Contactless electromagnetic method for aluminium degassing

I.Kaldre, A. Bojarevics, T. Beinerts, R. Baranovskis, R. Nikoluskins, M. Milgrāvis, M. Kalvāns

Institute of Physics University of Latvia, Miera 32, LV-2169, Salaspils, Latvia

imants.kaldre@lu.lv

Abstract

Degassing of aluminium alloys is an important technological step. In this work the idea and mathematical, and numerical description of electromagnetic aluminium degasser is presented. Experimental electromagnetic device for degassing aluminium alloys is designed and tested to estimate the feasibility of this technology.

Degassing is a technological intermediate step in the production of aluminium between the melting and casting of the metal. Mainly hydrogen has been dissolved in liquid aluminium because of reaction with water vapor. To prevent the formation of pores during casting, hydrogen is removed - the liquid metal is degassed. Typically, degasification is achieved by injecting an inert gas in the metal, usually argon, which binds to hydrogen bubbles. For the industrial process to be more efficient, the size of the argon bubbles must be as small as possible. At present, the most widely used method to refine bubbles is to place a mechanical rotor inside the liquid metal. Although such mechanical bubble shredding fulfils the task, it also has significant disadvantages, hence alternatives are being sought.

Keywords: Aluminium, Electromagnetic stirring, degassing

Introduction

Dissolved hydrogen in liquid aluminium alloy cause problems during solidification, because of different solubilities in solid and liquid states. As a result, during casting excess hydrogen is released and causes porosity of the casted metal. Degassing is usually performed with fine inert gas (usually argon) bubbles, which rise through the liquid metal and collect small hydrogen bubbles. This method is only effective if argon bubbles are small, otherwise large bubbles rise too rapidly and process is not efficient. To acquire small bubbles turbulent shear flow in liquid metal needs to be created. Traditional aluminium degasser consists of specially shaped refractory or graphite rotor with holes as shown in Fig.1(a). Argon is supplied to the centre of rapidly spinning rotor, and as the bubbles go through the holes they are split in much smaller bubbles. In industrial setups differential velocity between rotor surface and liquid metal is at least 4 m/s. Large velocity difference and pressure fluctuations due to turbulent flows split bubbles into smaller ones, resulting in a much higher degassing efficiency [1]. Such intensive flow leads to rapid wear of the rotor, which pollutes the metal and causes additional costs due to rotor replacement. Main disadvantages of the setup are indicated with letters in Fig. 1(a): A) Complex design for motor drive, rotor clutch, gas inlets; B) Surface oscillations contribute to the rupture of oxide film; C) The rotor must be changed regularly; (D) Degradation of the rotor pollutes the metal; E) In some local areas, Al is not degassed.

Our proposal is to use electromagnetically excited liquid aluminium flow for bubble splitting and degassing of aluminium. Setup has been designed which enables the usage of contactless method to create the required flow for degassing in liquid metal [2]. Basic scheme of the experimental setup is shown on Fig. 1(b). Liquid metal container has special inner structure. Structure is designed in the way that liquid metal carrying large argon bubbles are pushed through the small holes in the inner chamber walls. At this point metal is subjected to large shear flow and argon bubbles are broken into small ones. Several such holes are created along the perimeter of the inner chamber. Flow is induced contactlessly by rotating permanent magnet assembly [3,4]. Depending on the type and size of magnet rotor different Lorentz forcing and flow can be achieved in the chamber, but general flow is rotation of the liquid metal. Flow is highly turbulent because force is larger at the bottom of the volume-closer to the magnets. Argon is injected via thin pipes in the chamber slightly off symmetry axis. When inert gas is injected in the region with the required shear velocity and turbulence, the degasification process takes place and small argon bubbles trap hydrogen and remove it from metal volume to the surface. One benefit of this setup is that the flow is induced without any moving parts inside the hot liquid metal environment. The developed technology can be scaled up and integrated into the production line, as well as adapted to different aluminium grades and other metals and alloys, like titanium aluminide [5]

