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PREDICTION OF MOULD FILM THICKNESS IN THE BISMUTH BASED ALLOY CONTINUOUS CASTING PROCESS

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ABSTRACT

PREDICTION OF MOULD FILM THICKNESS IN THE BISMUTH BASED ALLOY CONTINUOUS CASTING PROCESS. Continuous casting is an important manufacturing process for producing ingots, slabs and flat products. The lubricant known as the mould flux in the meniscus region of continuous casting process flows through the space between the solidified shell and water cooled mould wall under the influence of the mould oscillation, gravity and the casting speed. The lubrication process in continuous casting upper mould region is characterized as the hydrodynamic lubrication phenomena. The film thickness at this working region zone is considered to be important and it may determine the quality of the surface of the billet/slab during continuous casting. Maintaining an optimal film thickness is very important to prevent the metal-to-metal contact between the surface of the strand and the mould wall. In this work, the changes in diameter of the cast bismuth based alloy billet were monitored during continuous casting in order to estimate the film thickness of the lubricant inside the mould. The result denotes that the thermal induced viscosity play an important role in the film thickness formation of a continuous casting process.

Key words : Continuous casting, film thickness, bismuth based alloy

ABSTRAK

PREDIKSI KETEBALAN FILM MOULD PADA PADUAN BISMUTH DALAM CONTINUOUS CASTING PROCESS. *Continuous casting process* adalah salah satu proses manufaktur yang dipergunakan untuk membuat produk *billet*, *slab* dan *flat*. Pelumas yang biasa disebut dengan *mould flux* yang diaplikasikan pada daerah meniscus di *continuous casting process*, mengalir diantara lapisan dinding yang mengalami pembekuan pada proses *casting* dan dinding *copper mould* dalam pengaruh getaran, gravitasi dan kecepatan *casting*. Proses pelumasan pada bagian atas *mould* di sebut sebagai fenomena *hydrodynamic lubrication*. Ketebalan film pelumas pada dearah kerja merupakan hal yang sangat penting dan dapat menentukan kualitas *billet/slab* yang diproduksi selama proses *continuous casting*. Menjaga ketebalan film pelumas yang optimum diperlukan untuk mencegah terjadinya kontak antara metal dengan metal antara pemukaan metal yang membeku pada saat *casting* dan dinding *mould*. Dalam penelitian ini, perubahan diameter *billet* dari material Bismuth paduan di amati secara kontinu dengan tujuan untuk mengestimasi ketebalan film pelumas didaerah *mould*. Hasil penelitian menunjukkan bahwa viscositas dari pelumas yang dipengaruhi oleh panas karena proses *casting* mempunyai peranan penting dalam pembentukan ketebalan film pelumas pada *continuous casting process*.

Kata kunci: continous casting, ketebalan film, paduan bismuth

INTRODUCTION

The operation of the continuous casting process consists of many complex stages. In steel continuous casting, molten metal is poured continuously from a tundish into a water cooled copper mould, converted into a semi finished solid shape and withdraws as a continuous length of casting. Several parameters controls the shell formation in the mould such as the temperature of the incoming hot liquid steel, the dimensions of the mould, the oscillating mould, mould lubrication, the cooling water flow rate and the withdrawal speed of the solidified cast. Problems such as cracks may occur under less control or failure conditions during casting. For the condition where the shell is not thick enough the surface cracks may lead to leaking where liquid metal emerges from the mould's exit and this is known as breakout [1]. Breakout in continuous casting deteriorates slab quality and effects slab shape formation. It also reduces slab production and disturbs production schedule. It has been reported [2] that there are many reasons that cause the breakout. Among these reasons, the breakout may be caused by insufficient lubrication between the surface of the mould and the strand. Although satisfactory progress has been made in improving the continuous casting process, further work is still needed to obtain a better cast product. The current incapability to determine accurately the mould lubricant film thickness profile at the metal-mould interface provide scope for further research. The ability to develop an experimental rig for analyzing the luricant film thickness would significantly contribute to a better surface quality of product and reduce waste in the present continuous casting technology.

