Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 20
ISSUES 1-2
January-February
2007

# Inoculation of primary structure of pure aluminium

**J. Szajnar*, T. Wróbel**
Institute of Engineering Materials and Biomaterials, Foundry Department, Silesian University of Technology, ul. Towarowa 7, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: jan.szajnar@polsl.pl

Received 10.17.2006; accepted in revised form 15.11.2006

**Properties**

## ABSTRACT

**Purpose:** The main aim of studies was to determine common influences on EN AW-Al99,5 structure refinement of reverse or impulse reverse magnetic field and small amount of inoculants sort AlTi5B1, AlZr5 and AlV10 - less than obligatory standard PN-EN 573-3 (concerning about aluminium purity).

**Design/methodology/approach:** Factor variables of founding were: pulse frequency of magnetic field (f), magnetic induction (B), time of magnetic field action (t) and inoculant quantity (M). Degree of fineness was represented by equiaxed crystals zone content (SKR) on cylindrical castings cross-section of aluminium EN AW-Al 99,5, average area of equiaxed crystal (PKR) and average area of columnar crystal (PKK) were calculated by computer program to processing and image analysis after macroscopic metallographic research.

**Findings:** The results of investigations and their analysis show, that contribution of these both mechanism models of additional creystal nucleuses formation i.e. magnetic field influence and introduction of small amount of inoculant – less than in conventional modyfication process, should result in higher degree of fineness in pure metals structure. It is not possible, when we use one of these methods. We must use these two methods together.

**Research limitations/implications:** I further research, authors of this paper are going to identifiy the "washers" to heterogeneous nucleation, which influences on increase of size reduction in structure.

**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.

**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

Columnar crystals which are parallel to heat flow, creates primary structure of pure metals independently from type of crystal lattice (fig.1). This unfavourable structure for plastic forming of ingots can be eliminated by controlling of heat abstraction velocity from cast, change in chemical constitution and liquid metal convection [1, 2].

Effective method of columnar crystals zone elimination is using of inoculation with introduction into metal bath of specified substances, called inoculants. Inoculant increase grains density as result of creation of new particles in consequence of braking of grains growth velocity, decrease of surface tension on phase boundary of liquid – nucleus, decrease of wetting angle between nucleus and "washer" and increase of density of "washers" to heterogeneous nucleation. This leads to increase of equiaxed crystals zone (fig.2), which guarantee of mechanical properties improvement, decrease of constituents segregation and limitation of hot cracks [2, 3].

This method of inoculation of primary structure is limited for pure metals, because inoculants decrease the degree of purity specified in EN-PN standards. But introduction of small amount of inoculant can be strengthened by use of fineness other method i.e. use of ultrasonic vibration or magnetic field to force liquid metal movement in mould [1, 2, 4÷9].

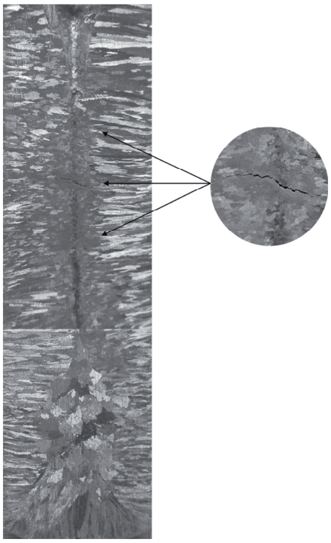


Fig. 1. Structure of aluminium ingot with hot cracks

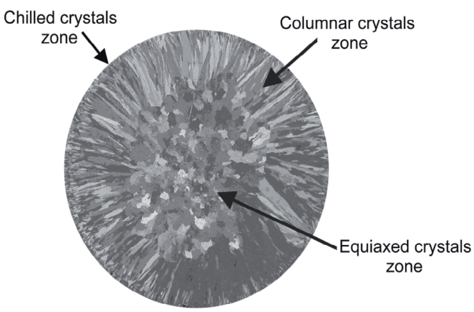



Fig. 2. Structure of ingot cross-section

Forced liquid metal movement influences in diversified way on changes in structure of casting i.e. by changes of thermal and concentration conditions on crystallization front, which decrease or completely stops the velocity of columnar crystals growth and by [1, 2, 4]:

- tear off of crystals from mould wall, which are transferred into metal bath, where they can convert in equiaxed crystals,
- parting of dendrite by coagulation and melting as result of influences of temperture fluctuation and breaking as result of energy of liquid metal movement (fig.3),
- crystals transport from free surface to inside the liquid metal,
- crystals from over-cooled outside layer of bath are transported into liquid metal.

