Plate Production Technologies for the 21st Century With a Focus on Plate-Steckel Mills

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Contrary to today's highly automated, efficient and low-cost production of hot-strip, plate mills can be generally characterized as low-volume interrupted processes with poor efficiencies. In this field of rolling, equipment developments and operational efficiency have not kept pace with increased demands in product quality and properties. This now seems to be changing. Plate-Steckel configurations, for example, enable higher production capacities to be achieved in combination with reduced production costs. Layout and technological solutions are described in this paper.

INTRODUCTION

In order to consider current and future trends in plate production it is necessary to first review the background of current technologies and also to consider advances in similar technologies, such as the rolling of strip products.

Since the early development of the conventional hot-strip mill for the rolling of strip products in the late 1930s and 1940s, there have been significant advances in all aspects of strip rolling. Tandem finishing trains have expanded to six and even seven consecutive stands, preceded by several roughing stands. However, these mills are characterised by high investment costs; high operating costs and, with relatively low specific coil weights, have a high cost per tonne to produce.

Subsequent "generation II mills" employed a reversing rougher in combination with a second non-reversing rougher. This provided some improvement with respect to lower investment costs and potentially lower operating costs.

In the late 1960s the Japanese developed the 'jumbo' hot-strip mills to produce coils with specific weights of up to 36 kg/mm. However, these mills were never able to reach their full potential due to the recession resulting from the oil crisis in the early 1970s. Since that time virtually all hot-strip mils aim at 18–24 kg/mm as a viable design limit (1).

After the oil crisis in 1973 several technologies focusing on energy saving emerged – the STELCO coilbox and the ENCOPANEL heat-retention system are two examples.

Simultaneously with improved rolling equipment and increased coil weights, considerable advances in continuous casting technologies were being made.

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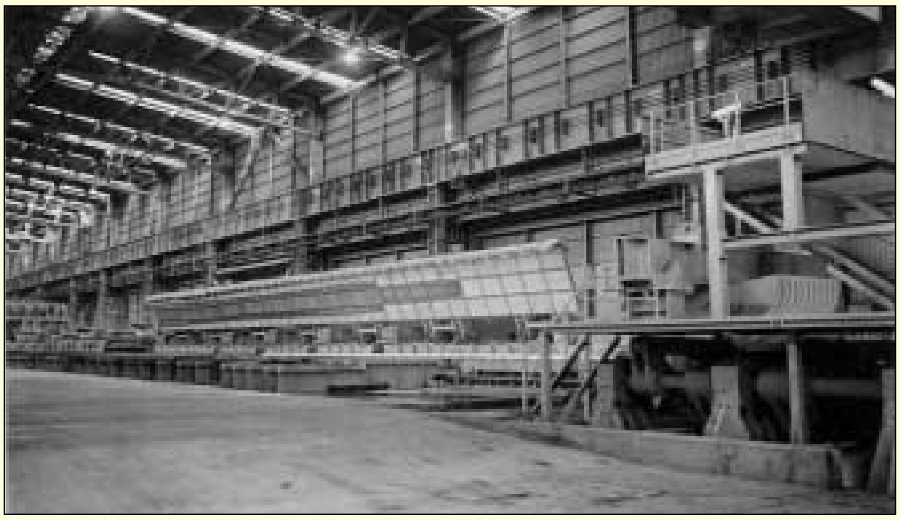

Figure 1: VAI ENCOPANEL System Installed at China Steel's No. 2 Mill.

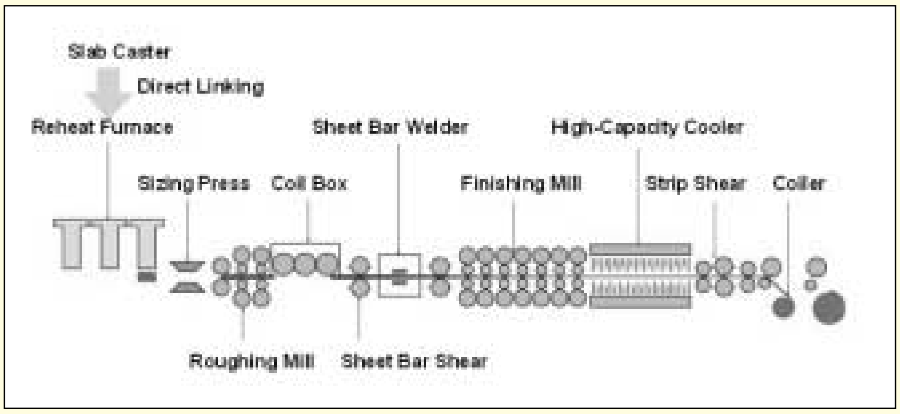

Figure 2: Schematic Diagram of the Endless Strip-Rolling Plant .

