

Thin-slab casting – New possibilities

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Abstract. Changes in the IT industry are known to proceed at a scorching pace. In sharp contrast, the rate of development in the steel industry is generally slow. Nonetheless, the impact of recent technical developments on the steel industry has been quite significant. The production chain from iron ore to final rolled steel is a long one and the shortening of this length has long been the endeavour of scientists and engineers. The initial development came in the form of speeding up the process of steelmaking by reducing the slow open-hearth process (8 h tap-to-tap time) with the 45 min tap-to-tap time of the Basic Oxygen Furnace (BOF) process. Significant developments thereafter have been in the process of continuous production of billets and blooms from liquid steel thereby doing away with the large blooming mills needed for rolling ingots.

For a fairly long time after the stabilisation of continuous casting, hot rolling involved reheating thick (200–250 mm) slabs and reducing them in a hot-strip mill. The advent of thin-slab casters has made even these large hot-strip mills redundant. The new installations produce thin slabs (50–70 mm) that are directly rolled into strips without the need of an intermediate furnace for raising the stock temperature; the so-called tunnel furnace prior to the rolling stands serving only to equalise stock temperatures. Additionally, what started as a step for reducing investment in hot rolling has, in fact, given new opportunity for direct hot rolling of thicknesses that were, for long, considered to be feasible only through the cold-rolling route.

This article discusses the slow but steady encroachment of hot-rolled sheets into the domain of strip thicknesses hitherto produced by cold rolling and tries to show how the development of thin-slab casters has allowed this process to be accelerated. A techno-economic analysis of thin-slab casting has been presented along with the benefits that arise when a thin-slab caster is linked to the blast furnace and basic oxygen route of steelmaking.

Keywords. Thin-slab casting; hot rolling; compact strip processing.

1. Introduction

Steel, apart from being fully recyclable, is an attractive material for construction of buildings, bridges, auto-bodies and a plethora of other things needed for daily use. This is in large measure true because the alloy, amongst all others, is the most cost-competitive,

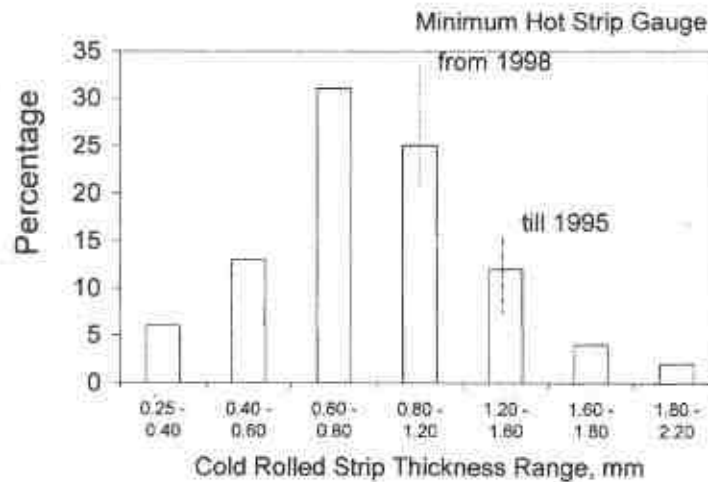


Figure 1. Typical distribution of strip thickness from a hot-strip mill until 1995.

though the metallurgists would rather believe that it is on account of its vast range of properties that can be obtained by heat treatment! The sheets of steel that are used for construction purposes are typically obtained by rolling slabs produced through continuous casting. For a very long time it was a strongly held belief that the lowest thickness that could be produced economically through the hot-rolled route was around 2.0 mm. For reasons of the dimensional tolerances required, it was felt that for lower strip thicknesses only cold rolling was viable. As can be seen from figure 1, hot-rolled strips with thickness lower than 2 mm, TGHR (thin-gauge hot-rolled) strips, constituted as little as 10.6% of the total production of hot-rolled strips till 1995; the thickness lower than 1.2 mm being only 0.3% (Anon 1991).

The frequency distribution for a representative product mix of a typical cold-rolling mill is shown in figure 2 (Bald *et al* 1999). It is clear from the figure that almost 60% of cold-

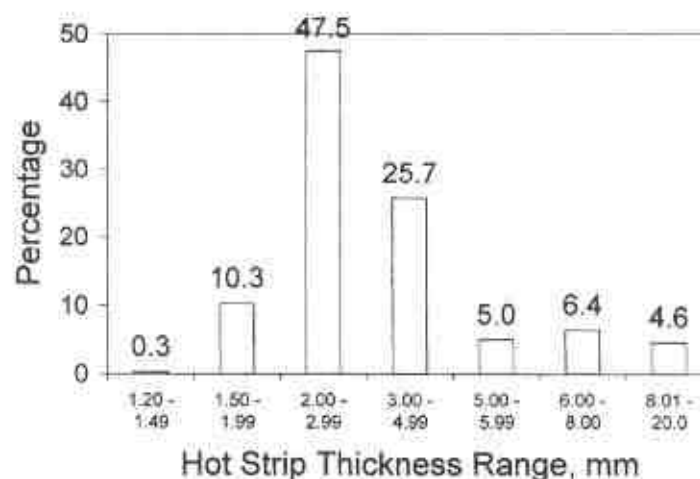


Figure 2. Typical product mix of a cold strip mill showing encroachment from ultra-thin hot strip.

Table 1. Cost of production of 1-mm strip through hot rolling alone and hot + cold rolling.