The mould of continuous casting is generally machined from a solid forged copper. It is designed to suit all strand shapes in accordance with the product requirements such as square, rectangular, round, hollow and polygonal section strands [3]. The design for all of this type of mould may be either straight or curved design. The liquid metal begins to solidify in the mould which then starts to produce the metal strand with various ranges outside the mould region. Mould lubrication or strand lubrication is necessary in any continuous casting process. Currently research on modeling and finding an effective mould powder lubricant are still in progress for performing higher casting speeds with reduced risk of breakouts [4]. Mould lubricant which are continuously poured over the molten surface of the metal cast during casting flows down between the copper mould surface and the strand. The mould lubricants consumption depends on the casting flux properties and casting conditions such as the geometry of the cast/mould and the casting speed. Lubrication on the contact surface between the steel strand and the mould is thus ensured by formation of the film thickness of the lubricant and a liquid slag film.

A new laboratory continuous casting experimental rig to produce a bismuth based alloy billet shape cast has been developed in the Advanced Manufacturing Laboratory – Royal Melbourne Institute of Technology University, Australia. The main objective of this development was to be able to conduct a continuous casting process in order to obtain film thickness formation data by varying various operational casting parameters. This is related to the hydrodynamic lubrication process and will be dealt within this work. Although the development of this experimental rig is limited to the laboratory scale, it brings benefits such as the operation flexibility and the ability to conduct numerous experiments without any time limitations or disruptions that may be faced if experiments were conducted in industry.

DEVELOPMENT OF CONTINUOUS CASTING RIG

The development of a small scale continuous casting model will benefit from the limitation on accessing valuable information which is only available from industrial continuous casting plant. General view of the designed and built continuous casting rig is shown in Figure 1.

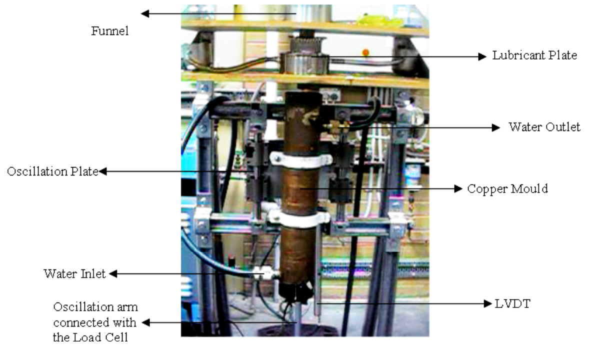

Figure 1. Developed Continuous Casting Rig

The continuous casting rig uses an oscillatory mould with variable oscillation speed and amplitude. During casting the mould oscillates in vertical direction with variable amplitude of less than 20 mm. The function of mould oscillation with proper lubrication in continuous casting is to prevent sticking of the strand to the mould's wall. Instead of supported rolls to pull the solidify cast located underneath of the mould a wire was connected to the dummy block and pulled down with controllable speed. Withdrawal of the solidify cast down from the mould was relying on this motor driven-wire mechanism. Water required for the mould cooling is supplied continuously from the inlet channel at the bottom of the mould through the outlet on the top of the mould. This water inlet and outlet system will deliver continuous cooling into the mould during casting. Water supplied into the system has an average temperature of 22 °C measured at room temperature. The water circulation will ensure continuously cooling of the cast by extracting the heat of the solidify cast material in the mould.

The billet mould was made from copper material which is usually used in real continuous casting. The mould is cylindrical shape formed of two concentric cylinders copper material with 1 mm thick and length of 400 mm. The inner diameter of the mould cylinder is 33 mm and the outer diameter is 74 mm. These two cylinders were welded together at bases to form a space for water. The function of this channel is to provide water circulation system in the mould and produce adequate cooling for the molten metal to solidify. Bismuth based alloy are used as the casting material. Similar to the production of ferrous and non-ferrous metals in continuous casting, Bismuth based alloy or Wood's metal can be continuously poured and withdrawn from the mould to resemble a continuous casting process. The safety and simplicity in melting were the main reason for selecting Wood's metal as the cast material in this work. The molten material is introduced from the top of the mould through the funnel. Underneath the funnel, the lubricant plate facilitates lubricating the mould surface during casting.