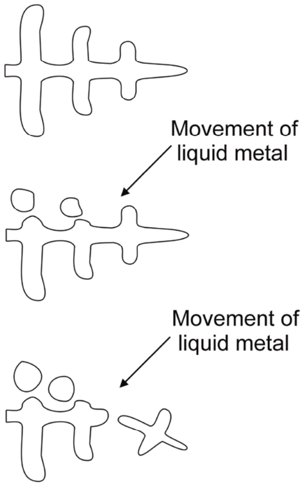
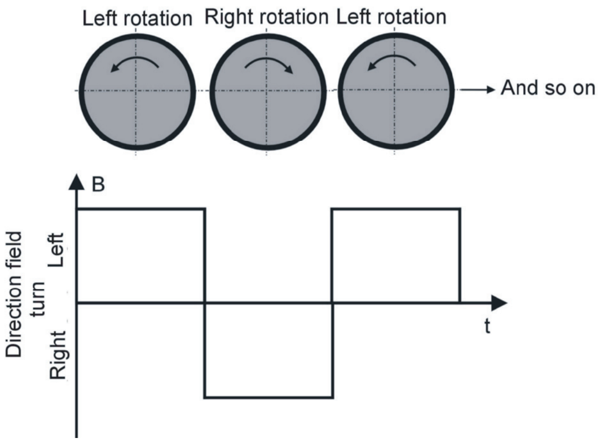



Fig. 3. Parting of dendrite as result of liquid metal movement [2]

a)




b)

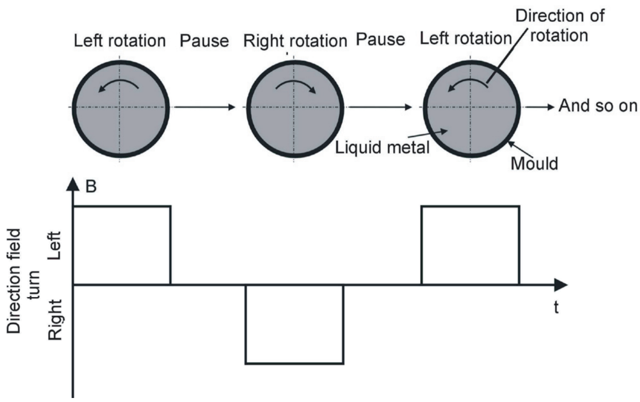



Fig. 4. Scheme of reverse (a) and impulse reverse magnetic field (b) influence on liquide metal

In investigations the influence on crystallization process can be realize by use of reverse – RPM (fig.4a) and impulse reverse magnetic field – IRPM (fig.4b). The main difference between this two magnetic fields is that continuous reversing movement in RPM was changed on reversing movement with pause between following changes of magnetic field direction in IRPM what enabled occurrence of considerably higher electrodynamical forces in liquid metal [10÷14].

Preliminary investigations showed, that contribution of these both mechanism models of additional crystal nucleuses formation i.e. magnetic field influence and introduction of small amount of inoculant – less than in conventional modyfication process, should result in higher degree of fineness in pure metals structure. It is not possible, when we use one of these methods. We must use these two methods together, what results from [11÷14].

## 2. Range of studies

The main aim of studies was to determine common influences on EN AW-Al99,5 structure refinement of reverse or impulse reverse magnetic field and small amount of inoculants sort AlTi5B1, AlZr5 and AlV10 - less than obligatory standard PN-EN 573-3 (concerning about aluminium purity).

Test castings were casted with exactly specified parameters: pulse frequency of magnetic field (f), magnetic induction (B) and time of magnetic field action (t), which became optimized on basis of earlier investigations of EN AW-Al99,98 [10÷14] and they were suitably 0,5 [Hz], 50 [mT] i 30[s]. After study of literature datas in investigations inoculants type AlTi5B1 [2, 3, 15], AlZr5 [3] and AlV10 [3] were used. Inoculants quantity were suitably (25Ti+5B) [ppm], (30Zr) [ppm] and (30V) [ppm].

Degree of fineness was represented by equiaxed crystals zone content (SKR) on cylindrical castings cross-section of aluminium EN AW-Al 99,5 and average area of equiaxed crystal (PKR) and average area of columnar crystal (PKK).

