Castrip LLC

FASTER

SMARTER

THINNER

BETTER

The Latest Developments With the Castrip® Process

By
W. Blejde, F.. Fisher – Castrip LLC
M. Schueren, G. McQuillis – Nucor Steel

The Tenth International Conference on Steel Rolling
Beijing, China
September 15-17, 2010

1915 Rexford Rd., Ste 150, Charlotte NC 28211

USA

Telephone: 704.972.1820

Facsimile: 704.972.1829

The Latest Developments With the Castrip® Process

Wal Blejde[1], Frank Fisher[1], Mike Schueren[2], Gary McQuillis[3]

(1. Castrip LLC, Charlotte, North Carolina, USA;

2. Nucor Steel, Crawfordsville, Indiana, USA;

3. Nucor Steel, Blytheville, Arkansas, USA)

Abstract: The twin roll casting of low carbon steel strip has progressed from the development stage carried out on semi industrial scale plants during the 1990s to commercial operation via the Castrip® process with two plants owned and operated by Nucor Steel in the USA that have produced over 1,000,000 tons of product. The Castrip process is producing a range of unique products with a much lower carbon footprint than any other strip manufacturing process and offers new licensees the strategic opportunity to enter the strip production business at a lower capital entry cost than was previously possible. This paper summarizes the current state of Castrip® technology.

Key words: Twin roll casting, UCS products, Castrip process, carbon footprint, near net shape

1. Introduction: Castrip a New Manufacturing Paradigm

The development of low carbon steel strip casting technology began in the late 1980's with the aim of developing a process capable of providing an economical feed material for regional cold rolling mills. However, it soon became obvious that the rapid solidification associated with the process enabled products with very unique microstructures and superior properties that in fact could directly replace cold roll material in many applications.

The consolidation of the world's steel industry into a smaller number of large companies has generated a need on the part of a significant number of medium to small scale coil conversion enterprises around the world to regain control of their supply chain. The scale of the Castrip process provides an affordable path to backward integrating these businesses to secure their coil feed, and increase their total profit margins. In addition to these coil processors, existing steel plants producing long products are afforded a low capital cost entry into the coiled sheet production business and are thus able to direct their liquid steel to the more profitable market segment (long products versus sheet products) during any business cycle. The unique features of the Castrip process enables these producers to use the same high residual scrap for sheet production that is used for their long products operation, thus further enhancing profit margins.

Currently there are two commercially operating Castrip plants, both owned and operated by Nucor Steel in the USA. One is on the site of a classic sheet mill business using thin slab casting which was pioneered by Nucor in 1989 at Crawfordsville, IN, USA. The second Castrip facility is on the site of Nucor's beam production facility at Blytheville, AR, USA. Castrip technology has generated a lot of interest worldwide, however potential licensing opportunities for Castrip technology outside of the USA have been temporarily put on hold pending resolution of the current world financial crisis and it is expected that the first offshore Castrip plant will closely follow the rebound of the world economy. At the time of writing this paper in excess of 1,000,000 tons of sheet steel have been produced by the Castrip process.

This paper will summarize the current status of Castrip technology.

2. The Basic Castrip Process

2.1 The Casting Process

Details on the Castrip process have been extensively published elsewhere (Ref:1,2,5,6)

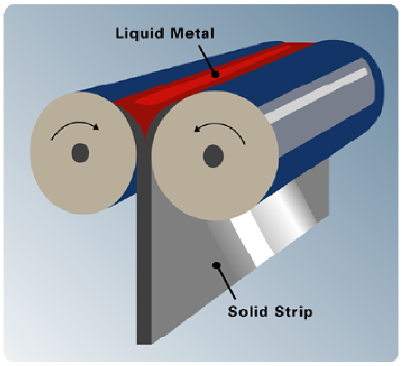

Fig. 1 Simple schematic of twin-roll casting.

The heart of the process consist of 2 water cooled rotating copper rolls (see Fig. 1) each 500mm in diameter on which liquid steel solidifies into 2 separate shells which are brought together at the roll nip to produce an as-cast strip that then undergoes thermo-mechanical treatment via an inline hot rolling mill and a cooling table.

