Progress in the implementation of the CASTRIP process

The direct casting of 1.2–1.6mm carbon steel sheet at Nucor’s, Crawfordsville Castrip plant is approaching commercial viability, with output rising rapidly, primarily for use in construction products.

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The world’s first commercial installation for direct casting of low-carbon steel sheet utilising CASTRIP technology is undergoing production ramp-up at Nucor Steel’s plant in Crawfordsville, Indiana. Construction of the plant began in February 2001 and the first ladle was delivered to the caster in May 2002. Since then, Nucor Steel has been working with technology partners BlueScope Steel (formerly BHP Steel) and IHI (Ishikawajima-Harima Heavy Industries) to fully commercialise this exciting new technology for the direct production of steel sheet less than 2mm in thickness.

Background

The CASTRIP process was jointly developed by BlueScope Steel and IHI, under the codename Project ‘M’. Following laboratory scale research through the 1980s, the companies agreed to collaborate on a larger scale project; at first a pilot plant, then a full-scale development plant. The original focus for the joint project was the casting of stainless steel (Grade 304) sheet between 2 and 3.5mm. However, during the mid 1990s, Project M was re-focused to the direct casting of low carbon steels for the construction industry.

BlueScope Steel is Australia’s premier flat rolled steelmaker and a significant portion of its output is directed at construction markets. After more than a decade of successful development and more than 30,000t of strip produced, BlueScope and IHI agreed that the technology was ready for full commercialisation. In late 1999, Nucor Steel joined the consortium and built a commercial plant at Crawfordsville, the same site as the world’s first thin-slab casting plant, commissioned in 1989. Construction of the new facility was initiated in late February 2001. Following 14 months of construction and cold commissioning, the first ladle was delivered to the Castrip facility on 3 May, 2002. Since that time, the plant has steadily made progress towards full commercial production of Ultra-thin Cast Strip (UCS).

Castrip LLC is owned jointly by BlueScope Steel (47.5%), IHI (5%) and Nucor (47.5%). All of the intellectual property, ie, patents, trademarks, trade secrets and know-how, associated with Castrip technology, are owned by Castrip LLC. Since the formation of the company, Castrip LLC has signed agreements with key technology partners; Siemens as the exclusive providers of automation for the technology, Hatch Associates for feasibility studies, engineering and construction management, and Danieli & Co. as providers of non-core equipment and complete plants.

Plant and process outline

The CASTRIP process, similar to all twin-roll casting operations, utilises two counter-rotating rolls to form two individual shells that are formed into a continuous sheet at the roll nip. A simple schematic in Figure 1 indicates liquid metal, rolls and the solid sheet. Although the concept of casting a continuous sheet in this manner was developed some 150 years ago by Sir Henry Bessemer, it is only in the past decade or so that availability of high-speed computing, advanced materials, fundamentals of early solidification and industrial casting know-how have been combined to provide the basis for a commercial technology.
The main components of the Nucor facility are shown in Figure 2. The process begins with a ladle of steel above the tundish. The ladle size is 110t, and both ladle and tundish are identical to those used at the thin-slab caster. The existing EAF shop, some 500m away, provides steel to the Castrip facility via a rubber-tyred carrier. An aerial view of the Crawfordsville site indicating the location of the Castrip facility and the existing meltshop is shown in Figure 3.

In addition to the main casting components, a ladle metallurgy station trims composition and temperature to final casting requirements. Referring to Figure 2, the tundish is located directly above a smaller tundish, or transition piece, that is designed to reduce the head of the liquid steel as well as distribute it across the barrel length of the casting rolls. The core nozzle receives streams of liquid steel from the transition piece and sits between the casting rolls, immersed in the melt pool. As casting proceeds and the liquid steel is transformed into a solid sheet, it exits downwards into a free loop below the casting rolls.

The casting speed is roughly 80m/min at a width of 1,345mm and solid strip thickness of typically 1.6mm or less. In order to limit scale formation on the strip surface, a protective atmosphere is maintained through use of a ‘hot box’, which contains the strip until entry into the hot rolling stand. Pinch rolls, located just before the stand as well as further down the run-out table, maintain tension on the strip. The in-line hot rolling stand is capable of up to 50% reduction of the sheet, however typical reductions are less than 30%. Two coilers, shown at the end of the line in Figure 2, allow continuous operation of the casting process with a typical coil weight of 20t.

A photograph of the Castrip process at Crawfordsville is shown in Figure 4. A ladle of steel is located at the top centre of the photo. The in-line rolling stand (identified by the Nucor sign across its top) can be seen in the middle of the photo. The corrugated steel structure straddling the line downstream of the rolling stand is a surface inspection station. Steel strip can be seen on the line, entering the cooling area. The second pinch roll and shear are located in the bottom right-hand corner of the photograph, however, not visible are the two coilers, which are to the bottom right just outside the field of view. Owing to the presence of the hot box containment system it is not possible to see the strip until it exits the rolling mill. Figure 5 shows the strip on the run-out table at the rolling mill exit. The steel is approximately 1,000°C at this point.
The solidification fundamentals of the twin-roll casting process are quite different to conventional or thin-slab continuous casting. In particular, the interface between the solidifying shell and the mould surface is created and maintained in a completely different manner. Whereas mould powder is used in continuous casting, the Castrip process does not employ any form of powder or lubricant. Further, the shell and the casting roll travel rotationally in intimate contact down through the melt pool, unlike conventional continuous casting where the mould is oscillated to break contact and facilitate withdrawal of the slab. Table 1 shows values of some key casting parameters compared to conventional thin- and thick-slab casting. As can be seen, the Castrip process operates in a regime of heat transfer that is an order of magnitude higher than conventional casting methods. This produces an extremely high cooling rate, resulting in a high rate of productivity for a small casting unit and a very fine solidification microstructure.