Slab casting, for example, progressed from cold-charged ingots to direct hot-connected continuously cast slabs. The emerging casting technology was also soon able to accommodate the slab widths required for the production of hot-rolled coil products.

Once hot charging had been established as an efficient and reliable process route, developments towards linked production processes proceeded, as exemplified by semi-endless and endless strip-rolling plants.

Linked production processes clearly have the lowest operating costs, the shortest throughput times and reduced lead times for orders (2).

Developments in the production of hot-rolled strip products have been discussed thus far, but what about hot-rolled plate production? This is the topic of the next section.

CONVENTIONAL PLATE MILLS

Production units for producing rolled plate have been in existence longer than the hot-strip mill, but superficially, there seems to be little difference between a plate mill of today and those of several generations ago.
Plate mills evolved from the early universal mill, and then advanced from the two-high single-stand to three- and then four-high single-stand configurations. Air-cooling and plate trimming units were then installed after the rolling stand. Offline heat treatment was required to obtain the required plate properties from the "as-rolled" plate.
Specific equipment developments focused mainly on the mill stand itself, leading to improved rolling load capability, higher slab-weight charging and to the production of multiple plates from a single slab rather than one plate from one slab. Developments in instrumentation and automation have improved dimensional tolerances and product yield. However, the overall process flow remained basically unchanged – plate production was still an interrupted, energy intensive process.
The addition of high-intensity water-cooling after the mill exit was introduced as an effort to conserve energy and to acquire certain mechanical properties in the rolled plate. This reduced (but not eliminated) the need for offline heat treatment. More recently, an improved understanding of the microstructural behaviour of steel during deformation led to the introduction of thermo-mechanical controlled rolling (TMCR). This further reduced the need for offline heat treatment by controlling the deformation temperatures throughout the rolling schedule, utilising the heat in the rolled stock. Combining this with the controlled cooling system and improved alloying practices enabled high-quality, high-specification plates to be produced directly off the mill line. This clearly had a major impact on energy consumption during the process and lead to significant reductions in operating costs.
A disadvantage of the TMCR practice is a reduced mill utilisation, but this can be substantially remedied by the practice of "interleaving". As higher specification plates are produced, the TMCR procedure requires that the gauge at which the product is 'held' during the rolling schedule be increased. This results in longer holding times to allow the correct temperature to be reached. This time can be used to start the initial rolling phase of a subsequent plate, during which time the first plate is held offline. In this way it is possible to interleave several plates and thereby improve the overall mill utilisation.
Despite the developments outlined abo-

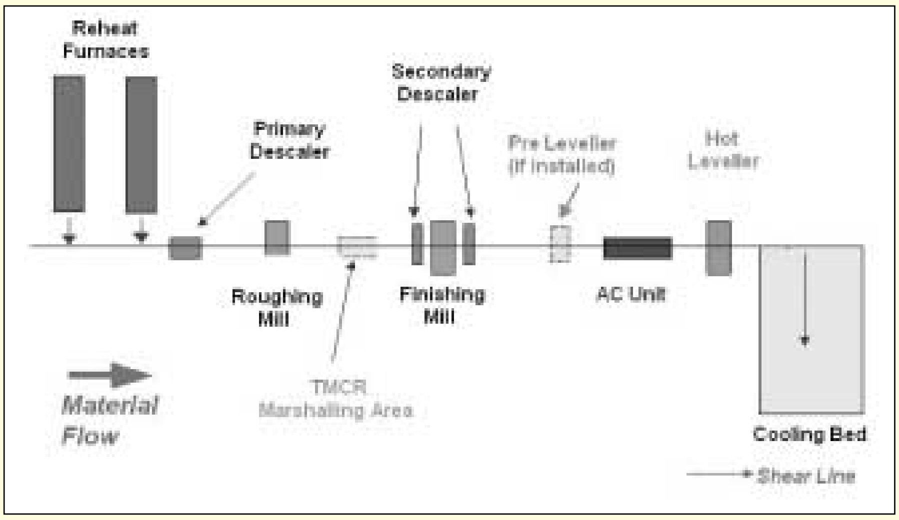

Figure 3: Typical Layout of a Conventional Plate Mill.

