doi:10.22364/mmp2017.42

VIII International Scientific Colloquium
Modelling for Materials Processing
Riga, September 21 - 22, 2017

Direct Chill Casting of Aluminium Alloys under Electromagnetic Interaction

A. Bojarevičs, I. Kaldre, M. Milgrāvis, T. Beinerts

Abstract

Direct chill casting is one of the methods used in industry to obtain good microstructure and properties of aluminium alloys. Nevertheless, for some alloys grain structure is not optimal. In this study, we test the principle of using electromagnetic interaction to modify melt convection near the solidification interface. Solidification under electromagnetic interaction has been widely studied, but usually at low solidification velocity and high thermal gradient, where influence by electromagnetic interaction is demonstrated. This type of interaction may succeed fragmentation of dendrite arms and transport of solidification nuclei thus leading to improved material structure and properties. Casting of 10 mm diameter Al alloy rod under electromagnetic interaction caused by DC magnetic field and electric current has been done.

Introduction

Aluminium alloys microstructure and physical properties may vary significantly depending on solidification velocity and temperature gradient at the solidification interface and melt flow near solidification interface as well. In industry, aluminium alloys for extrusion and forging is prepared by using crystallizers, which ensure controlled solidification velocity and oriented solidification front direction [1]. There are several technical solutions how to achieve rapid solidification up to 10 mm/s and large diameter ingots. One of the most popular is direct chill casting, where heat is evacuated by spraying oil and water at the solid part of the ingot [2]. It has been demonstrated that pulsed or AC electromagnetic interaction during directional solidification can significantly modify solidification structure of aluminium alloys [3]. Electromagnetic force may influence the melt flow in several ways. Static magnetic field has two effects. Firstly, it damps the melt flow perpendicular to magnetic field lines, but secondly applied magnetic field may interact with electric current near the solidification interface and drive melt convection [4,5] or even deform the solidified dendrite arms [6]. Electric current may arise because of thermoelectric effect between solid and liquid phases in presence of temperature gradient along solidification interface [7] or current can be injected directly, or induced by the alternating magnetic field. Different types of melt flow may result as a different effect on solidification structure, for example large scale flow in crucible scale may result as a change in solidification interface shape and influence the structure difference between core and outer crust of the ingot [8]. Whereas small scale flow in dendrite scale may succeed composition homogeneity and alter dendrite morphology. However there is no direct link between melt convection during solidification and solidification microstructure, thus for each alloy and electromagnetic interaction series of experiments should be done.

1. Experimental setup

Small scale direct chill casting experimental setup has been developed in Institute of Physics University of Latvia laboratory of MHD technology. Principal scheme of experimental setup is shown in Fig.1. Aim of the experimental setup is to test the possibility to influence solidification structure and impurity distribution in aluminium ingot. Vertical DC magnetic field is applied by the permanent magnet system placed around the solidification zone. Solidification interface takes place in graphite tube at the middle of permanent magnet system. Just below graphite tube solid part of the aluminium rod is cooled by water spray. DC magnetic field interacts with electric current in the aluminium near the solidification interface. This setup is designed to test several types of electromagnetic interaction including DC current injection perpendicular to solidification interface and induced current will be induced by the one turn water cooled copper coil fed from the capacitor bank.

