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Square rolling slabs from start of casting - the elimination of butt swell

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Abstract

The thickening of the bottom part of DC cast rolling slabs, butt-swell, is a well known problem in the aluminium business. The slabs are scalped, normally in the rolling plant, prior to rolling to a absolute rectangular shape. The rolling mill therefore prefers rolling slabs with geometry close to rectangular from the casthouse. Due to geometry specifications from the rolling mills the supplier casthouse has to cut off the bottom part of the slab before shipping. The bottom cut length is typically 0.3-0.6m (1-2') depending on the thickness and casting speed.

Extensive research has been done on the basic mechanisms of butt-swell and the phenomenon is today well understood. The thickening in the bottom is due to the absence of pull-in which is a thickness reduction phenomenon during the stationary phase of DC casting of rolling slabs. It is impossible to avoid butt-swell when using moulds with fixed geometry. To eliminate the butt-swell flexible moulds are developed. In this technology the mould shape is gradually changed during the initial stages of casting in such manner that the rolling slabs will be rectangular from start to end of cast.

This technology has been in industrial use since 1997 within Hydro casthouses. In addition to eliminating the butt-swell this technology allows for a large degree of freedom when choosing casting speed. Conventional moulds are designed to give rectangular slabs for a given casting speed, while the technology described in this paper may be adapted to any relevant casting speed.

This paper describes the basic principles behind the technology, a description of the equipment, and the operational experience so far.

For 600mm thick ingots flexible moulds typically reduce the total scrap rate in the casthouse with more than 5% compared to conventional moulds with fixed geometry.

Introduction

Rolling slab geometry is an important quality parameter. Due to the rolling process the rolling faces of the slab need to be absolutely flat prior to rolling. This is obtained by precision scalping of the surface. For many applications the outer surface with slow solidification (shell zone) needs to be removed prior to rolling to avoid unwanted aesthetical effects. The worse the geometry of the slab is, the more has to be scalped off to produce a flat slab, and thus more material is scrapped. Most rolling mills therefore specify an acceptance limit with regards to geometry. In Europe many uses the EN 487 standard that describes some tolerances for rolling slabs. It is a common assumption that these tolerances will tougher in the future. These limits will determine the butt cut-off length in the casthouse and will also limit the casting speed window than may be used when using conventional fixed moulds.

Elastical deformation of moulds during the initial stages of casting is not a new idea. Alcan patented a flexible mould as early as 1974/75, [Veilette 74], [Rodenchuk 75]. In 1976 R. R. Lawrence (Alcan) published a paper on flexible moulds, [Lawrence 76]. He lists up the following benefits with flexible moulds: 1) Reduce of eliminate the need to saw cut butts, 2) Reduce scalping, 3) Reduce aluminium melt loss due to reduction of scrap generated from an ingot, 4) Reduce overall equipment inventory as several different alloys can be cast with the same mould, 5) Increase effective capacities in casting furnaces, swarf furnaces, soaking pits, storage areas, scalping operations, saws, etc., 6) Reduce conveyor damage, 7) Permit higher casting speeds without forming a large ingot butt.

Theory

When using moulds with a fixed geometry the rolling slab will be thicker in the butt end. This phenomenon is commonly called "butt swell". The basic mechanisms behind the formation of the butt swell is well understood and is related to the inward bending of the rolling faces during steady state, see [Drezet 95], [Fjær 97]. This deformation is compensated for by making the moulds convex (thicker on the middle of the rolling faces). During the initial stages of casting the steady state thermal field is not established and the pull-in is close to zero. During the first ~2 slab thicknesses of casting the steady state thermal field is established and pull-in is gradually increased to the steady state level. The pull-in is varying across the rolling face of the slab and is largest on the middle (thickness reduction of ~5-9%), and smallest (~1.8%) at the corners.

C. E. Weaver (Alcan) was the first to point out that butt swell was related to the development of the thermal field during start-up and inevitable when using moulds with fixed geometry, see [Weaver 76]. He was also the first to point out that the pull-in was approximately proportional to the casting speed and to the square of the slab thickness. In other words will the optimal mould shape be dependent on the casting speed.