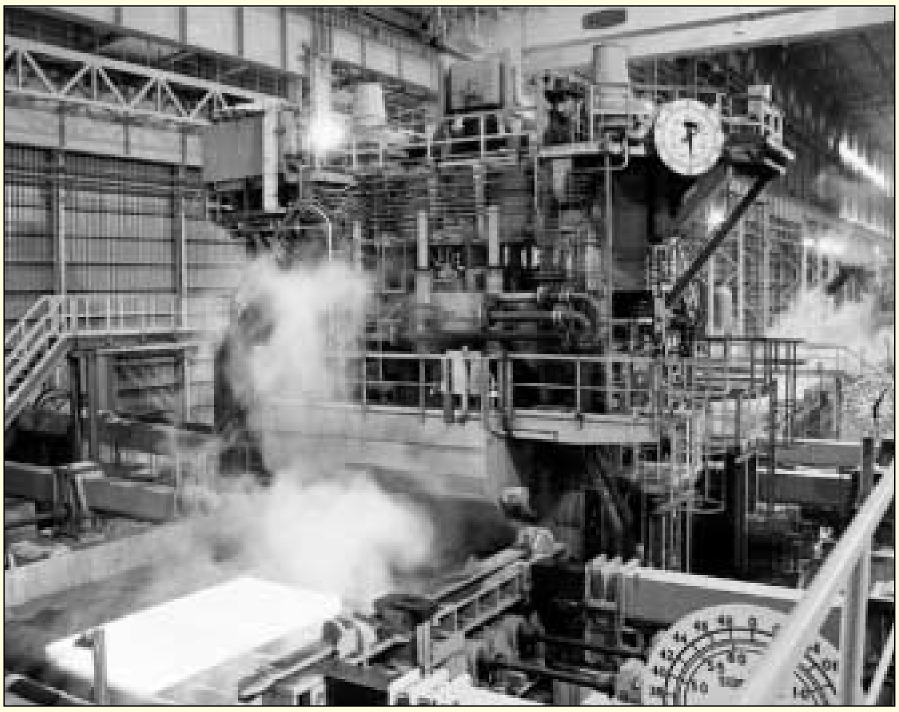

Figure 4: No. 2 Plate Mill, Dongkuk, Republic of Korea.

Figure 5: VAI Steckel Coiler Furnace Developments.

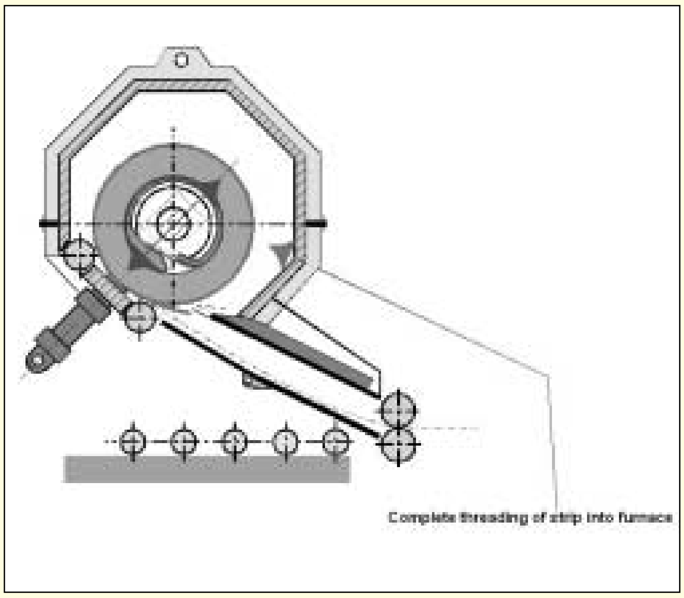

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Figure 6: MULPIC System at the Dillingen Plate Mill.

