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The Castrip Process: A revolutionary Casting Technology, an exciting Opportunity for Unique Steel Products or a New Model for Steel Micro-Mills?

By

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The CASTRIP™ Process: A revolutionary casting technology, an exciting opportunity for unique steel products or a new model for steel Micro-Mills™?

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ABSTRACT

Twin-roll casting of steels has been a dream for steel producers since Sir Henry Bessemer's patent related to twin-roll casting issued in 1857. With the turn of the millennium, it appears that that dream will finally become a reality. Following more than 12 years of intensive research, pilot plant and full-scale development, the CASTRIP™ process is on the threshold of changing many of the paradigms in the steel industry. Some of the key benefits of this new technology, i.e. low capital investment, multiple grades from a single composition, thin-gauge/high price product capability and low annual capacity, provide a platform for a new type of steel company – perhaps a true Micro-Mill™. The paper discusses some of the breakthroughs achieved by the BHP-IHI development team and how these translate to a unique new way of producing steel sheet products. In addition, an update on Castrip LLC's first licensee – Nucor Corp. and its Project 'C' caster at Crawfordsville, Indiana - is included.

INTRODUCTION

Near-net-shape casting of metal products has long been of interest to metallurgists and the metals industry. Obvious savings in equipment plus efficiencies related to hot and cold working as well as reheating have been the main driving force. For more than a decade, BHP and IHI have been collaborating on a twin-roll casting design at development facilities in Wollongong, Australia. The codename for this venture has been Project 'M'. Last year, Nucor Corporation joined forces with the team, forming Castrip LLC, a joint venture company aimed at commercializing the new technology. Construction is underway at Crawfordsville, Indiana where Nucor is building the first commercial plant, which is expected to begin commissioning in late 2001. Known as Project 'C', Nucor's caster will focus initially on the production of light-gauge carbon steels and later on stainless steels.

For the past decade or so, strip casting of steels has been an interesting technical curiosity for the steelmaking community. Many projects and collaborative efforts have been initiated practically worldwide, however none has been run at a full commercial level for extended periods. With the construction of the Project 'C' plant at Crawfordsville, all of this will change and many questions arise concerning the business model that best suits the new process. The following paper explores some of the technical breakthroughs made by the IHI-BHP team, the new product categories that have been created and the possibilities for a new type of steel producer or Micro-Mill™.

THE TECHNOLOGY

Project 'C'

The fundamentals of strip casting using two counter rotating rolls are not new in the metallurgical community. Sir Henry Bessemer's patent dates back more than 140 years and the basic process he envisioned is evident in the CASTRIP™ technology. Some of the key factors that have enabled only recent success with this process are high-speed computing and sensing for process control, precision robotics, durable and inexpensive refractories and fundamental understanding of early solidification phenomena. A sketch of the basic elements of a twin-roll design is shown in Figure 1. The process is extremely simple in design with molten metal being fed between two counter-rotating rolls. Missing from Figure 1 are the edge dams, which contain the molten steel at the ends of the rotating rolls.

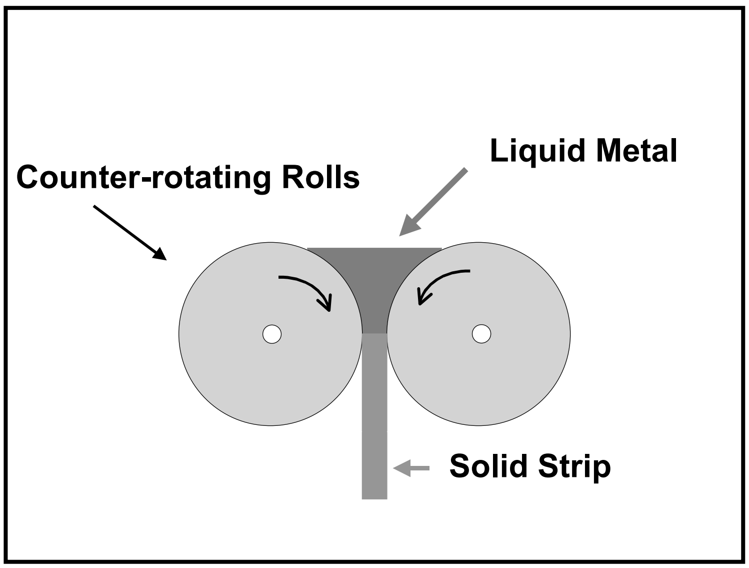

Figure 1 – Simple schematic of twin-roll strip casting process.

