IMPACT OF A ROTATING MAGNETIC FIELD ON THE MICROSTRUCTURE FORMATION DURING DIRECTIONAL SOLIDIFICATION OF ALSI7-BASED ALLOYS

G. Zimmermann[1], *A. Weiss*[2]

[1] *ACCESS e.V., Intzestrasse 5, 52072 Aachen, Germany*
(g.zimmermann@access.rwth-aachen.de)
[2] *IMM, RWTH Aachen, Germany*

Introduction. To control the behaviour of melts during the solidification process external magnetic fields are important tools in the foundry industry. Often continuous casting plants both for steel and high stressed aluminium alloys are equipped with electromagnetic stirring devices. The main objectives of using such facilities are the realization of a globular microstructure and the reduction of the centre-line segregation in the casting billets. For these purposes coil systems are used, which generate a rotating magnetic field around the sample. In the electrically conducting liquid metal Lorenz forces are induced by the alternating magnetic field resulting in a convective melt flow, which has a strong impact on the materials microstructure during solidification.

This paper shows the microstructure formation in AlSi7Mg0.6 alloy during directional solidification with different growth velocities and application of forced melt flow of different intensities. From analysis of the processed samples it is found that forced melt flow changed the microstructure substantially.

1. Experimental setup. For directional solidification a Bridgman–Stockbarger type furnace was used which consists of two independently controlled heating zones, a water-cooled copper chill and an insulating baffle in between [1]. The solidification process was realized via a motion of the furnace chamber relative to fix-mounted rod-like samples of $8 \cdot 10^{-3}$ m in diameter. For the experiments the ternary Al-7wt%Si-0.6wt%Mg alloy delivered by Hydro Aluminium GmbH was used. This alloy solidifies similar to A357, which is used in industry for light weighted automotive components. The process parameters for the directional solidification experiments were furnace velocities of $4.2 \cdot 10^{-6}$ m/s and $83.3 \cdot 10^{-6}$ m/s and an axial temperature gradient in the sample at the solid-liquid interface of $1.0 \cdot 10^{4}$ K/m.

Forced flow in the melt was induced by a rotating permanent ring magnet integrated in the baffle disc (Fig. 1). The rotation of the magnet was achieved by a belt drive which allowed up to 3000 revolutions per minute. In the centre of the ring a maximum magnetic field strength of $2.5 \cdot 10^{-2}$ T was measured in radial direction. For the experiments performed constant rotational frequencies in the range between 0 and 50 Hz were applied.

2. Experimental results. The processed samples were metallographically prepared to analyse the microstructure. From axial and radial cross-sections the primary dendrites and the eutectic phase were determined using a light microscope. Concentration measurements were performed by using a scanning electron microscope with energy dispersive analysis.

Fig. 2 shows a radial and an axial cross-section of an AlSi7Mg0.6 sample directionally solidified with $4.2 \cdot 10^{-6}$ m/s and an applied magnetic field rotating

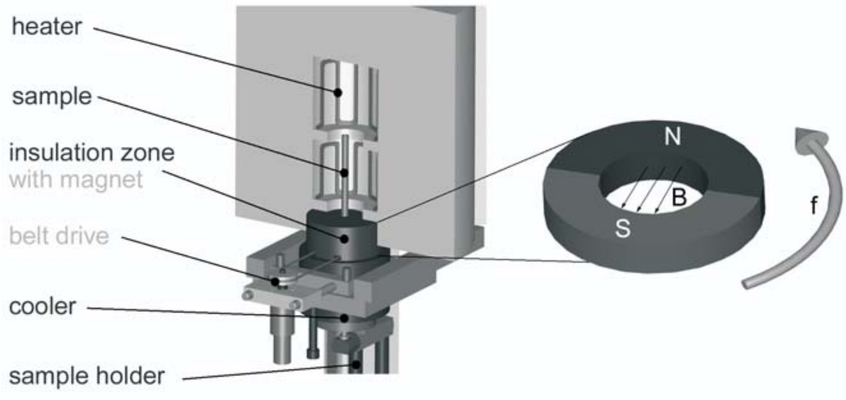


Fig. 1. Experimental set-up including Bridgman furnace and rotating permanent magnet.

with 3000 rpm. From both cross-sections a columnar grown microstructure of Al-dendrites with eutectics (dark-grey) in the interdendritic region can be observed in the out-of-centre part of the sample. In the centre part the amount of eutectic phase is significantly increased. Concentration measurements indicate that in the centre part the content of Silicon reaches the eutectic value of about 12.6 wt% Si. The investigation of the grain structure by using electrolytical etching technique shows that the enrichment of Si-phase also corresponds to a more equiaxed grain structure.