Commissioning progress
The first heat was delivered on 3 May, 2002. At that time, the plant was operating with two crews on a 5-day per week basis. Although the operating equipment was essentially the same as that used at the Project M development plant, there were some critical new designs that were being used for the first time. These included the cassette system for quick changing of the casting rolls and the hot box strip containment system after casting. (Although it is referred to as a hot box there is no additional source of heat within the system). The plant slowly advanced through the casting/commissioning process, achieving the first full-sized coil within six weeks, followed by the first sequence cast by mid-July. As is the case in any start-up, a number of small issues and delays had to be overcome. Casting progressed through the end of 2002, with improvements in productivity, quality and sequence length, and total production for the six months of casting in 2002 was just below 16,000t. In late 2002, two crews were added so that the plant could be operated on a 24–7 basis.

Despite the progress, it became clear during early 2003 that the process was not performing at the same technological level as had been the case at Project M in Australia. The first half of that year was spent investigating the fundamentals of the process to determine differences between casting conditions in Crawfordsville and Australia. By July, a breakthrough in understanding was achieved.
resulting in a step-change in product quality and casting reliability. Figure 6 shows the quarterly production beginning in mid-2002. As can be seen, a significant jump in production occurred during the latter half of 2003 and this trend is expected to continue into 2004 and beyond. Although this facility has a design annual capacity of 500,000t, throughput is currently limited by the EAF capacity. However, this situation will be altered by mid-2004 as Nucor has recently received permits required to boost bag house and hence meltshop capacity. As a result, the Castrip plant is expected to produce 110,000t in 2004 with a considerably higher output in 2005.

With the step-change in castability and reliability of the process achieved in mid-2003, commissioning work turned to increasing the sequence length of steel through the casting machine. In September 2002, two-ladle sequences became the standard and by October, a series of three-ladle sequences showed success, followed later that month with the first four-ladle sequence. The first coil from the fourth heat in the four-ladle sequence is shown in Figure 7. Figure 8 shows two ladles on the turret; the full ladle is in the background rotating into the casting position while the empty ladle in the foreground is being removed. As is the case for any casting operation, the number of heats that can be cast per sequence is a critical factor in the economics. Calculations on conversion costs, particularly related to refractories, indicate that the process is viable with a minimum of three-ladles per sequence or ~330t. One of the critical refractory components is the pair of side dams which contain the steel at the ends of the casting rolls. The side dams are relatively expensive and have high demands for strength, wear resistance and thermal stability. Excellent performance has been made in understanding the critical variables controlling side dam life and current practice shows that three-ladle sequences and beyond are practical for the this process.

The sale of products from the Castrip process has been progressing steadily since mid-2002. To date production is some 75,000t of UCS products. Initially, the majority of the UCS had been sent to Nucor’s finishing lines at Crawfordsville for pickling, cold rolling and galvanising. This provided plenty of opportunity for inspection, testing and analysis of the product performance. Further, early sales were limited to Nucor’s building product divisions where they were roll formed into applications such as structural deck. Once again, roll forming operations were closely monitored for product performance. Over time, product applications have broadened to include external customers and for a variety of applications, primarily in the construction industry. Small samples from some of the typical end uses are shown in Figure 9. Recently, Nucor has begun to sell more UCS coils as replacement for light-gauge hot rolled in applications such as tubing.

Currently, the Crawfordsville facility is capable of making three structural grades of steel sheet, based on ASTM A1011M; Table 2 illustrates properties for the SS Grade 275 material. Trial material has also been exported to potential licensees for Castrip technology during late 2003. That material is being evaluated for application in a series of markets.
Conclusions and next steps

The start-up of the Castrip process at Nucor’s Crawfordsville plant marks the first commercial strip casting installation for the production of plain carbon steels. Commissioning has been proceeding well, although not without the normal challenges of a new technology.

To date, the Castrip process has demonstrated the following key strip casting milestones:

- Product quality of UCS has been shown to be suitable as a direct substitute for hot-rolled coil as well as feed for cold rolling operations
- Strip thicknesses as thin as 1.1mm have been produced, although the majority have been between 1.2 and 1.6mm
- UCS product has been galvanised without cold rolling, with properties suitable for construction applications
- Sequence lengths of three ladles and greater (more than 330t) have been regularly achieved. This is a critical factor for process economics
- Operating costs per tonne are constantly being reduced as throughput continues to climb. Critical cost elements (refractories, casting rolls) are performing at expected levels
- In addition to low-carbon grades, trial casts have been performed on stainless steel (Grade 409) with promising results

Still to be confirmed are the overall conversion costs and life of other critical components. This information will be obtained as the plant works its way towards full operating rates over the next year or so. The strategic vision of the Castrip technology has been to enable the production of wide, very thin carbon steels with conversion costs competitive with the best alternative conventional processes, but at a much smaller scale. All of the actual results to date indicate that this vision will be achieved.

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