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FILM THICKNESS FORMATION

Several computer models and experimental work have been conducted for continuous casting in the past. [5] have reported analyzing the mould wall temperature distribution for different casting flux/lubricant with reduced thermal conductivity. They proved that the hydrodynamic friction forces were fairly low due to the infiltration of the slag layer which also acts as the thermal resistance between the strand shell and the mould surface. Mathematical models to predict the flux layer thickness profile and the powder consumption rate have been conducted. [6] Figure 2 shows the flux layer thickness for a powder lubricant with density r = 2500 kg m^{-3} when casting speed of 1.07 m min^{-1} was applied during continuous casting.

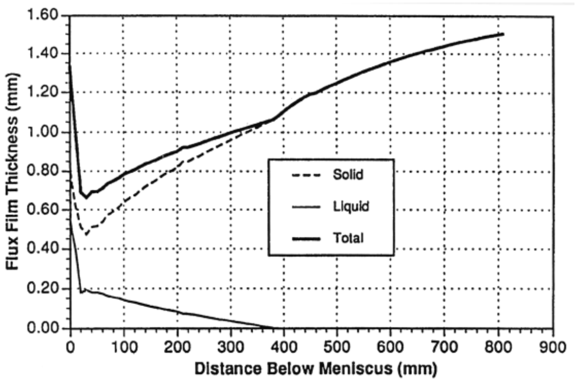

Figure 2. Flux layer thickness distribution in the top mould region

The reported to develop a relationship between the mould lubricant consumption and the heat flux in the continuous casting mould [6]. As shown in Figure 3, decreasing the mould lubricant consumption rate at constant casting speed causes the heat flux to be increased due to decreasing of the lubricant film thickness. Decreasing of the lubricant film thickness has proved to minimize the effect of the interfacial resistance. The same phenomena occurs when the casting speed increases which also means decreasing of the mould powder consumption rate.

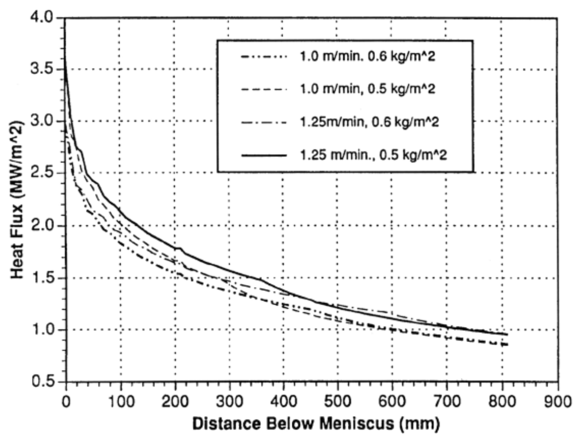

Figure 3. Effect on mould powder consumption and casting speed to heat flux in the mould [4]

In order to determine the lubricant film thickness in the steel meniscus of the continuous casting mould a heat balance equation has been developed [7]. The influence of casting parameters on the slag film thickness has been reviewed. It has been assumed, that the flow of the molten slag is steady state and that the local downward rate is even all over the free surface. During inflow of the molten slag from the steel meniscus continuous casting into the gap only the less viscous layer with the highest temperature which is in touch with the steel pool is likely to move sideways. Due to this behavior two layers present in the gap which are the solid slag close to the mould wall and liquid slag near the steel strand. Therefore, a local downward speed of the liquid flux could be determined but it is still considered difficult to measure exactly. So the only concern now is the overall consumption rate of the mould powder/ lubricant for the whole mould.

