of statistical factor design on two levels for three variables: pulse frequency, current intensity and inoculant quantity. The output parameters: area of equiaxed crystals zone, average area of equiaxed crystal, average area of columnar crystal and most important equiaxed crystals zone content were calculated by computer program Multi Scan Base (program to processing and image analysis) after macroscopic metallographic research.
**Findings:** The results of investigations and their analysis show relationship between area of equiaxial zone and pouring parameters: induction of magnetic field, pulse frequency of magnetic field and quantity of inoculant sort AlTi5B.
**Research limitations/implications:** Towards lack of resolute relations between casting parameters and structure was selected statistical analysis to determine these relations using stepwise regression. In order to obtain accurate results, authors of this paper are going to extend the resarch range and use Zr and V to inoculation.
**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. Thus, in some cases ingot skinning is needed, which rises the production costs.
**Originality/value:** The value of this paper resides in coupling of two fineness 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:** Working properties of materials and products; Magnetic field; inoculation; Aluminium

## 1. Introduction

The quality of continuous and semi-continuous casting is depending by degree of fineness and unification of structure, which represent equiaxed crystals zone content. Increase of equiaxed crystals zone content causes reduction of columnar crystals zone (fig.1). Columnar crystals zone results from directional solidification, which proceeds when thermal gradient on solidification front has a positive value, forces extrusion rate reduction and during the ingot rolling delamination of external layers can occur [1÷4].

This problem concerns founding of pure metals such as: Al, Cu etc., because soldification in conventional conditions i.e. in continuous casting mould results in structure only with columnar crystals. Columnar crystals zone can be eliminated by use of internal factor – introduction of inoculant. Inoculants cannot applied for pure metals casting because they decrease the degree of purity.

But introduction of small amount of inoculant can be strengthened by use of fineness second method i.e. external factor – influence of electromagnetic field on crystallization process.

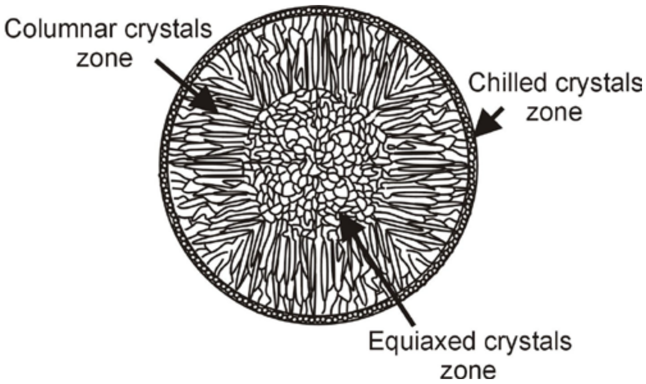


Fig.1. Scheme of ingot cross-section

Use of magnetic field to force liquid metal movement is a cause of additional crystal nucleuses formation by crystals dispersion which float in liquid, erosion of solidification front, crystals transport from free surface to inside the liquide metal etc. [5÷11].

Often, the influence on crystallization process can be realized by use of two types of magnetic field i.e. rotating – WPM (fig.2a) or impulse reverse – IRPM (fig.2b). The main difference is that rotational movement of magnetic field in WPM was changed into rotational – reversing movement with pause between following changes of magnetic field direction in IRPM [12÷15].

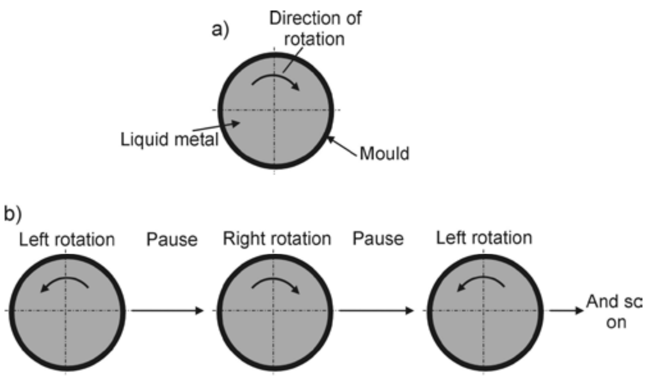


Fig.2. Scheme of rotating (a) and impulse reverse magnetic field (b) influence on liquid metal

## 2. Range of studies

The main aim of studies was to determine influence of magnetic field (rotating – WPM and impulse reverse – IRPM) which can be strengthened by use of small amount of inoculant (Ti+B) on grain refinement of pure aluminum casting. Test stand is shown in fig. 3. During the studies cylindrical EN AW-Al 99,98 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 with use of NiCr-NiAl thermocouple (pouring temperature was set to 740 $^{o}$C). Metal was poured into the mould placed inside the electric primer with engaged impulse reversing magnetic field with range of pulse frequency 0,4, 1 and 1,5Hz, current intensity 2, 4 and 10A, time of magnetic field action was 10 and 30s counted from the end of pouring. Moreover, metal was poured into the mould with engaged rotating magnetic field with current intensity 10A and time of magnetic field action 30s. Inoculant (Ti + B) content was 200+40 and 50+10ppm. Magnetic induction was measured before pouring with use of measuring instrument TH26. 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 [mm$^2$] and equiaxed crystals zone content SKR [%]. With use of emission optical spectrometry was measured true content of inoculant elements i.e. Ti and B. Full experimental plan is shown in table 1.

