C-DC and Mc-DC casting of Al-alloys-a comsol Approach

D. Walinjkar, A.K.Prasada Rao

PII: S0167-577X(15)30593-0
DOI: http://dx.doi.org/10.1016/j.matlet.2015.09.082
Reference: MLBLUE19598

To appear in: *Materials Letters*

Received date: 25 June 2015
Revised date: 12 September 2015
Accepted date: 16 September 2015

Cite this article as: D. Walinjkar and A.K.Prasada Rao, C-DC and Mc-DC casting of Al-alloys-a comsol Approach, *Materials Letters* http://dx.doi.org/10.1016/j.matlet.2015.09.082

C-DC AND MC-DC CASTING OF Al-ALLOYS - A COMSOL APPROACH

D. Walinjkar[1, 2], A.K.Prasada Rao[1]*

[1]Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, Pekan, Pahang, MALAYSIA, 26600
[2]Department of Metallurgical and Materials Engineering, IIT Kharagpur, INDIA, 721 302

ABSTRACT

Present work endeavours to understand the solidification behaviour in conventional direct chill casting (C-DC) of aluminium alloy billets. The simulations were generated for C-DC and MC-DC (melt-conditioned) processes. For the first time, COMSOL Multiphysics has been successfully used to simulate the heat flow in C-DC casting of Al-alloy billet. The results show that the temperature gradient in the sump is minimized in the case of MC-DC when compared with C-DC. The simulation results also revealed the effect of casting speed on the sump profile in both the cases.

KEY WORDS: Casting; Aluminium; solidification; COMSOL; Simulation

INTRODUCTION

Direct Chill casting popularly known as DC casting (termed herein as C-DC) is a widely used technology of producing wrought Al-alloy billets. This process falls under the category of continuous casting where the molten metal solidifies continuous cooling. It has been a challenging process owing to several casting and post casting problems such as bleed-outs, cold-shuts, hot-tears, macro segregation etc. [1, 2]. Several techniques were adopted in order to overcome the problems like hot-tears and macro-segregation. Some of the popular methods are electromagnetic stirring and melt-conditioned direct chill (MC-DC) casting [3-7]. These techniques have shown a promising improvement in the solute distribution and grain refinement of the billets cast. The MC-DC involves a vigorous stirring of the liquid above the solid-liquid interface using a rotor-stator device, during casting; this technique has also shown to result in grain refinement of the cast billets without the addition of a conventional grain-refiner. Earlier reports on melt-conditioning speculated that the key mechanism responsible for this grain refinement in the cast billets was due to the heterogeneous nucleation of α-Al triggered by the dispersed oxide particles [3, 4, 5, 8, 9]. However, recent work has shown that the mechanism responsible for the grain refinement is the heterogeneous nucleation caused by the fragmented dendrites, since they have superior coherency with the α-Al [6, 7].

Some studies reported the prediction of the casting behaviour of Al-alloys in C-DC casting [10, 11]. However, systematic modelling approach on MC-DC technique is not found to be reported yet. Hence, the present work has been aimed at understanding the temperature distribution in C-DC and MC-DC casting processes for an industrial scale casting (billet diameter 206mm; length 7000mm) for various casting speeds. The detailed methodology and results obtained are discussed in the following sections.

* Corresponding author: Dr. A.K.Prasada Rao, Associate Professor, Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, Pekan, Pahang, 26600, MALAYSIA; Phone: +60-9424 5853 (work); Fax: +60-9424 5888; **E-mail**: akprasada@yahoo.com

METHODOLOGY

COMSOL Multiphysics 4.4 is a software, which works on advanced numerical methods, for modelling and simulating physics-related problems. A heat-flow module with non-isothermal conditions has been chosen for modelling the C-DC and MC-DC casting processes. A temperature driven convective flow was chosen for the liquid in the C-DC billet-sump; while the flow in the MC-DC billet sump was forced convection (since stirring action is involved in MC-DC).