The microstructure formation depends strongly on the process parameters. Typical examples of the centre part region are shown in Fig. 3. The microstructures given in Figs. 3*a* and *b* belong to a solidification velocity of $83.3 \cdot 10^{-6}$ m/s and rotations of the ring magnet with 300 rpm and 3000 rpm, respectively. Even at the low rotation rate locally an enrichment of eutectics is observed, whereas for intense melt flow pronounced eutectic areas exist. The microstructure shown in Figure 3c occurs at a RMF with 3000 rpm and a rather slow growth rate of $4.2 \cdot 10^{-6}$ m/s. Compared with the microstructure in Fig. 3*b* the primary Al-phase is more coarsened, combined with a more regular distribution of the eutectics in between.

3. Discussion. The analysis of the processed samples shows that the forced melt flow alters critically the microstructure. To quantify the melt flow the magnetic Taylor number is used,

$$\mathrm{Ta_m} = \frac{B^2 R^4 \sigma \pi f}{\rho \nu^2}$$

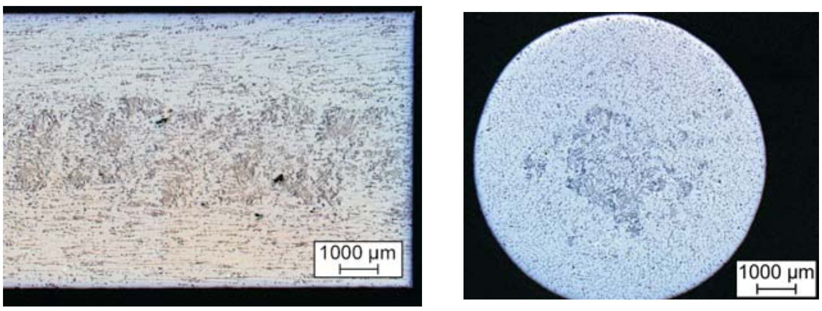
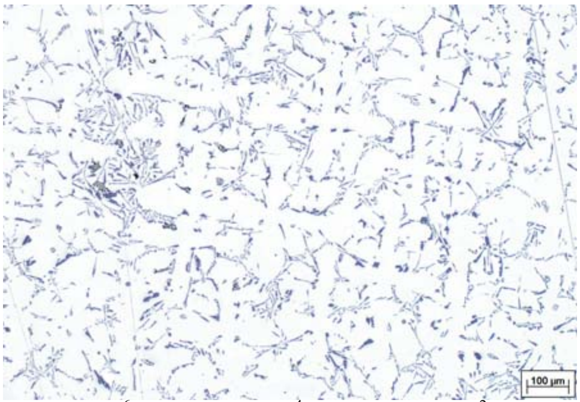
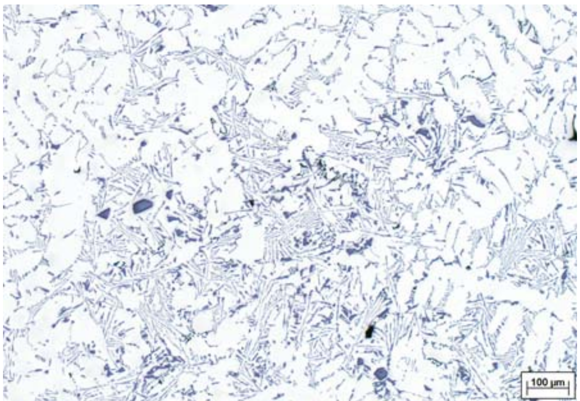


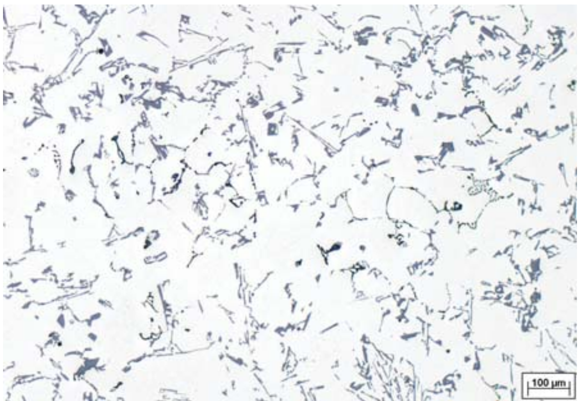
Fig. 2. Axial and radial cross-section of an AlSi7Mg0.6 alloy directionally solidified with $4.2 \cdot 10^{-6}$ m/s in an axial temperature gradient $1.0 \cdot 10^4$ K/m and an applied RMF rotating with 3000 rpm.



