

## THE HEAT FLUX AND THE EFFECTS OF MOULD SHAPE ON DISTORTION OF THE MOULD IN A THIN SLAB CASTER

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### Abstract

Geometrically, there are two kinds of mould to achieve high-speed casting: funnel-shaped and parallel mould. The mould shape and high casting speed leads to higher mould temperatures and shorter mould life than in conventional slab casters. Mould wall temperature measured in the plant was analyzed to determine corresponding the heat-flux profiles in thin slab moulds using an *Convective Inverse Heat Conduction model*, and this data was then used in an elastic-visco-plastic analysis to investigate the deformation of the moulds in service for different the mould shapes. The model predictions of temperature and distortion during operation match plant observations. During operation, the hot face temperature reaches 440-445°C and the copper plates bend toward the steel, with a maximum outward distortion of about 0.31-0.33mm. This occurs just above the center of the wide faces, and is smaller than the distortion of a conventional slab mould.

**Keywords:** Heat-flux, caster, distortion, mould-shape, slab

### 1. INTRODUCTION

The advanced continuous casting process for thin slabs with thickness of only a few centimeters allows hot direct rolling to be performed in-line with a few conventional finishing mills, eliminating the need for a roughing train and the associated capital costs. The role of mold heat convective transfer and distortion in these problems has received relatively little attention in previous literature. The mould is the most critical component of the thin slab caster, because, during casting, the copper mould plates control initial solidification of the steel product [1], which determines surface quality. During operation, although mould distortion due to the steep thermal gradient is small, it affects the size of gap between the solidified shell and the mould, which in turn controls heat transfer. The accompanying thermal stress may cause permanent creep deformation near the meniscus, which affects mould life as well. Therefore, maintaining a reliable, crack-free mould within close dimensional tolerances is also crucial to safety and productivity. The issue of thermal distortion in continuous casting moulds has been little discussed in the literature over the past years [2].

### 2. RESULTS

The mould was Cu-Ag-Nd-P with dimensions given by **Table 1** (SIDEX-GL). In this table, effective wall thickness is defined as minimum distance from water in the channels to the hot face.

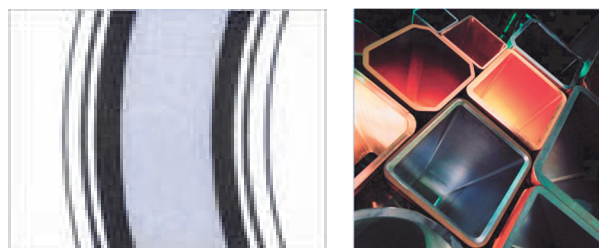
The total mould length was 1860mm. Thermocouples were embedded through holes drilled in the bolts to a depth of approximately 23-24 mm from the hot face.

**Table 1** The mould parameters - SIDEX-GL

Mould dim., (mm)	106x120x1860
Mould base copper alloy	Cu-Ag-Nd-P
Slab thickness, (mm)	71-72
Wall thickness, (mm)	Broad face: 30 narrow face: 25
Meniscus level, (mm)	91-95
Cooling water section (mm x mm)	5 x 15
No. of channels on broad faces	140
Cooling water velocity (m/s)	11.20
Water flow rate, ( l/min.)	Broad face: 4420 narrow face:3750
Casting speed, (m/min)	3.1-3.6

### 3. INNER SURFACE COATINGS

Metallurgists and Engineers have been working together to develop better continuous casting moulds. The steel companies require a more economical mould which will give a longer service life. Surface coating of the inner walls of the mould has given the best results to date. Today, coatings available are Chromium and Nickel plating. Also, a combination of the two gives some good results on slab casting, but we developed new HVOF coating technology. The rate of solidification in the continuous casting process dictates the speed of production. The molten steel, which is in contact with the inner faces of the copper mould, starts to solidify as rapidly as the heat is extracted, forming a shell. The shell increases in thickness as more heat is extracted and eventually total solidification is achieved. The process is similar to the solidification of ingots in ingot moulds. In continuous casting; the whole process is speeded up, with the aim to produce a homogeneous shell growth. To extend the life of copper moulds a plating is required to coat the inside wall. The quality of the coating of the inside wall has a most significant role in determining a mould's service life. Over the tests we have developed different coatings to improve continuously the quality and cost-efficiency of our continuous casting moulds. Now we use Twin-Parallel Tailoring Multiple-Stripes HVOF coating (TPTMS).