Table I – Project 'C' (Crawfordsville) Main Plant Specifications

Unit	Specification (in metric units)
Heat/Ladle Size	110 tonnes
Caster Type	500-mm Diameter Twin Roll
Casting speed	80 m/min (typical) 150 m/min (maximum)
Product Thickness	0.7 to 2.0 mm
Product Width	2000 mm maximum
Coil Size	25 tonnes
In-Line Mill	Single stand – 4 High with Hydraulic AGC

Unit	Specification (in metric units)
Work Roll Dimensions	475 x 2050 mm
Back-up Roll Dimensions	1550 x 2050 mm
Rolling Force	30 MN maximum
Main Drive	3500 kW
Cooling Table	10 top and bottom headers
Coiler Size	2 x 40 tonne coilers
Coiler Mandrel	760 mm diameter
Annual Capacity	~500,000 tonnes/year

The Project 'C' caster in Crawfordsville will employ some of the essential components of the BHP-IHI Project 'M' plant, developed over the past several years in Australia. Table I contains a listing of the general plant specifications for Project 'C'. Of critical note are the strip thickness range, 0.7 to 2.0 mm (0.028 to 0.08") and the width range, 1000 to 2000 mm (39 to 79"). The Project 'M' facility typically cast 1345 mm-wide strip (53") and the scale-up to wider widths is expected to be straightforward, as the most difficult challenges in twin-roll casting have proved to be at the edges.

The main components of the caster plant are shown in Figure 2. Steel will be supplied via Nucor's existing melt shop through a new LMF station dedicated to Project 'C'. As indicated in Table I, heat sizes delivered to the caster are expected to be 110 tonnes (121 short tons). The entire process, from liquid steel in the turret to hot rolled coils at the down coilers will take place in 60 m (197 ft) which is less than one-tenth the length of thin slab or conventional slab casters, including the requisite hot strip mill. Groundbreaking ceremonies were conducted at the site on February 27, 2001 and piling and excavation work had begun at time of writing. The project schedule calls for commissioning to begin in late 2001 and production of the first coils in Q1 2002.