The steady state "optimal" mould opening can be estimated using the equation given in [Håkonsen 97], see equation (1).

$$D_M = (1+\varepsilon_0)D + C_{Alloy}\Theta V D^2 \tag{1}$$
$$\Theta = \exp\left[-1{,}9(X_A)^{1{,}9}\right] - \exp\left[-1{,}9\left(\frac{W}{D} - X_A\right)^{1{,}9}\right]$$

D_M is the optimal mould opening, ε_0 the total thermal contraction during casting ($=\beta(T_{coh}-T_0)\approx 0{,}018$), D the nominal thickness of the ingot, C_{alloy} is a alloy dependent constant ($\approx 130 s/m^2$), V is the casting speed, X_A is the dimensionless distance from one short side (=x/D) and W is the nominal width of the ingot. Θ Is named the pull-in function and may be regarded as the dimensionless mould opening.

Equation (1) is a further development of the model proposed by Weaver. An observation worth mentioning is that the butt swell length and the thickness difference between bottom and steady state are both proportional to the casting speed and the square of the slab thickness. This thickness difference between the bottom and steady state is given by (1). The length of the butt swell is given by the casting length until steady state thermal field is established. It may be shown that this casting length also is proportional to the casting speed and the square of the slab thickness.

In Figure 1 the optimal (dimensionless) mould shape for different width to thickness ratios are shown.

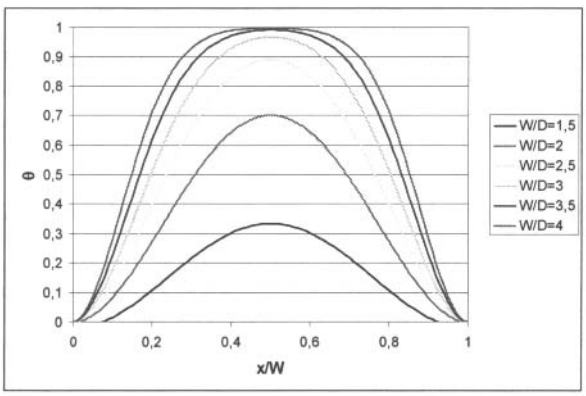

Figure 1. The dimensionless mould opening for varying width to thickness ratios.

Technology

The current understanding of the butt swell formation tells us that butt swell can not be avoided when using moulds with fixed geometry. We also know that moulds with fixed geometry have to be designed to give optimal slab geometry in steady state, for one fixed casting speed. In addition we know that the size (thickness difference) and length of the butt swell is proportional to the casting speed. Therefore most casthouses choose a low design casting speed to limit the need for butt cut-off.

Hydro applied in 1999 for a patent on flexible moulds where the stiffness of the rolling face mould wall is varied/designed to give a close to optimal shape when deformed, [Steen 99]. By this it is possible to make flexible moulds with close to perfect steady state geometry for any width to thickness ratio.

Based on this patented technology Hycast has in collaboration with Hydro developed a flexible mould to eliminate butt swell and to give the casthouse freedom of choosing different casting speeds for different alloys in the same mould set. 3D modeling tools are utilized in this design process, see Figure 2 for an example of calculated deformation. The figure shows an example of a mechanical deformation of the mould wall corresponding to maximum flexing during casting. Von Mises stresses are shown in the figure since yield in the mould wall material will give a lasting deformation, and thus Von Mises stress is a parameter of interest.

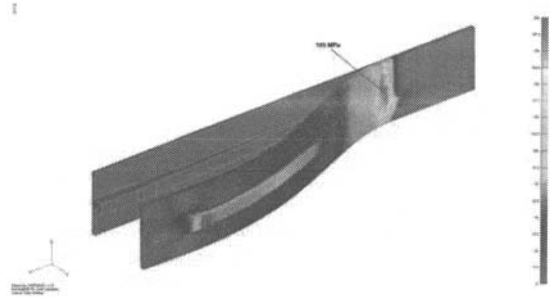

Figure 2. 3D simulation (ANSYS) of a deformed long side of a flexible mould. Equivalent tensile stress (Von Mises) is shown with different colours (0-200MPa scale).

