TWO-DIMENSIONAL SOLIDIFICATION ANALYSIS FOR TWIN-ROLL CONTINUOUS CASTING

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ABSTRACT:
A numerical algorithm for the two-dimensional solidification problem in the twin-roll continuous casting (C.C.) system is presented in this paper. Attention is focused on the elucidation of heat transfer and flow characteristics in both the liquid and solid phases. The present mathematical model can be applied to general full Navier-Stokes and energy equations, thereby covering the wide range of twin-roll casting conditions. The boundary fixing method (BFM) was adopted to handle the moving boundary.

In this paper, a general numerical methodology is presented for the C.C. problem and the quantitative relationship between the important control parameters in continuous casting of twin-roll type.

1. INTRODUCTION
In recent years a growing interest has been concentrated on the twin-roll continuous casting (C.C.) processes which have many advantages over other existing methods. The rapid solidification process using twin-roll is promising because it: (i) permits greater control over the material structure such as the formation of a quasi-steady stable phase, improves the solubility limit, establishes microcrystalline structure and mechanical properties, prevents segregation, and (ii) saves energy through a reduction of processes.

Although the twin-roll C.C. process is similar to the one as mentioned above, it is more difficult to control because of the existence of the deformation of the roll itself due to thermal expansion or thermal stress owing to the narrow roll gap. Further, if solidification is completed before the liquid reaches the minimum clearance point between the rolls, then deformation of the solid will occur. The plastic deformation of the material then has to be considered in this case.

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For the above mentioned reasons, it is necessary to develop efficient numerical tools to elucidate the complicated flow and heat transfer mechanism, which will be especially useful for designing optimum twin-roll C.C. systems. Solidification analyses for the C.C. of a slab have been done by Siegel[2,3,4], Koikkalainen et al.[5], Wang and Inoue[6], Lu and Zhi[7], Ohnaka[8], Ohnaka and Kobayashi[9], and others. A complete solidification analysis for the twin-roll C.C. including flow and heat transfer in the liquid and solid regions is limited, to the best of our knowledge, to the report by Miyazawa and Szekely[1]. The C.C. problems including the twin-roll technique have been reviewed by Szekely[11], Ohnaka[12], and recently by Ohashi[13].

This paper presents a numerical methodology for the two-dimensional heat transfer and flow phenomena in the liquid and solid regions in a twin-roll continuous casting system. The mathematical model presented covers the wide range of casting parameters since the two-dimensional transport in both phases was taken into account. Another objective is to provide a quantitative relationship between the principal casting parameters.

2. MATHEMATICAL FORMULATION

2.1 Numerical Model and the Governing Equations

A numerical model and the coordinate system are schematically shown in Fig.1. Molten metal is being fed from upstream into the nip of the two rolls rotating in opposite direction with an angular velocity \( \omega \). The surface of the molten metal \( OP \) is always kept constant by overflowing the excess molten metal from the small leveling mouth. As soon as the molten material is poured into the nip, solidification takes place on the roll surface which is cooled by recirculating water inside the roll. Now, we define two coordinate systems; \( (r,\phi) \) is the coordinate for the solid phase with the origin at the center of the roll, \( (r,\phi) \) is the coordinate for the liquid phase with the origin at point \( O \). The solidified shell which grew by the time \( t=t \) is represented by the functions \( F(\phi,t) \) and \( G(\phi,t) \) in the solid and the liquid phase coordinates, respectively.

The problem is then to find the steady solidification profile and the distributions of temperature and fluid velocities in both phases. Special attention is focused on the end point of solidification since the casting phenomena will