3D models of a C-DC and MC-DC processes were created using COMSOL multiphysics 4.4. Simulation for the casting of hypothetical Al-alloy billet (Solidification range of 80^{o}C) was generated using heat flow and fluid flow modules. The inlet of the liquid metal was considered to be 690^{o}C. The inlet water was at a temperature of 12^{o}C and with a velocity of 0.4 m/s. A time-dependent solver was used in order to monitor the profile at each time-step. Simulations for different billet speeds (0.01, 0.0167, 0.025 and 0.033 m/s) were run using the software for both the models for 1500s. As a result, temperature profile and isothermal curves throughout the billet, after attaining the steady state, were obtained. The results obtained in the present work have been critically analysed and compared with the earlier experimental work conducted on pilot-plant scale (Fig.3).

RESULTS AND DISCUSSION

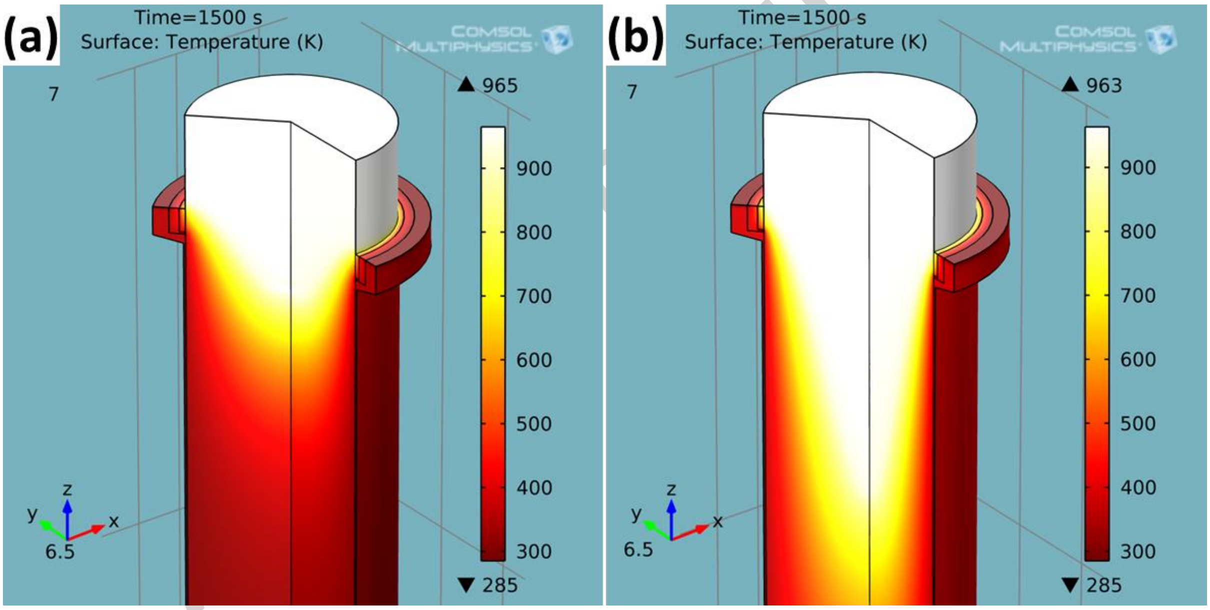

Fig.1.Temperature distribution across the C-DC cast billet corresponding to casting speed of (a) 0.01m/s and (b) 0.033 m/s

Fig.1 (a) & (b) represent the temperature profile across the billet sump during C-DC casting with casting speeds of 0.01 and 0.033 m/s respectively. It is found that the depth of the sump (solid-liquid interface) increases with the increase of the billet casting speed which is well in agreement with the state of art understanding of the C-DC casting [1, 2, 11]. The results also show a decrease in shell thickness with the increase of casting speed which is critical for understanding the cold-shut, bleed-out and other issues of C-DC casting. Similar trend was obtained for MC-DC casting as shown in Fig.2 (a) & (b), where Fig.2 (a) and (b) correspond to the casting speeds of 0.01 and 0.033 m/s respectively. However, the sump depths decreased during MC-DC casting when compared to its counterpart in C-DC casting.