In general, mould design optimization can be achieved by good understanding of the hydrodynamic mould lubrication process and the operational parameters of casting process. This can be achieved by carefully study the film thickness formation and the various operational casting parameters that contribute to the quality of the continuous casting product. The literature survey presented here has revealed that some aspects of continuous casting process require further study and investigation.

FILM THICKNESS PREDICTION OF THE BISMUTH BASED ALLOY BILLET CAST

The physical system of the inlet region near the meniscus is shown in Figure 4. U_1 is the mould oscillation velocity and U_2 is the casting speed. The film thicknesses of the lubricant are denoted respectively by h_0 which is the initial film thickness, h, which is the work film thickness. Two different zones are distinguished in the mould. The first zone, x_0 is the upper part of the mould in the meniscus region. This zone is considered as the inlet zone of the lubricating mould. The mould lubricant enters the gap from the inlet zone as the cast is proceeded forward to the trailing part of the mould. Next to the inlet region is the work zone. In this zone, the lubricant film continue to establish the separation between the oscillating mould's wall and the newly formed solidified shell of the cast slab. Both surfaces have different temperatures, T_1 and T_2, and move in the casting direction with velocity, U_1 and U_2.

Figure 4 shows the condition of the inlet zone during infiltration of the lubricant into the gap in the meniscus region of a continuous casting process. One of the important points is the effect of the Pressure of the molten metal. As shown here the static pressure determines the film thickness of the mould lubricant

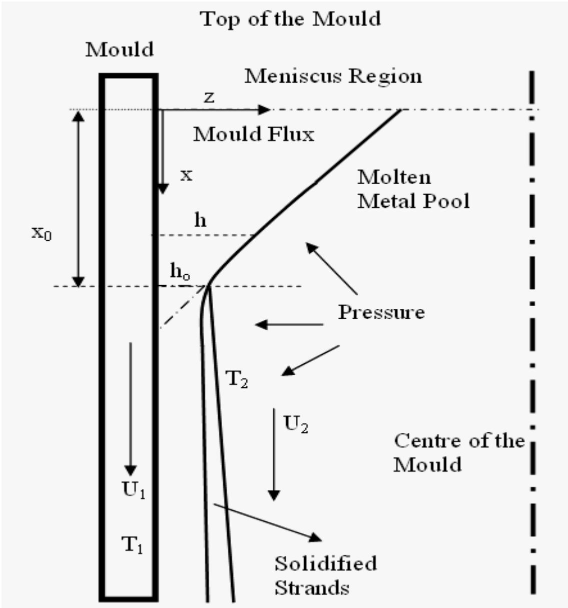

Figure 4. Infiltration of the mould lubricant

during casting. Decreasing of the static pressure can increase the liquid film thickness. An optimum film thickness must be determined to allow uniform lubrication in the mould.

Film Thickness Measurement

The changes in diameter of the cast metal billet were monitored during continuous casting in order to estimate the film thickness of the lubricant inside the mould. It was noted, in contrast to most common metals, that Bismuth based alloy (Bi=50%, Pb=25%, Sn=12.5, Cd=24.4%), [1] expands during the cooling phase. [7] The changes of the cast billet diameters in the hot and cold condition are shown in Figure 5.

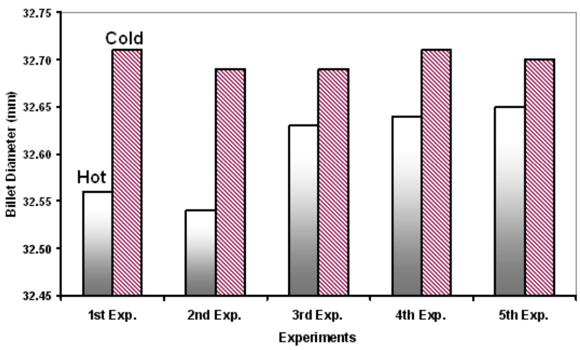

Figure 5. Comparison of the billet diameters in hot and cold condition

The hot the billet diameter was measured directly when the billet appeared at the mould exit. For the cold condition, the measurement of the billet diameter was taken at room temperature. The experimental results shown in Figure 6 were conducted for various mould lubricants. The mould was oscillated within 5 mm amplitude and billet withdrawal speed was 3.7 mm/sec.