Direct hot rolling from 2mm to 1mm		Cold rolling from 2mm to 1mm	
Processing stage	Cost of processing US \$/tonne	Processing stage	Cost of processing US \$/tonne
Additional hot rolling	16	Pickling	18
Skin passing or tension levelling	6	Cold rolling	20
Pickling	19	Batch annealing	13
		Skin passing	10
Total	41	Total	61

rolled strips lie within the thickness range of 0.6 to 1.2 mm. This market segment is, as of now, covered by cold-rolled steel but is increasingly under pressure from hot-rolled strips. While five years ago, the minimum strip thickness for TGHR was 1.5 mm and 2.0 mm for low carbon and high carbon strips respectively, significant progress in compact strip processing (CSP mills) is continuously pushing these limits further down the thickness ladder. At present, the minimum attainable thickness for profitably produced hot strips is 0.91 mm (CSP plant at Hylsa, Mexico), and Thyssen Krupp Stahl, Germany intend producing 0.75–0.9 mm hot-rolled strips in their recently commissioned CSP.

It is worthwhile comparing the operating cost of producing 1 mm strips by direct hot rolling and by the conventional cold-rolling route. Starting with a 2-mm hot rolled strip, the breakup of the operating cost in the two cases is shown in table 1 (Bald *et al* 1999). It is evident that the cost is in favour of the direct hot-rolled process by nearly \$ 20/tonne in spite of the extra cost of \$ 15/tonne incurred in the hot-rolling option on account of work roll wear and yield losses. A factor whose economic impact is significant, but which is not considered in these calculations, is the extra inventory cost of holding 2-mm hot-rolled (HR) strips for subsequent cold rolling—a cost not incurred in the case of ultra-thin hot-rolling of strips.

The process of hot rolling of slabs has undergone several dramatic changes. The conventional process involved casting of 200–250 mm slabs and subsequent reheating and rolling in a hot-strip mill. Almost all new installations now link casting and rolling. Slabs of 50–75 mm are now immediately hot-charged and rolled in one continuous process of compact strip processing. The advantages from this route are not merely in the process of producing thin strips but also in direct hot rolling of sizes less than 2 mm that tread into the regime of cold rolling. Several such configurations for the production of thin slabs are now commercially successful, but the CSP system of Schloemann–Demag is the most popular. Radically new opportunities have arisen from this development.

2. The hot-rolled strip scenario at Tata Steel

The proportion of steel continuously cast at Tata Steel has increased from the initial figure of 20–30% in the early Eighties to over 95% in the late Nineties. As part of the fourth phase of modernisation, Tata Steel installed a one-million tonne hot-strip mill capable of rolling slabs of widths 860 mm to 1550 mm and thicknesses 12.6 to 1.6 mm. The capacity of the mill was rapidly doubled by the year 1998 and a sixth strand was installed to increase the mill's capability to roll down to a thickness of 1.2 mm. The thickness range of hot-rolled coils is shown in figure 3. At the time when investments on the caster and the

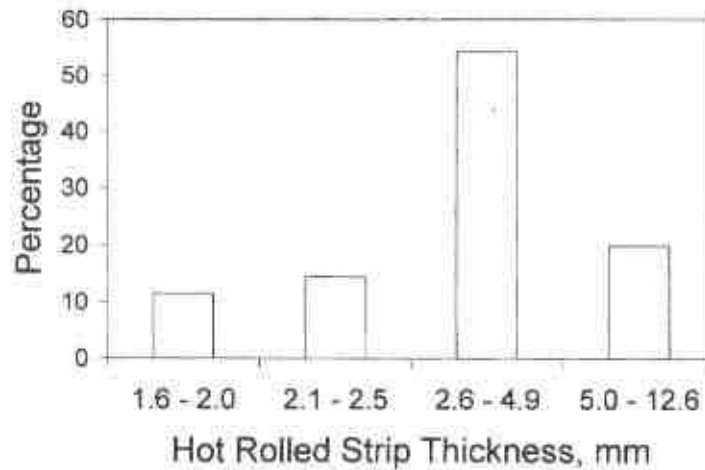


Figure 3. Product mix for Tata Steel's hot-strip mill.

associated rolling facilities were considered, thin slab casting was in a very nascent stage and Tata Steel chose the conventional casting and rolling route. This route now certainly has a disadvantage with respect to thin-slab casting in the area of commercial grades; the balance changing only for grades used for very high-end applications.

In the middle of 2000, Tata Steel commissioned a 1.2 million tpa (tpa-tonnes per annum) state-of-the-art cold-rolling mill. A large part of the feed to this cold-rolling mill is hot-rolled coils from the hot-strip mill. The distribution of the thicknesses of the cold-rolled coils is as shown in figure 4. A comparison of the thicknesses from the two mills shows that an overlap exists for the thickness range 1.2 to 2.0 mm. As has been mentioned earlier, processing of hot-rolled coils through the cold-rolling mill adds at least \$20/tonne to its cost. Under the circumstances, it would be worthwhile to produce the same thicknesses through the cold-rolled route only if the aesthetics of the strip surface or other attributes

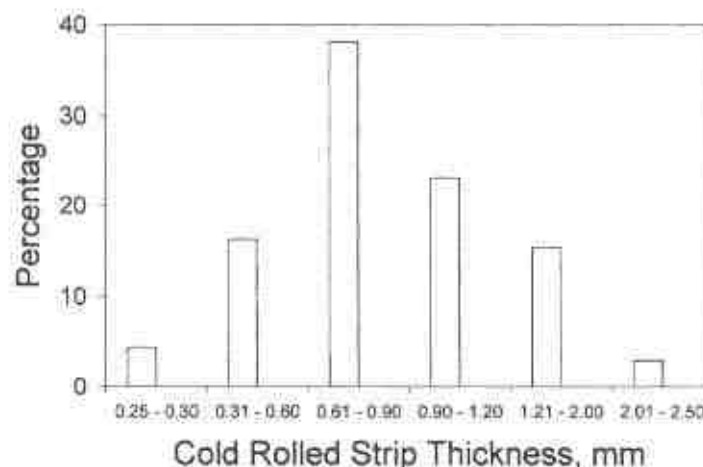


Figure 4. Proposed product mix for Tata Steel's cold-rolling mill.

justify the extra expenditure. Fortunately, such a niche market exists in the white goods and automobile external parts sector.

