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The Castrip® Process for the Twin-Roll Casting of Steel – Start-up Experience at Nucor's Crawfordsville Plant

By

Peter Campbell, Castrip LLC
Gerry Gillen, Nucor Indiana
W Blejde and R Mahapatra, BlueScope Steel

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2100 Rexford Road, Charlotte NC 28211

Telephone: 704.972.1820 Facsimile: 704.972.1829

www.castrip.com

THE CASTRIP® PROCESS FOR TWIN-ROLL CASTING OF STEEL – START-UP EXPERIENCE AT NUCOR'S CRAWFORDSVILLE PLANT

Peter Campbell*, Gerry Gillen+, Wal Blejde# and Rama Mahapatra#

With hot commissioning started in early May 2002, Nucor Crawfordsville has become the first fully commercial strip casting facility in the world. Employing the CASTRIP® twin-roll casting technology, Nucor aims to cast steel strip at 1.0 to 2.0 mm in thickness with a width of between 1000 and 2000 mm. At casting speeds approaching 100 m/min, the Nucor caster is capable of producing 500,000 tons per year. Over the past decade, BHP Steel and IHI have developed the CASTRIP process through pilot plant and full-scale development facilities in Australia; Nucor joined the effort in 2000. The following paper includes a discussion of the key process metallurgy breakthrough areas associated with the technology and a brief background on its development. A description of the Crawfordsville CASTRIP facility is also provided.

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 Steel and IHI (Ishikawajima-Harima Heavy Industries) collaborated on twin-roll casting design at development facilities in Wollongong, Australia. The codename for this venture was Project 'M' and the project covered laboratory, pilot plant and full-scale development facilities. In 2000, Nucor Corporation joined forces with the team, forming Castrip LLC, a joint venture company aimed at commercializing the new technology. Construction is now complete at Crawfordsville, Indiana, also home to the world's first thin slab caster. Hot commissioning and casting trials began in early May and the Nucor plant is expected to ramp up commercial production over the next 6 to 12 months.

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 Nucor CASTRIP® facility at Crawfordsville, the direct casting of sheet products will become a commercial reality. The following paper describes some of the key process fundamentals of CASTRIP technology and provides details on the first installation at Crawfordsville. Physical properties for typical CASTRIP products are also included.

* Castrip LLC, Charlotte NC USA
+ Nucor Steel Indiana, Crawfordsville IN USA
# BHP Steel, Crawfordsville IN USA

PROCESS OVERVIEW

The CASTRIP process is based upon the same concepts that Henry Bessemer patented in the mid-19th century. Figure 1 shows a simple schematic of the basics of the process – two counter-rotating rolls that provide a surface or mold against which molten steel solidifies. As the figure indicates, the steel begins to solidify against the rolls just below the meniscus and shell growth continues as they move as it moves downwards through the melt pool. At the roll nip or pinch-point, the two shells are essentially fused together forming a continuous strip, which then exits the caster in a downward direction.

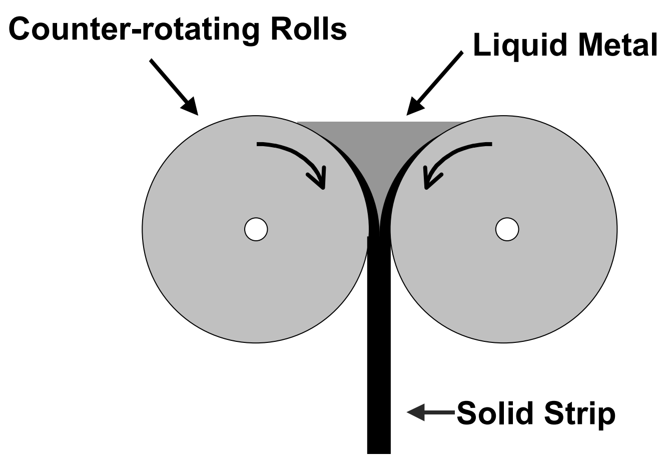


Fig. 1 – Simple schematic of twin-roll strip casting process.