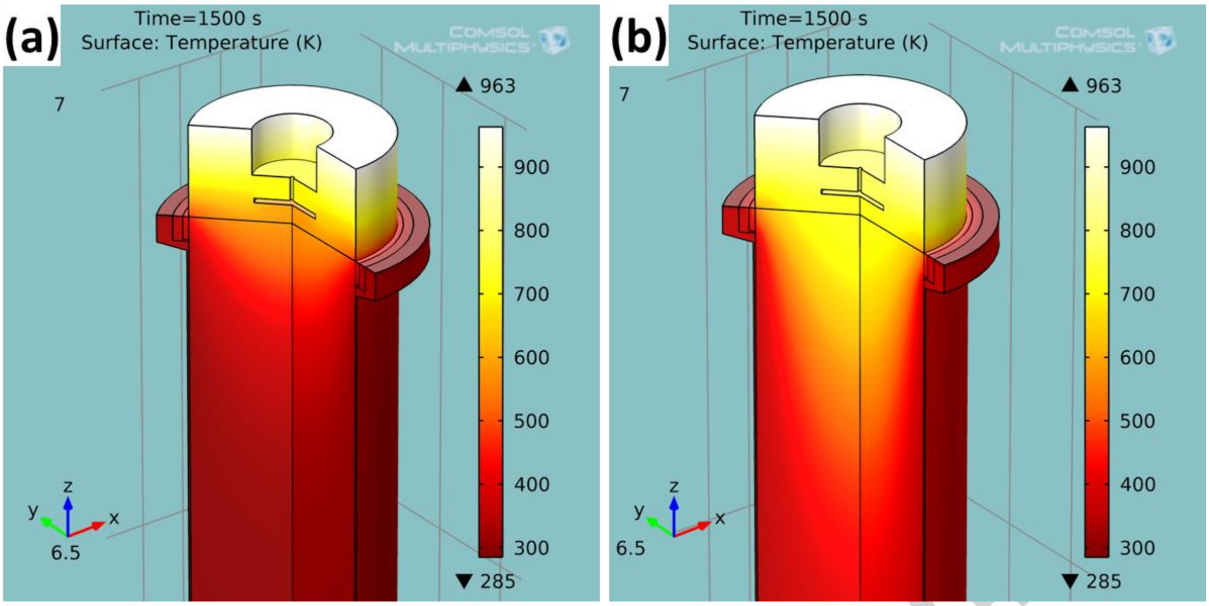

Fig.2. Temperature distribution across the MC-DC cast billet corresponding to casting speed of (a) 0.01 m/s and (b) 0.033 m/s

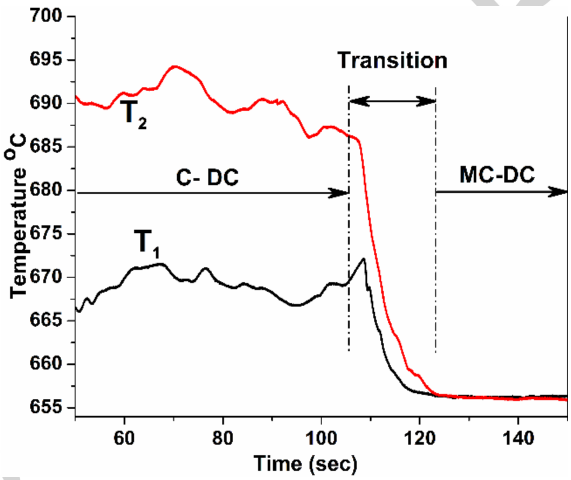

Fig.3 Variation as measured in the temperature gradients in C-DC and MC-DC casting experiments on pilot-plant scale [6] (reproduced with permission from Taylor and Francis)

Fig.3 shows the temperature profiles measured using two thermocouples (T_1 and T_2), which were immersed in the billet-sump during the casting process as demonstration in earlier report [6]. During this experiment the C-DC regime was obtained without-stirring, while the MC-DC regime was measured during stirring of the liquid in the billet sump. The detailed experimental procedure is reported elsewhere [6]. Some of the earlier reports on MC-DC casting claimed that the grain refinement obtained was essentially due to the heterogeneous nucleation phenomena triggered by the dispersed oxide particles [3, 4, 5, 8, 9]. However, recent work has demonstrated that the grain refinement observed in the MC-DC cast Al-alloys is due to the heterogeneous nucleation caused by the fragmented dendrites formed during the forced convection caused in MC-DC process [6, 7]. It was also shown that the nucleation and growth events take place in the isothermal regime of the MC-DC process [6, 7]. Present results also confirm that the isothermal regime in the billet sump is attained depends on the proximity of the stirring device from the solid-liquid interface as reported earlier [7].