The lowest viscosity lubricant (Castrol GTX) was used for the 4th and the 5th experiments. The highest viscosity lubricant was applied in the 1st and the 2nd experiments while Castor oil (medium viscosity lubricant) was applied for the 3rd experiments [8]. Figure 6 shows the variation of cast billet diameters at different location of cast billet diameters at different location of the billet length with various lubricants. A smaller diameter of the metal cast was produced for thicker lubricant film formed between the billet and the mould.

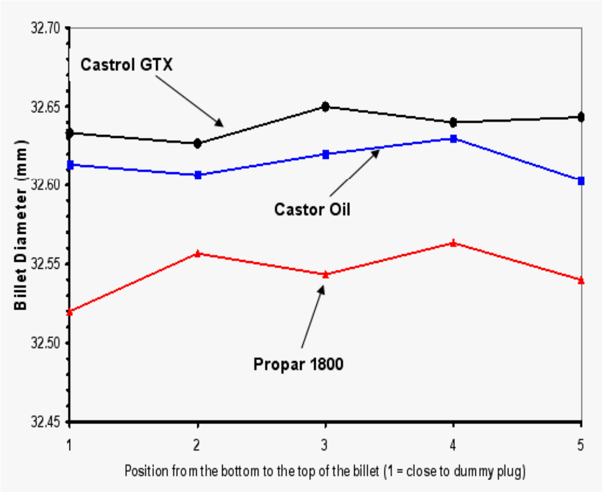

Figure 6. Billet diameter of Wood's metal during continuous casting

Maintaining an optimal film thickness is very important to prevent the metal-to-metal contact between the surface of the strand and the mould wall. On the other hand, the film thickness with high viscosity would favour higher surface temperatures affected by reducing the transfer of heat during solidification. High surface temperatures will decrease the thickness of the solidified strand of the cast billet during continuous casting and thus increase the likelihood of breakouts. Figure 7 shows the average film thickness variation estimated during continuous casting for various lubricants applied to the mould wall. The estimate was obtained as the half difference between the diameter of the cast billet and the mould wall during continuous casting. A higher estimate of film thickness was obtained for continuous casting where Propar 1800 lubricant was used. As shown

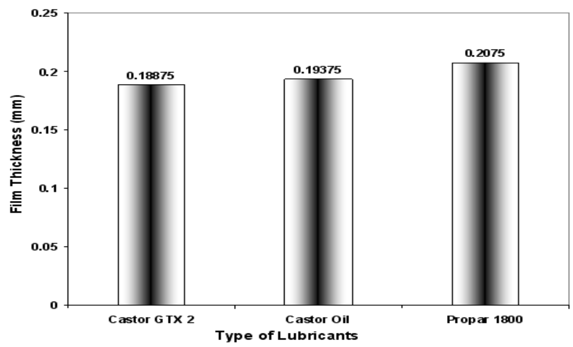

Figure 7. Film thickness variation during continuous casting

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in Figure 7, Castrol GTX2 with the lowest viscosity gave the lowest estimated film thickness during casting.

CONCLUSIONS

The continuous casting experimental rig was developed to analyse the mould film thickness of the bismuth based alloy cast billet under different operational conditions. The following conclusions were obtained in this work,

1. Low melting point material ie Bismuth based alloy material was successfully used in this continuous casting experimental rig to study the film layer formation of hydrodynamic lubrication at the strand mould interface.
2. The initial film thickness variation occurring during continuous casting as shown in Figure 6 is influenced by the viscosity of the lubricant.
3. The highest viscosity lubricant applied during casting produces the thickest lubricant film. A higher estimate of film thickness was obtained for continuous casting where Propar 1800 lubricant was used. Castrol GTX2 with the lowest viscosity gave the lowest estimated film thickness during casting

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