CH01 - The Impact of Skim Dam Design on the Molten Aluminium Temperature Uniformity at Sheet Ingot Mold Periphery

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Abstract

The molten aluminum distribution inside the ingot cavity from the exit of the distributor bag up to the mold-metal interface is critical to ensure uniform solidification of the sheet ingot outer shell. Both the forced metal flow out of the distributor bag and the convective flows resulting from heat transfer through the bag walls influence the thermal distribution at the mold periphery. A floating ring, often called a skim dam, is regularly used in sheet ingot casting to contain floating oxides and prevent them from reaching the meniscus region where they may produce ingot defects. The skim dam, penetrating into the liquid metal, also acts as a barrier for the hot metal flows. Results presented show that it is possible to substantially affect the temperature distribution at the mold-metal interface by modifying the skim dam penetration depth. An engineered skim dam can thus be designed to reach the desired temperature distribution profile across the mold periphery by reducing the skim dam penetration depth in front of areas needing an increase in temperature and increasing the skim dam penetration depth in areas where there is a need to lower the temperature.

Keywords: Molten metal distribution, DC casting, Skim dam, Sheet ingot, Rolling ingot.

1. Introduction

Adequate temperature distribution of the liquid aluminum at the mold is one of the many requirements known in order to produce high quality rolling ingots [1-3]. Uneven distribution around the mold periphery can generate a hot spot than can often lead to ingot cracks [1]. Also, numerous metallurgical features of the ingot can be influenced by the temperature distribution at the meniscus region. The temperature in the meniscus region was demonstrated to affect the average shell thickness [4] and the presence of floating crystals [5]. Having a uniform metal temperature around the ingot perimeter is thus important but it can simultaneously be judged as one of the most challenging feature to obtain [4]. This is generally achieved through modifications of the distributor bag size, opening locations, rigidity, mesh size and submergence [3-4].

Another important feature of DC sheet ingot casting is the use of a skim dam, which is a refractory ring floating on the liquid metal around the distributor bag. It is mostly used on high magnesium alloys to contain oxide patches. These can be generated due to turbulence during the initial ingot filling or during casting from the distributor itself. If not contained, these oxides can float up to the rolling side of the ingot and often lead to ingot cracks [1,3]. The use of this floating ring has thus been generally limited to oxide retention. However, numerical studies found that the skim dam has an impact on the metal distribution and resulting temperature distribution at the meniscus region [6]. Results obtained and reproduced in Figure 1 concluded that:

"*The skim dam, being partially submerged in the liquid aluminum, was found to act as a barrier for the convective flows happening at the surface. The hot metal moving from the distributor bag to the mold interface hits the skim dam, find its velocity reduced and must pass underneath the* *skim dam to continue. By passing underneath the skim dam it goes into a colder area of the sump and thus cools before continuing its course towards the meniscus."*

