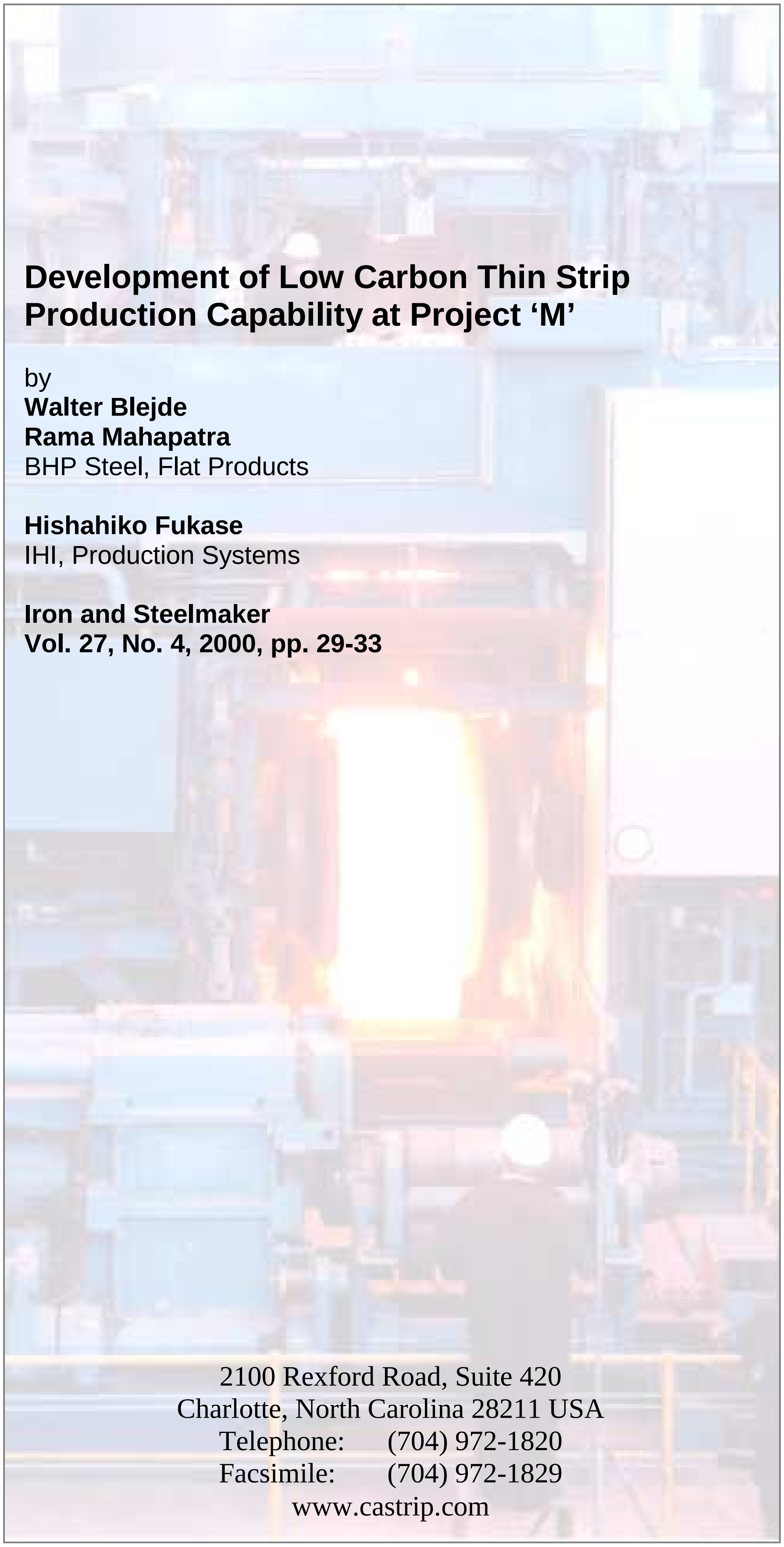
Faster

Smarter

Thinner

Better



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Key Words: Strip casting, twin rolls, thin strip, cold roll replacement, in-line rolling.

INTRODUCTION

Since February 1995, BHP and IHI have been collaborating on the development of low carbon steel strip casting technology using the twin roll process on a commercial scale development plant located at Port Kembla, Australia. Details of the plant layout, operation and machine specification have been described elsewhere [1].
Figs. 1 and 2 show a photograph and a section view of the plant.

