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MAGNESIUM TWIN-ROLL CASTING BENEFITS FROM ALUMINIUM HERITAGE

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Abstract

The history of twin-roll casting for Aluminium started in the 1950's, with the first Pechiney trials in 1956, a first patent filed in 1958 and the first industrial lines installed at the beginning of the 1960's. 60 years of technology development later, Aluminium twin-roll casting accounts for 20 to 30% of the world flat rolled production and is recognized as a low-cost flexible short route to produce a wide range of alloys with cast width up to 2300 mm.

In comparison, Magnesium twin-roll casting is a young process but the same promising future can be foreseen for it, as it can largely benefit from the technology developed for Aluminium.

From Pechiney to Novelis in the Aditya Birla Group, Novelis PAE has been a major actor in developing twin-roll continuous strip-casting technology for more than five decades, for Aluminium (more than 110 casters installed), and also for Magnesium (3 casters installed).

Twin-roll casting process principles

Twin-roll casting is the only process that combines both solidification and rolling in a single step. The liquid metal is fed through a nozzle (the "tip") into the bite of a 2-high mill where the rolls are designed to fill both a heat exchanger and a rolling function (see Figure 1). The rolls are made of two parts : a core and a shell shrink-fitted on the core. Water circulates between the core and the shell to cool down the shell, which is the part in contact with the metal. The metal exiting the tip solidifies on the rolls into a strip that is further work-hardened by the rolls. To prevent the metal from sticking to the rolls a release agent (most of the time a suspension of water with graphite) is applied to the rolls. This release agent acts both as a lubricant and as a thermal barrier that controls the heat exchange between the rolls and the metal. Metal feeding and roll lubrication are key elements in the control of the strip quality.

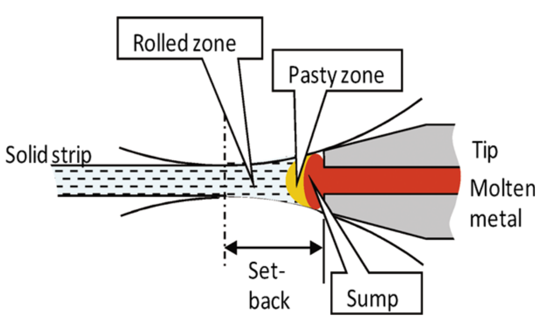

Figure 1. Schematics of the twin-roll casting principle.

The typical cast gauge obtained with the twin-roll casting process is similar to the hot mill exit gauge. Therefore, compared to the conventional DC casting and hot rolling route, the twin-roll casting route is more flexible and economical, avoiding expensive and time-consuming heat treatment steps and rolling passes. A key difference between twin-roll casting and DC casting is the solidification rate of the metal : while in DC casting it is limited to 1 to 50°C/s, it reaches 500 to 1000°C/s on a Jumbo 3CM® thin gauge continuous caster. This gives very fine structures (dendrite arm spacing, or D.A.S., about 5 µm) with small and finely distributed intermetallics, extended solid solution and fine grain size. Final product properties can benefit from that different metallurgical structure if the downstream processing route is adequately adapted.

A little bit of history

From Pechiney to Novelis, and today with Hindalco in the Aditya Birla Group, Novelis PAE has been a major player in developing twin-roll continuous strip-casting technology for more than five decades, mainly for Aluminium (more than 110 casters designed and installed), but more recently also for Magnesium (3 casters designed and installed).

The history of Aluminium twin-roll casting started in the 1950's, with the first Pechiney trials in 1956, a first patent filed in 1958 and the first industrial lines installed at the beginning of the 1960's. The size of the casting rolls (roll diameter and width) tends to determine the overall capacity of the equipment. In the 60's it was limited to 620 mm in diameter and dedicated to relatively narrow cast widths (below 1500 mm) and thick cast gauges (8 to 12 mm). In the late 70's and early 80's, the Jumbo 3C® 960 and 840 (for 960 mm and 840 mm roll diameters) were introduced and the cast width was increased up to 2000 mm, while the cast gauge was typically around 6 to 8 mm. With the 90's came the Jumbo 3CM® generation of machines with rolls of 1150 mm diameter, cast width up to 2300 mm and cast gauges as low as 3 or even 2 mm (see Table I).

Table I. The generations of Novelis PAE Aluminium twin-roll casters

Caster model	3C Caster	Jumbo 3C Caster	Jumbo 3CM Caster
Years	*1960-1975*	*1975...*	*1995...*
Roll diameters (mm)	620	620 to 1150	620 to 1150
Maximum strip width (mm)	1600	1500 to 2300	1500 to 2300
Strip thickness (mm)	5 to 12	5 to 12	2 to 10
Coil weight (t)	10	10 to 24	10 to 24
Productivity range at 1000-mm width (t/h)	0.8 to 1.2	1.3 to 1.6	1.6 to 1.9
Annual capacity (Kt/year)	up to 14	up to 24	up to 27

Today, after 60 years of technology development, Aluminium twin-roll casting accounts for 20 to 30% of the world flat rolled production and is recognized as a low-cost flexible short route to produce a wide range of alloys with cast width up to 2300 mm.