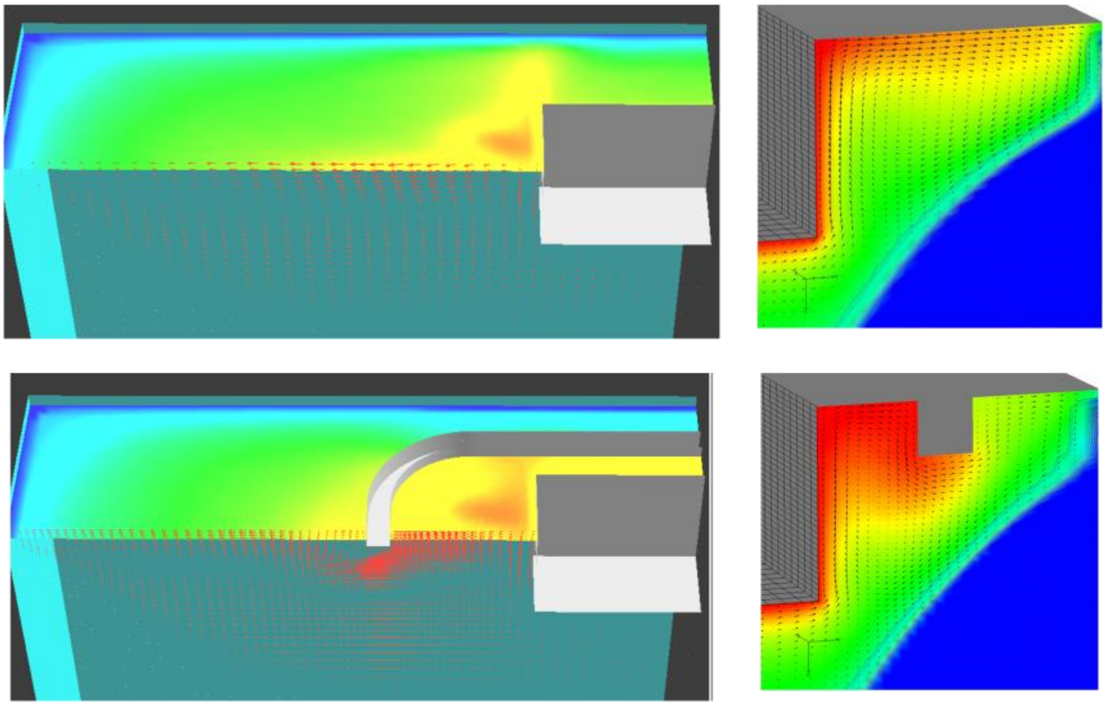


Figure 1. Simulation without and with a skim dam [6]. Left: centre cross-section parallel to rolling face, Right: centre cross-section perpendicular to rolling face.

The skim dam could potentially be used in combination with the distributor bag as another tool for the casthouse metallurgist to influence metal distribution and uniformity of temperature. However, physical studies on the impact of the presence and design of the skim dam on the temperature distribution at the meniscus region are non-existent.

2. Impact on the Presence of a Skim Dam on Metal Distribution

In order to validate the impact of the presence of a skim dam on the metal distribution inside the ingot, a cast of 3xxx alloy was made using a 448 mm by 1569 mm mold. A casting speed of 50 mm/min was used and a skim dam was present from cast start. Temperature measurements near the meniscus were done in steady state from 850 to 950 mm of cast length. The skim dam was then raised and the thermal conditions were let to stabilize before doing some new measurements from 1350 to 1450 mm of cast length. The temperature measurement at the meniscus were taken using an array of thermocouples, at 15 mm of depth under the liquid metal surface and 15 mm away from the mold face at a 100 mm interval along the mold face for a quarter of the ingot. The skim dam used was 33 cm × 75 cm with a L shape cross-section of 51 mm height by 51mm wide, having a leg thickness of 25 mm and penetrating approximately by 25 mm into the liquid metal as presented in Figure 2. The size of the distributor bag used was (W×L×D) 13.5 cm × 42 cm × 12 cm and having open mesh at both ends including 4.5 cm on both sides.

Figure 2. Use of a skim dam during casting. Left: skim dam design, Right: measurement during casting.

Results presented in Figure 3 clearly show a globally colder temperature at the meniscus around the mold periphery when using a skim dam. When removing the skim dam an increase in temperature for all the thermocouples except at the mold corner and at the center of the rolling face is measured. Also, the skim dam resulted in a temperature distribution spread from 654.0 °C to 657.8 °C, whereas the distribution is found to range from 654.3 °C up to 661.5 °C when using no skim dam. The presence of a skim dam thus effectively reduced the hot spot present by 3.7 °C. These results are in line with a numerical study where the temperature distribution at the meniscus was found to be colder when using with a skim dam [6].