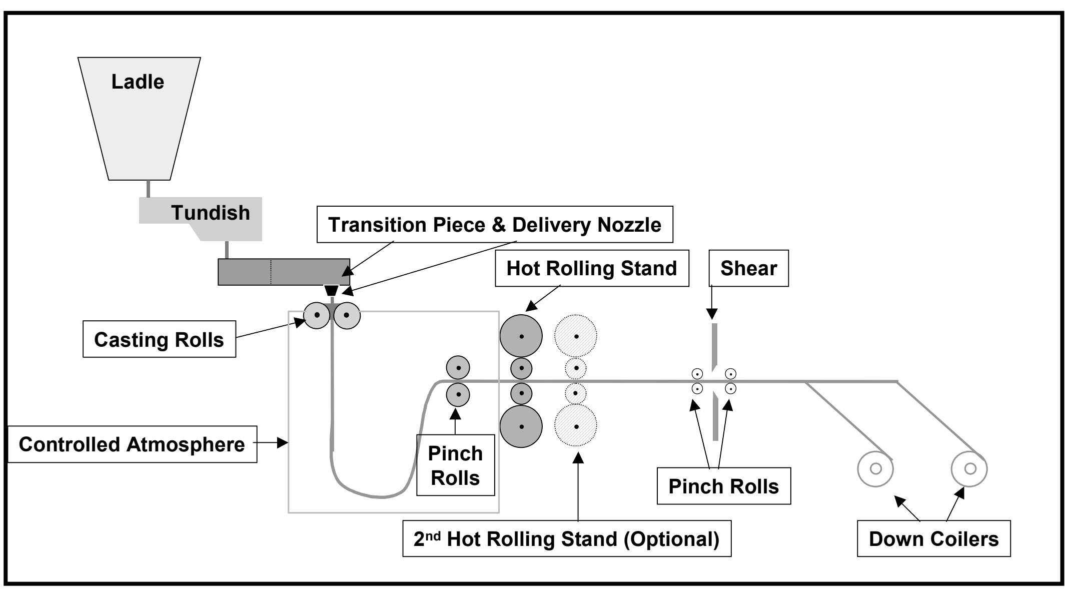

Figure 2 – Process schematic for Project 'C' plant layout

Process Metallurgy

Strip casting via the twin roll process is fundamentally different from conventional casting in several ways. Table II lists some of the main parameters related to the CASTRIP process, in comparison with thin-slab and conventional slab casting. As noted in the table, the time for solidification of the strip is extremely small in the CASTRIP process with total contact time between the solidifying strip and the roll equal to 0.15 seconds. This is contrasted with 45 and 1070 seconds for thin-slab and conventional casting, respectively. Similarly, solidification rates, heat transfer rates and casting speeds are all at least an order of magnitude higher for the CASTRIP process as compared to slab casting. As a result, despite the size of the machine and the small strip thickness, the CASTRIP process has an annual capacity approximately one-third to one-half that of a thin slab casting facility.

Table II – Key process differences among CASTRIP technology, thin slab and conventional slab casting.

	CASTRIP Process	**Thin Slab Casting**	**Conventional Slab Casting**
Strip Thickness	1.6	50	220
Casting Speed (m/min)	80	6	2
Average mold heat flux (MW/m^2)	14	2.5	1.0
Total solidification time (s)	0.15	45*	1070**
Average shell cooling rate (°C/s)	1700	50	12

* k factor = 29
** k factor = 26

For over a decade, the Project ‘M’ team worked at unlocking the secrets of how to apply Bessemer’s concepts to the thin casting of low-carbon as well as stainless steels. That work has culminated in nearly 200 patent families and over 1500 patents and patent applications worldwide. The research and development efforts were focused on several key areas of the twin-roll process that had to be conquered to produce commercial quality strip. These key areas were:

- Understanding of early solidification
- Providing uniform metal delivery
- Edge containment of the melt pool
- Controlling mold (roll) distortion
- Melt/refractory interactions

Several papers have been published on these topics by members of the Project ‘M’ team (1-4) over the past few years, however most of the basic understanding is protected through patents and/or trade secrets. The early solidification phenomena proved to be one of the most difficult to solve owing to the limited knowledge in the field. Conventional casting of steel has three fundamental differences to twin-roll casting (i) the mold moves or oscillates in relation to the solidifying shell, (ii) there is typically a lubricant or flux applied (oil or mold powder) and (iii) the time to complete solidification is measured in tens of seconds. As indicated above, solidification time in the CASTRIP process is ~0.15 seconds and the commensurate heat transfer rates between the solidifying steel and the rotating mold are in the order of tens of MW/m^2. If early solidification is not properly controlled in the strip, surface defects as well as porosity and an uneven shell are certain to arise.

Metal delivery to the melt pool proved to be an equal challenge as the input stream energy per unit pool volume is approximately ten times greater than for slab casting. Improper metal delivery can result in localized remelting of the shell and instability at the meniscus. The so-called "triple point" area at the edge of the pool, where the rolls, edge containment refractories and the molten steel come in contact, provides a different challenge. In addition to the requirements on the refractory for long life, it is also important to prevent freezing and metal buildup at this location. Proper preheating combined with metal delivery designs have been critical components of good strip edges.

