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PRODUCTION OF HIGH QUALITY THICK CONSTRUCTION PLATE FROM INGOTS AND THICK SLABS[1]

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Abstract
Today's market demand for high quality thick plate for the construction industry requires that the plates are rolled from either traditional ingots or thick cast slabs. Both create significant processing problems and yield loss from the final plate. Normally ingots have variations in both the thickness and width down their length which have to be removed during rolling. Traditionally this was done using a mill and a detached edger in a series of reversing passes. With the advent of high speed long stroke hydraulic gap control cylinders allied to powerful physical modelling, new strategies are available to remove the thickness and width variations. Once these variations are eliminated, the ingot can be processed in the same manner as a thick cast slab. In both cases the yield loss due to poor edge shape is evident and requires addressing during the rolling. This paper explores various plate mill control strategies to minimise the poor edge shape and increase the final yield in producing high quality thick plate.
Keywords: Ingot rolling; Plate mill; Edger; Rolling process models.

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1 INTRODUCTION

This paper describes recent work carried out to optimise the rolling of thick plates from ingots on a two stand plate mill line. Different challenges need to be met in the production of thick plates compared to conventional rolled products. Of prime importance is the control of the final plate geometry in order to maximum the yield and meet the customer requirements. The first part of this paper describes why it is necessary to use ingots in the rolling of heavy plate and the types of ingots that can be used. Following this a description is given of the theoretical way an ingot can be rolled to produce a square plate of uniform thickness and width. Finally the paper describes results from site of applying the theory to production rolling.

2 BACKGROUND

Until the metallurgy is considered, producing thicker plates seems a relatively trivial problem. Generating strength through grain refinement relies on sufficiency of strain, and since the grain size in a transformed phase is strongly dependent on the grain size of its precursor, sufficiency of austenite strain is a prerequisite for a fine-grained final product.(1) Thicker plate production also presents challenges in through-thickness homogeneity. In terms of strain penetration, low aspect ratios (ie roll diameters small relative to stock thickness) depart from plain strain deformation and hence give rise to non-uniformly deformed microstructures.

In order to meet the required mechanical properties for thick plate production, up to a target thickness of 250mm, it is necessary to use an ingot rather than a continuously cast slab. This is because the maximum thickness of the available slabs is about 350mm and as such the reduction that can be taken to get to the final plate thickness is too low to achieve the required grain refinement. The reduction to be taken between the incoming and the outgoing thickness to produce the desired mechanical properties should be at least 3:1 or ideally 4:1.

Typical industries where thick plate components are required range from the construction, shipbuilding, nuclear, hydroelectric power plants and the military. The quantity of thick plate is normally limited to around 2% of a plate mill's production due to the specialist nature of its end use. It is usual that the yield per plate is only around 84% due to the non-homogeneity of the solidified ingot and loss in order to produce a square final product.

Processing of the thick plate starts with the reheating of the ingots in soaking pits.(2) The duration of heating is between 12 and 18 hours depending upon the dimensions of the ingot Primary scale build up is removed using primary hydraulic descaling before rolling. A typical heavy plate mill line capable of rolling thick plates from ingots consists of two stands, one for roughing and one for finishing. The roughing mill is fitted with an attached edger which aids in the control of the final plate geometry and scale removal from the sides of the ingot. Normally the sizing and broadsiding phases are completed on the roughing mill, before the plate is transferred to the finishing mill for the final reductions. One key feature of the plate mill equipment is the high speed long stroke hydraulic gap control cylinders fitted to both the plate mill and the edger. This enables the fast gap changes to be take place which are required in the control of the plate geometry. Following the cooling of the finished plate, a square final product is produced by torch cutting.

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The ingots come in two types:
1. Traditional cast ingots with tapered thickness and width (Figure 1a)
2. Cuboid cast ingots (Figure 1b).

Figure 1. (a) Tapered ingot; (b) Cuboid ingot.