ve, conventional plate mills have made relatively little progress with respect to the throughput of the process route as a whole, when compared to the hot-strip mill. Although there are some technical restrictions to doing so, little use has been made of direct hot-charging techniques. The piece weights remain relatively low and the amount of work in progress is high.
A typical process route for a modern plate mill would consist of a large slab yard with slabs fed into a reheat furnace at ambient temperature and then heated to rolling temperature. This is followed by the actual rolling process itself (possibly with some form of TMCR practice), rapid cooling employing a high-intensity cooling system, hot levelling, further cooling across cooling banks, followed by shearline processing and possibly some offline heat treatment processing. Not only is this a very energy-intensive procedure, it can also be labour intensive – specifically in the shearline area.

EFFECT OF CONTINUOUS CASTING DEVELOPMENTS ON PLATE MILLS

VAI have been at the forefront of developments in continuous casting since the introduction of this technology in the steel industry. Examples include SMART, segments for soft reduction together with ASTC (automatic strand-taper control) for regulating the taper control and final strand thickness. This has led to significant improvements in internal slab quality. Reduced slab thicknesses decrease the required deformation work in the rolling process with a significant reduction in operating costs. Thinner slabs also mean a smaller casting-bow radius which reduces investment costs(3). The use of computational fluid dynamics (CFD) in the development of an optimized design for the submerged entry nozzle (SEN) provides better control of the steel flow in the mould, enabling wider slabs to be produced. Additionally, VAI's DynaFlex technology for precise control of mould oscillation, together with the MoldExpert optimisation system, has considerably improved the surface quality of slabs.
These developments in casting technology have given rise to major changes in the rolling process. Increased slab widths reduce the need for slab turning in the plate mill and improved internal quality means a reduced need for slab consolidation (compacting) to eliminate internal void structures. Longer slabs with higher piece weights can be cast and rolled. Temperature differences along the product length (temperature rundown) and the logistics of handling longer slab lengths mean that changes in the conventional plate mill design are necessary in order to fully utilize the improvement potential in plate production.

PLATE-STECKEL MILLS

The application of Steckel-mill technology (a development from strip production aiming at providing a low-cost alternative to the tandem strip mill) for the production of plates using longer slabs has enabled the problems associated with temperature losses during rolling to be overcome. VAI has considerable experience in the design of Steckel furnaces and has continued to improve this technology with solutions for

- Improved thread guidance to reduce cobbles
- Complete coiling of the product to reduce head- and tail-temperature losses
- Precise product steering to improve coiling quality
- Increased coiling thicknesses
- Reduced coil eccentricity
- Increased coiling weights.

Combining state-of-the-art casting technologies and Steckel rolling with further improvements in the alloying strategy and TMCR techniques – including cooling systems such as MULPIC or ADCO – provides the potential for a plant configuration which benefits from high utilisation and low operating costs per ton of product.
The advent of the Plate-Steckel mill in the mid-1990s unites all of these improvements and, together with the installation of a downcoiler, provide a highly flexible and cost-efficient process route. Depending on the steel grade, continuously cast slabs can be hot charged into the reheat furnace. These slabs can be as much as 65 tonnes in weight – a significant increase compared with conventional slabs which are typically below 15 tonnes. The slab is rolled out with a single stand until the gauge is sufficient for Steckel rolling (approximately 25 mm). The Steckel furnaces then accumulate the increasing length and maintain the temperature along the piece length. Plates exceeding approximately 25 mm gauge are rolled with flat passes only. Once the final gauge is reached the developed length (which, dependent on gauge, can be several hundred metres in length) is either divided into discrete plate lengths on a flying shear, or coiled on the downcoiler. A cooling system is used for further development of mechanical properties as required. Discrete plates can then be processed through a hot preleveller before transfer onto a cooling bank. The plates are then trimmed and inspected on a shearline in preparation for shipping.
As with all new configurations, there are some technical challenges to be overcome. Micro-alloyed products are sensitive to hot charging. The requirement to ensure that the precipitates are in solution, particularly those of niobium, can preclude hot charging for some grades. The increased width obviously has an effect on machine design, such as the Steckel coiler furnaces and the flying crop shear. Downstream of the mill the rolled length must be divided into discrete lengths at a speed to match the last pass on the mill. Immediately following the crop shear it is desirable to maintain a constant speed in the water-cooling section. A gap must then be created between the plates to avoid clashes at the hot leveller or cooling bank entry.
All of these factors place additional demands on the process equipment, pushing conventional plate-mills to the limit and beyond – this is where the expertise of a specialised equipment supplier, such as VAI, becomes invaluable.