High heat flux through the rotating copper rolls inevitably leads to distortion, regardless of roll design and construction. In order to provide strip with thickness variations that meet the demands of the market, it was critical to understand the relationship between the initial shape of the roll and the inherent distorted shape during casting.

Finally, the refractories used in the CASTRIP process have been another area requiring understanding and innovation. Defects in the strip surface have been linked to the evolution of carbon monoxide from the interaction between the melt pool and the alumina-graphite nozzles. Specific materials for eliminating this interaction have been developed.

As learning progressed in Project 'M', another important feature about the process became apparent. Whereas the project was originally aimed at a strip thickness of 2.0 mm and greater, to target the heart of the hot rolled steel market, it was found that the process actually produced better quality material as thickness was reduced. Earlier thinking in the field of strip casting suggested that the strip be cast at least 2 mm in thickness to allow for the removal of porosity through subsequent hot reduction. Instead, Project 'M' development work reported by Blejde *et al* (3) showed that porosity-free strip was possible under 2 mm.

Unique Product Capabilities

Owing to the high solidification rates in the as-cast strip, the microstructure developed during subsequent hot rolling and cooling is significantly different from conventional hot-rolled steels. In a previous paper by Mukanthan *et al.* (1), a detailed explanation of the how these microstructures develop and their effect on the subsequent properties is provided. The key difference between strip-cast and slab-cast microstructures is the size and shape of the austenite grain size prior to cooling and transformation to lower temperature transformation products. In strip-cast material, the austenite grains are elongated in shape, 100 to 250 μm wide and 300 to 700 μm long. In contrast, prior austenite grain morphology in slab-cast/hot strip mill products is equiaxed and ~25μm in size. This difference in grain size leads to a significant difference in transformation products during cooling. Whereas cooling of conventional low-carbon, hot strip mill products generally leads to the formation of equiaxed ferrite grains with a size of ~10 μm, CASTRIP low-carbon products transform to a mixture of polygonal and Widmanstätten ferrite. Mukanthan *et al.'s* work also showed that changes to the cooling rate during austenite to ferrite transformation results in significant differences in the final microstructure produced in the strip cast material. The consequence of this phenomenon is that multiple grades of steel can be produced from a single melt composition.

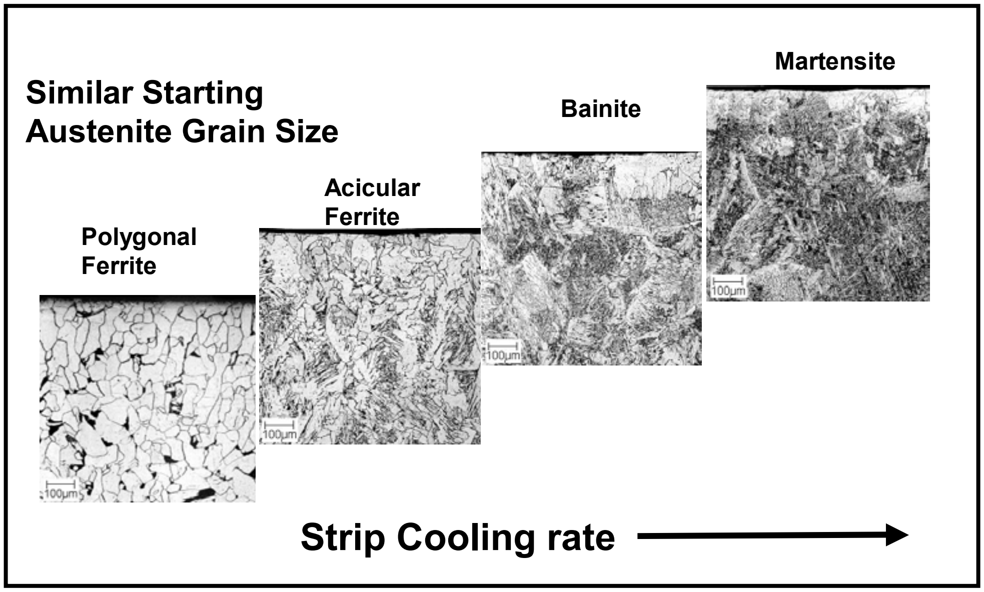

Figure 3 – Relative effect of cooling rate on the final microstructure of Castrip steel products