Table 1. Typical sizes of tapered ingots

Width x Thickness [mm] Maximum and minimum dimensions	Length [mm]	Weight [tonnes]
1,800 x 850 1,750 x 795	3,000	30
2,000 x 910 1,940 x 840	3,300	40
2,250 x 950 2,180 x 880	3,600	50
2,450 x 1,000 2,370 x 920	3,800	60

The cuboid ingot is essentially a thick slab and as such can be rolled conventionally on the plate mill. The piece should ideally be processed using a two turn strategy in order to control the plan view shape of the final plate. Using the two turn strategy also allows the edger to be used during both broadside and finishing phases to control the edge overlap that occurs when rolling such large pieces. Figure 2 illustrates the shape defects associated with a typical finished plate, the head, tail and sides being overlapped. When rolling any thick product, the deformation tends to be a surface effect. As a result the top and bottom surfaces of the piece elongate preferentially compared to the centre. This causes the 'folded over' effect that can be seen in Figure 2.

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Figure 2 Final plate shape.

The Tapered ingot however has to be rolled using a specific strategy in order to remove both the thickness and width tapers.

3 ROLLING TAPERED INGOTS

As shown, the traditional cast ingot is tapered in both thickness and width down its length. If this type of ingot is processed like a conventional slab then the width taper will increase as the thickness is reduced. The result is a plate with uniform thickness but with a width that tapers down the length. The taper is significantly more than on the original ingot due to the lateral spread during rolling, see Figure 3.

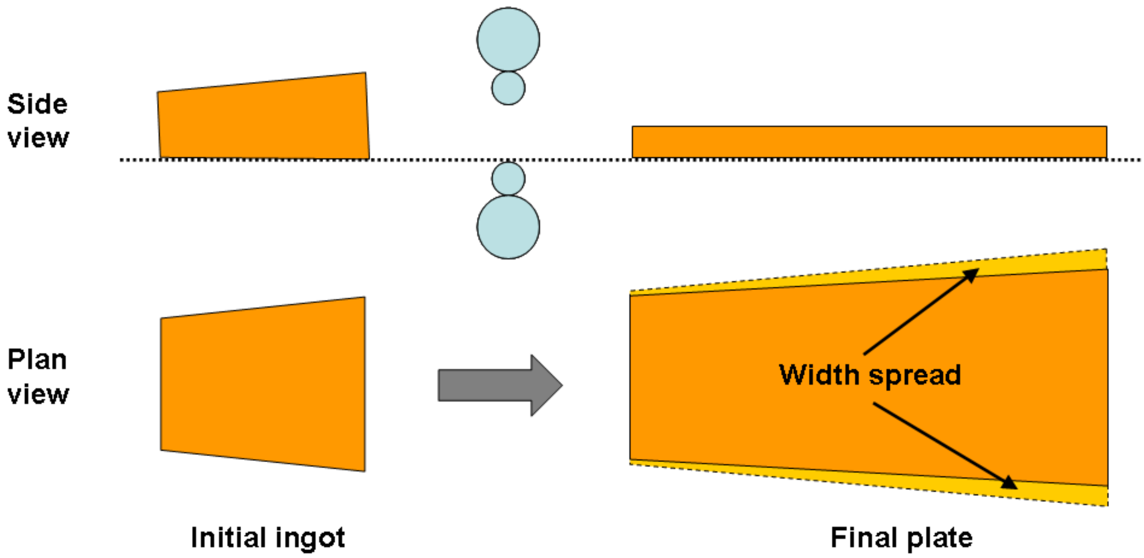

Figure 3 Width Spread of tapered ingot.

In order to reduce the width taper and the lateral spread during rolling a specific ingot control strategy is required. Traditionally this has been done with a detached edger, allowing several edging passes to be carried out without passing the ingot through the roughing mill. Whilst this is clearly possible with the attached edger, by using dummy roughing mill passes whilst edging, it is not an ideal situation.

During ingot sizing there are draft limitations when using an attached edger in conjunction with the roughing mill. The edger efficiency is reduced as the 'dog bone'[3] shape produced during edging spreads back when rolled in the roughing mill.

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This means that the attached edger has to be used on many passes whilst rolling through the roughing mill and consequently the piece elongates on each pass. However the piece length is limited due to the constraints of the turn tables and sideguides to allow a turn to occur after sizing is complete.