CONCLUSION

Successful and efficient models for simulation of C-DC and MC-DC casting have created using COMSOL for the first time. These models are in agreement with the experimental based literature and help us to understand these mechanisms more clearly. This work reconfirms the mechanism proposed based on the experimental results reported earlier. And hence, in the MC-DC process the heterogeneous nucleation is predominantly based on the dendrite fragmentation, followed by growth in isothermal regime.

AKNOWLEDGEMENTS

The corresponding author would like to thank Indian Institute of Technology Kharagpur, India, to allow its student to carry out his summer internship at Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, Malaysia. D. Walinjkar, the student of IIT Kharagpur, would like to acknowledge the kind gesture of acceptance by the Universiti Malaysia Pahang, Malaysia, for offering the internship.

REFERENCES

[1] Grandfield JF, Eskin DG, Bainbridge IF. Direct-chill casting of light alloys. Hoboken, New Jersey: John Wiley & Sons, Inc.; 2013.

[2] Eskin DG. Physical Metallurgy of Direct Chill Casting of Aluminium Alloys. Boca Raton: CRC Press, Taylor and Francis Group; 2008

[3] Fan Z, Xia M, Zhang H, Liu G, Patel JB, Bian Z, Bayandorian I, Wang Y, Li HT, Scamans GM. Melt Conditioning by Advanced Shear Technology (MCAST) for Refining Solidification Microstructures. Int. J. Cast Met. Res. 2009;22(1–4):103–7

[4] Jones S, Prasada Rao AK, Fan Z. Melt Conditioned Direct Chill Casting (MC-DC) of Al Alloys. Trans. Indian Inst. Met. 2013;66(2):117–21

[5] Zuo Y, Li H, Xia M, Jiang B, Scamans GM, Fan Z. Refining Grain Structure and Porosity of an Aluminium Alloy with Intensive Melt Shearing. Scripta Mater. 2011;64(2):209–12

[6] Prasada Rao AK. Understanding the Evolution of the Microstructure in Melt-Conditioned Direct-Chill Cast Al Alloys, Mater. Manuf. Process. 2014;29(7):848–52

[7] Prasada Rao AK. Nucleation in Aluminium alloys processed by MCDC casting, J. Mater. Engg. Perf. 2015;24(6):2219-24

[8] Li HT, Wang Y, Fan Z. Mechanisms of Enhanced Heterogeneous Nucleation During Solidification in Binary Al-Mg Alloys. Acta Mater. 2012;60(4):1528–37

[9] Li HT, Xia M, Jarry Ph, Scamans GM, Fan Z. Grain Refinement in a AlZnMgCuTi Alloy by Intensive Melt Shearing: A Multi-Step Nucleation Mechanism. J. Cryst. Growth 2011;314(1):285–92

[10] Sabau A, Kuwana K, Viswanathan S, Saito K, Davis L. Heat transfer boundary conditions for the numerical simulation of the DC casting process. In: Tabereaux, editor. Light Metals 2004:667-72

[11] Baserinia AR, Ng H, Weckman Dc, Wells MA, Barker S, Gallerneault M. A simple model of the mold boundary condition in direct-chill (DC) casting of aluminum alloys. Metal. Mater. Trans. B 2012;43B:887-901

Figure Captions

Fig.1.Temperature distribution across the C-DC cast billet corresponding to casting speed of (a) 60 mm/min and (b) 200 mm/min

Fig.2. Temperature distribution across the MC-DC cast billet corresponding to casting speed of (a) 60 mm/min and (b) 200 mm/min

Fig.3 Variation as measured in the temperature gradients in C-DC and MC-DC casting experiments on pilot-plant scale [6] (reproduced with permission from Taylor and Francis)

HIGHLIGHTS

- 3D simulation model for DC and MCDC casting has been created using COMSOL for the first time.
- It reconfirms the dendrite fragmentation based heterogeneous nucleation mechanism in MCDC.
- The effect of casting speed on the billet sump has been well demonstrated by the models.
- The effect of forced convection on the billet sump has also been well demonstrated by the models.
- The models are in complete agreement with the experiment based literature.