## 3. Results and analysis

Full experimental plan with results of equiaxed crystals zone content (SKR) on cylindrical castings cross-section of aluminium EN AW-Al 99,5 and average area of equiaxed crystal (PKR) and average area of columnar crystal (PKK) measurements are shown in table 1.

Results of metallographic research are presented on fig.5÷12. The most favourable influence on size of equiaxed crystals zone from applied inoculants has AlTi5B1 (tab. 1, fig. 6÷8). Moreover, influence on structure refinement of impulse reverse magnetic field (fig.9) is stronger than reverse magnetic field (fig.10).

Common influence of impulse reverse magnetic field and inoculation with (Ti+B) (tab.1, fig.11) result in larger equiaxed crystals zone content and smaller size of macrograin than in standard sample (fig.5) and comparable in sample which was casted only with inoculation (Ti+B) (fig.6) but it has larger size of macrograin than sample which was casted with influences of magnetic field and inoculation.

Table 1.
Range and results of investigations

| Sample number | Variable factors of casting | SKR [%] | PKK [$mm^2$] | PKR [$mm^2$] |
|---|---|---|---|---|
| 1 | Type of field: lack<br>Inoculant sort: lack | 24,34 | 7,75 | 26,32 |
| 2 | Type of field: lack<br>Inoculant sort: AlTi5B1 | 51,44 | 1,38 | 4,45 |
| 3 | Type of field: lack<br>Inoculant sort: AlZr5 | 2,56 | 6,78 | 29,05 |
| 4 | Type of field: lack<br>Inoculant sort: AlV10 | 21,06 | 7,32 | 24,67 |
| 5 | Type of field: IRPM*<br>Inoculant sort: lack | 32,05 | 7,23 | 0,68 |
| 6 | Type of field: RPM**<br>Inoculant sort: lack | 28,06 | 8,99 | 0,68 |
| 7 | Type of field: IRPM<br>Inoculant sort: AlTi5B1 | 45,74 | 7,20 | 0,36 |
| 8 | Type of field: RPM<br>Inoculant sort: AlTi5B1 | 37,12 | 7,33 | 0,49 |

* - IRPM – impulse reverse magnetic field,
** - RPM – reverse magnetic field;