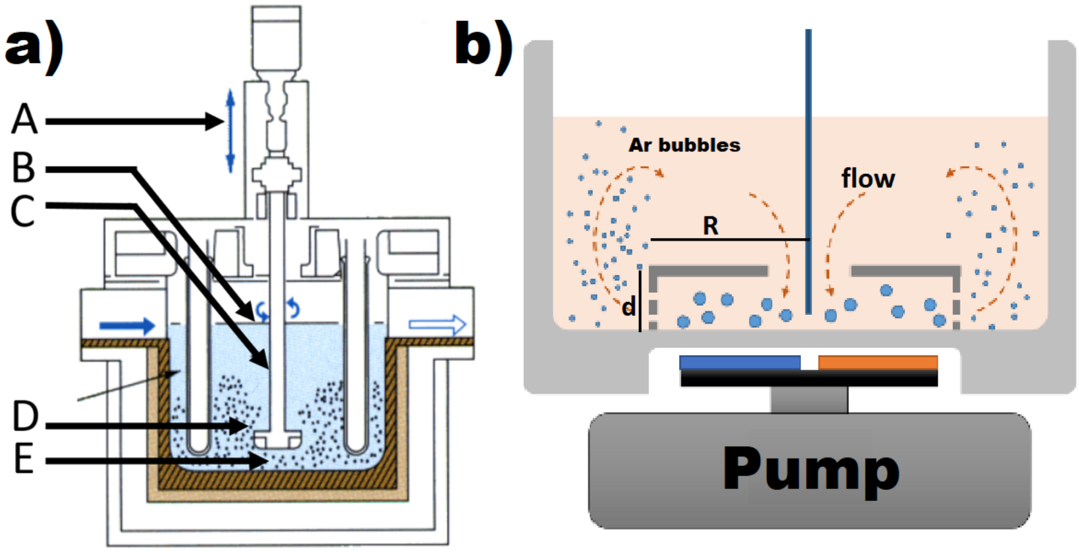

Fig. 1. A) The current degassing process using rotary gas intakes; b) proposed degasser design using permanent magnet rotor to refine Ar bubbles

Results and discussion

To demonstrate the working principle of the proposed setup experimental facility is designed and series of experiments are planned. One of the biggest challenges is the fact that liquid aluminium is contained in refractory material containers which normally have thick walls for better thermal insulation. This is a problem because the magnetic field created by permanent magnets or electric windings decays rapidly with the distance. In this article we are looking at the permanent magnet assembly, which can be rotated, thus setup for flow induction in liquid metal is as simple as possible. Fig. 2 compares two different designs of permanent magnet assemblies which could be used. Fig. 2(a) shows the rotor of a cylindrical electromagnetic pump [6], where several magnet pole pairs are placed on a ferrous plate. Fig. 2(b) shows the concept by using single permanent magnet cylinder. Ferrous yokes in magnetization direction may be used to increase the field penetration distance. Numerical simulations and analytical solution shows that for the current task it is better to use a single permanent magnet cylinder, because liquid metal chamber is placed far away from the magnet surface and magnet diameter should be as small as possible because of difficulties to make large thin wall in aluminium chamber.