Fig. 1: Interior of the development plant

The initial business vision for Project "M" was to develop a technical capability for casting strip in the thickness range of 1.8 to 2mm that could be used as feed for cold rolling mills. This milestone was achieved in December 1997 with the production of first commercial quality low carbon Si-killed steel coils (2mm x 1345mm). An extended casting campaign was further undertaken in the middle of 1998 to confirm repeatability of the casting process for this operating regime. Details of the cast product quality have been described elsewhere [1]. Material produced was successfully side trimmed, pickled, cold rolled to 0.42mm thickness, and then metal coated (Zincalume® (55%Al/45%Zn) and Galvanized), painted and roll formed into a number of roofing and walling profiles. The final product was utilized in actual building projects.

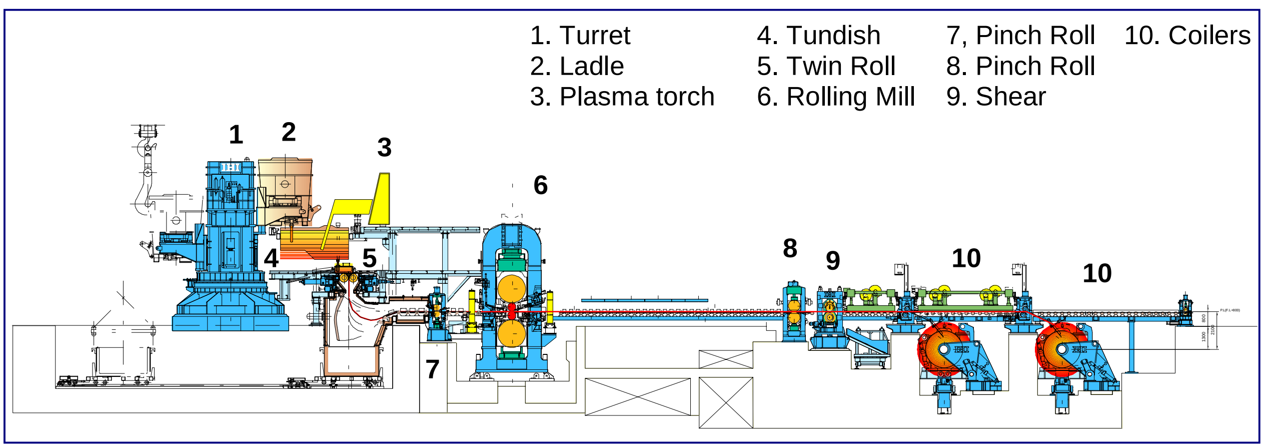


Fig. 2: General Arrangement of the Port Kembla Development Plant

In addition, a limited quantity of as-cast material was converted to pipes (21.3mm to 88.9mm diameter sections) and tubes (25x25mm and 50x 50mm square sections).

After demonstrating a capability to cast 1.9mm thick material for cold mill feed, development efforts were directed towards increasing the caster productivity from 40 t/m/hr to 60 t/m/hr and also on the production of thinner gauge material specifically down to 1.0mm thick strip (see Fig. 3). The business driver for this direction was to improve the economics of strip casting by firstly improving the return on capital invested (by improving productivity to the point where a typical plant would produce around 500kt/a) and secondly producing a product that can compete in specific markets with material currently supplied via the cold rolling process.

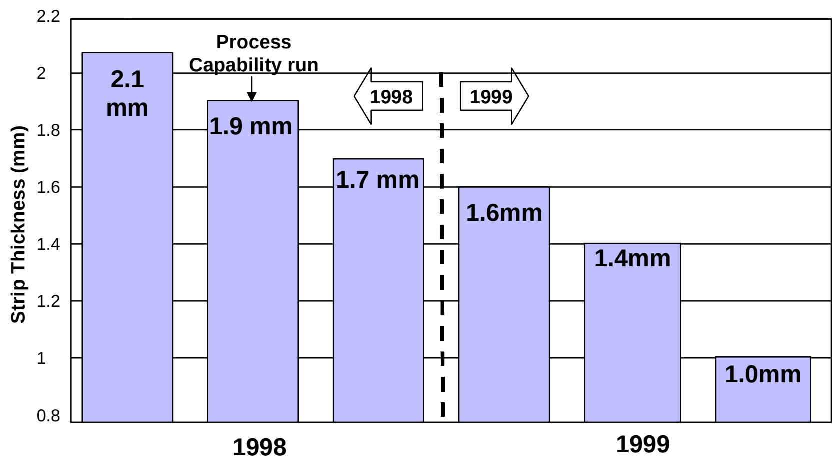


Fig. 3: Thin strip development trajectory

This paper presents the results achieved to date from thin strip development work with a focus on product quality, properties and product processing trials.