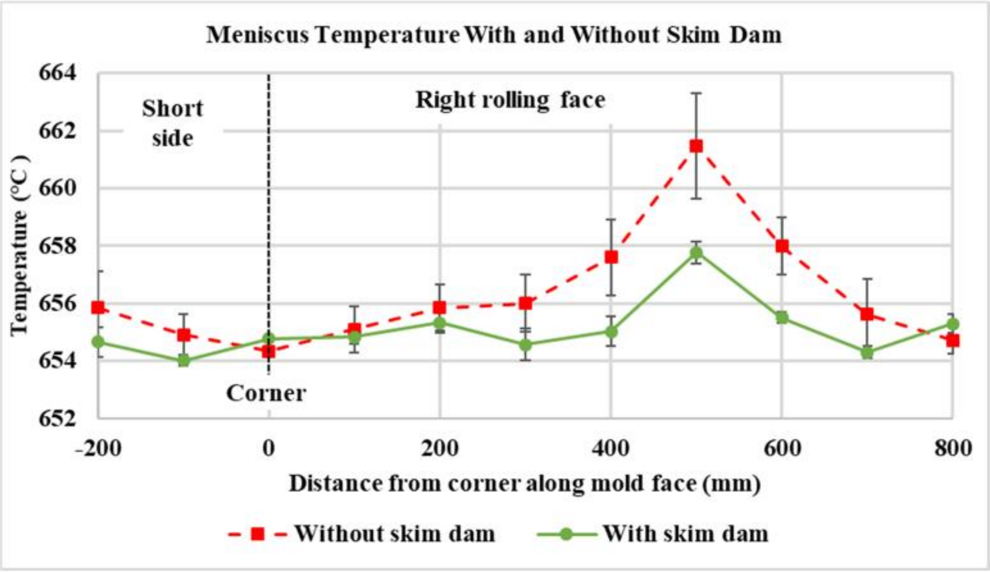


Figure 3. Temperature distribution at the meniscus along the mold periphery.

3. Impact of the Skim Dam Design on Metal Distribution

3.1 Adjusting Skim Dam Penetration Depth

According to a previous study, anything that affects the depth of submergence of the skim dam and the distance bag-skim dam-mold was deemed to have an impact on the uniformity of the temperature at the meniscus [6]. One can thus formulate the hypothesis that varying the penetration depth in specific location around the skim dam periphery would influence negatively or positively the uniformity of the temperature distribution. To validate this hypothesis and study the extent of the influence of the skim dam geometry on the metal distribution, two opposite skim dam designs were fabricated.

In order to design the first geometry, simple numerically modeled flow lines and thermal distribution were studied. As shown in Figure 3 and 4, the colder zones are found at the center of the rolling face, at the corner and, to a lesser extent, at the center of the short face. A hotter area can be seen approximately at a quarter on the rolling face. By following the flow lines from the mould face back to the distributor outlet, it is possible to identify various sections of the skim dam directly in the path of these specific forced flows. The first design was engineered with the objective to bring more heat to colder zones. Knowing that the presence of a skim dam reduces the flow velocity and cools the metal passing underneath, the penetration depth was adjusted, ranging from 0 mm to 25 mm, in the sections A to F according to Figure 4 and Table 1.

Another skim dam was fabricated with a geometry totally opposite of the first one in order to evaluate the potential maximum variation attainable. Both skim dams are shown in Figure 5.