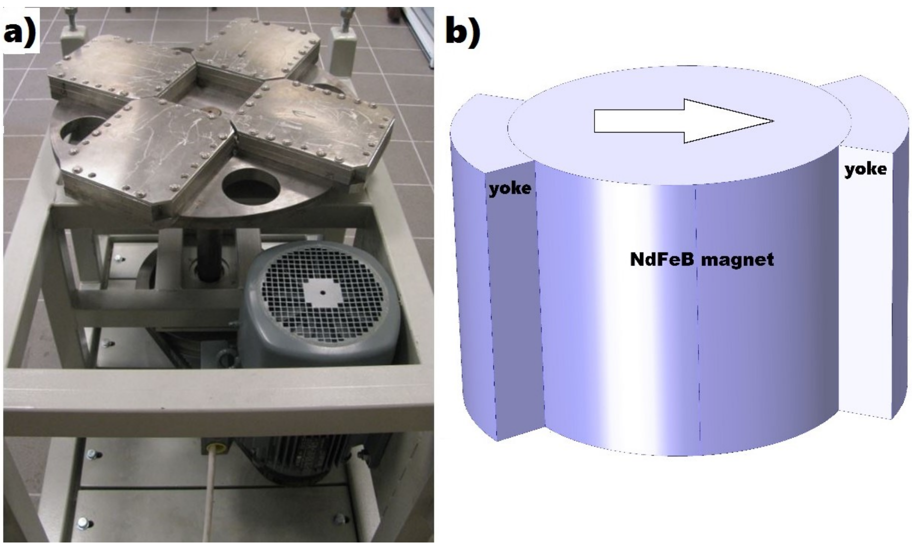

Fig. 2. Comparison of two different permanent magnet rotor designs: a) four rectangular magnet poles on the ferrous plate; b) Cylindrical magnet with yokes for magnetic flux optimization

Experimental setup is designed for inner chamber radius of R=150 mm and thickness of d=20 mm. NdFeB magnet rotor diameter is 120 mm and height is 100 mm. 20 mm thick yoke segments (60°) are placed on both sides of the magnet. Minimum possible distance between magnet and the bottom of liquid aluminium is 35 mm. Magnetic field distribution around magnet rotor is calculated by a 3D Comsol model. Comparison with and without ferrous yokes are given in Fig. 3(a,b,c). Magnetic field distribution along the middle plane of liquid metal layer (with yokes) is shown on Fig. 3(d). Yokes increases magnetic field by approximately 20 %, but the benefit is also the increase of effective magnet radius. Magnetic field of 0.12 T is directed along the diameter of the liquid metal layer. Liquid metal column in cylindrical container has been analysed by several authors [7,8]. To achieve sufficient flow intensity for degassing, magnet rotor is being rotated with at least 40 rps. Hartmann number Ha (eq.1) square is the ratio between electromagnetic and viscous forces. Lorentz force versus inertia is characterized by magnetic interaction parameter N (eq.2). To characterize the alternating magnetic field magnetic Reynolds number Rm (eq.3) is defined, which shows the significance of induced magnetic field and skin effect.

$$Ha = BR\sqrt{\frac{\sigma}{\mu}} \tag{1}$$

$$N = \frac{\sigma B^2 R}{\rho u} \tag{2}$$

$$Rm = \mu\sigma u R \tag{3}$$

Where σ is electric conductivity, μ is dynamic viscosity, ρ is density. Using setup parameters and liquid aluminium properties we get Ha=200 and N=1 and Rm=0.3, such parameter combination means that dominant forces are electromagnetic and inertial forces, and considerable skin effect is present. Lorentz force has mainly azimuthal component, which is much larger closer to the centre of the liquid metal chamber. Simple analytical estimation can be done by balancing viscous and electromagnetic forces in liquid metal: $u \approx B\cdot R\cdot sqrt(\sigma\cdot f/\rho)$. For liquid aluminium this estimation gives approximate liquid metal rotation velocity of 2 m/s.