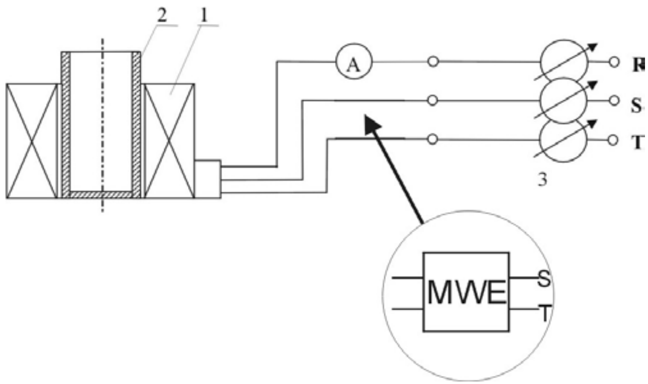


Fig. 3. Test stand scheme: 1- magnetic field coil, 2- mould, 3- three-phase transformer, A- ammeter, MWE –multivibrator (only for IRPM)

## 3. Results and analysis

Results of equiaxed crystals zone content (SKR) and true content of inoculant elements measurements are presented in table 1. Whereas, selected results of metallographic research are presented on fig. 4÷13.

Fig. 4. Macrostructure of sample number 0

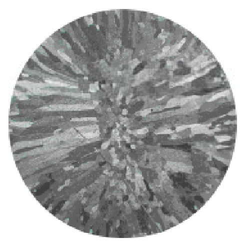

Fig. 5. Macrostructure of sample number 01

Table 1.
Range and results of investigations

| Sample number | Type of field | f [Hz] | I [A] | B [mT] | t [s] | Assumption content Ti [ppm] | True content Ti [ppm] | Melting loss Ti [%] | Assumption content B [ppm] | True content B [ppm] | Melting loss B [%] | SKR [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | - | - | - | - | - | - | - | - | - | - | - | 1,78 |
| 01 | - | - | - | - | - | 200 | 136 | 32 | 40 | 23 | 57,5 | 23,12 |
| 02 | - | - | - | - | - | 50 | 35 | 30 | 10 | 5 | 50 | 2,40 |
| 03 | IRPM | 0,4 | 10 | 50 | 30 | - | - | - | - | - | - | 7,19 |
| 04 | WPM | - | 10 | 50 | 30 | - | - | - | - | - | - | 10,08 |
| 1 | IRPM | 1 | 8 | 45 | 30 | 200 | 132 | 34 | 40 | 11 | 72,5 | 26,30 |
| 5 | | 1 | 8 | 45 | 30 | 50 | 42 | 16 | 10 | 5 | 50 | 7,38 |
| 7 | | 1 | 2 | 30 | 30 | 200 | 146 | 27 | 40 | 23 | 42,5 | 20,12 |
| 9 | | 0,4 | 8 | 45 | 30 | 200 | 144 | 28 | 40 | 19 | 52,5 | 28,34 |
| 19 | | 0,4 | 2 | 30 | 10 | 50 | 71 | - | 10 | 3 | 70 | 4,32 |
| 20 | | 0,4 | 2 | 30 | 30 | 50 | 55 | - | 10 | 3 | 70 | 4,13 |
| 22 | | 0,4 | 2 | 30 | 10 | 200 | 141 | 29,5 | 40 | 24 | 40 | 11,42 |
| 24 | | 0,4 | 8 | 45 | 10 | 50 | 31 | 38 | 10 | 5 | 50 | 3,56 |
| 26 | | 1 | 2 | 30 | 10 | 50 | 26 | 48 | 10 | 2 | 80 | 4,15 |
| 1A | | 1,5 | 8 | 45 | 30 | 200 | 130 | 35 | 40 | 25 | 62,5 | 20,0 |
| 9A | | 0,4 | 10 | 50 | 30 | 200 | 136 | 32 | 40 | 17 | 42,5 | 38,63 |
| 24A | | 0,4 | 10 | 50 | 30 | 50 | 35 | 30 | 10 | 5 | 50 | 9,07 |
| 1B | WPM | - | 10 | 50 | 30 | 200 | 144 | 28 | 40 | 20 | 50 | 50,77 |
| 2B | | - | 10 | 50 | 30 | 50 | 33 | 34 | 10 | 4 | 60 | 31,96 |