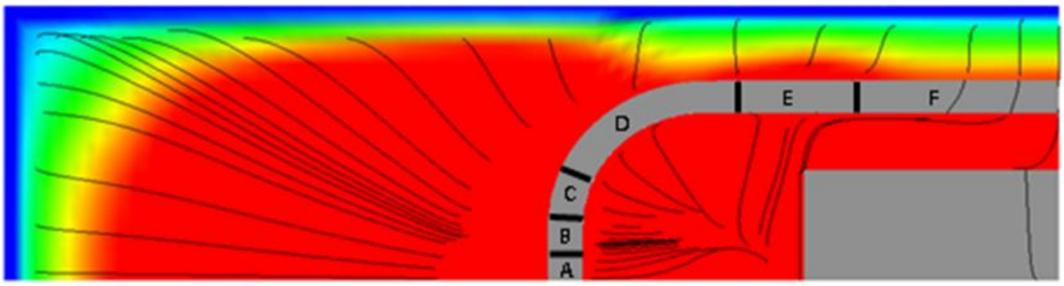
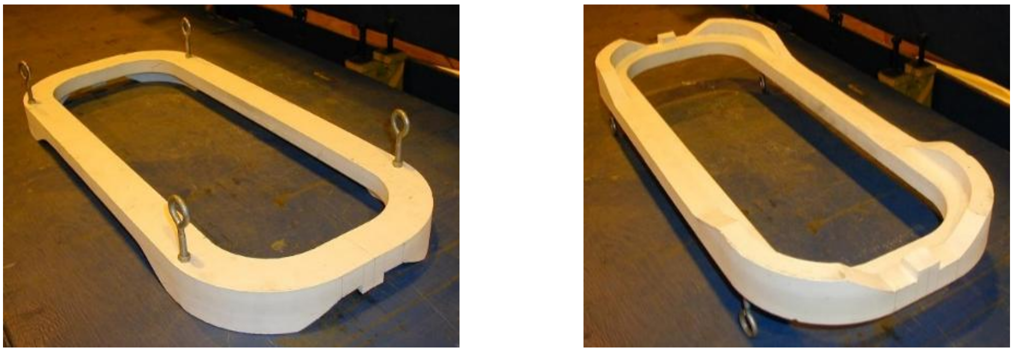


Figure 4. Simulated flow lines and thermal distribution.

Table 1. Skim dam penetration depth (mm).

Designs	A	B	C	D	E	F
1) Open center of rolling face and short side	13	0	slope	25	slope	0
2) Open first quarter of rolling face	0	25	slope	0	slope	25



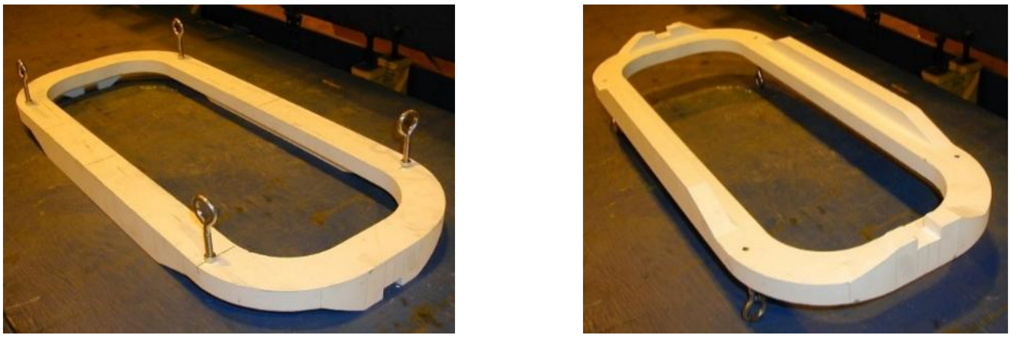


Figure 5. Skim dam designs. Top: open center of rolling face and short side, Bottom: open first quarter of rolling face.

3.2 Validation During Casting

Two casts of 1xxx series alloy were performed using a mold of 446 mm x 1422 mm and a casting speed of 70 mm/min. Both cast used a distributor bag of size (W × L × D) 15.5 cm × 38 cm × 12.5 cm having open mesh only at both ends. An array of thermocouples were positioned along half of a mold 20 mm into the liquid metal and 20 mm away from the mold. Temperature distributions were taken at a 100 mm interval along the mold face. The first cast was made using the first skim dam design presented in Table 1 and the last cast with the second design. Both skim dams are of size 33 cm x 75 cm with a L shape cross-section of 51 mm height by 51mm wide, having a leg thickness of 25 mm.