The Castrip process produces very unique products by virtue of its rapid solidification regime which is highlighted in Table I which compares the Castrip process key parameters with those of thin slab and conventional slab casting.

Table I Comparison of fundamental casting parameters among the CASTRIP process, thin slab casting and thick slab casting

	CASTRIP® Process	Thin Slab Casting	Thick Slab Casting
Strip Thickness (mm)	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

A typical plant schematic is presented in Fig. 2 which shows that the cast strip exits the casting rolls into an enclosure with a controlled atmosphere called the "hot box" after which it goes to a single in line hot rolling mill, then onto a cooling table for mechanical property evolution and finally onto a coiling station via a pinch roll and shear.

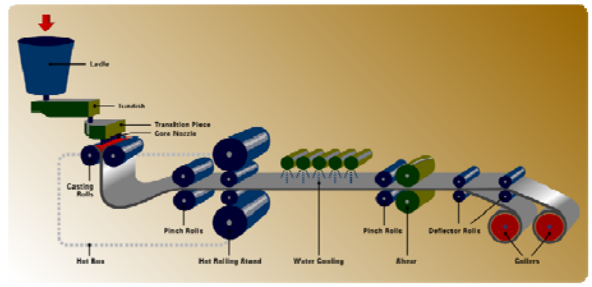

Fig. 2 Main components of the CASTRIP process

2.2 In Line Hot Rolling

One particular Castrip process challenge arises from the attempt to use a single rolling stand to produce a cold roll replacement material. Thus rather than refine the incoming microstructure as is the case in conventional hot rolling, the Castrip process maximizes the benefits of the initial coarse austenite grain structure and the engineered inclusions within the steel to produce a range of very unique steel products. The main functions of the rolling mill include:

- Ensure no centerline porosity in the strip product
- Improve surface quality
- Increase gauge flexibility
- Produce a strip of satisfactory dimensional tolerance and flatness

The existence of a loop of thin strip, at higher temperatures than encountered in conventional hot mills, has made strip tension control and strip steering immediately before the rolling mill particularly challenging. A new patented pinch roll design in conjunction with innovative process control strategies has enabled stable hot rolling. In addition to the above, hot rolling of cast strip poses unique flatness and profile control challenges which have required a novel control strategy for the mill. Fig. 3 (ref 3) summarizes the method used to optimize strip profile and flatness against the incoming cast strip profile.

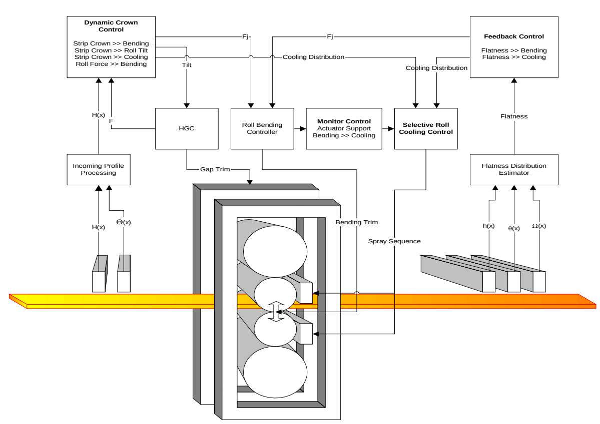

Fig. 3 Mill control philosophy

The strip entering the roll bite of the rolling mill is essentially scale free (unlike conventional hot rolling mills that have the benefit of a minimal amount of scale for roll bite lubrication) and, in the absence of any means to control roll bite lubrication, the strip will weld to the work rolls and cause severe roughing of the surface as shown in Fig. 4.

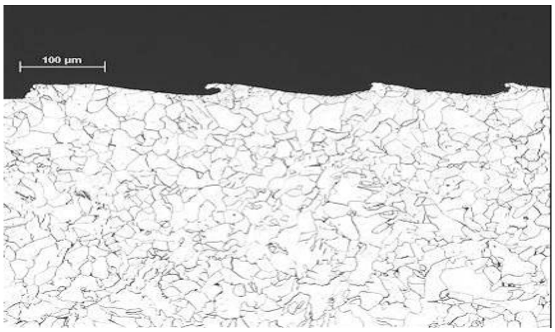

Fig. 4 Showing the impact on the strip surface caused by strip welding onto the work roll surface

This problem has been solved by developing unique roll-bite cooling and lubrication strategies that enable post rolling surface roughness figures (Ra) of about 1 micron.