Compared to Aluminium, twin-roll casting of Magnesium is a quite young process with only a few casters in operation, most of them for research and development work [1, 2]. However, the same promising future can be foreseen for this process with little doubt, as it can largely benefit from the technology developed for Aluminium.

Physical and thermal properties

In order to define the proper technology for twin-roll casting of Magnesium and how much can be derived from Aluminium twin-roll casting, a comparison of the physical and thermal properties of both metals shall be done. Looking at the main twin-roll casting process parameters for a reference as-cast strip gauge of 5 mm, it is experienced that the lower density of Magnesium is compensated by a higher casting speed (see Table II). The productivity (expressed in tons of metal cast per hour and per meter of cast width), or the mass metal flow rate through the caster, is indeed very similar for Aluminium and Magnesium. It is therefore reasonable to compare physical and thermal properties per mass unit.

Table II. Comparison of Aluminium and Magnesium main twin-roll casting parameters

Typical TRC process parameters	Aluminium	Magnesium
Reference as-cast gauge	5 mm	5 mm
Typical casting speed	1.6 m/min	2.5 m/min
Density – solid at 25°C	2.70	1.74
Productivity	**1.30 t/h/m of width**	**1.31 t/h/m of width**

The main physical and thermal properties involved in the twin-roll casting process for Aluminium and Magnesium are compared in Table III. Three main conclusions can be derived from this comparison :

- The operating temperature range is almost identical for both metals. Thus, from a thermal point of view, the materials and equipment used for twin-roll casting of Aluminium will be suitable for Magnesium
- Taking the specific heat in the liquid state, the heat of fusion and the specific heat in the solid state into account, it can be calculated that the energy to be extracted in the caster roll gap by the solidification and cooling system is very similar for both metals, in the range of 600 to 650 $kJ.kg^{-1}$. Therefore, the heat extraction technology developed for twin-roll casting of Aluminium will be adequate for Magnesium
- Comparing the surface tension of both metals, it is clear that liquid Magnesium has a higher tendency to leak than liquid Aluminium. As a direct consequence, any sealing in the metal feeding equipment will be more challenging. Moreover, the meniscus that creates between the lips of the tip and the surface of the caster rolls will be less stable with liquid Magnesium, making tip geometry consistency and tip positioning accuracy and stability of paramount importance for twin-roll casting of Magnesium.

Table III. Comparison of Aluminium and Magnesium physical and thermal properties

Physical & thermal properties	Aluminium	Magnesium
Density – solid at 25°C	2.70	1.74
Density – liquid at melting point	2.32	1.60
Melting point	660°C	650°C 630°C for AZ31 595°C for AZ91
Specific heat – solid at 25°C	897 $J.kg^{-1}.K^{-1}$	1025 $J.kg^{-1}.K^{-1}$
Specific heat – liquid at melting point	1025 $J.kg^{-1}.K^{-1}$	1323 $J.kg^{-1}.K^{-1}$
Heat of fusion	400 $kJ.kg^{-1}$	368 $kJ.kg^{-1}$
Surface tension	865 to 1100 $mJ.m^{-2}$	560 $mJ.m^{-2}$

Twin-roll casting technology

Figure 2 shows what would be the typical cross section of a Magnesium twin-roll casting line designed for continuous operation.

Several main functional units can be identified following the metal flow (from left to right on Figure 2) :

- The ingot preheating and loading unit : this is the preparation stage of the incoming raw material to be charged into the melting furnace
- The melting furnace, to melt the incoming raw material and the alloying elements. Continuous mixing ensures a homogeneous alloy composition
- The holding furnace, continuously fed from the melting furnace. It is the molten metal reservoir feeding the tundish or headbox
- The twin-roll caster stand, concentrating the heart of the solidification and rolling process. It converts the incoming molten metal flow into a solid strip
- The strip operation units : pinch rolls to apply tension to the strip, X-ray gauge to measure the strip gauge and cross profile, edge cutter to remove the strip edge heterogeneities (edge cracks and segregations), shear to cut samples or change coil
- The coiler unit, possibly equipped with a wrapper.

The heart of the process is of course localized in the twin-roll caster stand, where three main technology areas shall be considered : liquid metal feeding (which includes the nozzle or tip), solidification and heat extraction in the caster roll gap (which includes roll gap control and roll cooling system), and shell lubrication and coating control. In addition, an in-line monitoring of the strip cross and longitudinal profile is highly recommended to check that the strip quality remains under control.

