Industrial Usages of Various Electromagnetic Stirrers in SSM Processing

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Received: April 21, 2018
Accepted: May 20, 2018

ABSTRACT The current investigation work illustrates several techniques developed for production of non-dendritic microstructures like mechanical stirring and electromagnetic stirring. In addition, it also highlights about the various processes like linear, rotary and helicoidal, stirring practices involved in electromagnetic stirring for producing non-dendritic microstructure. Furthermore, it also demonstrates about three different electromagnetic stirrer geometries such as linear, rotary and helicoidal, stirrers. The electromagnetic stirring is recognized as a perspective technique to produce large feed stocks of non-dendritic microstructure with unswerving quality. Regardless of, very few issues and challenges, this technique may also be used for commercial production of semisolid cast billets with non-dendritic microstructure morphology.

Keywords: Electromagnetic; Semisolid, Slurry; Billet; Aluminum Alloy; Casting.

I. Introduction
It is well accepted that in the entire chain of activities of SSM process, the production of unswerving quality raw material (in the form of billets with non-dendritic microstructure) plays the key role. Over the past thirty five years ever since the invention of SSM process, researchers and industries all over the world have tried and experimented numerous techniques to produce non-dendritic microstructure. As of today, various methods have been adopted, and can be broadly classified into two categories. Fragmentation of dendrites by means of forced convection, examples of which are (a) mechanical stirring and (b) electromagnetic stirring.

(a) Mechanical stirring
The simplest and the most direct method for producing non-dendritic structure is agitation of the melt, which is kept within the freezing range, using a mechanical impeller. A schematic diagram of mechanical stirring is shown in figure 1. The main drawbacks of the process include undesirable reaction between the impeller and the corrosive liquid metal, and entrapment of gases during agitation.

Fig 1. Schematic of mechanical stirring. Fig 2. Schematic of an electromagnetic stirring.

(b) Electromagnetic stirring
The melt undergoing solidification is subjected to an electromagnetic force field, which creates forces in the metal to stir and shear the dendrites formed at the solid/liquid interface. A schematic diagram of this process in the context of direct chilled casting is shown in figure 2. Although it may seem to be an expensive proposition due to high energy costs involved, the major advantage is that the stirring device has no physical contact with the melt. As a result, this method can overcome some of the disadvantages pertaining to mechanical stirring.
While majority of the methods described above is restricted to laboratory research, only some are successfully implemented. All the currently adopted methods have their own merits and demerits and an ideal method to produce desirable microstructure consistently with minimal defects is yet to emerge. Such an ideal process, which can also be scalable for commercial production, is the key objective for most current researchers engaged in the development of SSF technology. Among all the methods, EM stirring in SSF is gaining popularity from a commercial point of view to produce large feed stocks having non-dendritic microstructure and consistent quality.

II. Role of Electromagnetic Stirring in Producing Non-dendritic Microstructure

Electromagnetic stirring influences solidification during the casting process by inducing strong rotation of melt in the mould. The intense forced convection promotes homogenisation of the melt temperature and fragmentation of dendrites at the solidification interface. The fragmented dendrites are transported into the bulk liquid and form a semisolid slurry in the melt. These surviving broken dendrites then form additional nucleation sites upon which further grain growth will occur, thereby resulting in grain refinement in the final casting products. Thus, the billet produced by this process has a microstructure composed of clustered degenerate-dendritic particles. Also the intense stirring causes uniform macrosegregation patterns at the interface, thereby resulting in a more or less uniform final composition in semisolid billet formed by SSF technique. Electromagnetic stirring harnesses the electrical conducting properties of metals to induce eddy current by external magnetic fields. The externally imposed magnetic field and induced eddy currents generate electromagnetic forces in liquid metal, eventually resulting in stirring of the melt. One of the biggest advantages of EM stirring is that the nature of stirring, intensity, and direction can be modulated externally. A number of examples can be found in the literature in which electromagnetic forces have been applied to induce fluid flow during solidification in order to refine grain size. It is found that the dendritic structure is greatly affected by convection during early stages of solidification. In the limit of vigorous convection and slow cooling, grains become spheroidal.

III. Various Type of Electromagnetic Stirrer

The electromagnetic stirrers are designed to produce forced convection in the melt. Magnetic fields generated by low-frequency currents are known to produce Lorentz forces with better penetration into the molten metal pool. Various EM stirring techniques are in operation for producing semisolid slurry of aluminium alloys. Essentially, there are three main types of stirring systems that exist, as shown schematically in figures 3-5. The three common stirring systems are linear, rotary, and helicoidal. A linear stirrer operates essentially in the same way as an induction furnace. The design entails the placement of a stack of coils around the casting metal to generate a primary motion that recirculates along the casting direction. In the case of linear stirring, as shown in figure 3, the dendrites are fragmented near the solidification front, and are recirculated up to the hotter zone of the stirring chamber where they may partially remelt.
A rotary stirrer is similar to an electric motor. It uses a rotating magnetic field to produce a swirling flow in the liquid pool as shown in figure 4. In rotary stirring, there is a probability of dendrite growth at the mould centre due to weak or complete absence of stirring in the central regions of the mould. In addition, rotary stirring may result in free surface deformation and depression at the top due to centrifugal action. However, these problems can be overcome by using linear stirring or helicoidal stirring. Figure 5 represents helicoidal stirring that combines the arrangements of both rotary and linear stirring techniques. There can be other arrangements to provide stirring action in the melt. One such method involves generation of a rotating magnetic field created either by rotating permanent magnets or by rotating the mould. There can be other combinations of rotary and linear stirring to create multiple rotating loops in the melt. As it can be imagined, a large number of combinations are possible. Therefore, it is not surprising that this subject is still at the heart of today’s research and that a comprehensive picture of combination stirring is yet to emerge.

Fig 5. Helicoidal electromagnetic stirring.

IV. Conclusion

As previously illustrated extravagantly, the electromagnetic stirring is well known as a very perspective method to produce large feed stocks of non-dendritic microstructure with unswerving quality. In spite of very few issues and challenges, this method can also be used for commercial production of semisolid cast billets having non-dendritic microstructures. With this viewpoint, the overall research relating to the electromagnetic stirring system can also be extended for casting of aluminum alloy semisolid billets. Through this research, the roles of process parameters such as superheat, cooling rate and the key issues/challenges can also be highlighted. A356 aluminum alloy, a popular die casting aluminum alloy widely used in transport industries may also be chosen as the candidate material for experimental, numerical together with analytical investigations.

References