

Continuous Casting of Hypereutectic Aluminum-Silicon Alloy Billets Using Electromagnetic Stirring Technique

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Abstract

The use of aluminum silicon alloy is widely accepted in many fields of applications, including automotive, aerospace and military. Hypereutectic aluminum silicon alloys has silicon contents commonly between 14% and 20%. The use of hypereutectic aluminum silicon alloys give a number of benefits such as low specific gravity, high resistance to wear and reduced thermal expansion. In the continuous casting of hypereutectic Al-Si alloy billets, the size and distribution of primary silicon become important to obtain uniform and excellent physical properties. In this study, electromagnetic stirring technique was applied to control the size and distribution of primary silicon. Rotational move of melts induces the segregation of primary silicon around casting surface. Turbulent flow of melts by electromagnetic stirring enhances the distribution of primary silicon. In results, the distribution of primary silicon is greatly enhanced by applying two way electromagnetic stirring technique. Finally the mechanical and wear properties were examined and compared with different samples and discussed about the usefulness of electromagnetic stirring to control the size and distribution of primary silicon in billet casting.

Keywords: aluminum silicon alloy, billet continuous casting, electromagnetic stirring

Introduction

Hypereutectic aluminum silicon alloys have gained a great attention due to its excellent properties such as high wear resistance, low thermal expansion coefficient, low density, good castability and good formability. The microstructure of hypereutectic aluminum silicon alloy is composed of primary silicon particles and eutectic structure of alpha aluminum and silicon. The high strength and wear resistance of these alloys are attributed to refined and uniformly distributed silicon particles. However, due to formation of coarse and segregated primary silicon during continuous casting of billets, these alloys shows low ductility and poor machining properties, which restrict the continuous casting of billets of small diameter. Conventional continuous casting processes can lead to premature crack initiation and fracture in tension and deteriorating mechanical properties. Therefore, primary and eutectic silicon must be refined and uniformly distributed in order to achieve fine and dispersive silicon phase with desirable properties.

General methods to refine primary and eutectic silicon have been applied to investigate the morphological evolution of silicon phase in aluminum silicon alloys, such as adding modifiers or nucleation agents, semi-solid processing, melt superheating treatment, outfield treatment and quench modification. Among the various methods, chemical modification via adding phosphorous modifiers into melt has been widely used in continuous casting of billets. Hypereutectic aluminum silicon alloys can be effectively modified by adding Al-Cu-P and Cu-P master alloy due to forming AlP particles that can act as refining agent of primary silicon. However the distribution of primary silicon becomes irregular because of severe segregation of primary silicon phase. It is successful to refine primary silicon by adding phosphorous agent but segregation of primary silicon limits the continuous casting of large diameter billets so far.

In this study, the electromagnetic stirring was applied to refine silicon phase and also to obtain uniform distribution of primary silicon particles. The effects of electromagnetic stirring processing parameters on continuous casting of hypereutectic aluminum silicon alloys were investigated and optimized billets were obtained. Then the billet was subjected to heat treatment and extrusion process and its mechanical properties were evaluated.

Experimental Method

Hypereutectic Al-15Si alloy was used as master alloy which contains 0.45wt% Cu, 0.8wt% Mg, 0.15wt% Mn, 1 wt% Zn, 0.1wt% Ti and 0.1wt% Sr. For the chemical modification of primary silicon alloys, Ti-based modifier was added to melt. The alloy was added to magnesia crucible and melted by electrical resistance furnace. The melt was brought to a temperature of 750 °C and degassed using argon bubbling method. Subsequently 0.1 wt% of modifier was added into the melt in the form the pieces. After skimming the slag, the melt was poured into a preheated tundish and then poured into the mould of billet casting machine. The casting speed was 80 mm/min and mould and billet was cooled by spraying water. The schematic diagram of continuous casting equipment is shown in figure 1.