Although the concept is extremely simple, its application at a commercially viable production level has proven to be extremely difficult. Several technical advancements have occurred in recent years that have made twin roll casting possible at a commercial level. These include:

- High speed computing and process control
- Advanced ceramics and materials (including copper alloys)
- Sensing technology
- Mathematical modeling of physical phenomena

In addition to these advancements, the Project 'M' team had to significantly increase the body of knowledge related to several key areas of process metallurgy directly connected to the twin-roll process. Previous papers have discussed the development of the CASTRIP process (1-4); these advancements or breakthroughs are what sets CASTRIP technology apart from other twin roll processes and can be divided into 5 key areas:

1. Metal delivery
2. Early solidification
3. Edge containment
4. Roll distortion
5. Refractories

Metal delivery - Metal delivery to the melt pool is critical for a number of reasons. Unlike conventional casting, the melt pool is very small in the CASTRIP process. This is particularly so due to the 500-mm diameter casting rolls, which are significantly smaller than rolls utilized in other twin roll casting projects (5). As a result, the ratio of mass flow rate into the pool divided by the pool volume is nearly an order of magnitude higher in the CASTRIP process compared to slab casting. Thus, the metal delivery nozzle or core nozzle utilized in the CASTRIP process is completely different than that used for conventional casting, with major emphasis on reducing the turbulence in the steel as it enters the melt pool plus theand the need for effective distribution of metal along the roll length. A further requirement of the metal delivery system is to provide metal to the meniscus in a stable and repeatable manner. Any disturbance at the meniscus invariably manifests itself as a strip defect; thus the process must be stable and in control at all times to ensure excellent surface quality.

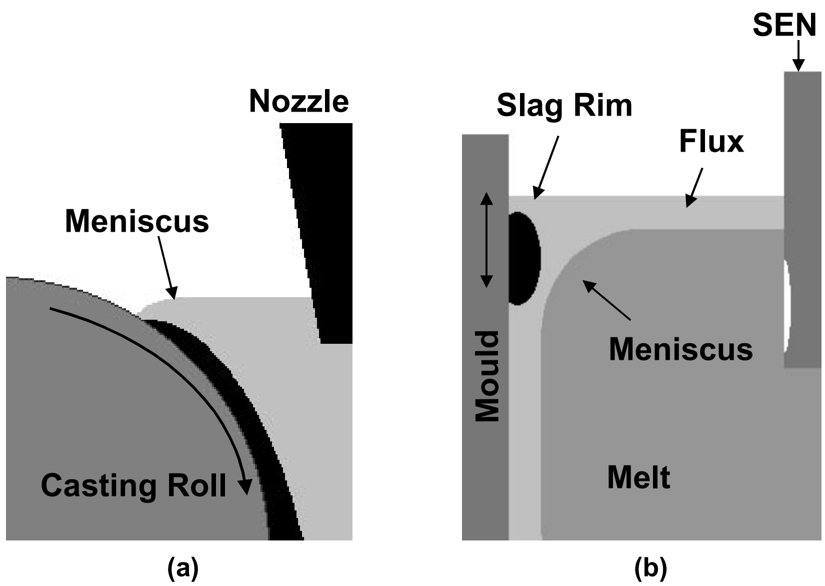
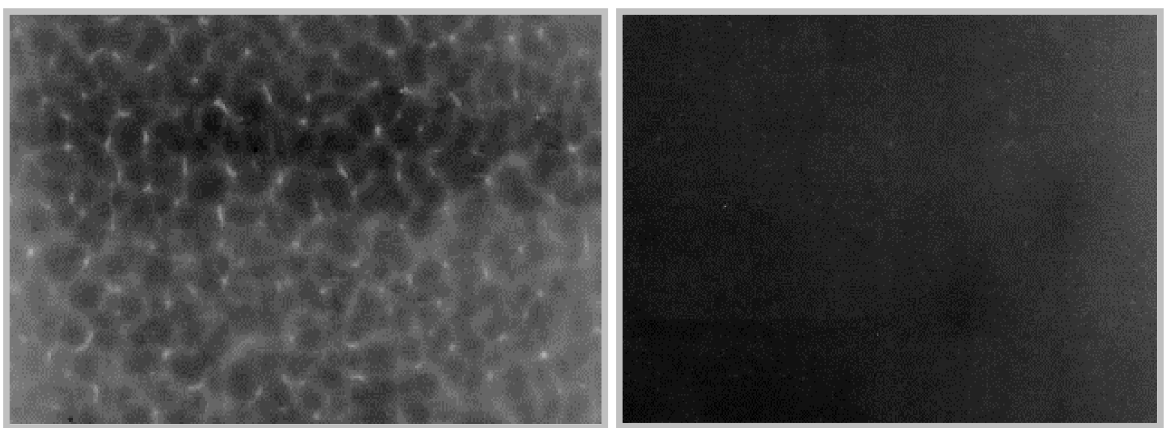


Fig. 2 – Comparison of the meniscus region in (a) the CASTRIP process and (b) conventional slab casting.

