ALLOYING ELEMENTS MACROSEGREGATION IN 6XXX ALUMINUM ALLOY BILLETS OBTAINED BY CONTINUOUS CASTING WITH ELECTROMAGNETIC STIRRING

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Abstract

An important scientific and utilitarian challenge is to provide repeatability of the chemical composition in volume of billets, which guarantee the uniform yield stress during hot metal forming processes. During real billet manufacturing processes the segregation of chemical composition is observed. It depends on the type of alloy, solidification process conditions, and technological factors. This segregation can occur in the microscale (microsegregation) or in the macroscale (macrosegregation). The microsegregation can be reduced by the homogenisation but macrosegregation is an indelible defect. An effective way to reduce macrosegregation is electromagnetic stirring of liquid metal before solidification. The effectiveness of this mixing depends on the position of the stirring coil in relation to the solidification area.

The paper presents the impact of selected continuous casting process parameters (casting speed, cooling medium flow in the primary cooling) on the alloying elements macrosegregation in the billets. Additionally macrostructures of billets were reported and electrical conductivity of material as an alternative measure of the alloying elements content was done. The distribution of alloying elements on the billet diameter shows a maximum set asymmetrically relative to the axis of the billet (horizontal casting). Variation of the silicon content is greater than for the magnesium. Changing the conditions of the mould primary cooling - increase the flow of cooling medium results in a decrease of solidification zone distance from the mixing coil and causes mainly the reduction of magnesium macrosegregation.

Keywords: Macrosegregation, aluminum alloy, continuous casting, electromagnetic stirring

1. INTRODUCTION

During solidification of liquid metal in continuous casting process the mass exchange between the liquid to the solid takes place at the phase boundary (solidification front). In the case of horizontal casting, the solutes flow in the liquid phase is caused by the diffusion of the solute, termo-solutal and forced convection. The relative high continuous casting speed determines the non-equilibrium solidification conditions contribute to solute and temperature gradients. As a consequence, there is an unequal distribution of alloying elements on the cross section of the cast [1]. This phenomenon is undesirable due to metal forming. Therefore, different innovations are implemented to optimalization of solidification conditions. Recent studies [2-6] show that electromagnetic stirring in the solidification zone contribute to the reduction of the macrosegregation of the alloying elements in material. In addition, the intense forced flow of the liquid metal in the solidification zone results in a reduction of the columnar grains structure in the obtained EN AW-6060 aluminum grade casts. In industrial practice chemical modification is broadly applied mostly by addition of grain refiner which inhibits the growth rate of grains and nucleation. Refinement of casting structures is extremely important due to the possibility of further processing of the material by extrusion, limitation of sheet splitting during rolling or the possibility of good quality forgings production with the use of die forging process and primarily reduction of macrosegregation of alloying elements in the casts obtained by continuous casting [7-8].

2. METHODOLOGY OF RESEARCH

In the industrial line dedicated to horizontal continuous casting of aluminum alloys with electromagnetic stirring in the primary cooling zone, EN AW-6060 aluminum grade rods has been produced. The feed material was obtained by metallurgical synthesis of full-value aluminum scrap and certified master alloys (AlSi50 and AlMg50). Metal cooler was fitted out with 90 mm diameter graphite insert. Foundry castings were carried out with following steps: 10, 20, 30 and 40 mm and 10 sec stop with intensive and extensive cooling conditions of deionized water at 21 °C. In some cases 200 ppm Ti (in a AlTi4B1) was added to liquid metal bath in for grain refining process. The rods were tested for chemical composition and electrical properties with the use of Master Foundry Xpert and SIGMATEST 2.069 (**Figure 1**) devices. **Figure 2** shows a scheme of continuous casting process as well as casting rods obtained with the use of above mentioned technology.