a) v = 83.3·10^{-6} m/s, G = 1.0·10^{4} K/m, B = 2.5·10^{-2} T, f = 5 Hz



b) v = 83.3·10^{-6} m/s, G = 1.0·10^{4} K/m, B = 2.5·10^{-2} T, f = 50 Hz



c) v = 4.2·10^{-6} m/s, G = 1.0·10^{4} K/m, B = 2.5·10^{-2} T, f = 50 Hz

Fig. 3. Microstructures taken from the centre part of samples solidified with different velocities and frequencies of the RMF, leading to different microstructures.

with B the amplitude of the magnetic field, R the sample radius, σ the electrical conductivity of the melt, f the rotational frequency of the magnet, ρ the density of the melt and ν the kinematic viscosity. From this it follows that the highest rotation rate with 3000 rpm corresponds to a magnetic Taylor number of about 38000 [2].

Numerical calculations performed by Dagner *et al.* [3] show that for such high magnetic Taylor numbers not only an azimuthal melt flow exists but also

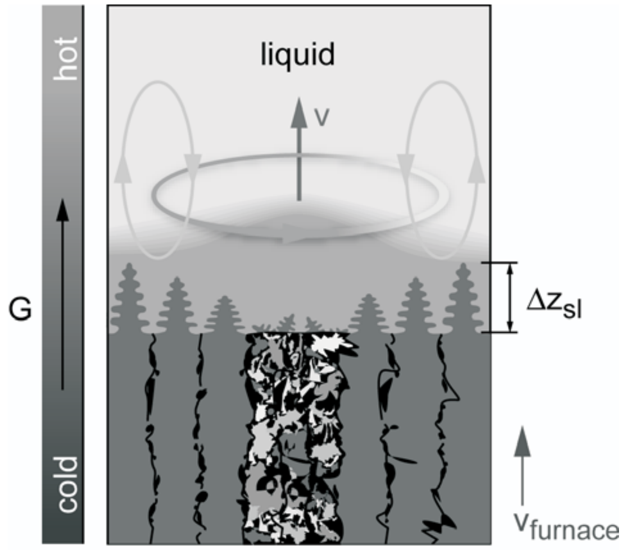


Fig. 4. Simplified sketch of microstructure formation with intense melt flow.

secondary convection rolls appear, which may additionally be time-dependent. Simulations performed by Wang *et al.* [4] predict a similar behaviour. Additionally they predict that the secondary melt flow originates in an enrichment of Silicon in the centre, as observed experimentally. Fig. 4 summarizes in a simplified sketch the complex interaction between the formation of different microstructures and grains in consequence of the forced melt flow ahead of the growing solid-liquid interface.

4. Conclusion. This paper demonstrates experimentally the impact of a magnetic field rotating with frequencies up to 50 Hz on microstructure formation in directionally solidified AlSi7Mg0.6 alloy. The induced melt flow results in strong modifications of the solidification morphology.

These investigations are part of the ESA MAP programme "MICAST", whose main objective focus on a global understanding of microstructure formation under diffusive and magnetically controlled convective conditions.

REFERENCES

1. A. Weiss, G. Zimmermann, R. Salber, Z. Mbaya. Microstructure development in solidification of Al-Si alloys under magnetically controlled flow conditions.. In *Proceedings of the Electromagnetic Processing of Materials International Conference EPM 2003* (Lyon, France, 2004), pp. 43–48.
2. A. Weiss, G. Zimmermann. Influence of electromagnetic stirring on the directional solidification of AlSi alloys. In *Proceedings on International Symposium on Heating by Electromagnetical Sources HES-04* (Padua, Italy, 2004), pp. 693–700.
3. J. Dagner, A. Weiss, M. Hainke, G. Zimmermann, G. Müller. Global modelling of directional solidification processes of binary and ternary Aluminum alloys using software package CrysVUn. In *Solidification* & *Gravity 2004* (Miskolc, Hungary, 2004; Trans Tech Publications, in print).
4. X. Wang, A. Ciobanas, F. Baltaretu, A.M. Bianchi, Y. Fautrelle. Control of the macrosegregations during solidification of a binary alloy by means of AC magnetic field. In *Solidification* & *Gravity 2004* (Miskolc, Hungary, 2004; Trans Tech Publications, in print).