THE BUSINESS ASSET

Development of equipment and plant configurations are only beneficial if they show suitable margins on operating costs

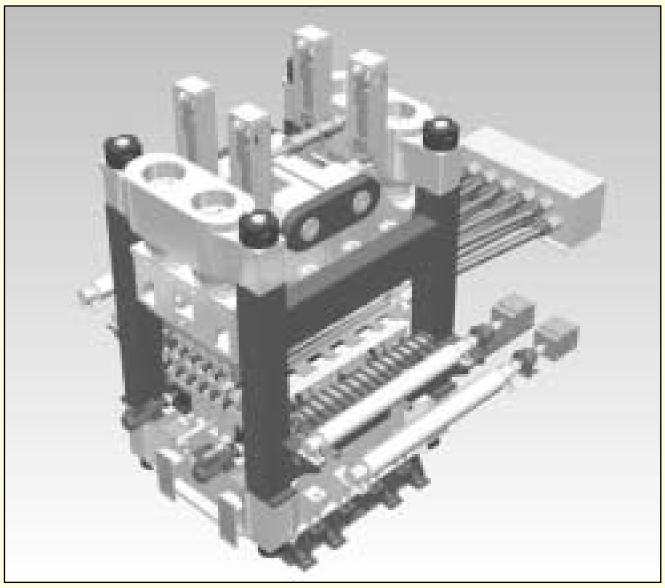

Figure 7: Leveller.

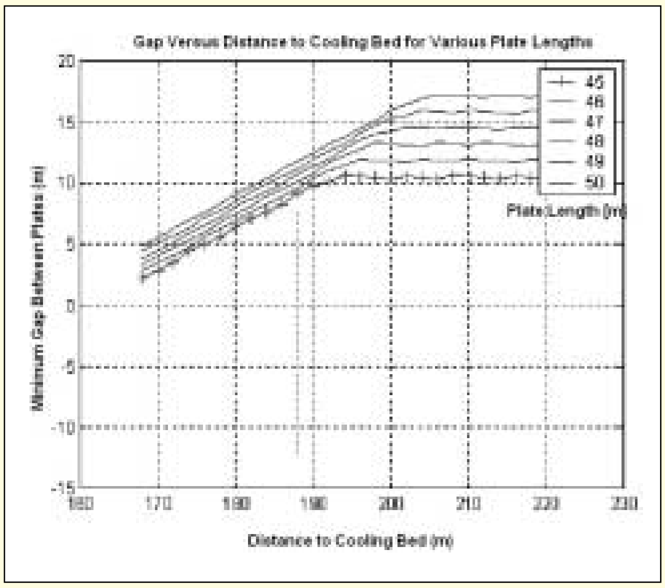

Figure 8: VAI Simulation Model Output.