The deformation of the mould walls is done by one or two flexing actuators and a system to transfer the actuator movement to the moulds – the flexing system. The flexing movement is accurately controlled by a PLC system and a pre-programmed flexing curve. This curve may be dimension and alloy dependent allowing different casting speed, and thus flexing, for different alloys. A typical casting system with two flexible moulds is shown in Figure 3.

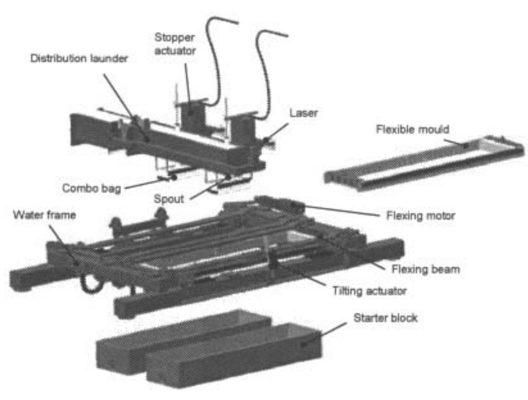

Figure 3. Hycast ™ Rolling Slab Casting System. A typical setup with two strands is shown.

Results

Figure 4 shows measured geometry of a typical rolling slab from a fixed mould. The classical butt swell may be seen in the first ~800mm of the cast. In contrast Figure 5 shows the measured geometry of a comparable rolling slab produced with a flexible mould. The geometry is significantly better than the conventional slab, and the butt swell is clearly eliminated.

Figure 6 shows the centerline thickness for the two ingots in Figure 4 and 5 in addition to a second slab produced with a flexible mould. As can be seen in the figure the "conventional" slab needs half a meter of casting until the geometry is within 600mm ± 5mm while the fleximould slabs is within 600 ± 3mm from start. Figure 7 and 8 shows photos of typical slabs produced with flexible moulds.

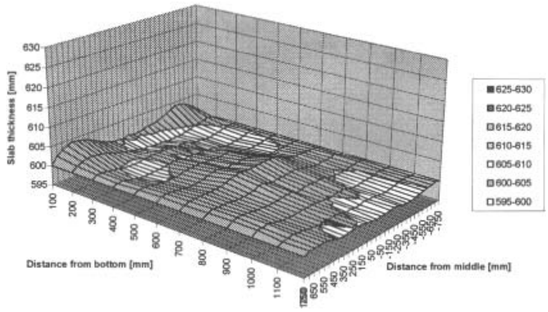

Figure 4. Measured thickness for a slab produced with a conventional fixed geometry mould. Alloys AA1200, casting speed 70mm/min, slab size 600x1750mm.

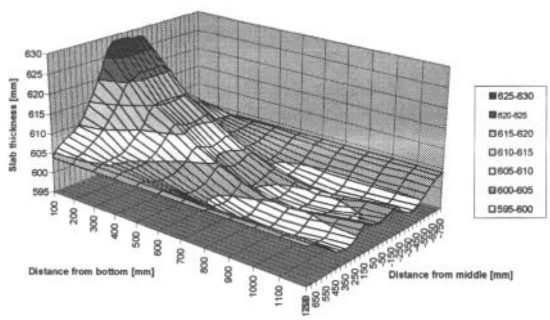

Figure 5. Measured thickness for a slab produced with a flexible mould. Alloys AA1200, casting speed 70mm/min, slab size 600x1750mm.

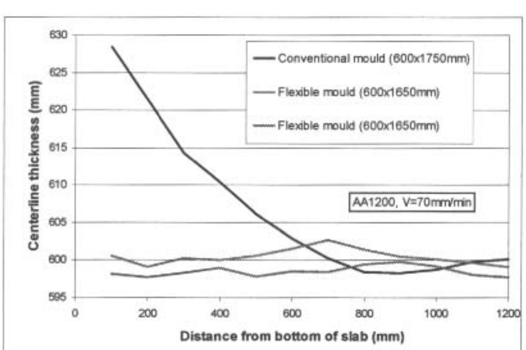

Figure 6. The measured centerline thickness for one slab produced with a conventional mould and two slabs produced with flexible moulds. All slabs are of alloy AA1200 and the casting speed is 70mm/min.