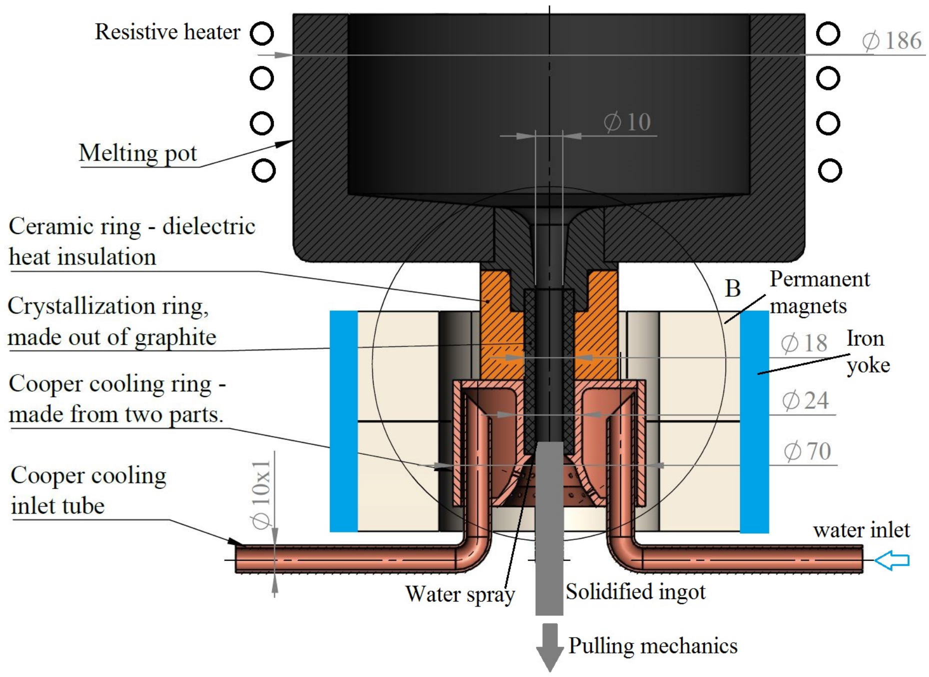

Fig. 1. Principal scheme of the experimental setup

2. Results and discussion

Parameters of experimental system has been measured and compared to numerical models. Permanent magnet system is assembled from segment magnets and iron yoke. Inner cavity of magnet system is 80 mm in diameter and axial magnetic field induction at the middle is about 0.45 as shown in Fig.2. For the first experiments, it is planned to apply axial 50 Hz electric current through the solidification interface. In this case in the bulk of the solid and liquid parts magnetic field and current are parallel, thus there is no Lorentz force. However, at the dendritic solidification interface current redistribution takes place due to significant difference in electric conductivities between solid and liquid phases. It has been shown by previous work that such type of interaction may induce liquid phase flow in dendrite scale and modify solidification microstructure and segregation of the components [9].

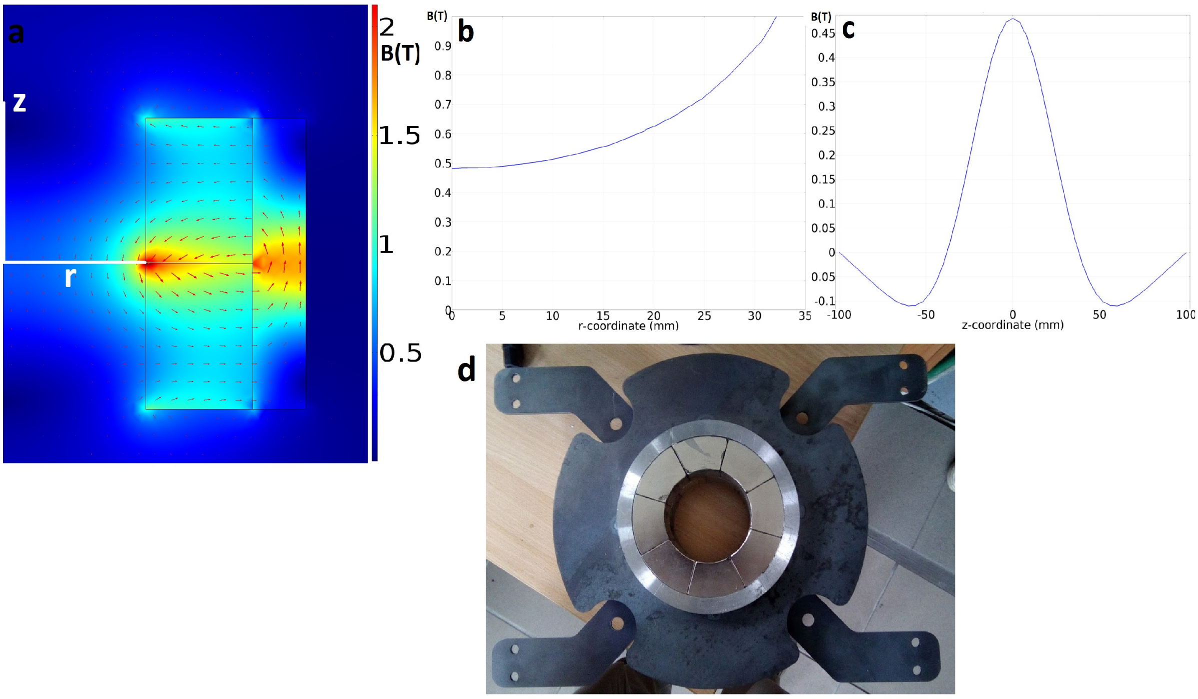

Fig. 2. Magnet system: a) axysymmetric Comsol model; b) Magnetic field induction along r; c) magnetic field induction along z; d) Assembled permanent magnet system

In this work planned current density is about 1 A/mm^2. If electric conductivities differ two times then current at the dendritic solidification interface is redistributed as shown in Fig.3. In this case current component perpendicular to magnetic field creates Lorentz force and local convection vortices around each dendrite arm is created.