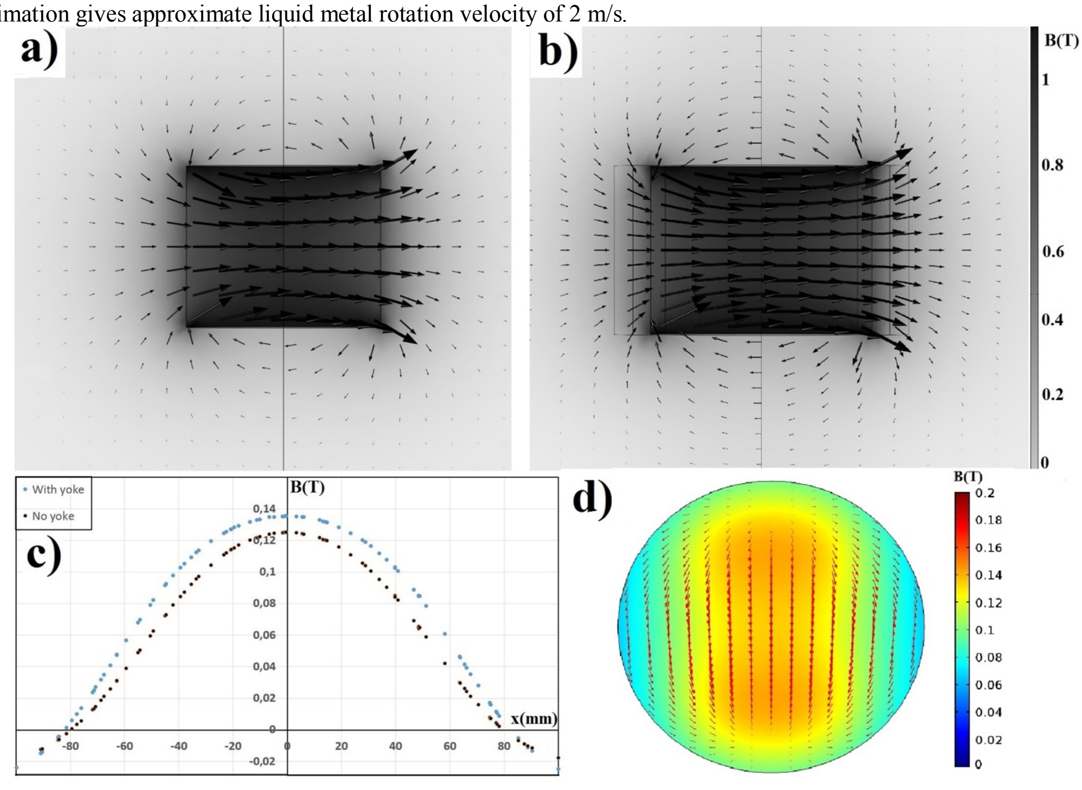

Fig. 3. Magnetic field induction: a) cylinder magnet; b) Cylinder magnet with yokes; c) comparison of B vertical component at the middle plane of liquid metal volume; d) field distribution at the middle plane of liquid metal volume

Conclusions

Design of permanent magnet degasser for liquid aluminium has been made. Preliminary analytical estimations and numerical simulations show that this setup is capable to create sufficient liquid aluminium flow in the chamber. Based on our previous works with permanent magnet liquid metal stirring and pumping, required velocity can be achieved. Proposed electromagnetic system is simpler and more robust than immersed rotary degasser, main rotating parts is placed outside the liquid metal and repairs and modifications are easier.

Acknowledgment

This work was supported by the effective cooperation project of University of Latvia ”New contactless electromagnetic degassing system”, ERDF project No. 1.1.1.1/16/A/085. “Electroslag process for better titanium sediment morphology”. Described technology is patent pending.

References

1. L. Zhang, X. Li, A.T. Torgerson, M. Long, Mineral Processing and Extractive Metallurgy Review, 32-3(2011)
2. A. Bojarevičs, R. Baranovskis, I. Kaldre, M. Milgrāvis, T. Beinerts, IOP Conf. Ser. Mater. Sci. Eng. 228 (2017), 012022
3. T. Beinerts, A. Bojarevičs, I. Bucenieks, Y. Gelfgat, I. Kaldre. Metallurgical and Materials Transactions B: Process Metallurgy and Materials Processing Science, 47 (2016), 1626-1633
4. I. Bucenieks and K. Kravalis. Magnetohydrodynamics, 47-1 (2011), 89-96
5. Adrian P. Mouritz. Titanium alloys for aerospace structures and engines, In Introduction to Aerospace Materials. Woodhead Publishing (2012), 202-223
6. A. Bojarevics, T. Beinerts, Y. Gelfgat, I. Kaldre. International Journal of Cast Metals Research, 29 (3), (2016),154-157
7. Witkowski, L.M, and P Marty. European Journal of Mechanics, B/Fluids. 17-2 (1998). 239-254
8. Y. Gelfgat, L.A. Gorbunov, V. Kolevzon. Experiments in Fluids.15 (1998). 411-416