THIN STRIP CASTING OVERVIEW

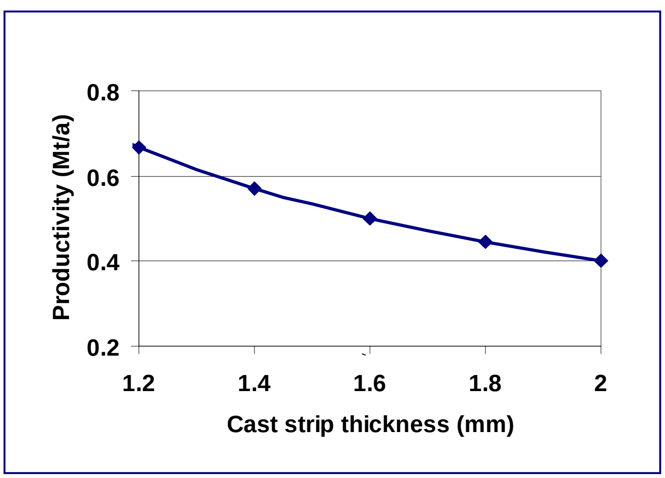


Fig. 4: Effect of cast strip thickness on machine throughput (1233 mm wide, k-factor=16.25, Yield=94.1%)

The twin roll casting process is ideally suited for producing thin strip. Machine throughput in strip casting increases with decreasing strip thickness unlike conventional strip production processes where productivity declines. A typical throughput characteristic curve for a twin roll caster is presented in Fig. 4 which indicates that as the cast thickness decreases from 2.0mm to 1.6mm the throughput increases by approximately 25%.

The capability to produce thin strip from strip casting is enhanced by the introduction of an in-line hot reduction mill.

THIN STRIP DEVELOPMENT

The 1999 thin strip development program was focused on thicknesses in the range of 1.4mm to 1.0mm. This represented the first stage of a cold rolled strip replacement product strategy that would move in the medium term to 0.7mm thick material with the ultimate potential to go to 0.4mm.

The thin strip was produced by a combination of casting and in-line hot rolling. The typical cast strip thickness exiting the mould was 1.4mm cast at a speed of 80 m/min. This material then entered an in-line hot reduction mill which is capable of up to 50 % reduction. The production route for the 1mm product is summarized below.

Cast thickness 1.4mm @ 80 m/min $\xrightarrow{\text{29\% hot reductio}}$ 1.0mm

Operational problems associated with strip steering through the rolling mill were initially encountered in the thin strip production regime. These problems have been resolved by implementing an improved strip steering control system.

PRODUCT QUALITY

Details of the product performance achieved to date with thinner material are presented in this section. Actual methodologies used for product assessment have been described elsewhere [1].

Surface Quality

Strip surface quality was routinely examined using a number of techniques which included on-line inspection during casting, and also pickling and dye penetrant testing of pickled samples. Increasing productivity from 40 t/m/hr to 60 t/m/hr led to a deterioration of surface quality. Crack-free coils have been produced from 1.4mm as-cast product down to gauges as low as 1.0mm at a productivity rate of 52 t/m/hr.

Fig. 5 shows significant improvements in surface finish obtained by introducing roll bite lubrication. However, localized roughening of the strip surface has been observed with large hot reductions at higher rolling temperatures. Work is in progress to overcome this issue.

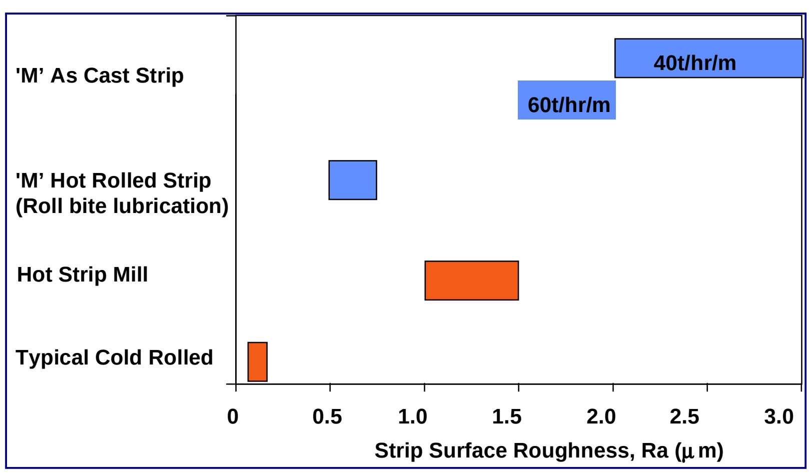


Fig. 5: Comparison of strip surface finish

Scale levels on strip surface have a significant impact on process economics. Elimination of pickling would lead to significant reductions in operating costs.