Fig. 6. Macrostructure of sample number 02

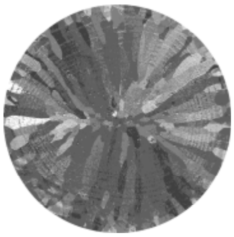

Fig. 7. Macrostructure of sample number 03

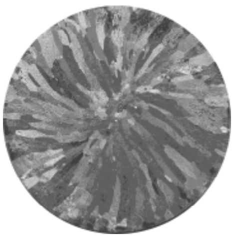

Fig. 8. Macrostructure of sample number 04

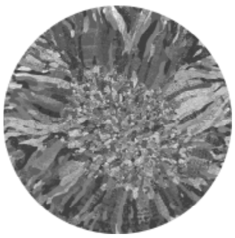

Fig. 9. Macrostructure of sample number 9

Common influence of internal factor – introduction of inoculant (Ti + B) and external factor – rotating or impulse reverse magnetic field (fig. 9 ÷ 13) on degree of fineness in structure is stronger than influence of these two factors separately (fig. 4 ÷ 8).

With decrease in impulse frequency increase in equiaxed crystals zone is observed (tab. 1). It results from high velocities that are attained in liquid metal and which lead to columnar crystals tearing occurring on crystallization front and additional crystal nucleuses formation. Magnetic field power represented indirectly by current intensity shows influence on equiaxed crystals quantity in ingot transverse section. With increase in current intensity and / or magnetic field induction, grain refinement increases (fig. 14). Investigations show, that most important parameter of process is inoculant content (fig. 15). Introduction of 200ppm Ti + 40ppm B assure largest fineness of structure than introduction quadruple less of the same inoculant irrespective of magnetic field type.

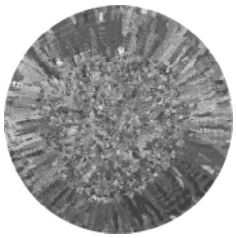

Fig. 10. Macrostructure of sample number 9A

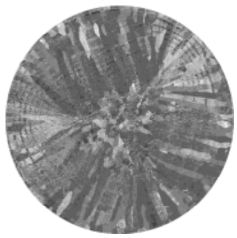

Fig. 11. Macrostructure of sample number 24A

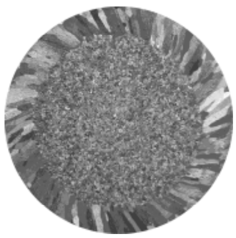

Fig. 12. Macrostructure of sample number 1B

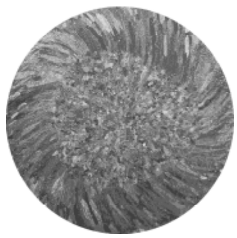

Fig. 13. Macrostructure of sample number 2B

Moreover, time of magnetic field action does not influence on degree of fineness in casts. Whereas, influence on structure refinement of rotating magnetic field is stronger than impulse reverse magnetic field.

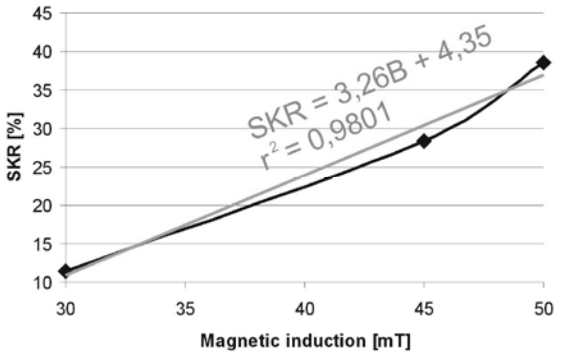


Fig. 14. Equiaxial crystal zone content – SKR in magnetic induction - B function (f = 0,4[Hz], M = (200Ti + 40B)[ppm], t = 30[s])

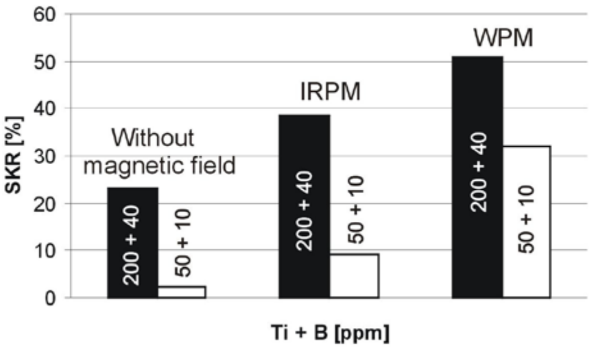


Fig. 15. Influence of inoculant (Ti+B) content on equiaxial crystal zone content - SKR

## 4. Conclusions

Based on conducted studies following conclusions have been formulated:

1. Common application of inoculant (Ti + B) and magnetic field increase equiaxed crystals zone in cast.
2. The most important parameter which influences on equiaxed crystals zone content is inoculant addition introduced into liquid metal.
3. Influence on degree of fineness in structure of rotating magnetic field is stronger than impulse reverse magnetic field.
4. Increase of pulse frequency and decrease of current intensity feeding the electric primer decreses the efficiency of impulese reverse magnetic filed influence on refinement of structure.
5. Time of magnetic field action does not influence on degree of fineness in casts.

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