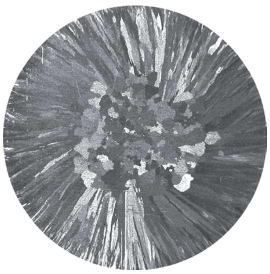


Fig. 5. Macrostructure of sample number 1

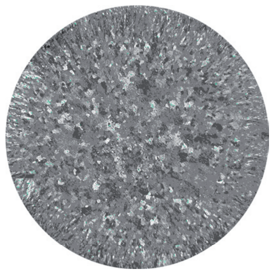


Fig. 6. Macrostructure of sample number 2

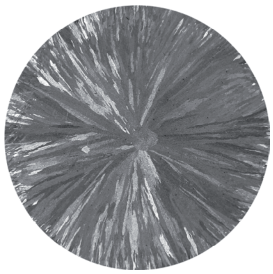


Fig. 7. Macrostructure of sample number 3

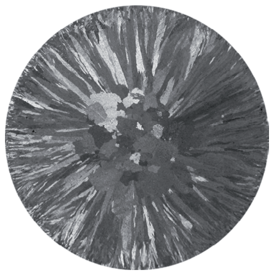


Fig. 8. Macrostructure of sample number 4

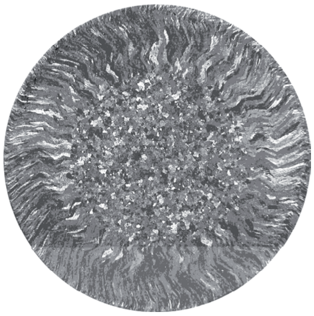


Fig. 9. Macrostructure of sample number 5

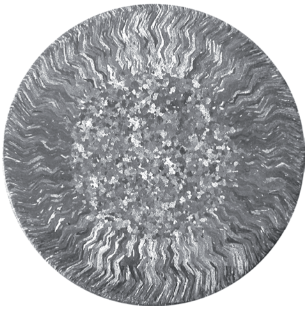


Fig. 10. Macrostructure of sample number 6

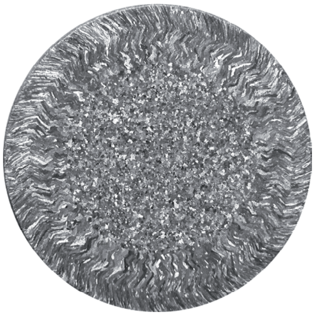


Fig. 11. Macrostructure of sample number 7

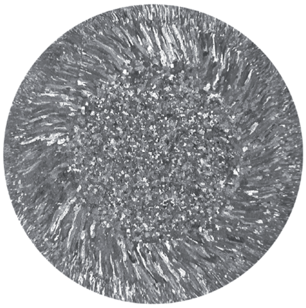


Fig. 12. Macrostructure of sample number 8

## 4. Conclusions

Based on conducted studies following conclusions have been formulated:

1. Influence of impulse reverse magnetic field on solidification process of pure aluminium, aided size reduction, which creates mainly by introduction of small amount of inoculant sort AlTi5B1 - less than obligatory standard PN-EN 573-3 (concerning about aluminium purity).
2. Influence on structure refinement of impulse reverse magnetic field is stronger than reverse magnetic field.
3. Influence only of magnetic field creates less increment of equiaxed crystals zone width than influence only of inoculation with (Ti + B).

## Acknowledgements

Scientific project financed from means of budget on science in years 2006-2008 as resarch project 3T08B02430.

## References

[1] J. Szajnar, The columnar to equiaxed transition at casting solidification with convection forced by rotating magnetic field, Scientific book of Silesian University of Technology, Mechanic, 138, Gliwice, 2001 (in Polish).
[2] E. Fraś, Crystallization of metals, WNT, Warszawa, 2003 (in Polish).
[3] S. Jura, Modeling research of modyfication process in metals, Scientific book of Silesian University of Technology, Mechanic, 32, Gliwice, 1968 (in Polish).
[4] J. Szajnar, The influence of rotating reversing magnetic field on solidification process of cast. Doctors thesis, Silesian University of Technology, Gliwice, 1986, (in Polish).
[5] J. Szajnar, J. Gawroński, The influence of electromagnetic stirring of a flowing metal stream on the cast structure, Proceedings of the 1st International Scientific Conference Achievements in Mechanical & Materials Engineering AMME, Gliwice, 1992, 183.
[6] J. Szajnar, J. Gawroński: The influence of stirring liquid metal in mould by means of magnetic field on the structure and the characteristic of castings, Proceedings of the 2nd International Scientific Conference Achievements in Mechanical & Materials Engineering AMME, Gliwice, 1993, 209.
[7] J. Szajnar, J. Gawroński, Effect of the magnetic field on the transformation of columnar structure of the castings, Foundry Review, vol. 55, No 4, 2005, p.232, (in Polish).
[8] J. Szajnar, The columnar crystals shape and castings structure cast in magnetic field, Journal of Materials Processing Technology, 157-158, 2004, 761.
[9] J. Szajnar, J. Gawroński, Method of aluminium and aluminium alloy casting. Patent PL nr 134 861, 5.03.1987 (in Polish).
[10] J. Szajnar, M. Stawarz, T. Wróbel, Influence of impulse magnetic field reaction and inoculation with Ti + B addition on aluminium structure. Archives of foundry, N$^o$ 18(1/2), vol. 6, 2006 (in Polish).
[11] J. Szajnar, T. Wróbel, Influence of magnetic field and inoculation on columnar structure transformation. Journal of Achievements in Materials and Manufacturing Engineering, vol. 17, 2006, 209.
[12] J. Szajnar, M. Stawarz, T. Wróbel, Inoculation of pure aluminium structure with Ti+B addition in impulse magnetic field. Journal of Achievements in Materials and Manufacturing Engineering, vol. 14, 2006, 64.
[13] J. Szajnar, M. Stawarz, T. Wróbel, Inoculation of pure aluminium structure with Ti + B addition in impulse magnetic field, The 11th International Scientific Conference on the Contemporary Achievements in Mechanics, Manufacturing and Materials Science CAM3 S 2005, (on CD), nr 1.173.
[14] J. Szajnar, T. Wróbel, Modyfication of pure aluminium structure by internal and external factors. Archives of foundry, N$^o$ 22, vol. 6, 2006 (in Polish).
[15] Z. Poniewierski Z, Crystallization, structure and properties of silumines, WNT, Warszawa, 1989 (in Polish).