In order to avoid the limitations of the attached edger, it was decided to reduce the width taper using a roughing mill strategy, utilising the high speed long stroke roll gap cylinders. The sequence is as follows.

3.1 Detapering

Firstly the roughing mill is used to remove the thickness taper by rolling the unturned ingot. As previously mentioned this causes the width taper to increase due to lateral spread (Figure 3). The thickness taper is removed using a series of 'discontinuous' passes and during each pass the automatic gaugemeter control is disabled so the gap is kept constant. As a result the material is not in contact with the work rolls along the entire length of the pass. Figure 4 illustrates the shape of the ingot during a typical series of detapering pass.

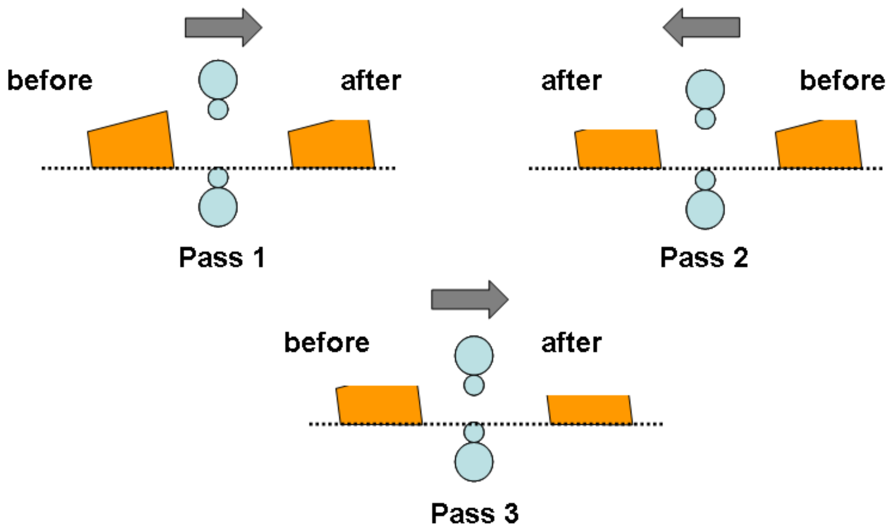

Figure 4 Detapering process.

3.2 Retapering

Once the thickness of the piece is uniform, a pre-calculated thickness taper is re-introduced down the length of the slab in a series of passes. The thinnest section being at the widest part of the slab (Figure 5). The aim of the retapering is to equalize the cross sectional area of the material along its length.

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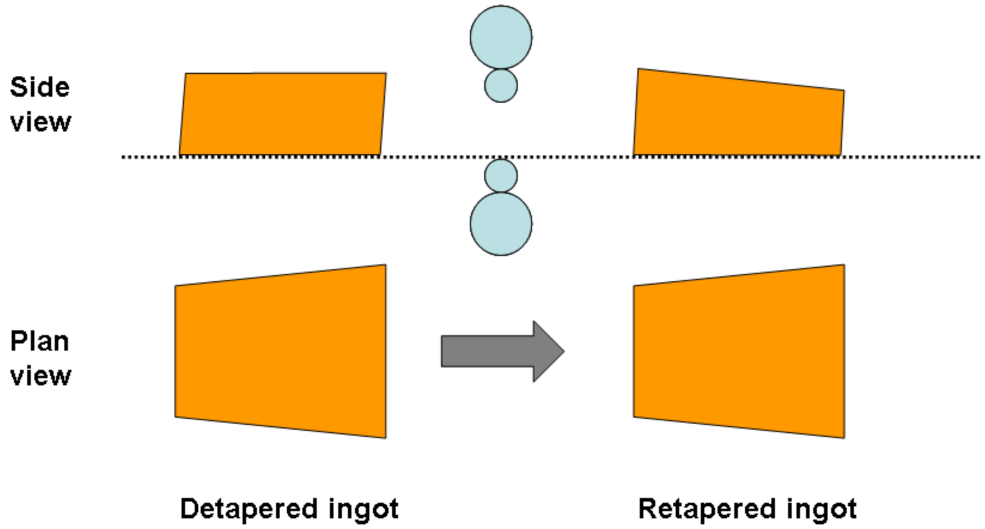

Figure 5. Retapering process.

