Journal of Materials Processing Technology 218 (2015) 48–56

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Process parameters and roll separation force in horizontal twin roll casting of aluminum alloys

Yun-Soo Lee[a], Hyoung-Wook Kim[a,b], Jae-Hyung Cho[a,b,*]

[a] Light Metals Division, Korea Institute of Materials Science, Changwon 642-831, South Korea
[b] Korea University of Science and Technology, 217 Gajeong, Yuseong, Daejeon 305-350, South Korea

ARTICLE INFO

Article history:
Received 5 June 2014
Received in revised form
14 November 2014
Accepted 16 November 2014
Available online 22 November 2014

Keywords:
Twin roll casting
Modeling and simulation
Roll separation force
Aluminum alloys

ABSTRACT

A two-dimensional finite element analysis was carried out to predict roll separation force, temperature distribution, and the shape of the mushy zone during horizontal twin roll casting of A7075 aluminum strips. Various effect of roll speeds and initial temperatures of the melt on casting was considered. Modeling twin roll casting focused on roll separation force had merits of predicting mechanical interaction between the rolls and solid strips, in addition to temperature distribution. The roll speed has a great effect on roll separation force, compared with heat transfer coefficient and melt temperature. The predicted roll separation force was compared with the measured one during twin roll casting. The results can be used effectively to reduce the experimental trial-and-error procedures of twin roll casting process.

1. Introduction

Aluminum alloys have attracted much attention for the automotive industry due to their significant advantages such as high specific strength, good corrosion resistance, recyclability, and weight reduction related to fuel efficiency. Miller et al. (2000) summarized the recent developments in high strength aluminum alloys to improve formability, surface quality and bake hardening response for automotive industry. The manufacturing cost of the high strength aluminum sheets by conventional direct-chill (DC) casting is usually high, because numerous thermo-mechanical steps of DC casting, scalping, homogenizing, hot rolling, cold rolling, and heat treatment should be applied. As a result, high strength aluminum sheets manufactured by the conventional DC casting process have few advantages in cost over steels, and their wide application in automotive industry has been hindered.

One way to reduce high manufacturing cost of aluminum sheets is to use twin roll casting (TRC). The process possesses the significant merit of one-step processing from the liquid melt to the solid wrought strips by combining the casting and hot rolling processes. In addition, fast cooling speed during the TRC frequently improves mechanical properties. Haga et al. (2004) reported vertical type twin roll caster to fabricate aluminum alloys. Both semisolid strip casting and low superheat casting were effectively carried out to improve mechanical properties and increase casting speed of the strip. Kim et al. (2010) obtained a fine microstructure and secondary particles that were closely related to the mechanical properties using TRC process with a high cooling rate.

This technique, however, has to be performed within a narrow working window in order to avoid defects that cause expensive trial-and-error operations. The TRC is a complex process containing solidification followed by hot deformation, and it is necessary to control numerous parameters, such as the initial melt temperature, melt feeding rate, casting speed, nozzle shape, roll gap, amount of coolant and so on, in a narrow solidification region from the nozzle tip to the roll nip (or kissing point). It is also important to understand the mutual interaction between these parameters. Modeling and simulation of the TRC process are very helpful to reduce the experimental time and cost of trial-and-error.

Previous reports on modeling TRC process have mostly examined thermal or thermally coupled flow behaviors. Zhang et al. (2005) predicted micro-segregation of carbon and stainless steels using a finite difference model. Bae et al. (2007) used the finite difference and finite element models in the analysis of the pool region and the cooling roll to reduce computing time and to improve the accuracy of calculation, respectively. Sahoo et al. (2012) developed a comprehensive CFD-based modeling of high speed TRC using FLUENT commercial software. Saxena and Sahai (2002) separately

* Corresponding author at: Korea Institute of Materials Science, Light Metals Division, 797 Changwondaero, Changwon 642-831, Gyeongnam, South Korea.
Tel.: +82 55 280 3306; fax: +82 55 280 3299..
E-mail addresses: jhcho@kims.re.kr, chunsoo.cho@gmail.com (J.-H. Cho).

http://dx.doi.org/10.1016/j.jmatprotec.2014.11.031
0924-0136/

Nomenclature

R_{inner}	inner radius of the roll (mm)
R_{outer}	outer radius of the roll (mm)
L	distance between the nozzle tip and roll nip (mm)
d	thickness of solidified strip (mm)
k_{roll}	thermal conductivity of roll (W/(m K))
C_{proll}	specific heat of roll (J/(kg K))
v	roll speed (rpm)
$m_{roll\text{-}strip}$	friction coefficient between roll and strip
T_{roll}	initial temperature of roll (K)
T_{melt}	initial temperature of melt (K)
$T_{atmosphere}$	temperature of atmosphere (K)
$T_{coolant}$	temperature of coolant (K)
$h_{roll\text{-}strip}$	heat transfer coefficient between the roll and the strip (W/(m^2 K))
$h_{roll\text{-}coolant}$	heat transfer coefficient between the roll and the coolant (W/(m^2 K))
$h_{strip\text{-}atmosphere}$	heat transfer coefficient between the strip and the atmosphere (W/(m^2 K))
$h_{roll\text{-}atmosphere}$	heat transfer coefficient between the roll and the atmosphere (W/(m^2 K))

computed temperature and fluid flow using FIDAP, and then stress distributions using ANSYS commercial software. The effects of inlet velocity of the melt and contact strip/roll heat transfer coefficient on the stress in the strip and the rolls were discussed.