The electromagnetic stirring apparatus was attached under the mould of continuous casting machine. Three phase alternating current flows through the coils of 12 poles, rotating magnetic field is induced and aluminium alloy melt is stirred and its intensity was changed by applying current and frequency. The mould has 180mm inner diameter and its magnetic intensity inside the mould is simply controlled by adjusting coil current. So, in this study ac current value is directly related to stirring action. Four samples were fabricated by different electromagnetic stirring conditions during continuous casting which are direct chill casting(DC), electromagnetic stirring one way with 80A current(EMS 80A), electromagnetic stirring two way of 5 and 10 seconds switching and 40A (EMS 40A 5s, EMS 40A 10s). The cooling rate of aluminium billets was controlled by adjusting the cooling water and fixed amount of cooling water is used to determine the effect of electromagnetic stirring.

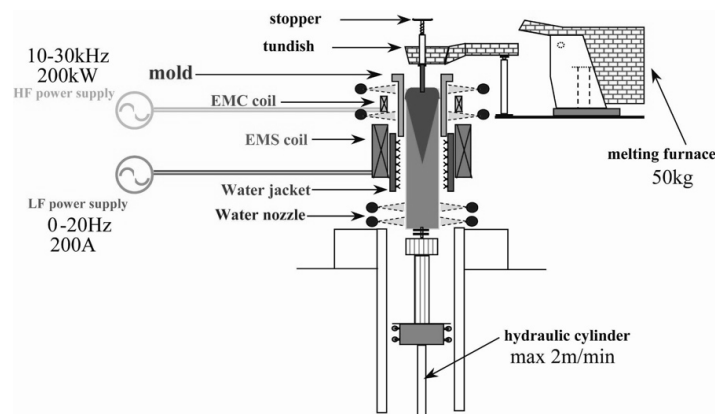


Fig. 1: schematic diagram of continuous casting equipment with electromagnetic stirring equipment

Microstructural survey of billets were conducted on optical microscopy and image analysis and the size and distribution of primary silicon particles were determined for each condition. As following steps, heat treatment of homogenization was conducted at 530 °C for 15 hours. Cast billets was subjected to extrusion process. Initial temperature of billet was 340 °C and extrusion ratio was 30. After extrusion, the samples was subjected to further heat treatment of age hardening. Mechanical properties of samples were tested via tensile test and wear test.

Results and Discussion

Continuous casting of hypereutectic aluminium silicon alloy billets were successfully carried out by adjusting experimental conditions. Hot cracking or tear-out was not occurred during the casting experiments. Figure 2 shows photograph of cross sectional view of cast billets. The diameter of billet is 180 mm and primary silicon is segregated in outer 20mm region. In case of EMS one way with 80A casting, primary silicon segregation becomes more severe and primary silicon is rarely found in the centre region. However, EMS is applied as two way 5s to suppress segregation problem, which means clockwise direction for 5s and counter clockwise direction for 5s subsequently. In case of EMS 5s two casting, primary silicon segregates as island shape and its distribution becomes more uniform. If EMS is applied as two way 10s, it is clear that segregation of primary silicon is less and more uniform distribution of primary silicon in cast billet is obtained.

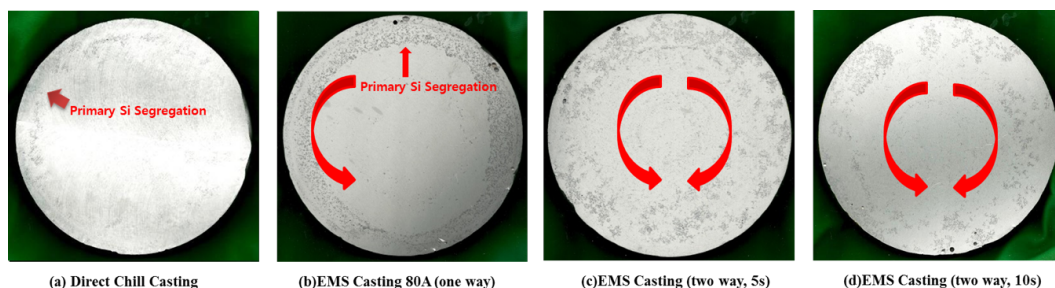


Fig. 2: Cross sectional views of cast billets, (a) Direct Chill, (b) EMS one way 80A, (c) EMS Casting 40A two way 5s and (d) EMS Casting 40A two way 10s