Figures 3 and 4 show the microstructures developed in the strip and the subsequent affect on mechanical. As indicated, a single steel composition is capable of producing a wide array of strength/elongation combinations, dependent on the cooling rate from austenite to the lower temperature transformation products. This phenomenon has particular interest for steelmakers and steel consuming customers in that the hardenability of CASTRIP strip products may allow for substitution for CRFH (cold-rolled full-hard) and HSLA (high-strength low-alloy) grades, at lower overall cost.

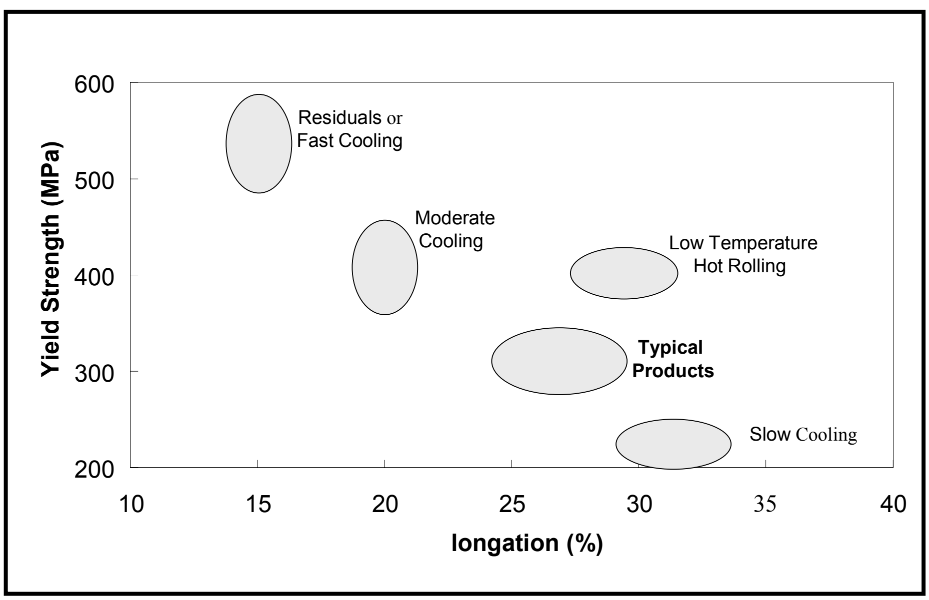

Figure 4 – Effect of cooling rate on the mechanical properties of CASTRIP strip products

Energy and Environmental Performance

One of the key features of the CASTRIP process as compared to conventional steelmaking routes is the lower usage of energy combined with the reduced emissions. Table III details some of the expected energy consumption rates for the CASTRIP process along with data from conventional and thin-slab casting plants. The comparison is for the casting process through hot rolling; steelmaking and finishing operations are thus excluded. The main reason for the drastically lower energy usage for CASTRIP technology is that it does not require reheating and there is only one hot reduction stand. In comparison, slab casters require large quantities of energy to reheat slabs then additional energy to roll them in a multi-stand hot strip mill. Overall, the CASTRIP technology's energy savings are expected to be between 80 and 90% of the conventional processes. Similar to the energy savings, emissions from the CASTRIP process are a small fraction of that from slab casting routes. Table III contains data on the GGE or greenhouse gas equivalents that are produced by the various casting methods. As can be seen, the CASTRIP technology lowers GGE production between 71 and 80%.