3. Castrip Plant Specifications

A typical section through a Castrip plant is presented in Fig. 5. The typical line length is of the order of 50 meters and typical ladle sizes can range from 70 to 110 metric tonnes.

The first Nucor Castrip plant was hot commissioned in Crawfordsville Indiana, USA in May 2002 and the second in Blytheville Arkansas, USA in October 2009.

A comparison of the Nucor Crawfordsville and Blytheville Castrip plants is presented in Table II.

Table II Comparison of Crawfordsville strip caster general specifications versus the specifications for the Blytheville plant

Unit	Crawfordsville Specification	Blytheville specification
		
Casting line length (centre turret to no. 2 coiler)	58.68m	49.0m
Pass line elevation	EL+800mm	EL+3680mm
Ladle heat size	110 tonnes (metric)	110 tonnes
Tundish weight	18 tonnes	18 tonnes
Caster type	500 mm diameter twin roll	500 mm diameter twin roll
Max caster width	1345 mm	1680 mm
Steel grade	Low carbon Mn/Si killed	Low carbon Mn/Si killed with high residuals
Product thickness range	0.76 to 1.8 mm	0.7 to 2.0 mm
Casting speed	65 m/min typical, 120 m/min max	65 m/min typical, 120 m/min max
Max coil size	25 tonnes	25 tonnes
Inline rolling mill	Single stand, 4 high with hydraulic roll bending and automatic flatness control with work roll zone cooling	Single stand, 4 high with hydraulic roll bending, automatic flatness control, work roll shifting and zone control cooling
Work roll dimensions	475 mm x 2050 mm	560 mm x 2100 mm
Backup roll dimensions	1550 mm x 2050 mm	1350 mm x 1900 mm
Maximum rolling force	30 MN	27.5 MN
Cooling table	10 top and bottom headers	10 top and bottom headers
Coiler size	2 x 40 tonnes with belt wrappers	2 x 32 tonnes with belt wrappers
Coiler mandrel	762 mm	762 mm
Annual capacity	540 kt/yr	674 kt/yr

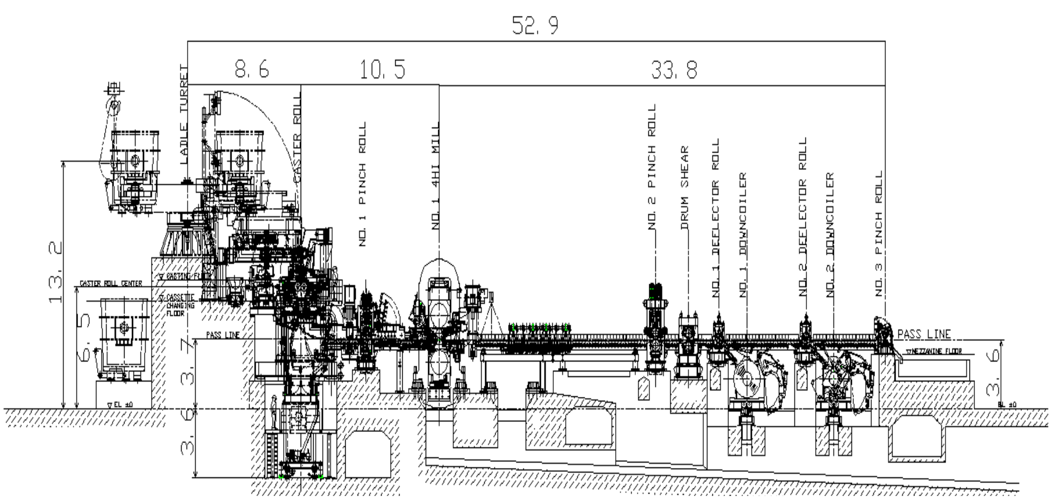

Fig. 5 Typical section through a Castrip Plant

A number of enhancements were introduced into the Blytheville plant design. These include:

- Capability of wider casting- up to 1680 mm cast width, increasing the annual capacity to 680k tpa
- Single pass casting roll cooling with alternate feed giving much lower temperature rises and more uniform temperature profile along the roll barrel and around the roll circumference
- Balanced casting roll cassettes with superior roll gap and force control
- Inline work roll shifting
- Upgraded automation system
- Revised layout of casting deck mechanicals for higher productivity
- Elevated pass line to reduce foundation costs
- Enable use of low cost scrap mix for higher margins
- Spray mist cooling and a shorter roll table

4. Engineered Products with Unique Performance

4.1 Strip Dimensions

The thickness versus width domain for the Castrip process is presented in Fig. 6 which shows that the Castrip process is ideally suited for thin material (<2.0mm) and wide material (>1100mm wide)

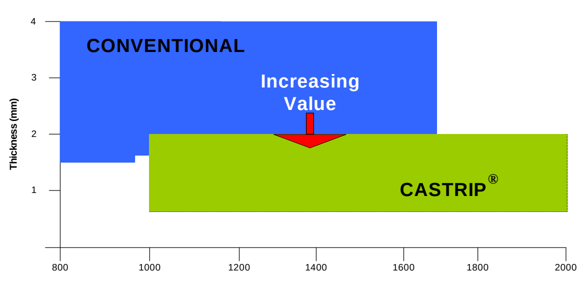

Fig. 6 Contrasting the thickness vs width domain of Castrip with conventional hot strip production

4.2 Strip Properties

The range of product regimes currently being supplied by the Castrip process or under development is presented in Fig. 7.

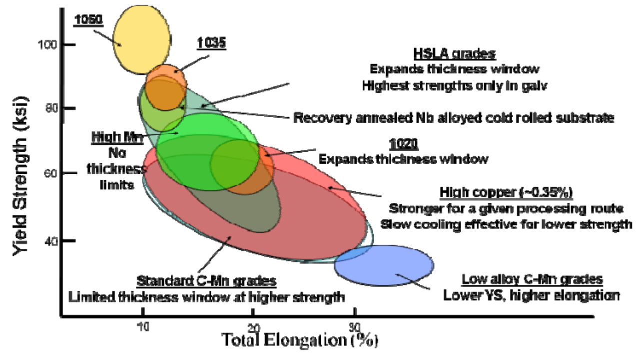

Fig. 7 Expanded Product Range

4.2.1 Microstructure Evolution

During the production of Castrip product known as UCS (Ultra-thin Cast Strip), great care is taken to produce uniformly dispersed, engineered inclusions prior to solidification and then to optimize austenite grain size during rolling. This enables the evolution of novel uniform microstructures that produce unique mechanical properties.

An example of how the microstructure can be developed on a cooling table after hot rolling to take advantage of the engineered inclusions is presented in Fig. 8 (ref 4,7). Fig. 8 shows how, following medium intensity cooling, allotromorphic ferrite will evolve on austenite the grain boundaries and then a very uniform acicular ferrite matrix will be stimulate by the engineered inclusions uniformly dispersed in the original austenite matrix.

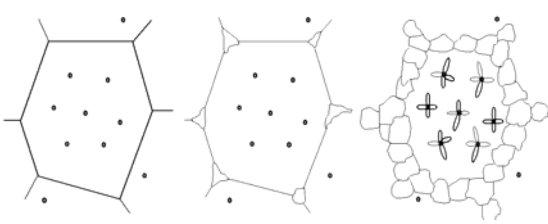

Fig. 8 Schematic representation of the formation of acicular ferrite microstructures. [11]

Fig. 9 shows a sample of globular inclusions produced in UCS, whilst Fig. 10 presents an actual micrograph of acicular ferrite growing from an inclusion.