It is interesting to note that capital intensive investments in conventional hot-rolling mills can be economically viable by producing grades that cannot, as yet, be obtained from the thin-slab caster route, on the one hand, and by encroaching on strip thicknesses that have been so far the exclusive purview of cold rolling. While the latter strategy, viz. lower thickness through hot rolling, is likely to challenge the cold rollers, it is extremely doubtful if the hot-rolled thin product would be from the conventional hot-rolled route! Thus conventional hot-strip mills are in the unenviable position of being hemmed in from both sides: A fresh young challenger on the hot-rolled side and a well-established old-timer—the cold-rolling mill—on the other. Thus, it is perhaps not premature to "crystal gaze" that the last conventional hot-strip mill may already have been built!

3. Enter thin-slab casters

Certain developments in the area of steelmaking and casting appear to be a direct result of steelmakers' efforts to reduce complexity. Thus, the normal process of teeming liquid steel into cast iron moulds, waiting for the steel to solidify, stripping the ingot moulds at the stripper yard, placing the ingots in the reheating furnace and subsequent rolling through a blooming and billet mill was shortened considerably by the evolution of the process of continuous casting. Liquid steel, from about the Fifties, can be poured into oscillating water-cooled copper moulds in the desired shape needed for final rolling. The long route from ingotmaking to billet rolling stood truncated in complexity though not in end-quality.

The turn of the last but one decade (1st July 1989) has seen the commissioning of a new technology—in Nucor Steel, Crawfordsville, USA—which by directly linking the casting process to rolling has brought about further improvements in yield, saving of energy and reduction in product cost. This epoch-making technology is called thin-slab casting (TSC).

The main manufacturers of thin-slab casting machines are the following.

- *SMS* (Schloemann Demag) with the Compact Strip Process (CSP).
- *MDH* (Mannesmann Demag Huettentechnik) with the In-line Strip Process (ISP).
- *DANIELI* with the Flexible Thin Slab Caster (FTSC).
- *VAI* (Voest-Alpine Industrieanlageneinbau) with Continuous Thin Slab Casting and Rolling Technology (CONROLL).
- *SMI* (Sumitomo Metals Industries) with High-Speed Medium Thick Slab Caster.

By far the most numerous installations are from SMS and the main features of this machine are discussed.

3.1 *The compact strip process from SMS*

In this process of thin-slab casting, the casting machine is of the vertical type with a straightening withdrawal unit, followed by a pendulum shear and a roller hearth furnace. This, in turn, is followed by a finishing mill (4–5 stands), laminar cooling bed and a coiler as shown in figure 5.

3.1a The casting mould: The chromium–zirconium–copper mould is the heart of a CSP casting machine and is 1100 mm long. Developed and patented by SMS, the design seeks

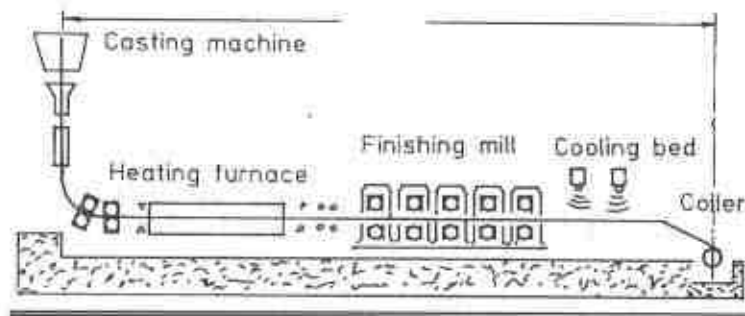


Figure 5. Layout of a CSP unit.

to overcome a universal problem of thin-slab casting – feeding liquid steel through a SEN (submerged entry nozzle) into the confines of a narrow mould cavity – by flaring the inlet of the mould in the form of a funnel. This funnel terminates approximately in the middle of the mould length beyond which, the broad side walls of the mould are parallel and are separated by a distance of 50–70 mm, which is the exit thickness of the slabs. The sides of the mould wall are tapered to compensate for the shrinkage of the solidifying steel (as in a conventional slab-caster mould). A schematic view of the CSP mould is shown in figure 6. The mould is oscillated at 1 Hz per m/min of casting speed with a stroke length of 6 mm which translates into a negative strip time of 0.031 s at a casting speed of 5 m/min.

3.1b The sub-mould region: On account of the rapid solidification of the thin slab, it is necessary to provide strand guidance over a length of around 4.5–5.0 m only, even at a high casting speed of 6 m/min. This compares very favourably with the 25 to 35 m of guidance needed in conventional slab casters. The reduced length of the guide in the case of

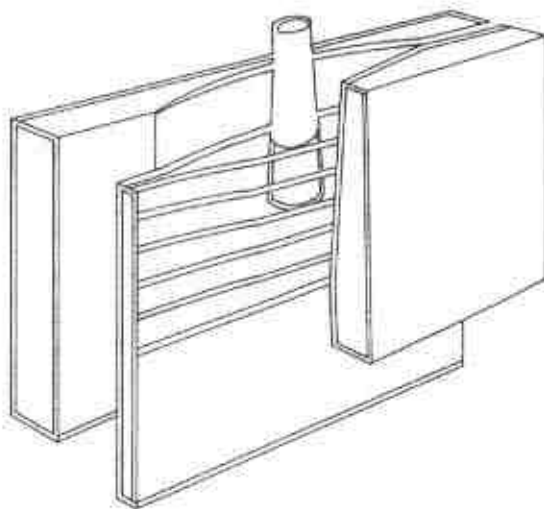


Figure 6. The funnel shaped-CSP mould.