Figure 7. A rolling slab without butt swell produced with the flexible mould technology described in this paper.

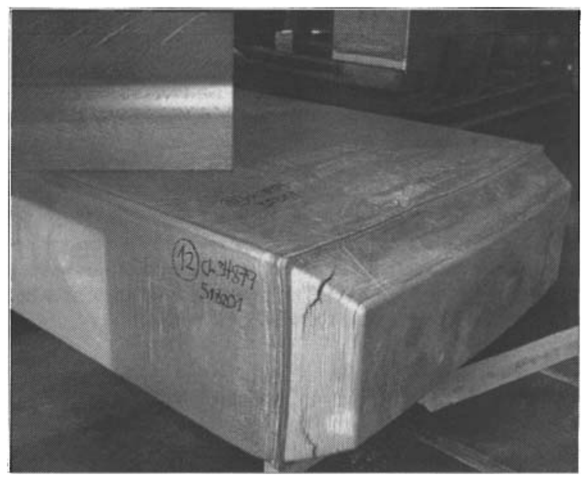

Figure 8. Flexible mould rolling slab; 600x1600mm, AA5182, Casting speed 60mm/min.

Operational experience

The first flexible mould was installed in Hydro in 1997. The technology is today in regular production in two casthouses. The mould lifetime has proven to be >10 years, e.g. no fatigue problems of the moulds have been observed. The alloys currently produced in this technology are 1xxx, 3xxx, 5xxx, and 8xxx. The dimension ranges from 535-610mm thickness and 1450-2200mm width. The typical casting speed is 70mm/min for most alloys.

The maintenance cost and the cost of consumables is comparable to conventional moulds (fixed geometry) in the two casthouses.

The flexing is performed fully automatically and the control is integrated in the control system of the casting machine. The flexing curve is described by several breakpoints and is treated as a casting parameter in the recipe of the dimension and alloy.

Discussion and potential

The motivation for developing the flexible moulds was to reduce the bottom cut-off in the casthouse. The typical cut-off length in operation when using the flexible moulds are 150-200mm. Normally it is not the geometry but surface and metallurgical issues that determines this length. When using conventional moulds the cut off length is typically 300-500mm in casthouses today for 600mm thick slabs to meet customer's demands. The difference in cut-off represents a reduced scrap rate of typically 3-7% when replacing conventional moulds with flexible moulds. The effect is of course dependent on the total casting length.

Assuming 200$/mt in remelt cost a difference of 5% scrap rate corresponds to 10 USD per tonnes aluminium produced.

The above mentioned freedom of choosing different casting speeds for different alloys may give a higher productivity in the casthouse. This because conventional moulds have to be designed to cover all alloys they should cast. The casting speed of the most difficult alloy is then normally chosen as design speed. The fact that the length of the butt swell is approximately proportional to the casting speed is also an argument for keeping the casting speed low when using conventional moulds. The business potential related to increased productivity potential of the casting center is however difficult to estimate since this is dependent on whether the casting is the bottleneck in the casthouse or not. This consideration do also have some impact of the business potential of the reduced bottom cut-off since the re-melting may limit the production since it steals melting capacity that could be used to produce more tonnage. In this case it is not only the re-melt cost, but also the margin that has to be taken into account when estimating the business potential of flexible moulds.

The benefits pointed out by Lawrence listed above stills hold. Especially the reduction in conveyer maintenance as a consequence of flat slabs has been reported as a clear benefit in the casthouse.

Conclusions

A rolling slab casting technology that eliminates the butt swell has been developed and implemented. In this technology the mould shape is gradually changed during the initial stages of casting in such manner that the rolling slabs will be rectangular from start to end of cast. The rolling face mould wall stiffness is designed to create a close to optimal shape when deformed/flexed. The technology has been in regular operation for close to 15 years. The mould lifetime is more than 10 years. The typical reduction in scrap rate due to reduced bottom cut-off is 5%.

Acknowledgement

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The flexible moulds described in this work are now available outside Hydro for the external market, and is marketed by Hycast AS.

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