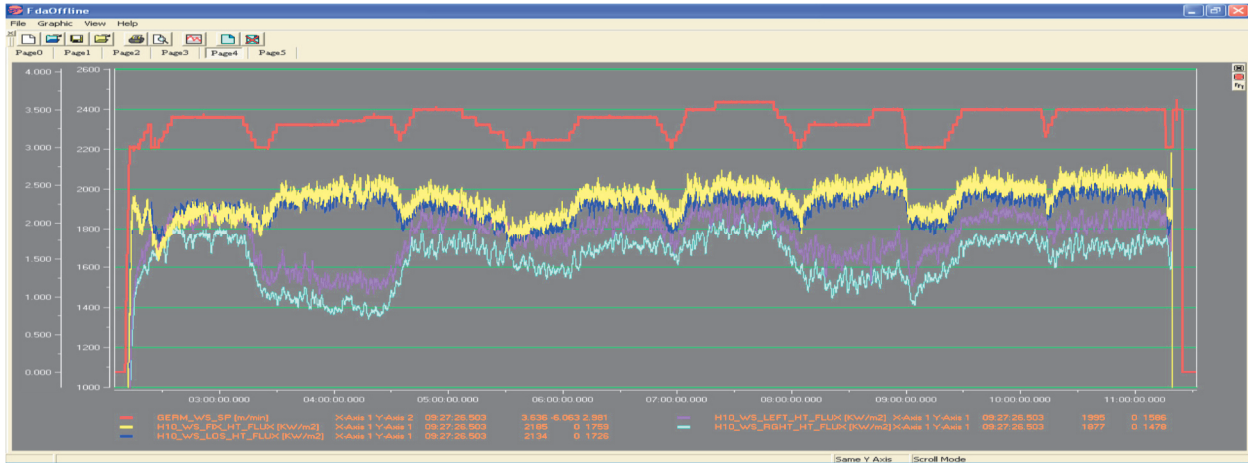


**Fig. 1** Twin-Parallel Tailoring Multiple-Stripes HVOF coatings

Prevents direct contact between the strand and the copper, compensates hot spots, controls thermal losses (in all cases, not dissipation) by varying the thickness of the TPTMS HVOF coating and improves service.

### 3.1 Heat flux profiles

The calculated axial profiles of the mould hot-face heat flux are shown in **Fig. 2**. Heat flux profiles in red, show the same tendency as measured temperature profiles.



**Fig. 2** Heat fluxes of broad and narrow faces sequence no.312 - Strand#2

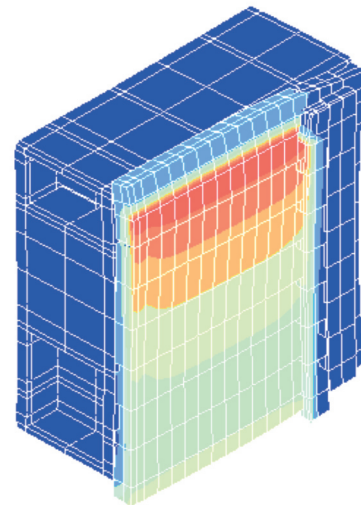
### 3.2 Heat flow model

Heat flux data was input to the exposed surfaces of copper elements on the mould hot faces as a function of distance down the mould based on previous studies.

The water-slot heat transfer coefficient  $h=38 \text{ kWm}^{-2}\text{K}^{-1}$  is determined from the dimensionless correlation.

### 3.3 Mould distortion behavior

The typical temperature and distorted shape of the TPTMS HVOF coatings, during operation are shown in **Fig. 3**. It shows the mesh, temperature contours on the hot face (red areas), and the distorted shape of the mould, exaggerated fifty-fold. At the hot face, the maximum temperature is found to occur approximately 20-25mm below the meniscus.



**Fig. 3** Distorted shape of the quarter mould

## CONCLUSION

A 3-D thermal-elastic-plastic-creep model has been developed to predict distortions during operation match plant observations.

- Small bolt holes in the front of the steel water jacket which constrain expansion of copper plate should be avoided.
- Catastrophic cracks are most likely to initiate at the root of the deepest water slot during cooling after a drop in mold level. Rounding the water slot roots does not appear to significantly reduce the danger of cracks.
- Water slots should be uniform in depth in order to avoid detrimental stress concentration.

- The effect on copper hot face temperature variations is around  $\pm 10^{\circ}\text{C}$ .
- Clamping forces should be optimized to avoid crushing the narrow face corner while balancing the ferrostatic pressure.
- Water slots should be extended as close to the top, bottom, and edges of the mold as possible.
- The meniscus should not be allowed above the height where the water slot depth begins to decrease.
- This minimizes both mold surface temperature and temperature fluctuations.

**REFERENCES**

- [1] K. Hibbit and J. Sorensen, ABAQUS, Providence, RI, 1996.
- [2] Slicher, C. A., and Rouse, M. W. (2005) Int. J. Heat & Mass Transfer 18, 677-683.