3.3 Retaper Removal

Following the introduction of this taper, the piece is then turned for the first pass of the broadside phase. The thickness taper now occurs across the width of the ingot and as it is rolled in the roughing mill, the thicker and shorter side will elongate more than the thinner and longer side. This effectively removes the width taper and this process is shown in Figure 6.

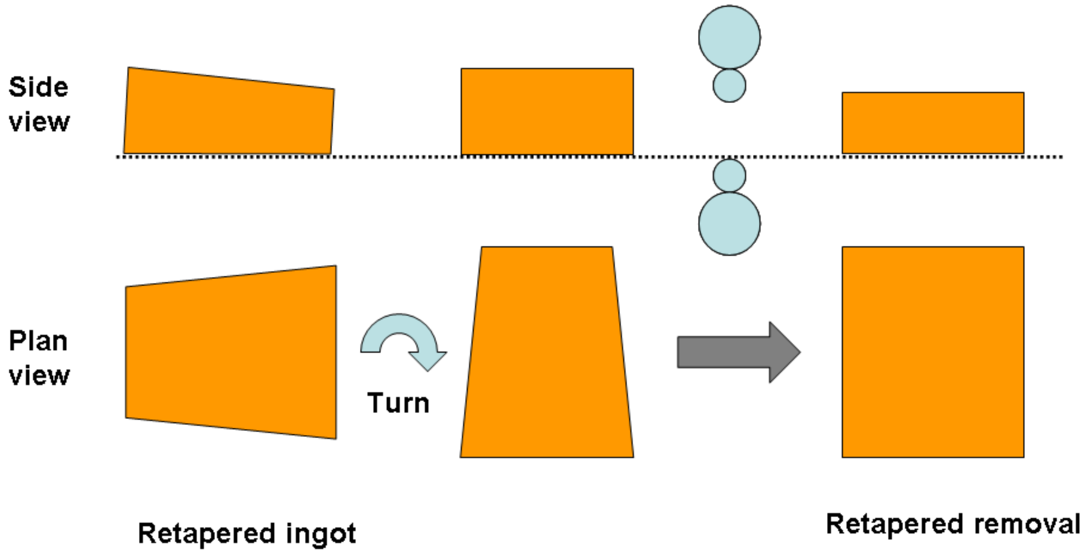

Figure 6. Retaper removal process.

3.4 Normal Rolling

Following the retaper sequence the material has a cubic shape similar to a normal slab. The rolling can then be continued with presizing, broadsiding and finishing, as required. The piece is rolled to the correct width before the final turn which allows a combination of roughing and edging passes to optimise the width of the plate. Once transferred to the finishing mill the final plate thickness is then achieved.

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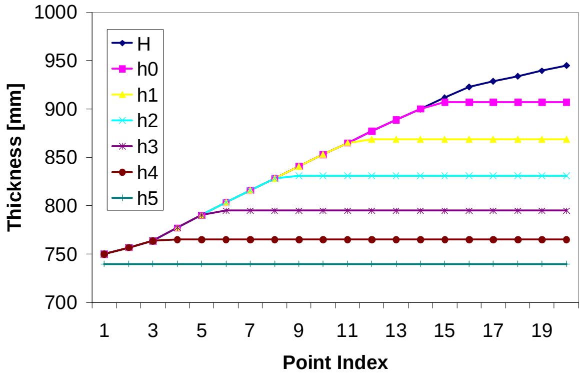
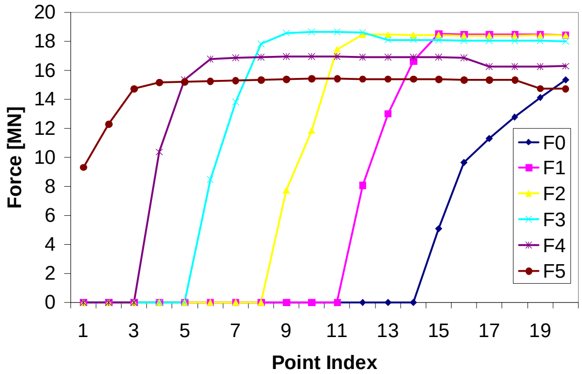
4 PRODUCTION ROLLING