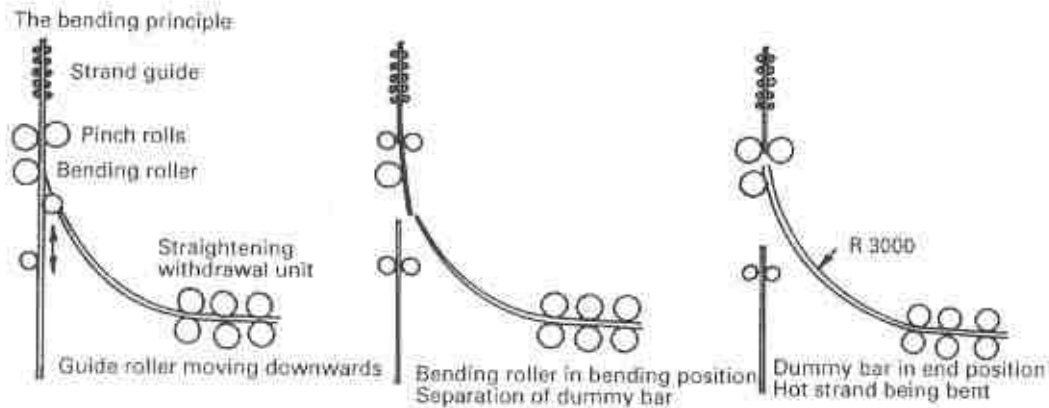


Figure 7. Dummy bar and bending arrangement for the CSP machine.

these thin-slab casters translates into just two segments which can be changed individually, or as one unit, along with the mould. A set of bending rollers below the strand guide separates the dummy bar from the hot strand and then bends it in a radius of 3 m, so that it enters the straightening/withdrawal unit in a horizontal direction as shown in figure 7. A pendulum shear subsequently divides the strand into rollable lengths of around 40 m.

3.1c The roller hearth furnace: The caster and the rolling mill are connected together by a roller hearth furnace. Upon separation at the caster shear, the individual slabs are accelerated into the tunnel furnace to create a gap between them.

The roller hearth furnace is in excess of 160 m in length and is divided into heating, soaking and buffer zones. The capacity of the buffer zone is so designed that a complete roll change (time taken 8 min) or an inspection of the rolling mill can be carried out without interrupting the casting. The thin slab remains in the furnace for only around 22 min with heating time accounting for 10 min. The normal entry temperature of the slabs is between 950 and 1050°C – the temperature difference between the centre and the surface of the as-cast slab accounting for some of the self heating.

The furnace very effectively de-couples the casting process ($V_C = 5.5$ m/min) from the rolling process ($V_r = 18$ m/min). At an appropriate location in the tunnel furnace, the slab is accelerated to the speed needed for entry to the hot mill. Cobbles, if any, at the mill entry are taken care of by an emergency shear. The balance of the slab in such a situation can then be transferred back into the tunnel furnace, if so desired.

3.1d The CSP rolling mill: The CSP rolling mill consists of 4 to 7 four-high stands with an upstream emergency shear and a high pressure descaling facility and a downstream runout roller table with a laminar flow strip-cooling system and a coiler unit. The mill has a hydraulic roll gap adjustment system with continuously variable crown, on-line grinding, and work roll shifting and bending.

To obtain a finished gauge of 2.5 mm, a 50-mm slab undergoes an average reduction of 45% per stand. It is important to note that this is about twice the level of reduction given in most conventional hot-strip mills.

4. Advantages of CSP

The capital required for a new steel plant is a deterrent to investment. Matters are not helped by the fact that the minimum capacity required for an integrated steel plant producing flat products to fully utilise the equipment installed is in excess of 3 Mtpa (Kolakowski 1992). Against this background, the lower capital requirement for the installation and operation of a thin-slab caster arrangement makes the technology imminently attractive.

4.1 Installation cost

In order to compare the investment required for the two process routes, it is necessary to establish the minimum production level necessary for economical operation of both individually. As already mentioned, this minimum level is at least 3.0 Mtpa (million tonnes per annum) for the conventional caster as even if the production were to be brought down to 2.8 or 2.5 Mtpa, it would not permit a reduction in the number of roughing or finishing trains or a lowering in the investment in the reheating furnace (Kolakowski 1992). At 3.5–3.6 Mtpa the facilities are utilized to the maximum.

It is interesting to compare these figures with that needed for the optimum utilization of a thin-slab caster installation. Figure 8 is strictly applicable to the SMS thin-slab caster technology but can be taken to be broadly representative of the investment cost for all thin-slab casters. It shows that the capital cost per tonne of steel for a single strand thin-slab caster with a capacity of 0.8 Mtpa is only around 80% of that of a conventional caster of 3.6 Mtpa capacity. The reduction in cost arises as a result of the elimination of the slab-conditioning shop and from the savings in the casting machine itself. Marginal savings also