Table III – Energy Consumption and Emissions - Ladle through Hot strip

	Energy Consumed (GJ/t)	GGE (t CO2 equiv/t)*
Thick Slab Caster + Hot Strip Mill	1.8	0.2
Thin Slab Caster + Hot Strip Mill	1.08	0.14
CASTRIP process	0.2	0.04
Savings – CASTRIP vs. Thick Slab	89%	80%
Savings – CASTRIP vs. Thin Slab	81%	71%

* - Greenhouse Gas Equivalent or tons of CO_2 equivalent per ton of steel produced

BUSINESS IMPLICATIONS

The Market

In terms of market opportunities for the CASTRIP products, there are some obvious applications that are extremely suitable. In fact, in a recent research report by CRU International Ltd. (7), the market for thin-gauge hot rolled (TGHR) and ultra-thin-gauge hot rolled was described in significant detail. The report denoted TGHR as 1.2 to 2.0 mm (0.048 to 0.08"); UTGHR is below 1.2 mm (0.048"). The most suitable initial markets for TGHR products are tubing, metal goods, construction and automotive. CRU contended that there are four possible routes for TGHR to increase share. These are:

- Substitution of cold rolled by TGHR
- Substitution of heavier gauge hot rolled by TGHR
- The use of TGHR as a substrate for coating
- The use of TGHR as feed for cold reduction

Although the CRU report notes growth rates in excess of 6% between 1997 and 2007, their analysis did not assume that strip-casting technologies would be a component of the growth. Their findings assumed incremental change in current thin-slab technology as a means of increasing the supply of lighter-gauge hot band. Thus, with the availability of processes such as the CASTRIP technology, it is believed that the market may actually grow much more quickly, particularly in certain geographic regions. Figure 5 shows the CRU-estimated market size for TGHR in 1997 with projections for 2002 and 2007. The figure shows that the market size increases from ~21 million tonnes (23 million short tons) in 1997 to more than 37 million tonnes (41 million tons) in 2007. Once again, CASTRIP and other thin casting technologies may well accelerate the availability and acceptance for this new type of material.

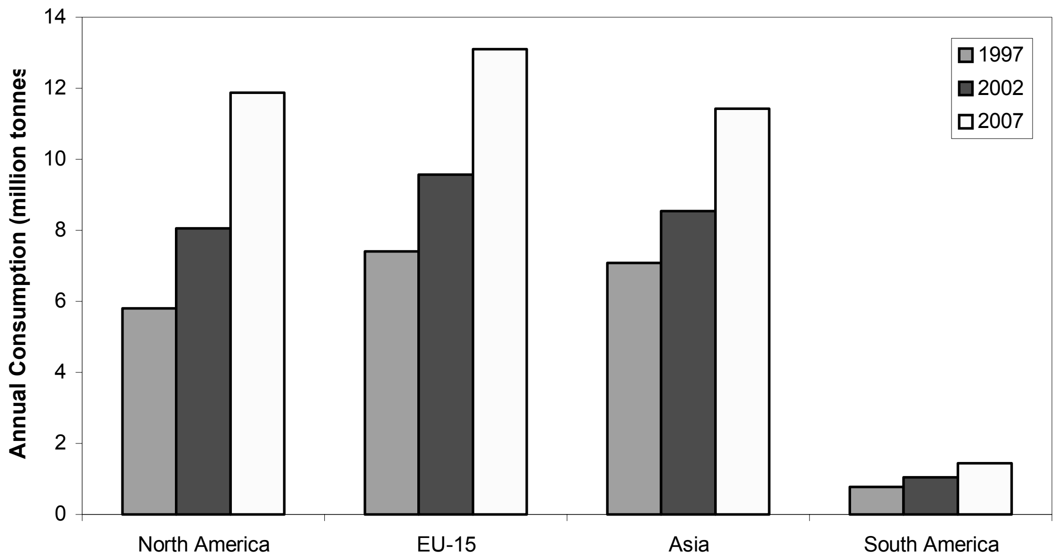

Figure 5 – Estimated market size for thin gauge hot rolled products; 1997 through 2007 from CRU (7).