Actual measured scale thickness values obtained are shown in Fig.6 which reveals that the level is typically within the range of 4 to 7µm. This performance is similar to products currently produced by hot strip mills.

The Project 'M' short term goal is to achieve scale levels within 2µm by effective shrouding and strip temperature control.

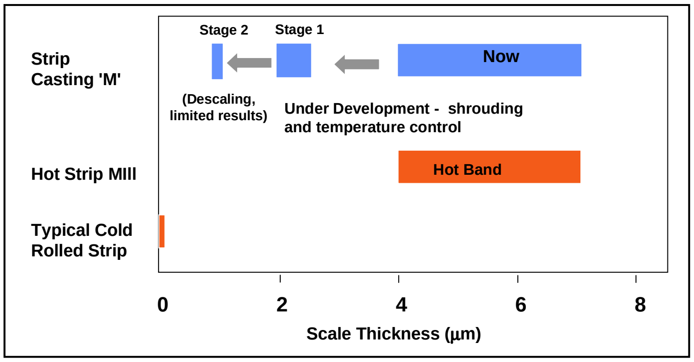


Fig. 6: Comparison of scale levels on strip

The medium term vision is to produce scale-free surfaces suitable for direct metal coating applications. Limited work has been carried out using a descaler (on the top surface only over a 70mm wide band). Results to date have been very promising as shown in Fig. 6 which indicates that scale levels within the range of 0.8 to 1µm are possible.

Edge Quality

Production of good edges is one of the significant challenges of strip casting. Good cast edges are produced by effective control of metal delivery and solidification in the edge region [1].

The use of the in-line mill to produce thinner gauge material has led to edge splitting (occurring within 40mm from the edge). The splitting was induced by tensile strains generated as a consequence of insufficient hot rolling in the edge drop region.

Significant progress has been made towards overcoming this problem through the reduction of edge drop associated with the profile of the as-cast material.

Dimension Control

Strip thicknesses were continuously measured throughout each cast using two on-line X-ray gauges. One device was dedicated to measure the strip profile and the other device was utilized to measure centerline thickness.

Thickness variations are presented in Table I which indicates that the thickness variation level is reduced by almost 50% with the in-line hot reduction.

Table I: Strip thickness variations	**As-cast**	**Hot rolled**
Strip thickness, mm	1.6 -1.9	1.0 - 1.4
Centreline gauge variation, mm	± 0.054	± 0.034
Full width variation (50mm side trim), mm	± 0.077	± 0.042
Full width variation (25mm side trim), mm	± 0.103	± 0.045
Typical crown (40 mm side trim) mm	0.05	0.05

Strip dimensional performance was also assessed in light of two currently available standards, namely the ASTM [2] and also the Australian Standards [3] for hot rolled and cold rolled sheet products (See Table II). It can be seen that the as-cast material generally falls within half of the ASTM hot rolled tolerance. Dimensional performance of thinner products is within one quarter to one third Australian Standard tolerance. (note that there is no hot rolled ASTM specification for 1.0mm gauge, Table II).

Table II. Thickness tolerance standard for Hot Rolled and Cold Rolled Sheets

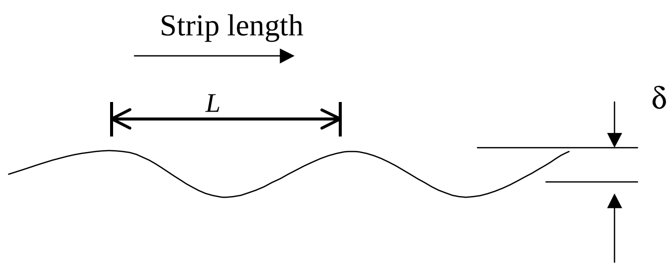
	Thickness		
	1.9mm	1.4mm	1.0mm
ASTM (Hot Rolled Sheets)	$\pm$0.18	$\pm$0.18	N/A
Australian Standard (Hot Rolled Sheets)	$\pm$0.18	$\pm$0.16	$\pm$ 0.16
ASTM (Cold Rolled Sheets)	$\pm$0.13	$\pm$0.10	$\pm$0.10

The dimensional performance for 1mm product is around half of the ASTM tolerance for cold rolled material. The current target is to produce thinner material conforming to quarter ASTM tolerance to improve the market offer for applications which are currently serviced only by cold rolling mills.