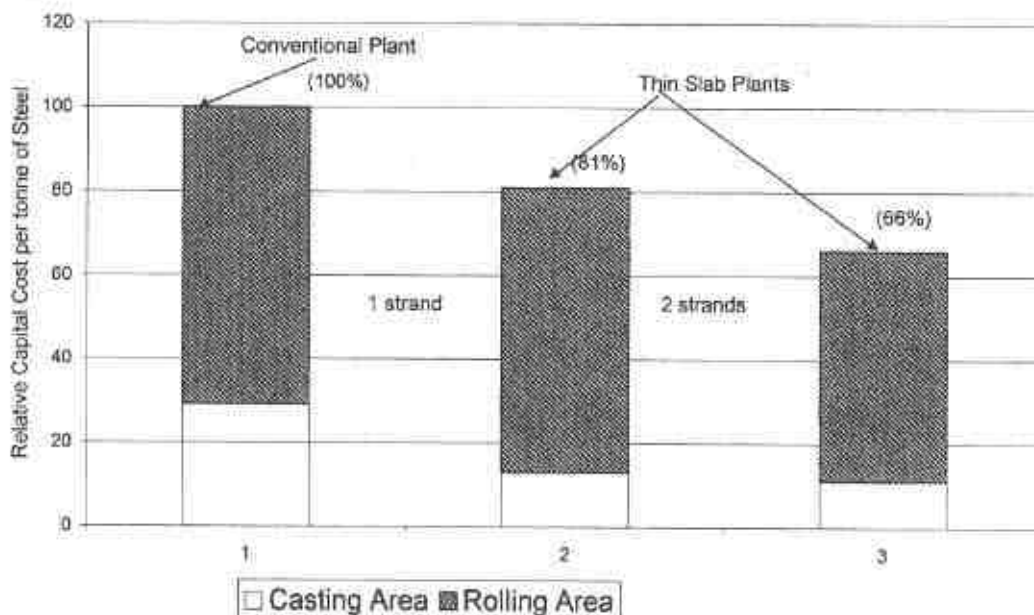


Figure 8. Investment cost for a CSP *vis-à-vis* conventional plant.

accrue from the rolling mill area (inclusive of the reheat furnace) as the rolling facilities required are less intensive. With a two-strand plant for producing 1.5 Mtpa, the extra investment is only in the casting machine and the reheating furnace (both sets of slabs can be rolled through one mill by having an enclosed shuttle car that can alternately feed the mill from strand one or strand two). At this capacity, the rolling mill is fully utilized and the capital cost per tonne for the thin-slab caster is only around 65% of that for a conventional plant.

The investment cost advantage, therefore, clearly puts the thin-slab caster ahead of its conventional counterpart.

4.2 The cost of production

A comparison of operating costs for the two options presents an extremely interesting picture – the cost of producing strip being significantly lower for the thin-slab caster route.

For the first time, thin-slab casting technology permits the direct combination of casting and rolling for 100% of the production, nearly 70% less energy consumption is anticipated from theoretical calculations. Figure 9 shows the comparison in the theoretical specific-energy consumption in a conventional slab-casting plant with cold (at 20°C) and hot charging (at 600°C) and in a typical thin slab casting plant (ECSC Report 1995). It should be noted that the impact of lower slab thickness on the energy needed for rolling is marginal; by far the biggest saving arises on account of lower energy consumption during the reheating of slabs. Labour and maintenance costs are estimated to be lower by 40% each compared with the costs on these items in a conventional caster. Additionally, apart from two or three cropping cuts at the beginning of a sequence, it is necessary only to make dividing cuts on the slabs in accordance with the requirement of coil weight. In the conventional rolling process, the so-called "fish-tail" resulting from rolling in the roughing stands has to be eliminated before entry into the finishing mill. Furthermore, for a thick slab, each metre cut leads to a greater loss (up to 5 times more) of material compared with a cut in a thin slab. It has been estimated that the yield from liquid steel to the final strip

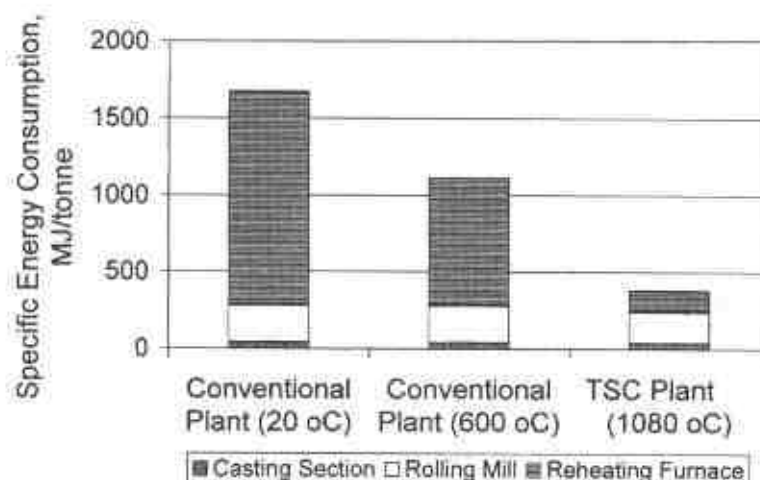


Figure 9. Specific energy consumption at a conventional caster (cold- and hot-charge) and a CSP set-up.

would be about 2% higher for a thin-slab caster. In the evaluation of the authors, the operating cost advantage is around \$20/tonne in favour of the thin-slab caster. Even if 100% direct or hot charging were to be practised in a conventional slab casting plant, this figure would reduce only by \$3/tonne.

In the face of all these advantages there is one area where, as of now, a thin-slab caster is unable to compete with the conventional slab caster, viz, product quality in certain critical applications. The excessive mould turbulence associated with feeding a thin slab caster mould with liquid steel at a reasonable production rate leads to a slab surface that (particularly in the absence of scarfing of slabs) produces a strip unsuitable for use in *exposed auto body parts*. Thus, the product mix of a conventional caster can potentially be richer than that from a thin-slab caster. Additionally, casting of peritectic and crack sensitive grades requires reduction of speeds to one-third of normal casting speeds to prevent breakouts. While this is also true in normal slab casting, the lower speeds needed for the peritectics are too low in a thin-slab caster, leading to premature freezing of the steel in the restricted mould. Thus, these grades have to be altogether avoided in a thin-slab caster product mix which is not always the case in conventional casters.