The image analysis of the micrographs was conducted to calculate the primary silicon aerial fraction. The result is shown in figure 3. In case DC casting, primary silicon is segregated at the region of 20 mm from billet surface. Primary silicon move outward in case of EMS one way 80 A casting samples and the region of 10 mm from billet surface shows high aerial fraction of primary silicon. However, primary silicon is well distributed at EMS two way 10s casting sample. The segregation of primary silicon is mainly due to the flow melt. In case of DC casting, melt flow from nozzle move outward and primary silicon sticks to mush zone region. If EMS is applied to melt pool in the billet, the movement of primary silicon toward outer surface is accelerated and segregation of primary silicon becomes more severe than direct chill casting. The phenomena is also studied by other group and it says high current value of EMS induces congregation of primary silicon. Previous study reports that low current value of EMS is helpful to reduce the congregation phenomena. In this study, EMS two way casting method is applied to reduce the congregation of primary silicon. Two way magnetic field generation with time interval generates the turbulent flow of melt in the casting billet. The turbulent flow of melt does not push primary silicon into outer surface so it is possible to distribute primary silicon uniformly through the billet. From the experiments, 10 seconds is more effective than 5 seconds alterations. The frequency and interval of EMS two way casting is needed to improve by adjusting its value.

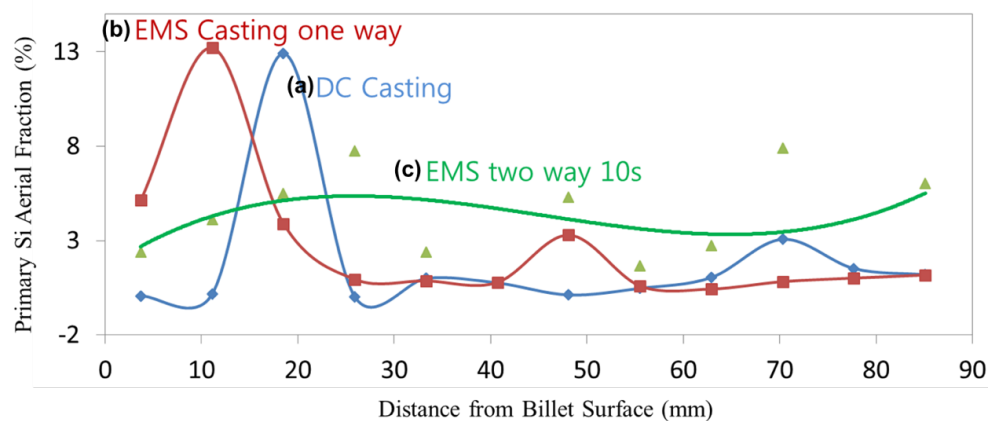


Fig. 3: Primary silicon aerial fraction of cast billet with different casting conditions (a) direct chill casting, (b) EMS casting one way 80A and (c) EMS casting two way 10s 40A

The billets of direct chill casting and EMS two way 10s were subjected to extrusion process and bar type samples were fabricated. Also heat treatment of T6 was applied to enhance the tensile strength of samples because this alloy have some precipitates. Three samples for each conditions were tested and the results are shown in figure 4. The yield strength of samples were 349.9 and 347.8 MPa and tensile strength of samples were 394.2 and 394.7 MPa. The strength of each sample shows no significant difference between DC and EMS two way samples. However the elongation of DC casting is 4.8% but elongation of EMS two way 10s is 7.1%. EMS casting samples shows excellent elongation property than DC casting samples. Primary silicon congregation is main source of failure because it acts as a crack initiation defect. The matrix of used alloy in this study shows excellent yield and tensile strength but the crack initiates from the primary silicon congregation. The low value of elongation from direct chill casting samples is explained by this phenomena and the observation of fracture surface is also good evidence.