Figure 1 Spectrometer Master Foundry Xpert and SIGMATEST 2.069

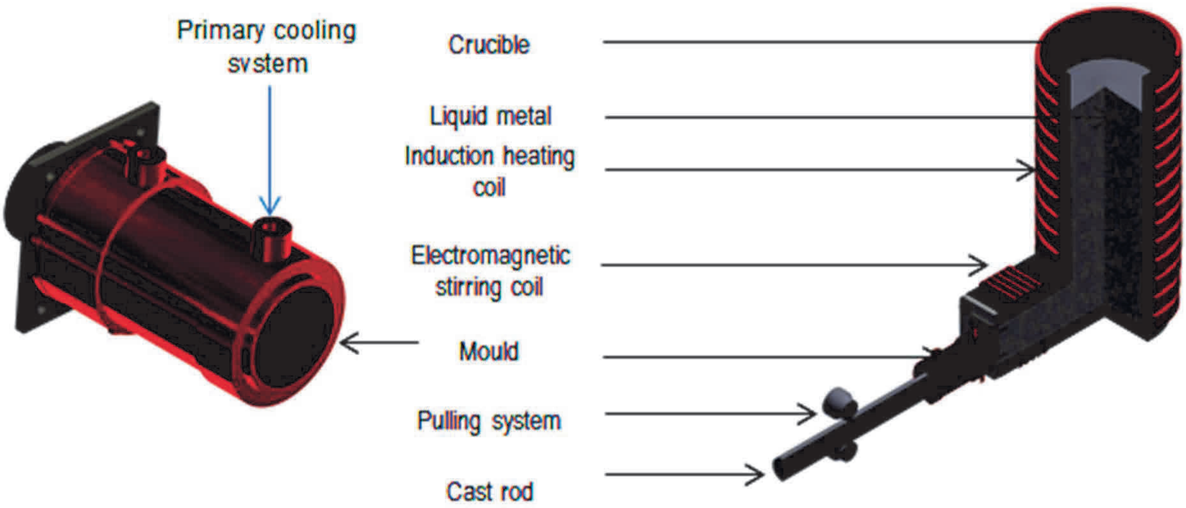


Figure 2a) Scheme of continuous casting process

Figure 2b) Industrial continuous casting process and casting rods

3. RESULTS

Figure 3 presents the results of spectrometric analysis of chemical composition and electrical conductivity tests on the cross-section of in EN AW-6060 grade aluminum casts. **Figure 4** presents macrostructures at transverse direction of casts obtained with different casting speeds, cooling conditions and chemical composition.