Early solidification - Most of the effort related to the understanding of solidification in steels has been confined to continuous casting over the past 20 years. There are some major differences between CASTRIP technology and slab casting that have significant effects on the formation and growth of the shell. Figure 2 shows a close-up of the meniscus area in both processes. Among the main differences between the two processes are, that the CASTRIP technology does not use any type of mold powder or lubrication and that the mold (roll) and steel shell remain in direct contactmaintain the same velocity, i.e. no mold oscillation. As a resultBecause there is no mold powder, there is significantly better contact between the roll surface and solidifying shell, starting at the meniscus and extending down to exit at the roll nip. Significant work has been done in trying to understand the mechanisms for shell formation and growth as well as heat transfer between the steel and roll surface. This work has been described previously by Mukunthan *et al*. (1) and it is critical that the variables affecting the early solidification of the shell and its subsequent growth be understood for the production of quality strip. Recently, independent research work at Carnegie Mellon University has provided further detail related to interfacial phenomena and the solidification of carbon steels during strip casting (6).

One of the many problems that can arise from poor control of solidification and uneven shell growth is depicted in Figure 3. As indicated in the X-ray map taken of a strip with poor solidification control (Figure 3 (a)), the formation of porosity is a result. This is because the uneven solidification of the shell creates an uneven solidification front, which can trap liquid steel below the roll nip. Bringing nucleation and early solidification under control results in a smooth solidification front, thereby preventing porosity (Figure 3 (b)).



(a) (b)

Fig. 3 – X-ray maps indicating the level of porosity in the solidified steel strip, (a) early casts showing porosity and (b) later casts with no porosity.

Edge containment – Although most of the surface area of the solidifying strip is confined to contact against the face of the rolls, the edge containment of the melt pool proved to be a technical challenge that required significant focus during the development of the CASTRIP process. The problem is related to the fact that freezing is most likely to occur in this area because of heat loss through the side dam material as well as through the rolls. Premature freezing can lead to poor edge quality as well as triggering a series of events that eventually lead to the cessation of casting. Many materials have been tested for use as side dams before a suitable refractory was found. Also, it was found that the design of the metal delivery system could greatly affect the performance of the side dam through the proper supply of liquid metal towards the edges of the melt pool. Figure 4 shows a typical untrimmed sidewall of a coil cast at Project 'M'.

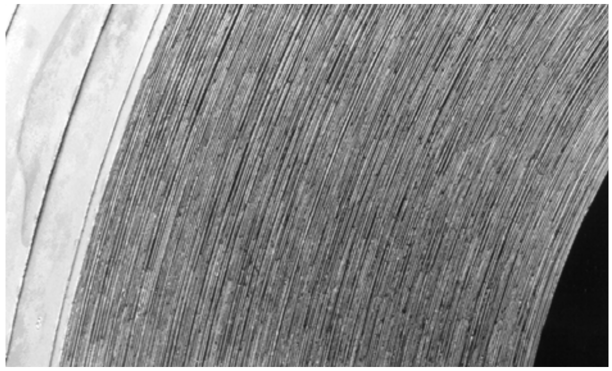


Fig. 4 – Photograph of typical coil sidewall produced with the Castrip process at Project ‘M’.

Roll distortion – Roll distortion is caused by the generation of thermal stresses as the casting rolls become heated by the solidifying steel. The proper design of casting rolls must take into account this unavoidable distortion in order to produce strip with a desired thickness profile. Previous publications have demonstrated the variation in heat flux and temperature across a casting roll (2). This work also showed that rolls with a machined in crown where the center is smaller in diameter than the edges will provide the optimum strip profile.

Refractories – The interaction between the liquid steel in the melt pool and the refractories utilized for the metal delivery nozzle hasve been shown to cause defects in the strip cast material (2). Active oxygen contained in the pool was shown to combine with carbon in the alumina graphite nozzle, resulting in the formation of CO bubbles. These bubbles caused disturbances at the steel surface and at the meniscus, where they inevitably resulted in surface defects in the strip. Defects caused by this mechanism have been eliminated through the selection of appropriate refractory materials.

Table I – Typical CASTRIP **UCS** product attributes as compared to conventional material.