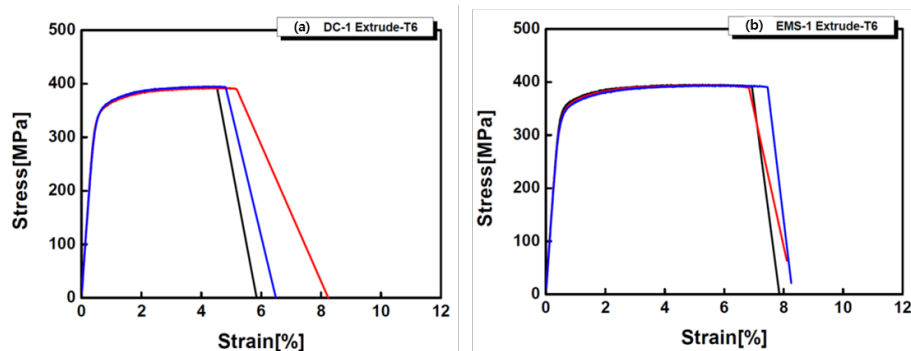


Fig. 4: Stress strain curve of tensile test of (a) direct chill casting-extruded-T6 heat treated and (b) EMS two 10s 40A casting-extruded-T6 heat treated of 3 samples

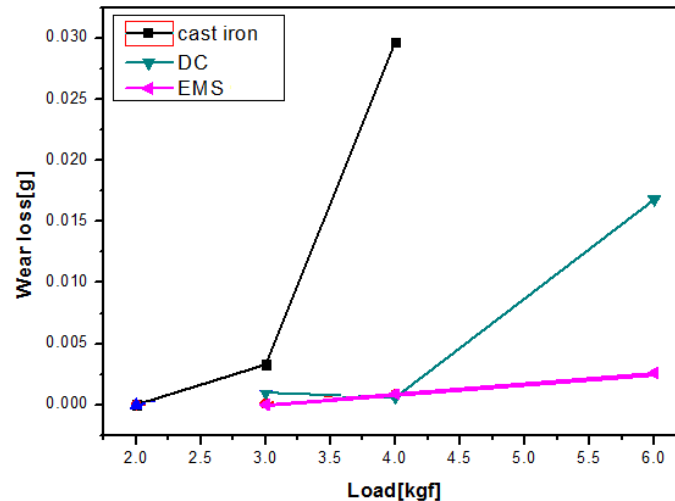


Fig. 5: Wear test of pin on disc and the graph of wear loss vs. load

Finally these samples were subjected to wet condition pin-on-disc wear test and it is shown in figure 5. Wear loss of each sample was compared with cast iron sample. Wear loss of hypereutectic aluminum silicon alloy shows less value than cast iron. Especially in high load condition of 6.0 kgf, EMS two casting shows excellent wear properties than direct chill casting sample. Pulled and fractured primary silicon is easily observed from the micrograph of wear tested surface. However primary silicon in EMS two way casting sample remain as not fractured after wear test. Wear properties of hypereutectic samples are largely affected by the shape and distribution of primary silicon and electromagnetic stirring is effective way to improve wear resistance.

Conclusions

Continuous casting of hypereutectic aluminum silicon alloy was conducted as direct chill casting and electromagnetic stirring applied casting. One way rotational electromagnetic stirring induces congregation of primary silicon around the outer surface of billets. Two way rotational electromagnetic stirring have positive effect to reduce segregation of primary silicon and is helpful to uniform distribution of primary silicon. The elongation of electromagnetic stirring samples shows excellent values than direct chill casting samples. Also electromagnetic stirring is effective to improve wear properties of hypereutectic aluminum silicon alloy.

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