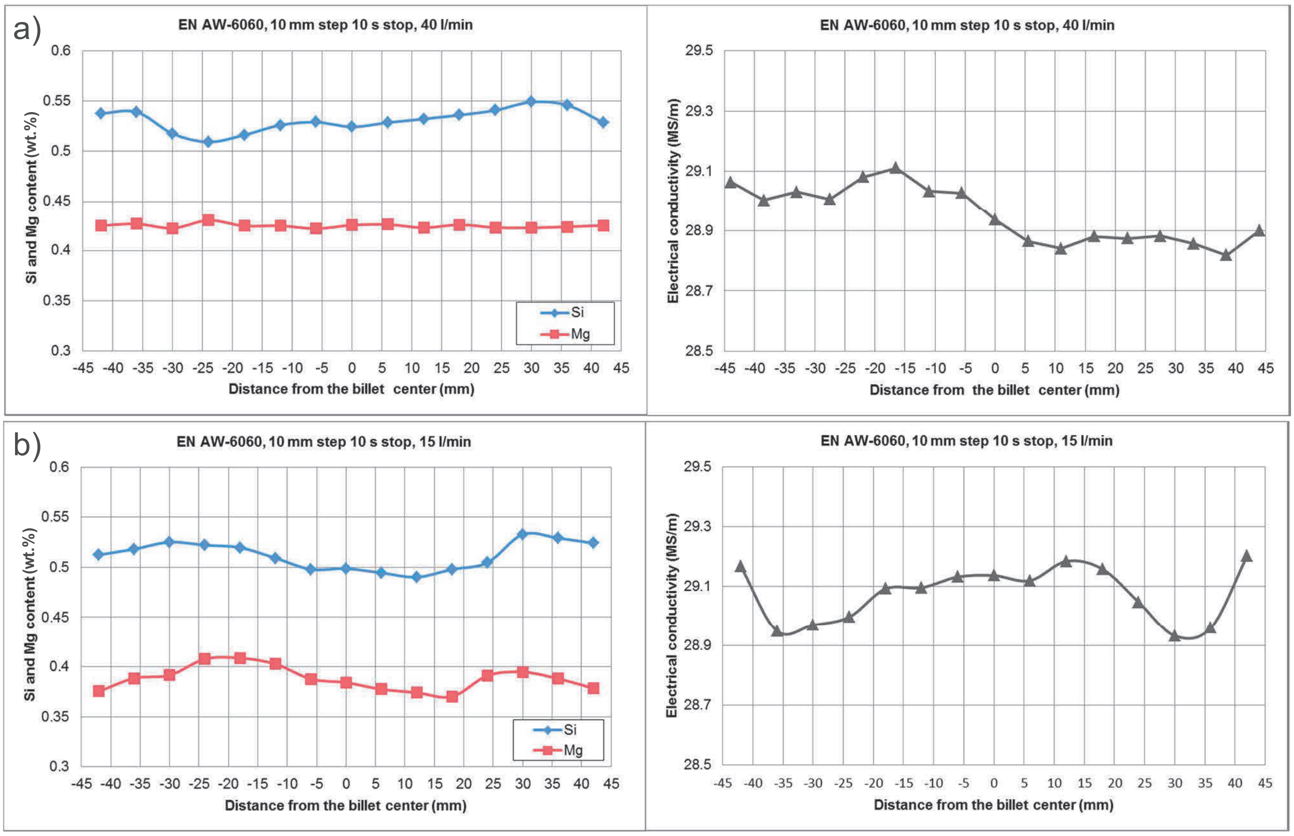


Figure 3 Deviation of Si and Mg content and changes of electrical conductivity in continuous casting EN AW 6060 aluminum alloy billet 90 mm diameter:
a) 10 mm step/10 s stop, 40 l/min, b) 10 mm step/10 s stop, 15 l/min

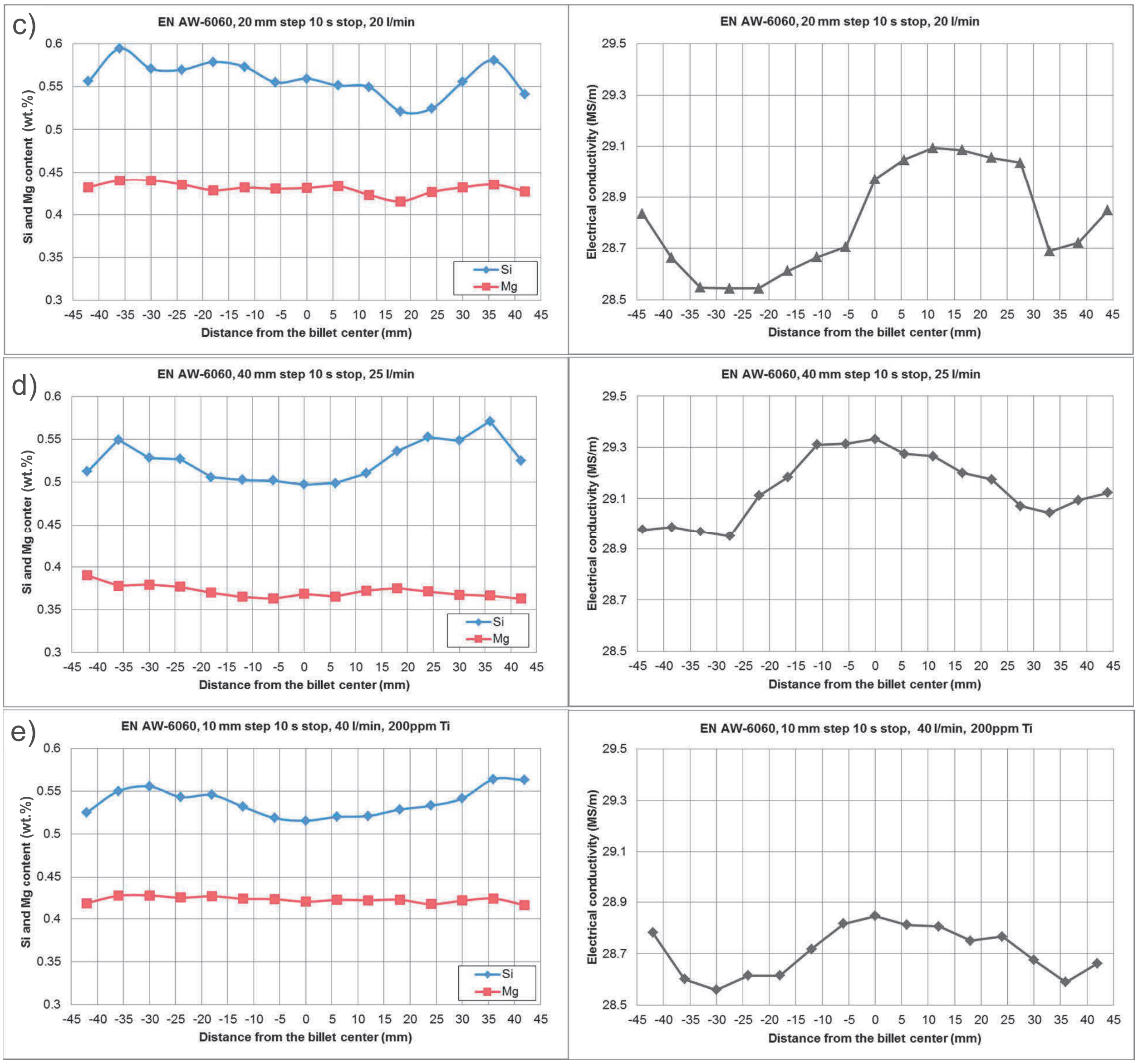
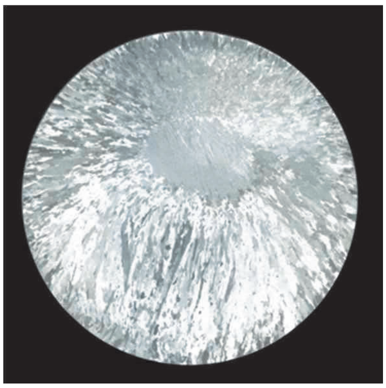
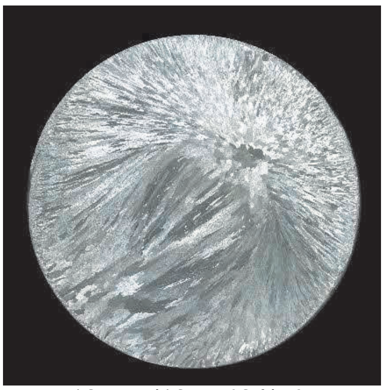
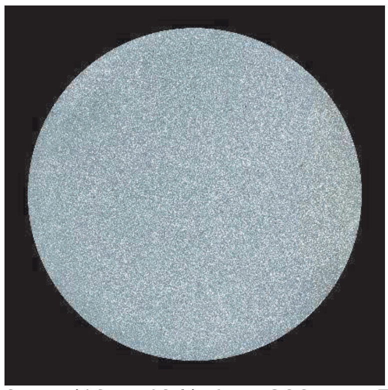
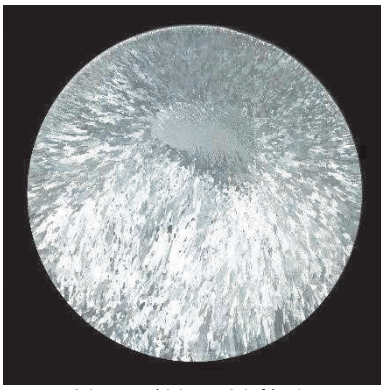