Proposed Business Models

Considering the benefits of the CASTRIP technology as stated in the previous sections, there are several alternatives for the adoption of the technology in existing steel production business structures. Further, the technology will also allow for a new type of steel production firm or Micro-Mill that is specifically tuned for a particular end-user group or geographic area. The actual pace of adoption of the process and the business model that becomes most dominant is expected to vary with size of steel market, level of steel development in the region, control of steel distribution channels and the ability of the CASTRIP process to deliver on key benefits. As with other "disruptive technologies" (6), there will be a certain amount of trial and error in terms of the adoption of the technology. The main contributing factors will be the relative benefits provided by the technology for each possible business case. Table IV contains some of the key features of the technology and the corresponding benefits to the various process users. This section discusses potential business models for adoption of the CASTRIP process.

Table IV – Key CASTRIP Process Features and Corresponding Benefits for Potential Licensees.

Potential CASTRIP Technology Licensee	Key Process Features	Corresponding Benefits for Licensee
Greenfield Micro-Mills	▪ Small capital investment ▪ Low energy consumption and emissions	○ Financing within reach of smaller investors ○ Easier permitting plus lower cost
Backward Integrator	▪ Manageable annual capacity	○ Easily matches with annual consumption
Integrated Mills	▪ Small physical size ▪ Light-gauge HR products	○ Easily situated on property, lower capital costs ○ Potential for higher margins, augments existing product line,
Flat Rolled Minimills	▪ Small physical size ▪ Light-gauge HR products	○ Easily situated on property, lower capital costs ○ Potential for higher margins, augments existing product line,
Long Products Producers	▪ Light-gauge HR products ▪ Unique product properties	○ Break into new product area with higher margins ○ Can produce wide flat rolled grade range from basic EAF steelmaking route

Greenfield Micro-Mill

The most "disruptive" business model for adoption of the CASTRIP process is a purpose-built, green-field plant with the intent of selling ultra-thin-gauge hot rolled (UTGHR) to a local steel market. There are many obvious implications for the industry as this model is adopted. Perhaps the first will be that a new class of hot band is created which actually competes more directly with cold rolled material than hot rolled. With the minimum thickness of this new ultra-thin-gauge hot rolled approaching 0.7 mm (0.028") or lower, many steel products, which are commonly made from cold-rolled feed, can directly utilize this material. In particular, coated construction products, tubes, containers, and unexposed auto components that are currently made from cold rolled are ideal targets. These Micro-Mills can be situated on much smaller parcels of land than typical flat rolled operations and will require less than 50 acres compared to ~500 acres needed for a typical minimill, thin-slab plant. Also, the capital investment required for a CASTRIP plant is substantially smaller than conventional processes, approaching $200 million (including a melt shop), thus financing should be easier and attract a wider base of investors. This business model makes most sense in geographic areas that are deficient in hot rolled and cold rolled supply and where demand can be matched to a CASTRIP plant capacity. Such a situation has an added advantage improving both costs and the environment as shipping distances for steel products will be reduced. Given these advantages, there is a compelling argument for the development of true Micro-Mills that serve local markets and end-user niches with specific new steel products. This new type of company may enjoy a less competitive business environment, particularly if a new product category of UTGHR is accepted in the marketplace.

