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Application of electromagnetic stirring for the homogenization of aluminium billet cast in a semi-continuous machine

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ABSTRACT

Several billets have been cast at different levels of current induced in the stirrer coil, they have been characterized under the microstructural aspects and their features have been compared with the characteristics of the as-cast billets and of the thermally homogenized ones, because these last ones are used in the typical and traditional technological route. The coupling of the computational simulations – performed by a multiphysic platform – allows us to estimate the flow patterns induced by the different current levels applied in the stirrer coil. The homogenization of the electromagnetically treated billet has certainly taken place implying a finer distribution of the intermetallic phases. The thermal homogenizing is always associated with a softening of the metal alloys whereas the electromagnetically refined structure shows a hardening phenomenon caused by the induced finest grain size. The flow pattern imposed by the electromagnetic stirrer is strongly dependent on the current intensity that is pointed out as the ruling variable conditioning the velocity field of the liquid pool. Thus, an electromagnetic stirring working at low frequency and a correct modulation of current intensity can be useful for improving the technological route finalized to the extrusion of the aluminium alloys, taking into account that such a route involves the use of extrusion machines featured by a higher power level.

1. Introduction

The homogenization treatment of the aluminium alloys represents a fundamental step for performing an efficient extrusion, but such a procedure implies a significant expense of time and energy to heat the billets and to maintain them at a thermal level that permits the development of the diffusion and dissolution phenomena.

Flemings et al. (1976) have provided a complete and very accurate analysis of the microstructure featuring the cast aluminium alloys, their main morphologic characteristics and the relation of the observed features and the imposed operative parameters. Fujii et al. (1984) have performed an exhaustive characterization of the aluminium–silicon cast alloys showing the relation between the microstructural features and the related mechanical properties. Those results have been confirmed by Adachi (1984) who has also pointed out the significant role played by the phase distribution in the modification and the modulation of the mechanical properties. The absence of the homogenization treatment causes a gradient in the distribution of the alloying elements, in the precipitated phases and in the resulting mechanical properties. Such a situation produces strong discontinuity within the strain field and this fact can induce a fracture in the worked material during the deformation thus creating core or surface defects that do not permit the application of the extruded product. Hafiz and Kobayashi (1994) have clearly indicated the favourable role played by the modification of the microstructure on the fracture toughness of a cast aluminium alloy and their observations confirm the role played by a homogeneous microstructure in increasing both the toughness and ductility. The thermal homogenization produces a more uniform phase distribution and a diffused softening of the aluminium alloys that reduces the stress field during the extrusion, the related force to be applied by the extrusion press and a lower increase of the heat development. The need of saving time and of decreasing the environmental impact leads to the experimentation of other technologic routes.

On the other hand, there are no clear data about the potentiality of the electromagnetic stirrer in varying the solidification structures and in its influence on the morphology, chemical and mechanical properties shown by the solidified grain structure and by the precipitated phases in the aluminium alloys: Zhang et al. (2003) have provided promising information about the casting of A 7075 focusing the attention on the variation of the macrosegregation and on the modification of microstructural characteristics, but a discussion in the variation of the mechanical properties is lacking, while the results proposed by Park et al. (2006) are mainly focused on the surface quality and their extension to other more

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Table 1
Chemical composition of the UNS A96060 alloy.

%Weight	Si	Fe	Cu	Mn	Mg	Cr	Zn
	0.3–0.6	0.1–0.3	0.1	0.1	0.35–0.6	0.5	0.15

frequent situations can be forbidden by the use of a slit mould. In this study the as-cast billets, the thermally homogenized billets and the ones electromagnetically stirred using different operative parameters (i.e. intensity of the applied induction current) have been compared in order to clarify the homogenizing effects and possible drawbacks caused by the electromagnetic stirrer.

The main aims of the study can be summarized as:

- improvement of the metallurgical microstructure produced by the solidification process;
- definition of the relationships existing among the applied operative casting parameters and the resulting solidification microstructures;
- evaluation of a technological route that permits to by-pass the thermal homogenization process in order to decrease the environmental impact.

2. Experimental procedure

The experimental trials have been performed on the UNS A96060 Al–Mg–Si alloy (Table 1) whose solidification thermal range is of 615–655 °C. This alloy has been cast in all the experimental trials at 685 °C. The casting on the semi-continuous machine has been performed applying a casting speed of 85 mm/min and the billets are featured by 250 mm diameter. The flow rate of the cooling water in the primary circuit has been maintained at 4.3 m^3/h for all the casting trials performed to obtain the observed billets. Two digital pyrometers have been located under the mould at a distance of 1 and 3.5 m. These pyrometers have measured the surface temperature of the billets in order to grant that those cast by different operative conditions have followed the same cooling patterns. The applied pyrometers have indicated that for the examined billets the maximum variations of the temperature revealed by pyrometers is below 9 °C and this assures that the imposed cooling patterns are analogous and the following observed difference in the microstructure cannot be attributed to a different undergone thermal pattern, but to the difference of the applied operative parameters applied for the stirrer.