Strip Shape

Control of strip shape is an inherent challenge in thin strip rolling. The majority of the thin strip material currently produced by conventional routes (HSM and Thin slab) undergo skin pass rolling to improve shape. Shape problems generally arise from non-uniformity in the amount of hot reduction across the width.

Strip shape was characterized from off-line measurements, as there was no provision for on-line monitoring. Strip shape was determined from physical measurements of amplitude and length of the waves as schematically illustrated in Fig. 7. The measured steepness values can be converted to International Units (IU's) units to characterize strip shape.



$$\text{Steepness ratio } = \frac{\delta}{L} \times 100(\%)$$

$$\text{I units} = 25 \text{ x (steepness ratio)}^2$$

Fig. 7: Characterization of strip shape

Actual strip shape performance is presented in Fig. 8 which shows a deterioration in shape with increasing levels of hot rolling with the effect most pronounced for the 1.0mm product. The target steepness ratio for 1.0mm strip has been set at 2% (100 I-units). At this value, shape correction via skin passing or tension leveling will produce good final product shape.

Tighter dimensional control of cast strip dimensions is essential to produce good shape. Strategies are in place for further improving profile and gauge variation of the cast material.

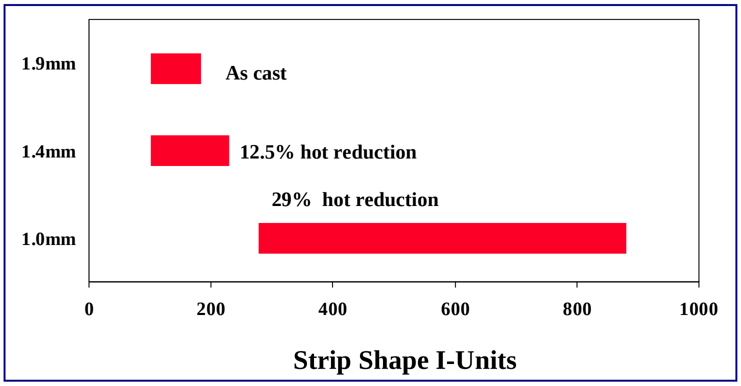
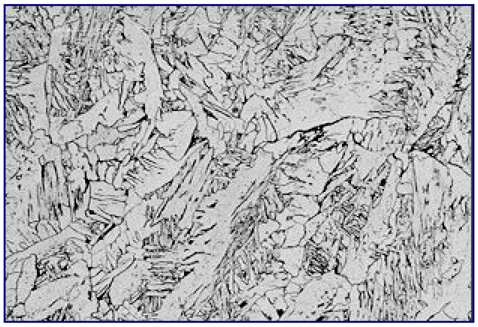


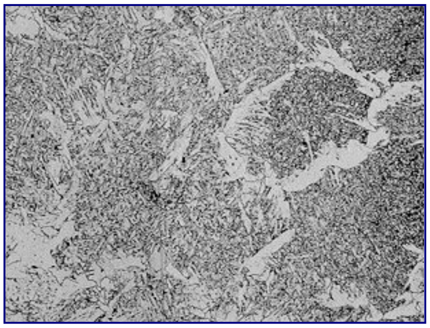
Fig. 8: Measured strip shape values.

PRODUCT MICROSTRUCTURES

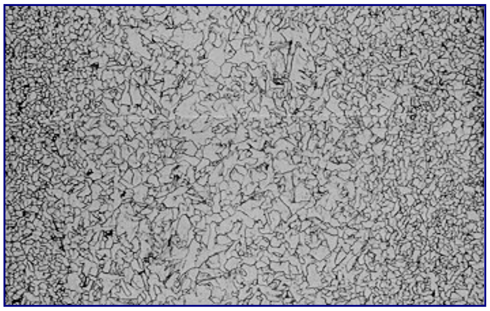
Microstructure evolution in strip casting is fundamentally coupled to the solidification process. The nucleation density during solidification can profoundly influence austenite grain size and thus the subsequent ferritic microstructure [4]. Fig. 9 shows micrographs obtained for three different product thicknesses namely 1.9mm, 1.4mm and 1.0mm.



