Journal of Materials Processing Technology 234 (2016) 217–227

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

A liquid aluminum alloy electromagnetic transport process for high pressure die casting

Xixi Dong[a,b,c,*], Xiusong Huang[a,b], Lehua Liu[a,b], Liangju He[d], Peijie Li[a,b]

[a] Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China
[b] State Key Laboratory of Tribology, Tsinghua University, Beijing 100084, China
[c] BCAST, Brunel University London, Uxbridge, Middlesex UB8 3PH, United Kingdom
[d] School of Aerospace, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 21 January 2016
Received in revised form 27 March 2016
Accepted 29 March 2016
Available online 30 March 2016

Keywords:
Aluminum alloy
Electromagnetic transport
High pressure die casting
Magnetic-flow coupling
Efficiency
Stationarity

ABSTRACT

For the electromagnetic transport (EMT) of liquid aluminum alloy during high pressure die casting (HPDC) by the plane induction electromagnetic pump (EMP), how to improve EMT efficiency and control EMT stationarity are key problems. Magnetic-flow coupling analysis was used to reveal effects of structural design and transport process parameters on EMT efficiency and stationarity. The output pump height of plane induction EMP was optimized by matching of iron core width W, coil width W' and pump ditch width b, i.e., b values of b_{opt} corresponding to 90% of the maximum output pump height, $b_{opt}/W = 1.27$ and $b_{opt}/W' = 1$. Both EMT efficiency and stationarity are achieved under the optimum transport current 32 A. With the increase of the transport height from 350 mm to 500 mm, the EMT flow rate decreases from 4.28 kg/s to 3.59 kg/s, and the fillings of shot sleeve are always stationary. The transport tubes suffer a maximum positive pressure of 1.8×10^4 Pa and a minimum negative pressure of -1.42×10^4 Pa during EMT. For the liquid aluminum alloy soup occasions of 4.5 kg, 6.5 kg and 12.0 kg, the transport time could be shortened significantly from manipulator's 16 s, 22 s and 38 s to EMT's at most 2.195 s, 2.75 s and 4.28 s, respectively. The developed EMT process with plane induction EMP for HPDC is a process with low cost, high transport efficiency and stationarity.

1. Introduction

The electromagnetic fields have been widely used in materials processing fields such as electromagnetic casting, electromagnetic brake and electromagnetic treatment during casting, plastic forming and welding. Le et al. (2007) reported the electromagnetic casting of magnesium alloys. Singh et al. (2014) simulated the electromagnetic field effect on transient flow during continuous casting. Zhang et al. (2015) fabricated the carbon fibers reinforced Al-Mg matrix composites by electromagnetic casting. Yu et al. (2008) and Miao et al. (2012) revealed the influence of electromagnetic brake on flow field during continuous casting. Wang et al. (2010) studied microstructure evolution of AlSi7Mg alloy under superheat electromagnetic stirring. Haghayeghi et al. (2015) investigated microstructure evolution of AA5754 aluminum alloy under electromagnetic ultrasonic merged fields. Psyk et al. (2011) reviewed the electromagnetic forming process. Cui et al. (2014) reported an electromagnetic incremental forming technology of aluminum alloy sheet. Weddeling et al. (2015) introduced an analytical methodology for the process design of electromagnetic crimping. Kore et al. (2008) reported the electromagnetic impact welding of aluminum to stainless steel sheets. Bachmann et al. (2014) developed an electromagnetic weld pool support system for high power laser beam welding.

During high pressure die casting (HPDC), manipulator is usually adopted for the transport of liquid aluminum alloy from the soup mouth of the holding furnace to the shot sleeve of the HPDC machine, as shown in Fig. 1(b). The liquid aluminum alloy soup mouth is exposed directly to the air, and it causes problems such as oxidation of liquid aluminum alloy and energy dissipation, as shown in Fig. 1(c). In addition, part of the liquid aluminum alloy adheres to the outer surface of the ladle when ladling, and falls off during the subsequent transport process, which not only decreases material utilization, but also harmful to safe production. The move of the ladle should be controlled steadily for the prevention of the spill of liquid aluminum alloy out of the ladle, so the transport efficiency of liquid aluminum alloy by the manipulator process is

* Corresponding author at: Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China.
E-mail addresses: Xixi.Dong@brunel.ac.uk, dxx617617617@163.com (X. Dong).