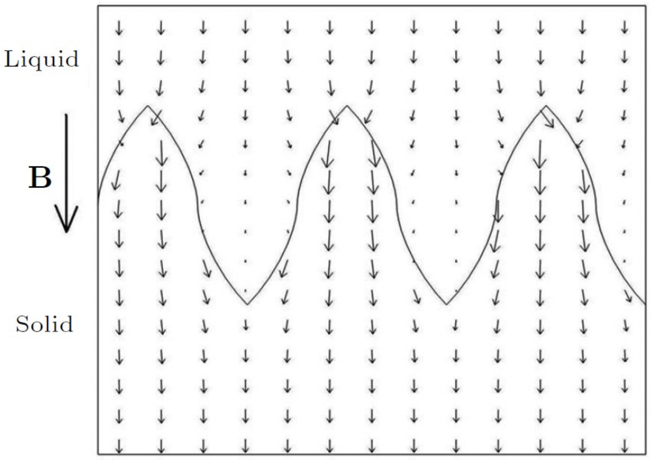

Figure 3. Electric current distribution at the dendritic solidification interface

Second type of electromagnetic interaction is by using capacitor bank discharge through the induction coil placed around the ingot near solidification interface. Capacitor bank is discharged through the coil up to 10 times per second. In this case pulsed radial force is created at the solidification interface. This force creates small amplitude liquid melt motion and alter heat and mass transfer within dendrite scale. Also in this case pulsed force prevents metal sticking to the mould thus potentially this technology can reduce or eliminate need to use oil.

Conclusions

Direct chill casting is one of the promising technologies for high quality aluminium alloy production maintaining certain properties. Our current work is aimed to improve existing technology by investigating the potential applications of electromagnetic interaction to the process. Electromagnetic interaction on liquid aluminium is perspective because of relatively low melting temperature, high electrical conductivity and low density of the material. Thus, electromagnetic elements can be placed close to the liquid metal and smaller magnetic field amplitude is necessary to achieve sufficient force density in the melt. So far, we have designed and built casting setup for 10 mm diameter aluminium rod and started the experiments with various electromagnetic interactions. Previous experiments in the crucible has demonstrated the potential of the technology.

References

[1] Grandfield, J.F., McGlade, P.T.: *DC Casting of Aluminium: Process Behaviour and Technology*. Comalco Research Centre, 15 Edgars Rd. Victoria 3074, Australia

[2] Schiffl, A.: *Direct Chill Casting of Magnesium using Hot-Top-Technology for Improved Casting Quality*. ARC Leichtmetallkompetenzzentrum Ranshofen GmbH (LKR), Ranshofen. August 2015

[3] R.Z. Wang, J.G. Qi, B. Wang, W. Zhang, J.Z. Wang, Solidification behavior and crystal growth mechanism of aluminum under electric pulse, *Journal of Materials Processing Technology*, Volume 237, 2016, Pages 235-242.

[4] Charles Vives, Christian Perry, Effects of magnetically damped convection during the controlled solidification of metals and alloys, *International Journal of Heat and Mass Transfer*, Volume 30, Issue 3, 1987, Pages 479-496.

[5] Wang, J., Fautrelle, Y., Ren, Z.M., Li, X., Nguyen-Thi, H., Mangelinck-Noel, N., Salloum Abou Jaoude, G., Zhong, Y.B., Kaldre, I., Bojarevics, A., Buligins, L. Thermoelectric magnetic force acting on the solid during directional solidification under a static magnetic field (2012) *Applied Physics Letters*, 101 (25), art. no. 251904.

[6] Jianbo Yu, Dafan Du, Zhongming Ren, Yves Fautrelle, Rene Moreau, Xi Li, Influence of an Axial Magnetic Field on Microstructures and Alignment in Directionally Solidified Ni-based Superalloy, *ISIJ International*, Vol. 57 (2017) No. 2 p. 337-342.

[7] Kaldre, I., Fautrelle, Y., Etay, J., Bojarevics, A., Buligins, L. Investigation of liquid phase motion generated by the thermoelectric current and magnetic field interaction (2010) *Magnetohydrodynamics*, (4), pp. 371-380.

[8] Wang, J., Fautrelle, Y., Nguyen-Thi, H., Reinhart, G., Ren, Z.: Thermoelectric Magnetohydrodynamic Flows and Their Induced Change of Solid–Liquid Interface Shape in Static Magnetic Field-Assisted Directional Solidification, *Metallurgical and Materials Transactions A*, March 2016, Volume 47, Issue 3, pp 1169–1179.

[9] Kaldre, I., Bojarevics, A., Fautrelle, Y., Etay, J., Buligins, L. Current and magnetic field interaction influence on liquid phase convection (2012) *Magnetohydrodynamics*, 48 (2), pp. 399-406.

Authors

Dr.Phys. Andris Bojarevičs
E-mail: andrisb@sal.lv

Dr.Phys. Imants Kaldre
E-mail: imants.kaldre@lu.lv

M.Phys. Mikus Milgrāvis
E-mail: mikus.milgravis@lu.lv

M.Phys. Toms Beinerts
E-mail: toms.beinerts@lu.lv

Institute of Physics
University of Latvia
Miera 32, LV-2169
Salaspils, Latvia