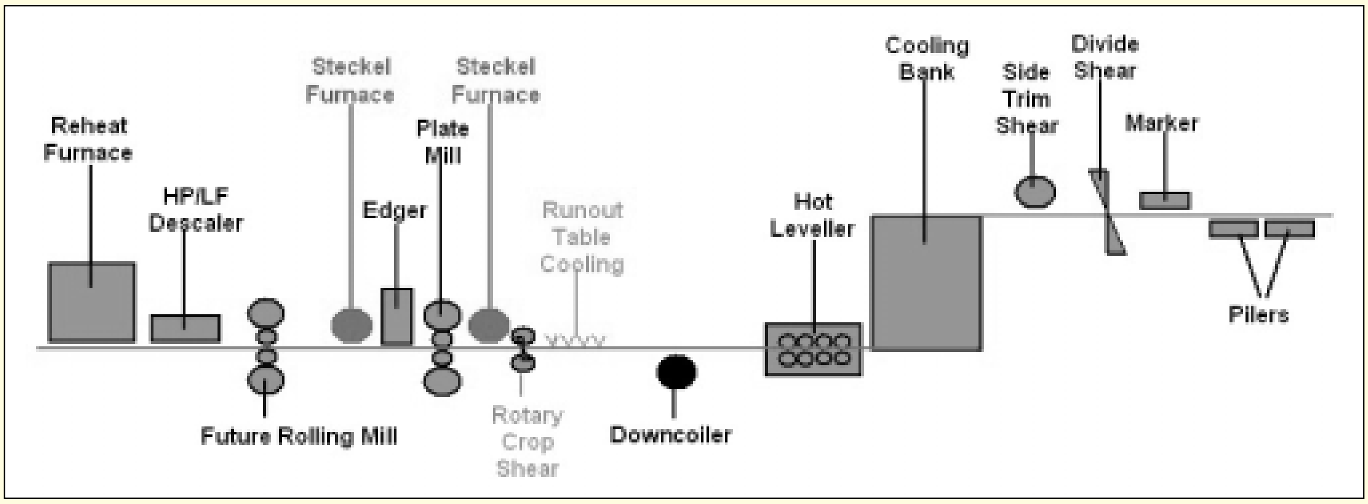

Figure 9: Layout of a Compact Plate-Steckel Mill.

to provide a return on capital investment. There are two basic approaches to achieving successful margins from a plate mill plant, each dependant on the added value of the product produced; low added value implies large volumes of product at low cost per tonne; higher added value products can withstand lower volumes with increased cost per tonne.

Typical plate mill tonnages are in the order of 0.5–0.8 million t/a for a single stand. Mills with a reversing rougher can increase this figure to 1.2–1.5 million t/a with a few mills achieving higher rates than this.

The Plate-Steckel layout enables approximately 1.0–1.2 million t/a to be produced from a single-stand configuration, with the potential to increase this to match, or even exceed, the world's highest capacity in conventional plate mills by the addition of a roughing stand.

The Plate-Steckel configuration enables the volume of the conventional plate mill to be increased – with a simultaneous reduction in re-heating and rolling costs – by utilising hot charging into the re-heat furnace and eliminating the need for cross-rolling. The practice of dividing very long rolled lengths into plates rather than the conventional process of cutting short slabs prior to rolling, provides significant yield increases and improved product consistency. Currently, other aspects of the process are comparable to conventional configurations on an operating cost basis.

Although the Plate-Steckel configuration is, to date, a combination of existing technologies which have been utilised in a different way – albeit with increased machine parameters – it clearly has the ability to provide relatively high production volumes at a lower cost per tonne, producing a product which is beyond the width capability of a hot-strip mill and uneconomical for a wider conventional plate mill to produce. It also has the flexibility to produce both wide coil and discrete plate products. This provides the operator with the ability to target a larger market whilst reducing lead times and stock inventories.

To date three mills of this type are in operation in North America. Nanjing Iron & Steel Co. (NISCO) is the first company outside the USA to adopt this modern and efficient plate production technology to satisfy increasing plate demands in the People's Republic of China. VAI was selected as the plant builder for the NISCO project, which features widest slab caster in the world (3250 mm) in addition to the Plate-Steckel mill and finishing lines. Two other similar configurations are also to be built in China.

FUTURE DEVELOPMENTS

The past and current status of plate production has been outlined above. There is still, of course, a market for very wide plates and, for the time being, this will remain the domain of the conventional wide plate mill. But what of the future?

In its current form the Plate-Steckel mill strives to provide a return based on high