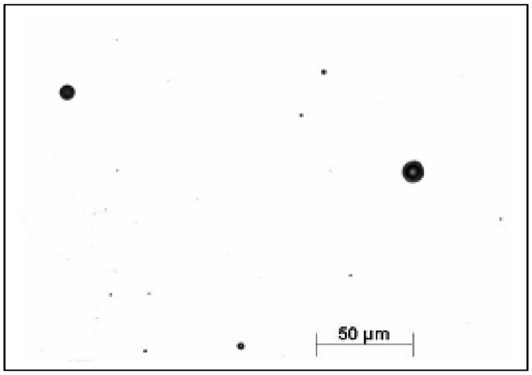

Fig. 9 Globular inclusions found in UCS steel.

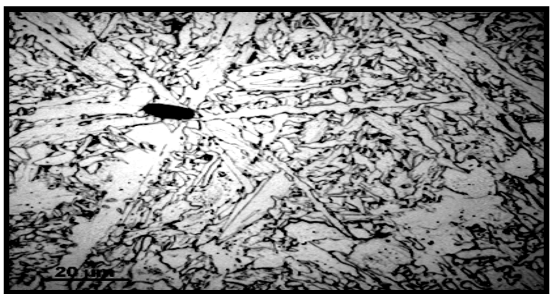

Fig. 10 A micrograph showing acicular ferrite growing from an inclusion

As a consequence of the very uniform microstructure, Castrip UCS can exhibit superior mechanical properties over conventionally produced steel strip. One specific example that highlights the performance of UCS is the hole expansion ratio tests. The hole expansion test (shown in Fig. 11) involves taking a sheet and punching a 10 mm hole and following this by a conical expander until the material begins to develop cracks on the hole circumference.

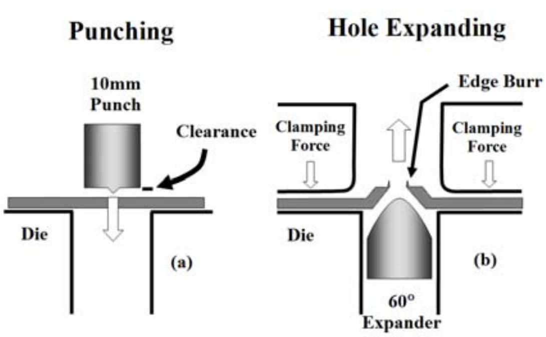

Fig. 11 Hole expansion test

The results are expressed as the hole expansion ratio "(λ_p)" which is the ratio of the change in hole diameter divided by the original hole diameter.

$$\lambda_p = \frac{d_f - d_0}{d_0} \times 100\% \qquad \textbf{Equation 1}$$

Where d_0 and d_f are the initial and final hole diameters.

A comparison of UCS with yield strengths of 275 and 380 MPa with conventionally produced hot roll (HR) material of yield strengths 200, 300 and 360 MPa and conventionally produced cold rolled and annealed (CR&CA) of yield strengths 300 and 350 MPa is presented with in Fig. 11 which provides a graph of hole expansion ratio vs tensile strength for all of these steels.

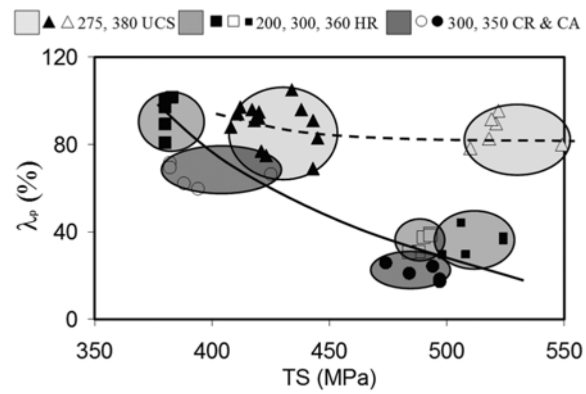

Fig. 12 Effect of production route on the relationship between tensile strength (TS) and the hole expansion ratio (λ_p).

At low tensile strengths around 425 MPa, UCS and conventionally produced sheets are comparable in performance: however, UCS performance is vastly superior at TS>450 MPa.