The ingot rolling sequence described in the previous section was put into practice in a production environment. An ingot was used which was tapered from a thickness of 940mm to 750mm and with a width taper of 2,090mm to 1,955mm and a uniform length of 2,835mm. The ingot was first detapered by rolling down to a thickness of 740mm. This was performed in 6 passes, 5 of which had partial contact with the ingot during rolling. Figure 7a shows the initial ingot thickness (H) and exit thickness (h) per pass while the rolling force (F) for each pass is given in Figure 7b. For each pass 20 points are shown along the ingot's length.



(a)



(b)

Figure 7. (a) Thickness per pass during detapering; (b) Force per pass during detapering.

The ingot was then retapered in a series of 6 passes starting with a thickness of 740mm. Following retapering the thickness of the ingot varied from 606mm to 586mm and the corresponding width was 2,005mm to 2,100mm. Figure 8a and Figure 8b show the ingot thickness and the rolling force for each pass during the retapering process

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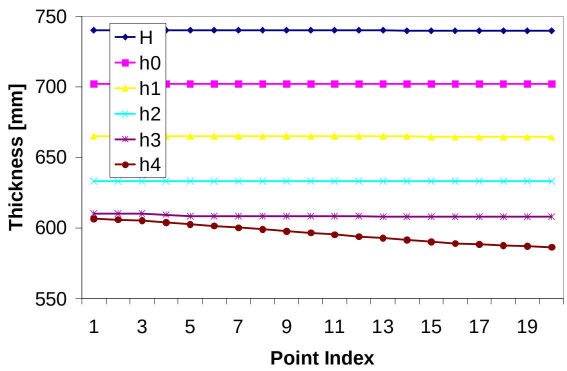

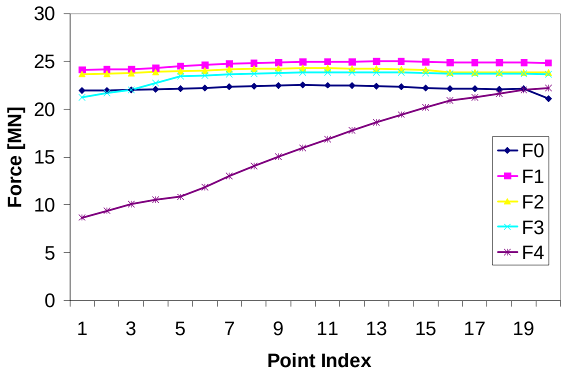

Figure 8. (a) Thickness per pass during retapering; (b) Force per pass during retapering.

Following a turn, the ingot's thickness taper was removed using a broadside pass. The resultant slab now had uniform width as a result of the rolling strategy described above. Broadsiding continued until the desired width of 3,090mm was achieved when the slab was turned again to allow the desired target thickness to be reached. The slab was rolled to a transfer bar thickness of 300mm on the roughing mill and then transferred to the finishing mill where it was further reduced to a final thickness of 200mm.

In the tests the plate was rolled on the roughing mill without using the edger and as a result the un-milled edges were trimmed in the gas cutting bay. In Figure 9 the cast riser is clearly visible on the end of the ingot. This riser can still be seen at the end of the plate on the cooling bed in Figure 10. This area is narrower than the rest of the plate and was trimmed off because the quality of the material is poor due to high slag content from the ingot casting process.

Figure 9 Ingot prior to Rolling.

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Figure 10. Final plate on the cooling bed.

5 CONCLUSIONS

This paper has described a rolling strategy for producing rectangular thick plates from an irregular shaped ingot. The strategy uses a set of mathematical models to calculate the pass schedule at each stage of rolling to optimise the finish plate geometry. Further improvements are under way to fully utilise the edger to achieve better edge shape of the final product.

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