a) 1.9mm (as-cast) X100



b) 1.4mm (12.5 % hot reduction) X100



c) 1.0mm (29 % hot reduction) X100

Fig. 9: Comparison of microstructures for 1.9mm, 1.4mm, 1.0mm product

Microstructure of the as-cast material is a mixture of polygonal ferrite and low temperature transformation products such as widmanstatten/acicular ferrite (Fig 9a). Refinement of the as-cast microstructure is most pronounced in the 1mm product which is the outcome of higher reduction ratios, typically 29% (Fig. 9c). The microstructure of this material is dominated by the presence of polygonal ferrite. The 1.4mm material was the outcome of 12.5 % of hot reduction which was not sufficient to modify the microstructure produced during the casting process (Fig. 9b).

The microstructure of 1.4mm product is dominated by the presence of acicular ferrite compared to 1.9mm strip which was predominantly a mixture of polygonal and widmanstatten ferrite. This was due to coarser austenite grain size in the as-cast material which was produced at a higher casting speed (80 m/min) in comparison to 1.9mm product cast at 45 m/min. The underlying reasons for coarser austenite with higher casting speed is not fully understood, and may be related to either solidification nucleation differences and/or more grain coarsening due to higher temperatures [5].

Thus the observed microstructures indicate that in-line hot rolling can refine the as-cast microstructure. More refinement is likely to occur with finer cast microstructures (those obtained at lower casting speed), lower hot rolling temperature and larger hot reduction.

PRODUCT PROPERTIES

Strip mechanical properties were routinely measured to determine strength and elongation values. The mechanical properties for a range of strip thicknesses including as-cast and in-line hot rolled material is summarized in Table III.

Table III: Summary of mechanical properties

Cast speed (m/min)	45	80	80	80
Cast thickness (mm)	1.9	1.6	1.6	1.4
Hot Rolling %	0	0	13	29
Final thickness (mm)	1.9	1.6	1.4	1
Hot Rolling temp (°C)	-	-	1050	1050
Yield Strength MPa	280	300	300	320
Tensile Strength MPa	420	440	440	450
Elongation %	28	26	26	28

The strength of strip cast products in general tends to be on the higher side due to the presence of low temperature transformation products like acicular/widmanstatten ferrite. Materials which are cast at a higher speed are associated with more acicular ferrite. This is reflected in the higher strength levels of 1.6mm cast product compared to 1.9mm.

Results also indicate that less than 15% hot reduction has no effect on changing as-cast strip properties. This is consistent with the microstructures described earlier. However, high levels of hot reduction increase the material strength and elongation as a direct result of the refinement of the cast microstructure.

Strength and elongation values obtained for thinner material compare favorably with those of Al-killed steel strip produced via hot strip mill route. Strategies are in place to further reduce strength.

A wide range of strip properties can be obtained with a single chemistry by controlling the microstructure of as-cast material, the rolling temperature, the amount of hot reduction and the rate of product cooling. The strip entry temperature at the rolling mill is currently governed by the casting speed. It is expected that further improvement in strength and elongation can be achieved by controlling the strip temperature upstream of the mill.

PRODUCT PROCESSING

Limited processing trials have been carried out to examine the potential for thinner gauge material produced by a strip caster with in-line hot reduction. Results from these trials are summarized below.

Pipes and Tubes

Strip thicknesses in the range of 1.2 to 1.4mm were successfully converted to pipes (19mm and 31.8mm diameter sections) and tubes (20x20mm, 40x40mm square sections). Some of these products were metal coated to Galvatube Plus® and also powder coated. These pipes and tubes were processed to final products such as tables, chairs, fence panels and a bicycle frame as shown in Figs. 10 to 12.

Fig. 10: Table made from final pipe product

Fig 11   a) Chair and b) fence from final pipe product.

Fig. 12: Bicycle frame from final pipe product.

Drums

1.4mm material was also successfully processed to complete 200 liters drums as shown in Fig. 13.

Fig 13: Steel Drum produced from 1.4mm strip.

CONCLUSION

Strip casting in conjunction with in-line hot reduction potentially provides a means to economically produce thinner gauge material for specific markets that can currently only be serviced by cold rolling mills.

The major challenge is to produce satisfactory shape that can be processed by skin pass rolling facilities to final commercial specifications. Improved casting machine components have been manufactured and appropriate strategies developed to improve the control of as-cast strip profile and centerline gauge variation to resolve outstanding strip shape issues.

Work is also in progress to improve surface quality particularly reduction of scale levels.

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