The electromagnetic stirrer has been applied just under the primary cooling system of the semi-continuous casting machine (Fig. 1) composed by a porous graphite ring lubricated by pressurized oil, while the cooling water film has been introduced by a round section just above the graphite ring. The electromagnetic stirrer is composed by one joke constituting the magnetic nucleus equipped by 8 turnings of copper wires (Fig. 2).

The trials performed through the application of the electromagnetic fields have been monitored through two Ultrasound Doppler

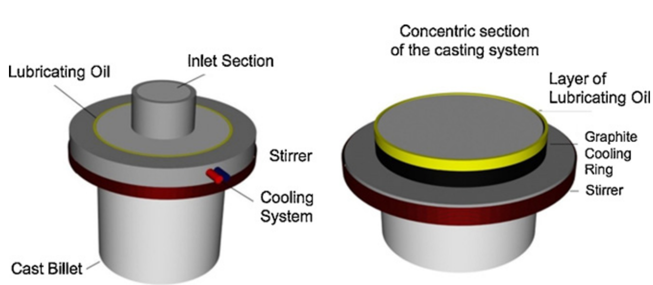

Fig. 1. Scheme of the observed semi-continuous casting machine.

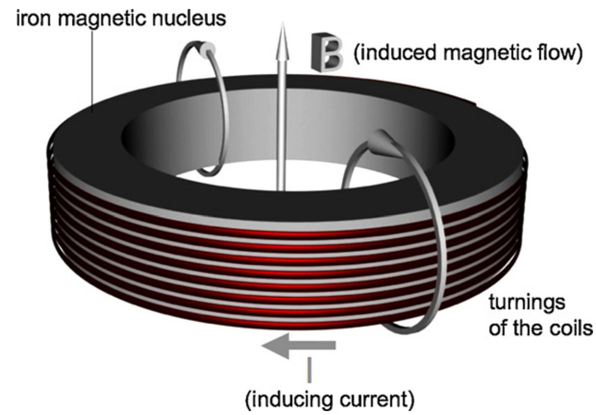

Fig. 2. Layout of the applied stirrer.

Velocimeters (UDV). According to the indications coming from similar experimental trials (Eckert et al., 2003) the UDV has been realized with a stainless steel wave guide in order to resist against the thermal exposition of the melt aluminium alloy, the working frequency of the transducers has been set at 4 MHz and the wave guide thickness has been fixed at 0.125 mm to provide a monomode behaviour of this wave guide. The length of the applied wave guide is of 90 mm and has an outer diameter of 5 mm. The monitoring time has been limited at 180 s for each trial because after this time the UDVs point out a very unstable and weakened signal probably due to the formation of oxide scales on the wave guide and to its partial localized dissolution. One of the UDVs is placed along the radial direction of the billet with an inclination of 35° from the vertical direction and the other UDV is placed along the tangent billet direction. The velocity measurements have been performed at 30 mm from the billet surface for the tangentially located UDV and at 45 mm for the radially located one, in order to avoid a significant mutual interference. In all the experimental trials the UDVs have been set at a 30 mm depth from the free liquid metal surface.

Two reference samples have been taken as a term of comparison to understand the effect produced by the electromagnetic stirrer on the solidification microstructure and to evaluate the difference between the thermally homogenized samples and the electromagnetically stirred ones. The as-cast samples have been indicated as R01 while the thermally homogenized ones have been indicated as X01. The homogenizing treatment has been performed by heating the aluminium alloy at 535 °C for 10 h and by a cooling at 250 °C/h. The other stirred samples have been treated using five different levels of the induction current (Table 2). The levels have been chosen in order to scan a range wide enough to point out significant effects on the fluid movement and the consequent modifications of the microstructure of the billet.

The examined coupons have been cut along a diameter of the cast billets (Fig. 3), they are featured by square shape (20 mm × 20 mm) and come from three positions along the sectioned diameter classified on the basis of their distance from the surface:

- the surface samples (S) at 10 mm from the surface

Table 2
Sample denomination and levels of the current applied for electromagnetic stirring.

Sample	Frequency (Hz)	Current (A)
S01	15	10
S02	15	20
S03	15	80
S04	15	130
S05	15	160