The quality of the final strips is closely related to the interactions of numerous working parameters, and the roll separation force is one of the most important factors that reflect the interplay of those parameters. Few papers, however, have discussed stress or mechanical responses of the strips during TRC. The roll separation force is a value that comprehensively reflects the mechanical response between the solid strip and moving rolls during TRC. The roll separation force is related to the location and shape of the mushy zone in which solid and liquid coexists. When the solidification of the melt is incomplete during contact with the cooled rolls, the roll separation force is low. This increases the possibility of a failure of the TRC process with spilling the melt out of the strips. The quality of the strips degrades due to insufficient solidification. On the other hand, if the solidification is complete long before away from the roll nip, the roll separation force increases too much. This causes the rolls to get stuck with the nozzle, and the possibility of the crack formation in the strip increases. The exit of the nozzle is also stopped and operation is affected. Overall, the control of the roll separation force is important in successful fabrication of strips. Modeling TRC process focused on the roll separation force can complement other TRC modeling stressed on fluid flow and thermal behaviors.

The main focus of this study was placed on prediction of the roll separation force. A commercial finite element code DEFORM was used to systematically predict the roll separation force and temperature distribution during horizontal TRC. The effect of asymmetric roll speed and nozzle shape on temperature distribution and the liquid fraction was examined. We discuss the variation of the roll separation force with the heat transfer coefficient and suggest a reasonable range of the heat transfer coefficient for computation. The influence of casting parameters such as roll speed and initial melt temperature on the roll separation force is also discussed in detail. The predicted roll separation force is compared with the measured values during fabrication of A7075 aluminum strips in a pilot-scale horizontal twin roll caster.

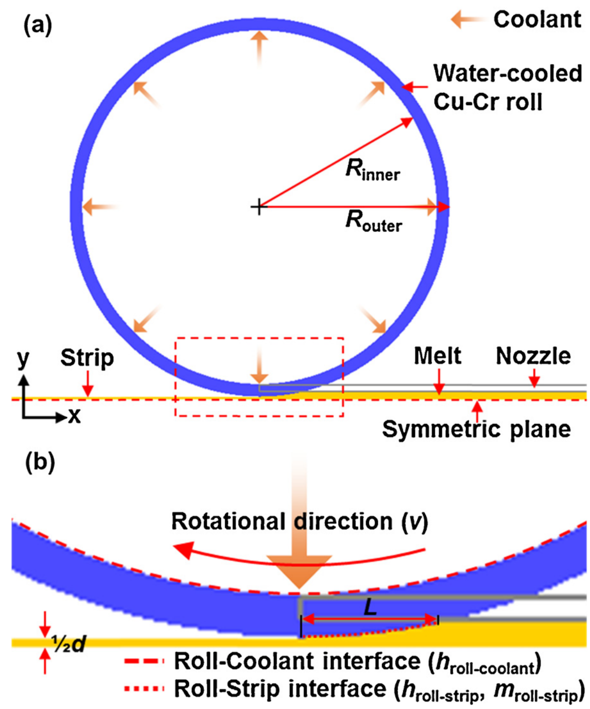

Fig. 1. Schematic representation of horizontal TRC process: (a) domain used for simulation with dimensions and (b) details in the vicinity of roll nip marked by the rectangle in (a).

2. Numerical and experimental procedure

2.1. Finite element model

Modeling and simulation of the TRC process were carried out on casting of A7075 aluminum strips with a thickness of 4 mm. A two-dimensional schematic representation of the horizontal twin roll strip caster is illustrated in Fig. 1. The width of the strip was generally large compared to the thickness of the strip, and the geometry of the modeling was approximated as two-dimension neglecting the end effect of the strip. To investigate the effect of differential speeds of the top and bottom rolls and asymmetric design of the nozzle on the shape of the mushy zone, the full geometry of the strip was modeled. To study the working parameters, just a half of the strips were modeled and the symmetric plane was applied on the middle plane of the strip. When the TRC process begins, the molten aluminum moves into the roll gap through the nozzle. Right after contacting the roll surface, solidification of the melt proceeds from the outer surfaces of the strip contacting the rolls toward the centerline. As solidification proceeds, the roll separation force obtained from the casting rolls increases. The mechanical properties at various temperatures and deformation rates of the A7075 aluminum were obtained from the DEFORM materials library. The temperature dependency of the thermal properties of the latent heat, the volume fraction of the solid phase, and the thermal conductivity of the A7075 were computed from JMatPro, and are presented in Fig. 2.

Specific heat, C_p, was given as a constant value. The friction between the roll and strip was considered as a sticking friction condition, and the frictional shear factor, m, was assumed to be unity. The temperature dependency of the heat transfer coefficient between the aluminum melt and the casting roll ($h_{roll\text{-}strip}$) was not considered and it was assumed to be constant. Instead, the effect of various heat transfer coefficients from 6500 to 10,000 W/(m^2 K) on the temperature distribution was examined. The effect of the working parameters of the roll speeds (v = 3, 4, 5 rpm, revolution