There are a few other concerns about the thin-slab caster, in particular the capacity per strand, which are covered in a subsequent section.

5. Thin strips from thin-slab casters

The issue of thin strips (<1.5 mm) from a conventional hot rolling mill has been briefly touched up on in a previous section. Some modifications that are needed for rolling of these thin gauges are described.

It is well-known that the strip width dimension is a function of the accuracy of the tension control. This implies that, particularly with small strip cross-section in the inter-stand area during thin strip rolling, the equipment design must be one of low inertia and low friction. With the rolling of thin strips at high speeds, the threading in and out of the strips needs to be accurately controlled. Thus, the *automatic levelling* of the mill stands with feed-forward controls assumes great importance. The flatness of the strip in the inter-stand region is crucial for rolling stability. Thus, *automatic flatness* control needs to be in place at least for the last three stands. Thin hot-strip rolling places very high demands on the mechanical equipment of the mill. Apart from the high accuracy required on the strip gauge, it is also necessary to have the mill hardware insensitive to errors in the rolling-force setup. To implement these features, high-speed *automatic gauge control* is a must. Additionally, *mass-flow errors* particularly during the threading-in phase need to be controlled rapidly to enable rolling to continue in a stable fashion. For this, optimised hydraulic loopers and control circuits are needed. Finally, rolling of thin end thickness leads to higher loads in the finishing train. A proper *roll-gap lubrication* system permits reduction of rolling force and acceptable level of roll wear.

Difficulties in the production of thin hot-strips from a thin-slab caster based CSP plant are somewhat less as the entry conditions (high uniform thin-slab temperature) for rolling in the finishing train are much more favourable. At 1100 to 1150°C, the thin-slab temperature lies well above what can be attained at the transfer bar stage of conventional hot rolling. This permits lower finish rolling speeds in CSP. Furthermore, uniformity of heating in the tunnel furnace implies that the temperature gradient from the strip centre to the strip edge is small even after the last stand. As a consequence, even at an end-rolling

temperature of around 850°C the demands of the austenitic rolling process can be completely met for low-carbon steels. This compares poorly with the 900°C temperature needed in the case of the conventional finishing train. Another major advantage of the uniformity of temperature along the length of the slab is that rolling and cooling can proceed at a constant speed without resorting to strip edge heating, temperature speed-up or variable inter-stand cooling.

Compared with the conventional hot-rolled route, the yield strength and tensile strength obtained for low-carbon sheets are higher for thin-slab rolling. This has been attributed to the delay in the precipitation of sulphur (as MnS) owing to the fast cooling during and after solidification in the case of thin slabs. The sulphur remains in solution and precipitates during rolling. As a result, the precipitates are very fine (less than 0.05 micron) and are homogeneously distributed with attendant benefits. The fine particles of MnS have a pinning effect on the grain, preventing grain growth with the result that in the cold-rolled and annealed sheet, the grain size is finer. Additionally, MnS is an effective site for precipitation of Fe₃C and influences the final precipitation. Thus the efficiency of the overaging treatment is expected to be more effective in sheets produced by the thin-slab casting process. It has also been seen that ferritic rolling for a conventional thick slab produces a product that has inferior yield strength and tensile properties compared to ferritically rolled thin slabs. It is felt that the fine MnS precipitates formed during rolling act favourably in the latter case.

On account of these advantages, it is now possible to have an "extra-long" slab of around 200 m cast and rolled in the finishing stand and cut to individual coil length. In doing so, the discontinuous (batch processing) mode of operation of the CSP can be extended into a semi-continuous one by merely installing a high-speed shear before the coiler station. In future it may be possible (figure 10) to design a fully continuous overall process that links the process from casting to final rolling.

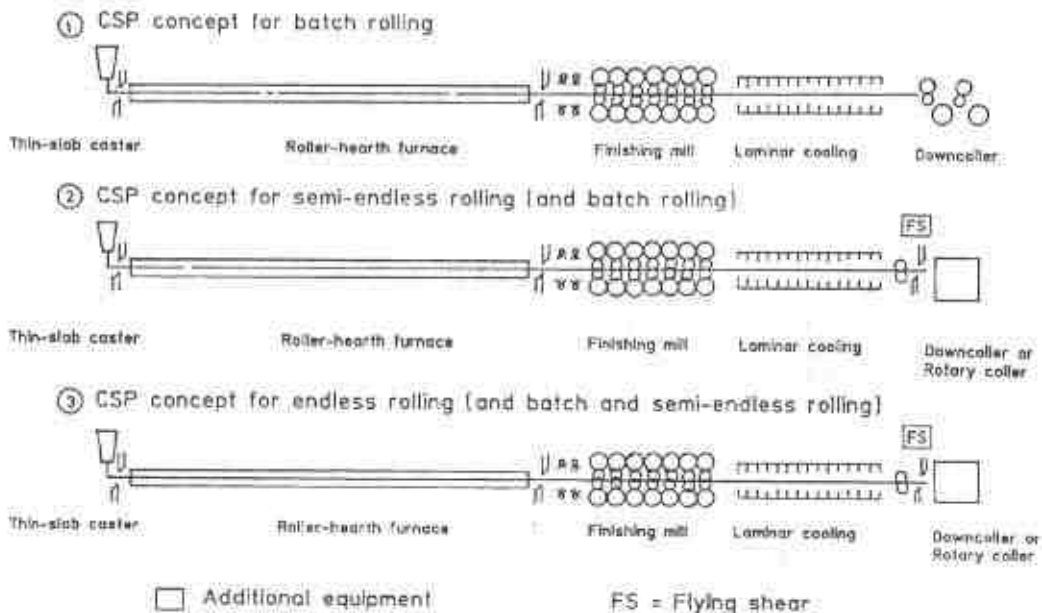


Figure 10. CSP configuration for batch, semi-endless and endless rolling.