5. Reduced Carbon Footprint

The Castrip process by virtue of the fact that it casts near net shape product dimension eliminates the need for slab reheating, multiple rolling steps (including cold rolling), and annealing, and thus requires far less energy than conventional strip production processes to convert liquid steel into final product. The green house gas production expressed as metric tonnes of CO2 per tonne of product for the Castrip process against other production routes is well documented (ref 8) and is presented in Fig. 13 . From Fig. 13 it can be seen the Castrip process achieves about 80% reduction in green house gases when compared to all other conventional strip production processes.

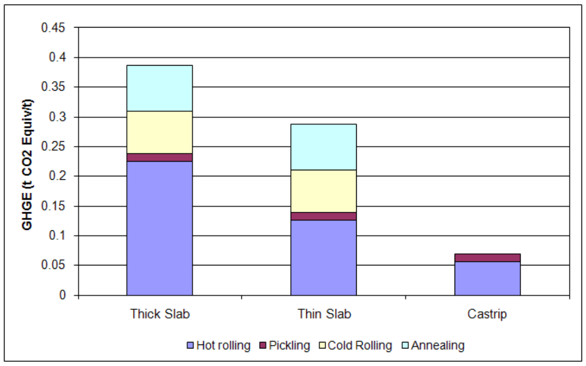

Fig. 13 Comparison of CO_2 emissions for the thick slab casting, thin slab casting and Castrip for the cold rolled products option, i.e. including hot rolling, pickling, cold rolling and annealing.

6. What is next?

Key directions for the future include:

- Continue to expand the steel grades available
- Continue to reduce the minimum thickness offering <0.5mm?
- Continue to expand product applications- "market pull"
- Continue to reduce strip scale levels
- Continue to increase strand productivity
- A worldwide network of Castrip plants

7. Conclusion

Two Castrip plants operated by Nucor Steel in the USA have produced in excess of 1,000,000 tons of strip product. The second generation Castrip plant provides the opportunity to contemplate even thinner and more exciting products whilst taking advantage of low quality (high residual) scrap.

The Castrip process provides an attractive low capital cost entry into the production of sheet steel that can replace cold roll steel in many applications with products that exhibit unique mechanical properties and thus provides a viable route for economic backward integration for existing sheet steel converters.

In addition to the opportunities to produce a range of unique steel qualities, the Castrip process has a much smaller carbon footprint than conventional strip production processes and will make a significant contribution to climate change control.

References

[1] W. Blejde, R. Mahapatra and H. Fukase: "Application of Fundamental Research at Project M", The Belton Memorial Symposium Proceedings, 2000, 253-261.

[2] R. Mahapatra, W. Blejde, G. Gillen, P. Campbell, and R. Wechsler, "The Status of Twin-Roll Strip Casting Technology – CASTRIP® Process", SCANMET II Proceedings, Vol. 2., 161-172.

[3] D Britanik, S. Domanti, J Mueller, G Wallace, W Blejde, "The road to hot strip mill flatness control", 9th International Steel Rolling Technology Conference, June 2006, Paris, France

[4] C. Killmore, H. Creely, A. Phillips, H. Kaul, P. Campbell, M. Schueren, J.G. Williams and W. Blejde, "Development of Ultra-Thin Cast Strip Products by the CASTRIP® Process", AISTech 2007 Proceedings, May 2007.

[5] M Schueren, P Campbell, W Blejde and R Mahapatra, "The Castrip Process-An Update on Process Development at Nucor Steel's First Commercial Strip Casting Facility", AISTech 2007 Proceedings, May 2007

[6] R Mahapatra, W Blejde. F Fisher P Campbell, G McQuillis,"The Castrip process-the current status of commercial low carbon steel strip casting", Stahl und Eisen, 128 (2008),107-111

[7] D Edelman, P Campbell, C Killmore, K Carpenter, H Kaul,J Williams and W Blejde,"Recent Developments with Ultra-Thin Cast Strip Products Produced by the Castrip Process" AISTech 2009 Proceedings, May 2009.

[8] M Schlichting, J Ondrovic, P Woodberry and D Michael, "Energy and environmental advantages with the Castrip process", Stahl und Eisen 129 (2009),44-51