3.3 Results

Figure 6 shows the temperature distribution measured for the two conditions. Table 2 compares key temperature distribution results. By changing the skim dam design it was possible to vary the temperature at the center of the rolling face by 7 to 9 °C. The two designs also influenced the hot spots on the rolling face, the first design having a more flat temperature distribution whereas the latter resulted in temperature peaks between 400 and 600 mm from the mold corner. The second design resulted in an overall temperature variation across the mold periphery of 18 °C vs 10 °C for the first skim dam design. The impact is even clearer if we consider only the temperature variation on the rolling face, which is critical as it affects shell zone and rolled surface microstructural uniformity. The second design resulted in a range of 12 to 18 °C while the skim dam designed to reduce variation on the rolling face resulted in a 6 to 7 °C variation. This is a 40 to 50 % change in temperature uniformity between both designs.

The temperature distribution obtained with design 2 is found to be uneven on the short face and corners. A more symmetrical distribution, similar to what is measured with design 1, was expected. This could potentially be the result of an off center skim dam, bringing more heat toward the right mold corner. However, it is not possible to confirm if this was the case.

Table 2. Temperature distribution.

Designs	1) Open center of rolling face and short side	2) Open first quarter of rolling face
Minimum temperature	667 °C	661 °C
Maximum temperature	677 °C	679 °C
Average temperature	672 °C	670 °C
Overall temperature variation	10 °C	18 °C
Temperature variation over each rolling face	6-7 °C	12-18 °C

4. Discussion

It is clear from the results presented, that by modifying the skim dam penetration depth it is possible to affect significantly the temperature distribution around the mold periphery. In order to illustrate its impact on the actual distribution of metal coming from the distributor bag, numerical modeling were done with a standard skim dam and with the two modified skim dam designs as presented in Figure 7. The temperature distribution and vectors shown are taken from 5 mm below the free surface. These simulations confirm the results seen during DC casting where a more uniform distribution is measured for the first design while the second design show a colder center of the rolling face and a hotter spot at the first quarter.

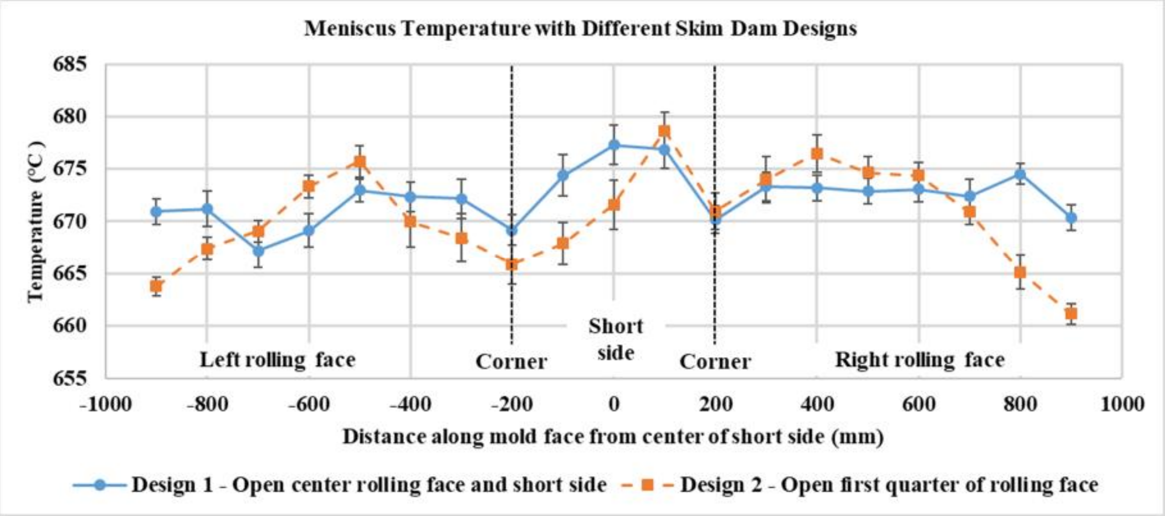


Figure 6. Temperature close to the mold face using two opposite skim dam designs.