		Typical CASTRIP® Products		
Attribute	**Units**	**As-Cast Product**	**In-Line Hot Rolled**	**Conventional Hot Rolled Product**
Yield Strength	**MPa**	300	320	250 - 300
Tensile Strength	**MPa**	440	450	380 - 450
Elongation	**%**	26	28	25 - 35
Surface Roughness	**μm**	1.5 – 2.0	~0.5	1 – 1.5
Surface Scale	**μm**	~2	~2	4 - 7
Centerline Gauge Variation	**mm**	± 0.054	± 0.034	*
Typical Crown	**mm**	0.05	0.05	0.025 – 0.075

* - ASTM Specification A568M Standard Thickness Tolerance for Hot-Rolled Sheet - ± 0.15 mm

The previous paragraphs describe the process metallurgy breakthroughs related to CASTRIP technology. Through this understanding plus process design, automation and control, the CASTRIP process has demonstrated the ability to make commercially acceptable product for a variety of applications. Details on the product attributes such as surface quality, dimensional control, mechanical properties and microstructure have been published previously (4), and some of them are summarized in Table I. The development work in Australia plus subsequent product evaluation by Nucor has shown that CASTRIP **UCS** (Ultra-thin Cast Strip) can be substituted for conventional hot and cold rolled steel sheet.

NUCOR'S CASTRIP PLANT

Construction of the Crawfordsville CASTRIP facility began in February 2001. Fed from the existing EAF shop located less than 0.5 miles away, the CASTRIP caster building includes a ladle metallurgy furnace (LMF) to make the necessary temperature and chemistry adjustments prior to casting. Figure 5 shows a sketch of the general building layout indicating a dimensions of approximately 135 meters in width and 155 meters in length. The total length of the casting operation, from ladle turret to coilers is only 60 meters. This is in contrast to a slab caster with reheat furnace and hot strip mill that typically requires 500 to 800 meters of length to make the same hot rolled products.

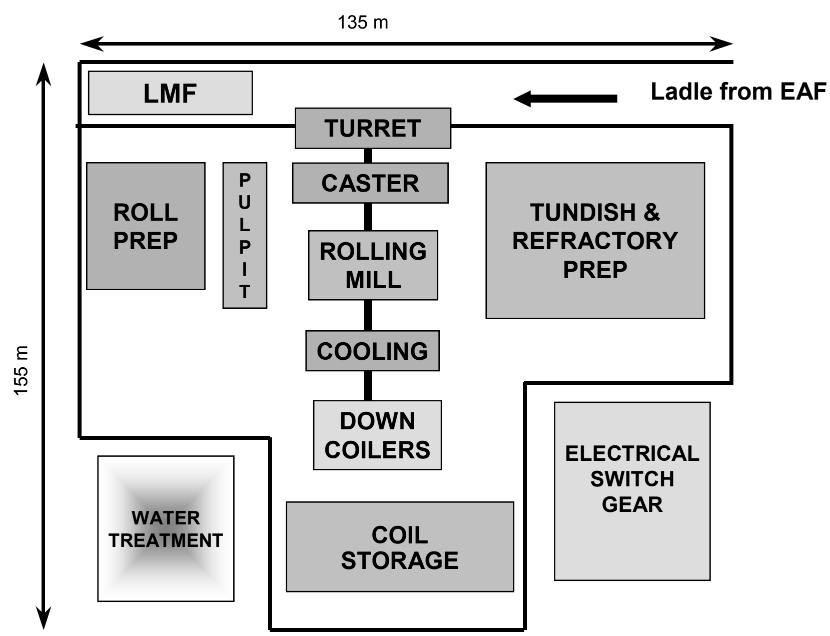


Fig. 5 – General layout of the Crawfordsville CASTRIP building.

A profile schematic of the Castrip facility is shown in Figure 6, indicating the main features of the process. The ladle and tundish are based on standard steel industry designs, as is the ladle turret (not shown). The tundish feeds a transition piece, which is situated just above the delivery (core) nozzle. The caster does not use a dummy bar for start-up. Upon exit from the casting rolls, the solidified strip is directed to a pinch roll and then through a hot rolling stand. In this transition, the atmosphere is controlled to limit oxide formation on the strip. Equipment from the hot rolling mill through the coilers is of standard steel industry design.