http://dx.doi.org/10.1016/j.jmatprotec.2016.03.028
0924-0136/

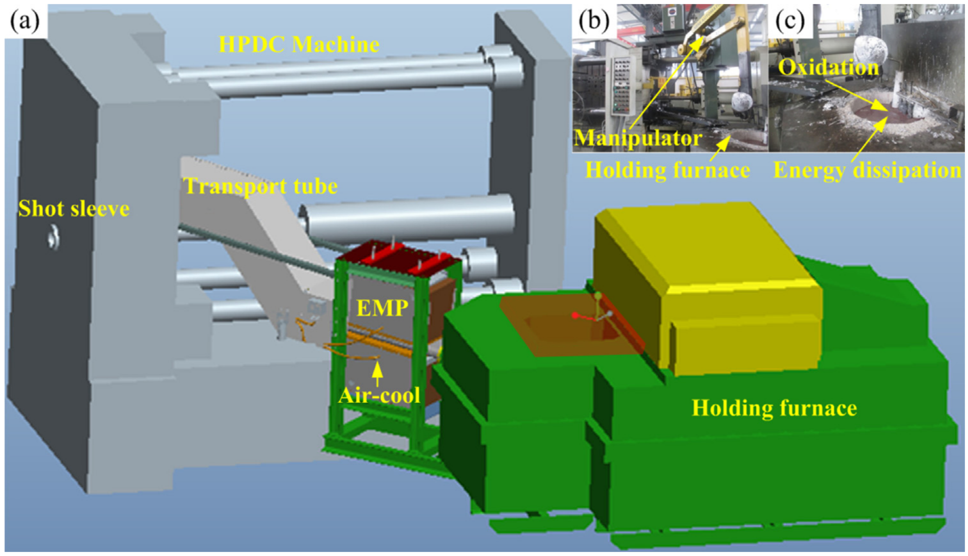

Fig. 1. (a) EMT process with plane induction EMP and (b and c) Common manipulator process for the transport of liquid aluminum alloys during HPDC.

relatively low. However, if electromagnetic transport (EMT) process was adopted for the transport of liquid aluminum alloy during HPDC, i.e., liquid aluminum alloy is driven by the electromagnetic pump (EMP) and transported rapidly to the shot sleeve of the HPDC machine through the sealed transport tube, problems such as oxidation, adhesion and falling of aluminum alloy, and energy dissipation would be eliminated, and the transport efficiency of liquid aluminum alloy would be improved.

Since the invention of the Cosworth Process (Campbell and Wilkins, 1982) which employed the EMP to transport liquid aluminum alloy during low pressure die casting, the application of the EMT process has been extended to high pressure, squeeze and gravity casting fields. Saito et al. (1989) developed the EMT apparatus for HPDC with outside mounted annular induction EMP. Mercer et al. (1995) designed the EMT apparatus for HPDC with submerged EMP. Cheng et al. (2000) reported the EMT apparatus for low pressure and squeeze casting of aluminum alloys with outside mounted planar direct current (DC) EMP. Miura et al. (2009) proposed the EMT apparatus for die casting with outside mounted annular induction EMP, and the transport of molten metal could be stopped by inert gas. The CMI Novacast inc. is improving and promoting the EMT apparatus with submerged EMP for pressure, squeeze and gravity casting. However, there are problems for the existing EMT process. The EMT process with submerged EMP is with high efficiency but also high cost, and it also has high demand for cooling. The EMT process with outside mounted planar DC EMP has high conductive and anticorrosive demands for the electrodes that are inserted directly into the highly active liquid aluminum alloy. The EMT process with outside mounted annular induction EMP requires the insertion of the heat resisting iron core to liquid aluminum alloy in the pump ditch to decrease the magnetic gap, and it is also inconvenient for cooling and maintenance. Thus EMT process with outside mounted plane induction EMP is developed to solve the above mentioned problems.

In addition to the control of EMT accuracy of liquid aluminum alloy, how to improve EMT efficiency and control EMT stationarity are key problems for the application of the EMT process with plane induction EMP during HPDC. In our earlier work (Dong et al., 2013, 2014), four structural parameters, i.e., magnetic gap, pump ditch height, iron core width and pump ditch width were found to have significant effects on the output efficiency of pump height of the plane induction EMP, the quantitative effects of magnetic gap on pump height was revealed, and the optimum pump ditch height was determined. However, the comprehensive effects of iron core width, coil width and pump ditch width on the output efficiency of pump height of the plane induction EMP are still unknown. The effects of the EMT process on the improvement of hydrogen porosity defect in aluminum alloy during gravity casting were reported (Dong et al., 2015b). The flow fields, and the effects of transport tube structural parameters on the outflow efficiency and the outflow stationarity in the transport tube, were uncovered by magnetic-flow coupling analysis (Dong et al., 2015a). Nevertheless, the effects of transport process parameters on the filling efficiency and stationarity of liquid aluminum alloy in the shot sleeve of the HPDC machine are still unclear.

In this paper, the comprehensive effects of iron core width, coil width and pump ditch width on the output efficiency of pump height of the plane induction EMP were investigated by electromagnetic analysis; the effects of transport process parameters on the filling efficiency and stationarity of liquid aluminum alloy in the shot sleeve of HPDC machine, and pressure distribution during EMT were studied by magnetic-flow coupling analysis; and the transport efficiency of liquid aluminum alloy during HPDC by the EMT process was compared with the common manipulator process.

2. EMT for HPDC

Fig. 1(a) shows the EMT process with plane induction EMP for the transport of liquid aluminum alloy during HPDC. Liquid aluminum alloy in the holding furnace flows into the rectangular section pump ditch of the plane induction EMP by gravity, and the induced current is formed in the pump ditch by the excitation of the travelling magnetic field that is generated by the EMP. The interaction of the magnetic field and the induced current generates the electromagnetic force, which transports the liquid aluminum alloy along the sealed transport tube to the shot sleeve of the HPDC machine. Under the EMT process, the open soup mouth in the holding furnace that is reserved for the common manipulator transport process can be sealed, so problems such as oxidation of liquid aluminum alloy and energy dissipation are avoided. Since liquid aluminum alloy is transported along the sealed transport tube under the EMT process, problems such as adhesion and falling of aluminum alloy can be eliminated during the transport process.

For the EMT process with plane induction EMP, the plane induction EMP is the core component, and it consists of the magnet yoke, the iron core, the coil and the rectangular section pump ditch, as