6. Linking BOF to CSP

Acme Steel, USA, Algoma Steel, Canada and Thyssen Krupp Stahl, Germany are the only three plants as of now that have linked the BOF to a thin-slab caster. The great popularity of thin-slab casters in electric arc furnace-based plants is due to the fact that flat products can, by this combination, be made now by mini mills of smaller installed capacity involving considerably lower financial investment. Electric arc furnaces have a tap-to-tap time of around 60 min which matches reasonably well with the time for casting a heat in a thin-slab caster. This makes the arrangement particularly amenable to sequence casting.

The cost advantages (capital as well as operating cost) of a thin-slab caster (TSC) product are so overwhelming that, for qualities that can be produced through the thin-slab caster route, a thin-slab caster product would cost much less than a conventionally cast product to the advantage of customers. It seems fairly clear that for such qualities, conventional slab casters are fighting a losing battle. It is only because certain profitable grades needed for outer car bodies cannot, as of now, be made in a thin-slab caster that a competition of sorts exists between the two routes. Considering the rapid technological progress being made in the thin-slab caster area, it may only be a matter of time before the obstacle of producing exotic auto grades is also breached.

It is the opinion of the authors that no new installation for flat products can be competitive without a thin-slab caster. One can even go so far as to say that even existing plants would be under pressure from new thin-slab casters in place of their fully depreciated conventional caster (as with Algoma Steel). However, some special issues need to be tackled with a BF-BOF-TSC route and these are discussed in subsequent sections.

6.1 Availability of a TSC arrangement

Out of the total number of days in a year, the "steel-in-mould" time for a thin-slab caster is only 290 days (80% availability). The break-up of this availability for a typical thin-slab caster is given in table 2 (Chandra *et al* 1997a). With this kind of availability, the maximum annual production per strand of a thin-slab caster would be 1.05 Mtpa (slab width: 1200 mm; casting speed: 5.5 m/min; slab thickness: 50 mm). Two machines at the very best would give 2.1 Mtpa. The production per strand for different thicknesses and widths has been given as a function of casting speed in figure 11 and 12. (*Note: The slab production figures have to be adjusted for yield (95%) to compute the production of steel.*)

Considering the fixed expenditure on infrastructure that has to be incurred independent of the annual tonnage, it is now accepted that any integrated steel plant built today should have a minimum capacity of 2.5 Mtpa. Under these circumstances, it is immediately

Table 2. Availability of a thin-slab caster in an integrated steel plant.

Activity	No of days
General maintenance (7 days/months)	14
Scheduled maintenance (8 h/week)	17
Operational disturbance/unscheduled outlays	23
Total time for re-stranding	19
Total outage	73
Steel in mould (365–373 days)	292

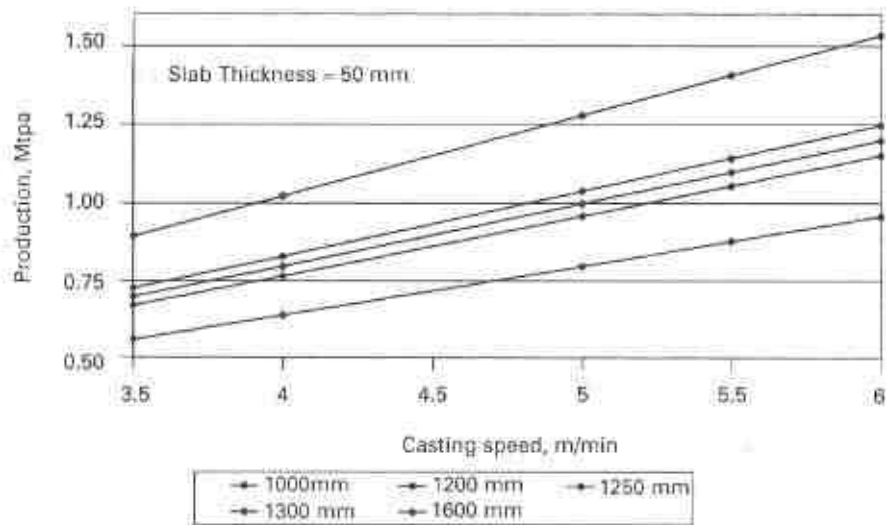


Figure 11. Production capacity of CSP for different slab thicknesses.

obvious from figure 11 and 12 that two strands of a thin-slab caster producing 65 mm thick slabs (at 1200 mm average width) would be needed to meet the demand of minimum capacity. Whether the two strands should be from one caster or from two separate casters is discussed in the next section.

When first introduced, thin-slab casters did not have an edge before the rolling mill. Thus all slab-width changes involved mould-width changes which complicated both the casting as well as the mill scheduling in addition to contributing to yield losses. However, edgers are now supplied with thin-slab casters and Gallatin Steel (a joint venture between Co-Steel of Toronto and Dofasco of Hamilton) has a vertical edger ahead of its 5-stand rolling mill. For the SMS caster, this is the first time an edger has been used.