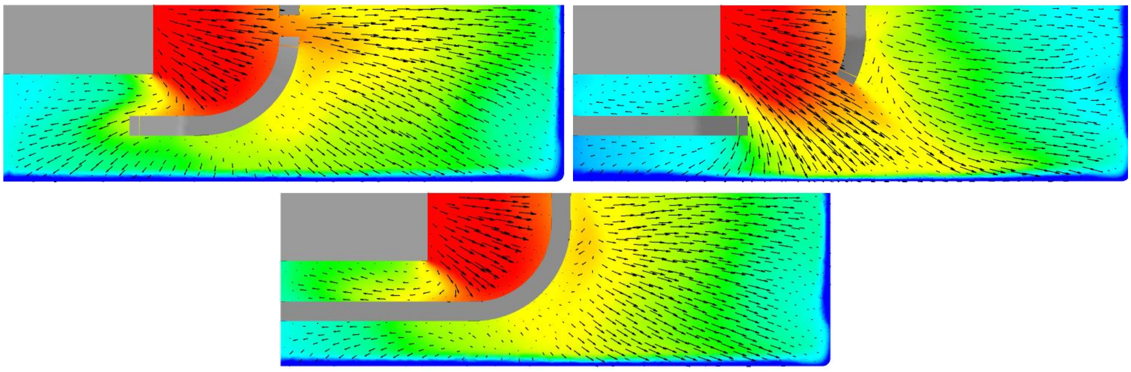


Figure 7. Impact of skim dam design on metal distribution. Top left: open center of rolling face and short side, Top right: open first quarter of rolling face, Bottom: standard uniform penetration depth.

These variations can be explained by how the refractory leg of the skim dam, penetrating in the liquid metal, hinders its movement. In areas where there is no penetration of the skim dam into the liquid metal, the flow can pass without being affected. In areas where there is penetration of the skim dam under the surface, it acts as a wall for the metal exiting the distributor bag. The metal loses its horizontal velocity and must passes under the skim dam, effectively cooling as it does so.

5. Operational Considerations

A few elements must be considered before operationalizing the use of a skim dam as an aid to obtain uniform metal distribution. First, a skim dam is not often used with non-Mg bearing alloys. Broadening the use of a skim dam to other alloy families adds another equipment that must be installed and maintained to ensure proper operation. Positive impacts must be seen on the scalping depth or rolled surface quality to warrant the use on non-Mg alloys. Secondly, the skim dam must be designed according to the distributor bag used, to complement it. Any changes in distributor bag type or size with ingot format or alloys should ideally be met with a change in the skim dam design. Thirdly, adequate centering of the skim dam around the bag during casting is important for performance and consistency. An off center skim dam will direct flows unevenly within the mold cavity. A more robust skim dam fixation than the simple chains used in this study is recommended to prevent horizontal movement of the skim dam while it floats on the liquid metal surface. Lastly, as the main purpose of the skim dam is to retain oxides, a minimal penetration depth is more than likely required to achieve this function. This was however not evaluated in this study.

6. Conclusion

The use of a skim dam during casting was found to generate an overall colder temperature distribution at the meniscus region around the periphery. Modifying the skim dam to have different penetration depth around its periphery demonstrated a significant impact on metal distribution. Areas with no penetration allow the unhindered passage of the hot metal while areas with significant penetration act as a wall and force the metal to pass underneath resulting in cooling. It was possible using engineered skim dams to vary the temperature uniformity along the rolling face of sheet ingot by 40 to 50 %. However, before using this to complement the distributor bag some operational aspects must be considered.

7. Acknowledgement

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8. References

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