Figure 3 Deviation of Si and Mg content and changes of electrical conductivity in continuous casting EN AW 6060 aluminum alloy billet 90 mm diameter:
c) 20 mm step/10 s stop, 20 l/min, d) 40 mm step/10 s stop, 25 l/min, e) 10 mm step/10 s stop +Ti


10 mm/10 s, 15 l/min


10 mm/10 s, 40 l/min


10 mm/10 s, 40 l/min + 200 ppm Ti



20 mm/10 s, 20 l/min

40 mm/10 s, 25 l/min

Figure 4 Macrostructures of casts obtained with different casting parameters

4. CONCLUSION

From the observations of cast macrostructures it was found that increase of casting speed contributes to the reduction of the dendrite size as well as the minimization of the negative effects of directional heat removal resulting in the decentralization of the core of the castings.

Main alloying elements macrosegregation shows complex distribution. Maximum content of elements in subsurface zone is observed while minimum content of elements is observed in the center of the cast or in the half of the cast radius.

Based on the analysis of the obtained chemical composition research results and mathematical calculations, the silicon segregation rate is higher than magnesium at the level of 9-15 wt.%, while for magnesium it is about 2-8 wt.% (depends strongly on casting conditions).

Electrical conductivity of the material is not uniform on the cross section of casted material. Higher elements concentration translates into lower electrical conductivity. Solidification rate and cooling rate in solid state is high. This prefers location of alloying elements in solid solution. Those elements strongly affect the electrical conductivity. According to Nordheim's rule there is a linear dependence of particular element concentration and electrical conductivity. On this basis electrical conductivity measurements can be a fast and easy alternative method for macrosegregation investigation.

Continuous casting with intensive electromagnetic stirring gives possibility to reduce macrosegregation. During intensive cooling, solidification front is close to the stirring zone which results in grain size reduction and minimization of chemical composition segregation. Unique effect is observed during simultaneous electromagnetic stirring and chemical grain refining. Macrostructure changes the character (no dendrites observed) and uniform alloying elements distribution on cast cross-section is observed.

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