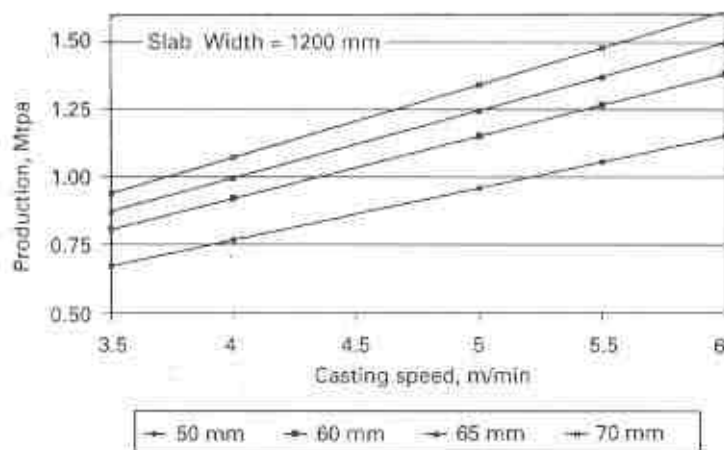


Figure 12. Production capacity of CSP for different slab widths.

stopped altogether in the large BOF, the production in the plant would be most severely affected.

- Proper positioning of the tundish, so that the nozzles of the two strands are simultaneously centred exactly in the mould, is a difficult task. This issue is of concern even in a conventional caster with twin strands but the problem is magnified many folds in case of a thin-slab caster because of the severely restricted mould opening.

6.4 Impact on blast furnace

The availability of a blast furnace is 340–350 days in a year. On the other hand, the availability of the caster-mill is at best only 330 days, allowing for periodic shutdowns of the plant for equipment maintenance. The size of the blast furnace will have to be chosen so as to get the required hot metal in only 330 days of operation. For the balance number of days, hot metal production has to be reduced considerably or another outlet identified for its use. It is to be appreciated that even if the caster is available for the production of slabs, the reheat furnace cannot take "cold slabs." The disposal of the extra production at the hot metal stage is possible if the metal is cast into pigs. To handle 7600 tonnes/day (the requirement of hot metal for production of 2.5 Mtpa) the pig-casting machine arrangement would be fairly large.

Another issue at the hot metal stage, linked to its association with a thin slab caster, is the transport of hot metal from the BF to the BOF shop. The modern trend is to use torpedo ladles and directly charge the metal to the LD vessel at the steel melting shop. This does away with the mixer—a standard feature in many steel melting shops today. Since there are likely to be interruptions in the rolling mills, which would necessitate stoppage in steel production, it is important that an arrangement be made so that the blast furnace production is largely left unhindered (Chandra *et al* 1997b). A possible solution lies in creating a largish buffer vessel between the BF and the steelmelting shop in the form of a mixer. The downside of this is that hot metal would need to be handled in open top ladles instead of torpedo ladles.

These are issues that need to be debated, since there are no obvious solutions.

7. Conclusion

Developments in the area of continuous casting have been considerable and their impact on the steel industry, quite significant. The important issues discussed in the paper are the following.

- Thin-slab casters are less expensive than their conventional counterparts both on account of capital and expected operating costs. It has been estimated that the investment cost per tonne for a 2-strand 1.5 Mtpa thin-slab caster is only 65% that of a conventional caster of 3.6 Mtpa capacity. The operating cost advantage is around Rs. 500–600/tonne in favour of a thin-slab caster.
- The BF-BOF-TSC route offers a few challenges. On account of lower availability of a thin-slab caster compared with the BF, arrangements have to be made (e.g. pig casting machines) to dispose of the hot metal produced during the downtime of the caster. From the experience at Thyssen Krupp Stahl and Algoma Steel it is now clear that a twin-strand caster, fed by a large 200–380 tonnes heat, can successfully overcome the previously perceived problem of nozzle centring in a twin-strand TSC.

stopped altogether in the large BOF, the production in the plant would be most severely affected.

- Proper positioning of the tundish, so that the nozzles of the two strands are simultaneously centred exactly in the mould, is a difficult task. This issue is of concern even in a conventional caster with twin strands but the problem is magnified many folds in case of a thin-slab caster because of the severely restricted mould opening.

6.4 Impact on blast furnace

The availability of a blast furnace is 340–350 days in a year. On the other hand, the availability of the caster-mill is at best only 330 days, allowing for periodic shutdowns of the plant for equipment maintenance. The size of the blast furnace will have to be chosen so as to get the required hot metal in only 330 days of operation. For the balance number of days, hot metal production has to be reduced considerably or another outlet identified for its use. It is to be appreciated that even if the caster is available for the production of slabs, the reheat furnace cannot take "cold slabs." The disposal of the extra production at the hot metal stage is possible if the metal is cast into pigs. To handle 7600 tonnes/day (the requirement of hot metal for production of 2.5 Mtpa) the pig-casting machine arrangement would be fairly large.

Another issue at the hot metal stage, linked to its association with a thin slab caster, is the transport of hot metal from the BF to the BOF shop. The modern trend is to use torpedo ladles and directly charge the metal to the LD vessel at the steel melting shop. This does away with the mixer—a standard feature in many steel melting shops today. Since there are likely to be interruptions in the rolling mills, which would necessitate stoppage in steel production, it is important that an arrangement be made so that the blast furnace production is largely left unhindered (Chandra *et al* 1997b). A possible solution lies in creating a largish buffer vessel between the BF and the steelmelting shop in the form of a mixer. The downside of this is that hot metal would need to be handled in open top ladles instead of torpedo ladles.

These are issues that need to be debated, since there are no obvious solutions.

7. Conclusion

Developments in the area of continuous casting have been considerable and their impact on the steel industry, quite significant. The important issues discussed in the paper are the following.

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- Some of the thin strips produced through cold rolling can now be obtained from hot-rolling itself and the thin-slab caster is uniquely poised to make this transition.

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