Directional solidification of metallic alloys and composites under electromagnetic interaction

Imants Kaldre
University of Latvia
Institute of Physics
Riga, Latvia
imants.kaldre@lu.lv

Andris Bojarevics
University of Latvia
Institute of Physics
Riga, Latvia
andris.bojarevics@lu.lv

***Abstract*— In this work metallic alloys with particle inclusions has been directionally solidified under electromagnetic interaction. Applied magnetic field and electric current creates melt flow which has impact on solidification structure and properties of the alloy. There are various effects taking place under electromagnetic fields during solidification. For different materials different effects can be dominant. In this work aim is to investigate aluminum alloys. Test experiments using low temperature alloys are presented as well. Experimental results are explained by analytical and numerical models.**

Keywords*— Aluminum alloys, Metal matrix composites, Directional solidification, electromagnetic ultrasound

I. INTRODUCTION

Solidification of metallic alloy is a complicated multiphysical process where numerous physical processes take part and influence each other in different ways. Structure of the metal or alloy is also significantly affected by heat and solute transport in the liquid melt in the vicinity of the solidification interface and in the mushy zone during solidification process. At low solidification velocity larger grains are forming and their size depends on temperature gradient along the solidification interface and solidification velocity. This relation is well known and studied. If electromagnetic force is present, then situation can be different.

Application of magnetic fields can be additional mechanism to affect and create convection in the liquid melt and mushy zone of metallic alloy. Combined alternating (AC) and static (DC) magnetic fields has been used to affect microstructure and impurity transport of the metallic alloys and metal matrix composites. DC magnetic field creates thermoelectromagnetic convection and melt flow perpendicular to magnetic field leading to anisotropic material structure [1]. Electric current and DC electromagnetic interaction has been studied showing that electromagnetic vibrations is one of the methods to disperse particles and refine grain structure of the metallic alloys.

II. METAL MATRIX COMPOSITES

Dielectric particles in metal matrix can significantly improve some of metal properties, like mechanical strength, thermal properties and radiation absorption properties. Particles added to liquid metal tend to form agglomerates due to Van der Waals forces and electromagnetic separation between metal and particles or their ensembles. Dispersion of these agglomerates is a technical challenge which limits the production of these materials in larger quantities. Electromagnetically induced vibrations is one of the means how to disperse particles contactlessly. In previous works it has been shown that combined AC and DC magnetic fields can create sufficiently high-pressure amplitude to disperse particles in some metals [2]. Application of AC and DC magnetic fields during directional solidification can be an effective approach to refine grain structure and to disperse particles.

III. EXPERIMENT

Directional solidification has been widely used to study solidification characteristics and its dependence on various external parameters. In this work series of experiments has been done by directionally solidifying SnBi and SnPb alloys. Principal scheme of experimental setup is shown in Fig.1. Metal is filled in corundum tube. Tube is pulled by programmable step motor through the AC coil which melts the sample and water-cooled heat exchanger. Solidification interface remains at fixed location between the coil and heater. DC magnetic field is provided by external permanent magnet assembly. Directionally solidified samples are then investigated by optical microscopy and EDX spectroscopy to visualize particle distribution.

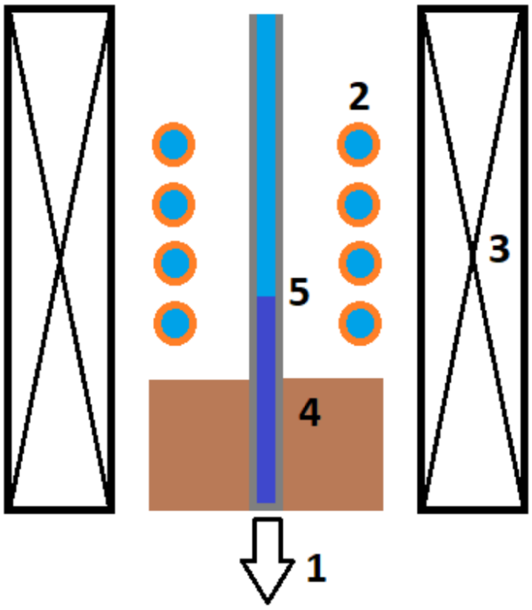

Figure 1. Scheme of the experimental setup: 1) Programmable pulling motor, 2) AC inductor, 3) DC magnet, 4) Cooler, 5) Solidification interface

Experimental setup allows us to achieve up to 0.6 T DC magnetic field, while AC magnetic field at 50 Hz frequency is 0.05 T. We use solidification velocities from 10 μm/s to 1 mm/s. Effect of electromagnetic vibrations under various magnetic fields are solidification velocity has been studied. However, result interpretation is difficult, because there are not always direct link between solidified microstructure and melt flow during solidification.

CONCLUSIONS

Electromagnetic effects can have significant impact on the solidification structure and impurity distribution. Results of these experiments show that superimposed AC and DC magnetic fields can be used to affect the melt flow near the solidification interface during directional solidification and to refine the grain structure, and to improve particle dispersion.

ACKNOWLEDGMENT

This work is supported by PostDoc Latvia Postdoctoral research grant « Electromagnetic methods for metal matrix nano-composite production » No. 1.1.1.2/VIAA/2/18/264

REFERENCES

[1] I. Kaldre, Y. Fautrelle, J. Etay, A. Bojarevics, L. Buligins, “Influence on the macrosegregation of binary metallic alloys by thermoelectromagnetic convection and electromagnetic stirring combination,” Journal of Crystal Growth, Vol. 402, pp. 230-233, 2014.

[2] I. Kaldre, A. Bojarevičs, I. Grants, T. Beinerts, M. Kalvāns, M. Milgrāvis, G. Gerbeth, “Nanoparticle dispersion in liquid metals by electromagnetically induced acoustic cavitation,” Acta Materialia, Vol. 118, pp. 253-259, 2016.