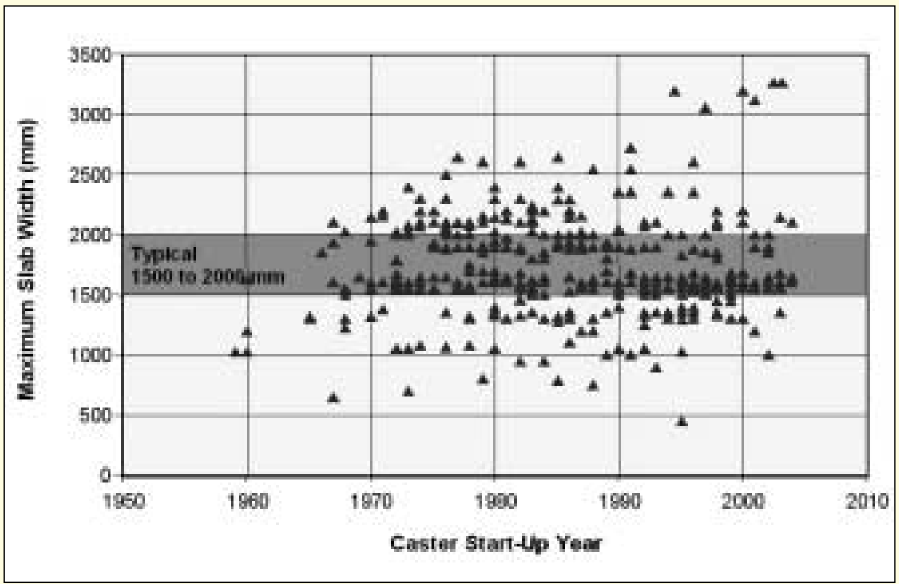

Figure 10: Trends of Increased Plate Mill Products Based on Cast Slab Widths.

volume, low-cost production. But with increasingly sophisticated end use demands perhaps there is a market niche for a plant that predominantly produces a specialist range of high added-value products. It could also provide a degree of production flexibility to complement the specialised products niche.

There are, however, certain limitations that must be considered. One area which is witnessing a significant increase in end user demand is that of pipeline steels. End users are demanding lighter weight pipe stock to reduce installation costs, but this down-gauging results in increased mechanical properties in terms of toughness and yield strength.

Conventional plate mills produce these products from a thick slab, which undergoes sufficient reduction to work the micro-structure and produce the required properties. However, the Plate-Steckel mill makes use of thinner slabs (typically 150 mm) to reduce the deformation energy required. This is certainly acceptable for producing the high volume commodity products, but is perhaps debatable as an optimal route for producing the highest specification pipeline products. Investigations are currently underway at VAI to establish an optimal slab thickness for a Plate-Steckel configuration.

Additionally, the elimination of cross rolling will have an influence on the isotropy and texture of the steel microstructure. It must still be determined to which extent this affects the service performance of the final products.

Assuming that a thicker slab would yield improved properties, the question is whether a Plate-Steckel route could still process a thicker slab in an economically viable manner. The caster would need to cast wide slabs at the thicker gauge. If the gauge is increased significantly the caster radius must be increased and, to maintain productivity, the caster run-out area must be lengthened to maintain a high casting speed. This all increases the investment costs for the caster.

However, the slab weight would be maintained by use of a shorter slab, potentially allowing a smaller re-heat furnace. This slab would then be rolled in the same way as in the current Plate-Steckel configuration so the rolling costs would be comparable to that of a thinner, longer slab. From this point on the processes would be identical. Overall, it is reasonable to assume that, despite a rise in initial investment costs for the caster, the added value for the higher specification product produced at a similar cost per tonne would enable a good return from the investment.

Further flexibility in production could be gained with the addition of a roughing stand. This can be used for the initial slab breakdown to either a transfer bar thickness or to an intermediate hold thickness for thermo-mechanically controlled rolling. This would then be transferred to the Plate-Steckel mill stand for final rolling. Once the finishing stand commences with Steckel rolling, a subsequent slab can be simultaneously processed in the roughing mill, thereby improving mill utilisation.

In this way, the current Plate-Steckel mill configuration can be improved to provide a high-utilisation, high value-added production unit, which, in this day of leaner business strategies and improved cost efficiencies, has the potential to provide a viable alternative to the medium-width plate mill.

CONCLUSION

The advent of the Plate-Steckel mill configuration represents a significant step for the production of plates. Currently, this mill configuration focuses on the production of medium-width plates, but this is mainly due to limitations in casting widths. Figure 10 shows how casting widths have increased (the advent of wide casters for Plate-Steckel mills can clearly be seen in the mid-1990s), and, if this trend were to continue, even the wide conventional plate mills would see strong competition from the more cost-effective Plate-Steckel route.

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