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Contact melting by a non-isothermal heating surface of arbitrary shape

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Abstract—Contact melting a material by a moving heater of arbitrary shapes with non-isothermal working surface is systematically investigated. A pressure exerted by the heater continuously squeezes the molten layer out of the close-contact region. The melting material has non-linear physical properties including temperature dependent conductivity, viscosity and non-Newtonian behaviors. By using a scale analysis momentum and energy equations are simplified. An iterative numerical procedure based on a boundary elements method is developed. Computed results show a good agreement with the analytical solutions that are available for a parabolic isothermal heating surface and constant physical properties. Influences of temperature distributions along the working surface and lengths of the heater on the thickness of the molten layer are found. A comparison between these factors is made. An appropriate distribution of the heat source within the heater is also proposed.

1. INTRODUCTION

Melting a solid by a close contact with a heating surface takes place in numerous natural and technological processes. Two types of applications can be categorized [1]. In one group the material lies on the heating surface and is pressed against it by some external force such as the weight of melting material. This situation occurs when the unfixed phase-change material melts in an enclosure. The other group of applications involves a moving heater melting its way through the surrounding solid. This phenomena arises in such fields as geology, nuclear technology, welding, oil industry and thermal drilling of rocks and glaciers.

Thermal drilling is commonly recognized as the most effective method to bore glaciers [2, 3]. Drilling rocks and soils by a thermopenetrator [4, 5] is a relatively new method in mining engineering. It has advantages over a traditional rotary drilling. For example, rock fracturing, debris removal and wall stabilization are accomplished in a single integrated operation.

Theories of contact melting have been developed since the last decade. Melting inside the capsules for energy storage was investigated by Moore and Bayazitoglu [6], Roy and Sengupta [7] and Saito *et al.* [8]. Bejan [9], and Tyvand and Bejan [10] studied contact melting induced by friction. They accounted for melting ice due to a decrease in the melting point by applying an external load. Enhancement of heat transfer and reduction of thermal resistance in the molten layer by machining slots on the heating surface were analytically, numerically and experimentally investigated by Saito *et al.* [11]. Contact melting under rotation conditions was studied by Taghavi [12]. Moallemi and Viskanta [1, 13] used a marching-integration procedure to obtain complete numerical results of contact melting for a moving horizontal cylindrical heater. Measured surface temperatures of the heater and melting velocities under rectangular and circular cylinder-shaped heater are provided by Webb *et al.* [14].

Although previous investigations highlight the main characteristics of contact melting, the effects of temperature-dependent properties were ignored. Heat conduction to the surrounding solid was also neglected. This is only valid when the latent heat is greater than the sensible heat in solid. Heat conduction in the heater was not investigated. The influence of the shape of heating surface and temperature distribution on it was not analysed. Although Fomin and Wei [15] accounted for shape factor and temperature dependent properties, the heating surface was assumed to be isothermal.

In the present study a general mathematical model of contact melting of a material with temperature-dependent physical properties is developed. The molten material is considered to be a non-Newtonian liquid of the Ostvald-de-Waele type, which was experimentally confirmed for a molten rock or magma [16].

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