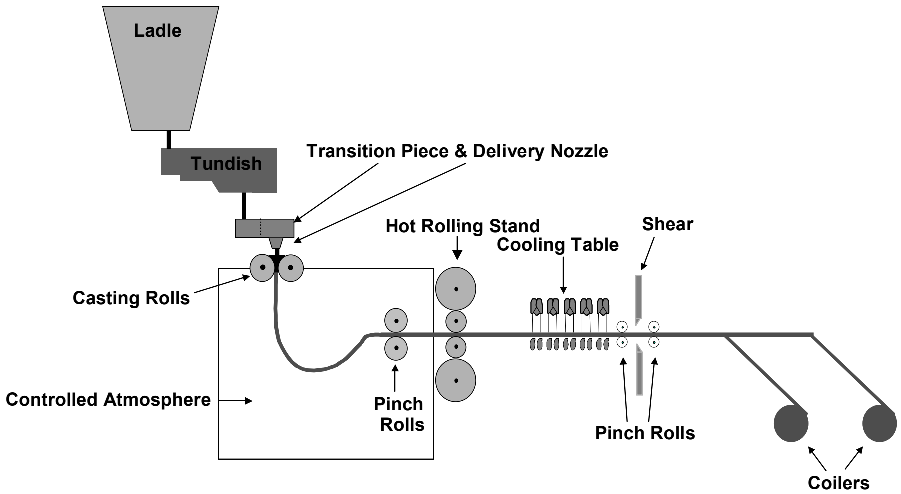


Fig. 6 – CASTRIP process schematic.

General specifications for the Crawfordsville CASTRIP facility are shown in Table II. Of particular note is the diameter of the casting rolls – 500 mm. This diameter is significantly smaller than other twin-roll casting projects and one of the main advantages of the CASTRIP process. Smaller rolls are less expensive to build, have a lower operating cost and are capable of producing thin, high quality cast products. The CASTRIP process has the capability of casting steel strip at 1.0 to 2.0 mm in thickness, plus a single hot rolling stand to reduce the material another 40%. At casting speeds of ~80 m/min and strip widths of 1345 mm and greater, the output of the plant is expected to be ~500,000 tonnes per year.

Table II – Crawfordsville CASTRIP Plant Specifications

Unit	**Specification (in metric units)**
Building Dimensions	155 m x 135 m
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
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

A photograph taken during commissioning of the CASTRIP plant at Crawfordsville is shown in Figure 7. The photo shows the strip emerging from the rolling mill with the caster deck and ladle in the upper background. The twin casting rolls are located below the ladle and behind the rolling stand.

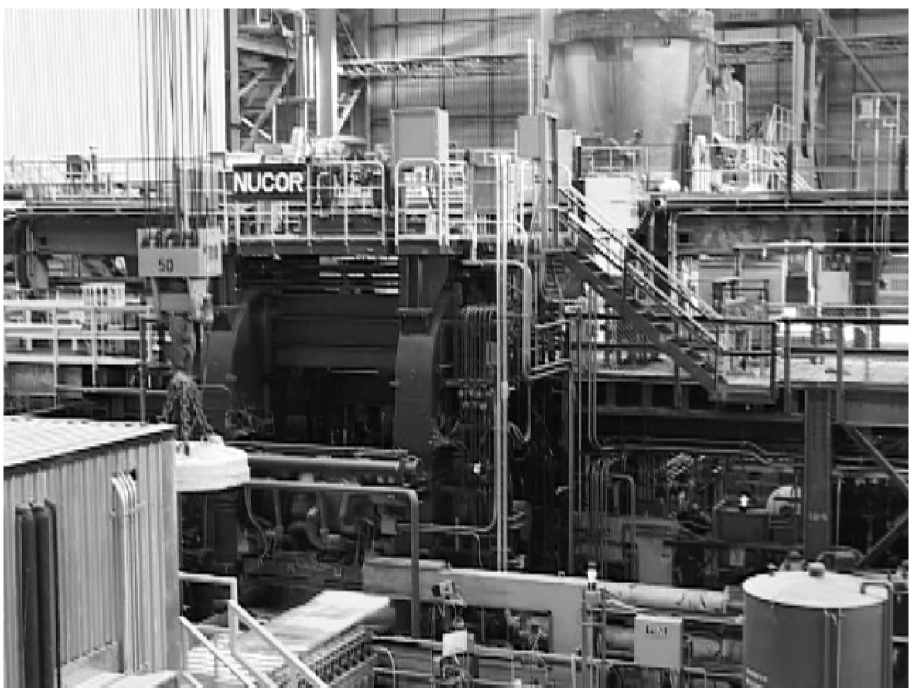


Fig. 7 – Photograph of Nucor's CASTRIP plant during commissioning. Note steel strip emerging from the single hot rolling stand.

CONCLUSIONS

The commercial-scale production of steel sheet products via the twin-roll casting process is imminent with the recent commissioning of Nucor's Crawfordsville CASTRIP facility. The production of flat rolled products utilizing the CASTRIP process has many advantages over conventional casting and rolling technology, including lower capital and operating costs, reduced energy usage and emissions, thinner higher value products and a smaller, more flexible operating dimensionsregime. Further, due to its lighter gauges (< 1.5 mm) and excellent surface quality, CASTRIP products can be substituted for cold rolled sheet in many applications and will likely create a new product category for flat rolled sheet products known as **UCS**.

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