Backward Integration

With an annual capacity of ~500,000 tons, the CASTRIP technology is nearing the purchasing volume of many large steel-consuming companies. In particular, industry segments such as tube mills, auto companies, service centers, coated (construction) steel producers, etc. will have the opportunity to own and control their steel supply chain. These industries can also take advantage of several other benefits offered by the CASTRIP process. The two most relevant are the thinner gauges of hot rolled that can be produced and a wide range of mechanical properties available from a single composition. For the tubers, there is the opportunity to save on utilizing light-gauge hot rolled as opposed to cold rolled feed. Automakers will be able to use the high-strength capabilities of CASTRIP products to make lighter-weight non-exposed parts. Service centers will be able to supply a significant portion of their hot rolled needs in house – it is even conceivable that smaller service centers would form small regional joint ventures to provide light gauge products for regional consumption. In the construction steel area, CASTRIP lines can be utilized to feed galvanizing and painting operations for the compact production of coated and painted steel sheet which can then be rollformed into deck, studs, purlins, roofing/walling, HVAC, etc. Companies that are currently purchasing these products from conventional steel companies will have the opportunity to take control of this key strategic ingredient to their products and take advantage of the unique benefits.

Incorporation by Integrateds

The small annual tonnage output of the CASTRIP technology and the commensurate low capital cost make it an ideal addition to an integrated mill that has excess melting capacity and wants to augment an existing product line. The small physical size of the plant makes it easy to situate on most existing integrated sites and fit within process routes. The process is ideally suited to avoid the revamp of a hot strip mill (and its major capital outlay) or extend the product range available from an integrated flat products mill. An ideal situation may also be where an integrated plant has excess steelmaking capacity compared to casting or rolling. A CASTRIP plant can be installed to provide an extremely economical gain of ~500,000 tons of flat rolled capacity. Further, products from the CASTRIP process would augment the product range of the flat-rolled producer and allow access to the growing high-margin, light-gauge end of the hot rolled steel market.

Flat Rolled Minimills

Similar to integrated mills, the EAF-based minimill companies could gain some tremendous benefits from adoption of the CASTRIP process at existing plant sites. In addition to the obvious benefits mentioned above, two features of the new technology have particular interest for minimill companies. The first relates to the ability to make a large variety of grades from a single chemistry. This provides the potential for savings in the melt shop and simplification of the steelmaking process. The second feature, which may become more critical in certain geographic regions, is the ability of the process to accept higher levels of residual elements in the scrap mix. Thus, there is potential to pay lower prices for scrap when utilizing the CASTRIP process or, in regions where good quality scrap is in short supply, there is the ability to buy more local, lower-grade scrap at lower overall costs. As with integrateds, the ideal situation for a minimill producer would be at least 500,000 tons/year of excess liquid steel capacity that could be consumed by a CASTRIP facility.

Long Products Producers

The principal advantage offered by the CASTRIP technology for long products producers is that it allows them access to a niche market within flat rolled products without having to commit to ~1.5 million tons/year of casting and flat rolling capacity and commensurate capital. The smaller annual capacity of the CASTRIP process will allow a long products company easy entry into the TGHR or UTGHR markets, possibly on a local or regional basis. This would further allow the company to avoid competition with the larger, flat-rolled producers in a less competitive and growing market. As for the business scenarios presented above, the ideal situation would include an existing steelmaking site with available land and excess steelmaking capacity. An additional consideration for long products producers is that many grades are available from one steel composition and the steelmaking requirements are not onerous.

CONCLUSION

The preceding paper provides a discussion of the technology development, features and benefits plus the business implications of the CASTRIP thin-strip casting process. This technology is expected to create a new product category for steels known as TGHR (thin gauge hot rolled) and UTGHR (ultra thin gauge hot rolled). Lower energy usage, reduced emissions, smaller economies of scale, unique product microstructures and lower costs are expected to be among the main selling features of the CASTRIP process. Castrip LLC has assembled the intellectual property necessary to make the CASTRIP process a commercial success, from its joint venture partners Nucor, BHP and IHI and will begin licensing the technology worldwide following the commissioning of the Project ‘C’ caster. Cost advantages in the process and the structure of existing steel pricing will allow significant margins for CASTRIP technology licensees, as well as for steel users. The authors salute the minimill visionary and pioneer Dr. Heffernan and feel honored to present a paper at the Gerald Heffernan International Symposium. We anticipate the twin roll casting technology and the CASTRIP process will allow steel companies the means to tackle the next industry frontier, the Micro-Mill.

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