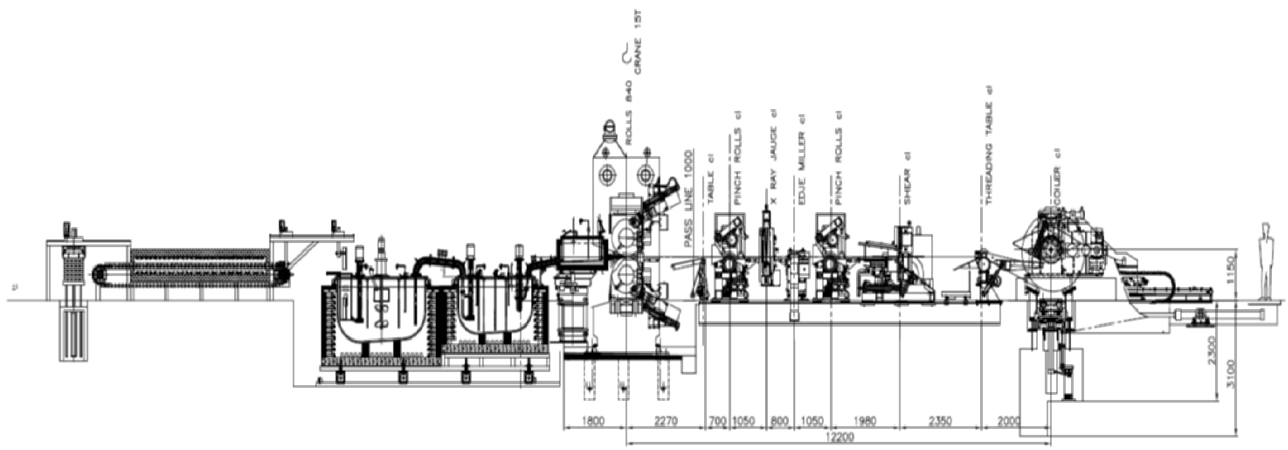

Figure 2. Typical cross section of a Magnesium twin-roll casting line.

Liquid metal feeding

An adequate metal feeding on a twin-roll continuous caster is obtained when the metal temperature field at the outlet of the tip leads to a regular solidification front [3, 4, 5, 6, 7, 8, 9, 10, 11]. This is a condition to obtain a proper strip cross profile and a uniform metal microstructure. The tip (or nozzle) is then the key element of the process to inject molten Magnesium into the roll gap (see Figure 3).

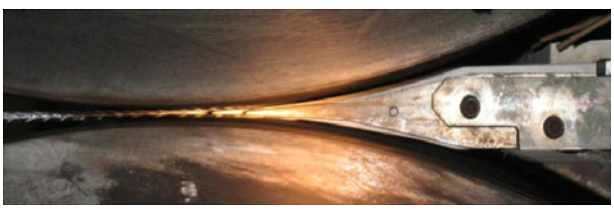

Figure 3. Zooming into the roll gap : solidification and rolling of the cast strip at tip outlet.

Two alternative tip technologies have been developed for twin-roll casting of Magnesium :

- The heated steel tip, where the tip top and bottom plates and lateral spacers are made of high-grade Nickel-free heat-resistant steel. Grooves are machined in the outer face of the plates to insert electrical heating elements that are used for tip preheating and to keep the tip plates at a temperature close to the liquid metal temperature during casting. This technology is relatively expensive and time-consuming for maintenance, but it has the significant advantage of being reusable
- The ceramic tip, based on the design developed for twin-roll casting of Aluminium, where heat losses through the tip are limited by using highly insulating materials. However, as liquid Magnesium strongly reacts with the silica contained in most refractory materials (either as a base component, or as a hardener), the inner face of the tip plates shall be wear-protected and the key is the selection of the right material/coating combination.

When using a ceramic tip, the risk is that the metal freezes in the tip during the priming phase at start-up. A tip preheating device is then required for safe operation. The heating is done by a hot air blower located on the exit side of the caster stand, mounted on a movable frame, the hot air flowing within pipes that come right at the tip outlet. This way, preheating can be done when the tip is already set in the start-up position and goes on until the very last minute before priming. Residual moisture possibly present in the refractory tip boards is then removed and the freezing risk at caster start-up is reduced.

Whatever the selected tip technology (heated steel or ceramic), an accurate positioning of the tip with respect to the rolls is necessary for a regular solidification front across the cast width. As for twin-roll casting of Aluminium, the tip table shall allow for every movement that may be necessary to obtain a perfect adjustment of the tip and a constant position of the tip once it has been set. When the tip is mounted on the tip support before start-up, the operator has to adjust the tip setback (distance from the tip outlet to the vertical plane that contains the roll axes) and the gap between the tip lips and the rolls (the roll gap). As the setback depends in particular on the roll diameter and on the cast gauge, the tip table allows for adjustment of the tip in the longitudinal and vertical directions. It also allows fine-tuning of the tip horizontality. It is very important to maintain a proper and constant gap between the tip lips and the shell surface as it affects the meniscus stability. A contact between the tip and the shell surface can be very detrimental to the integrity of the strip, not to mention the tip itself. A too-large gap can also lead to bleed-out or surface defects on the strip.

Solidification and heat extraction

As explained previously, the heat extraction needs are similar for Aluminium and Magnesium. Consequently, the same technology can be applied for roll gap control and roll water cooling system.

An accurate control of the roll gap and applied separating force is necessary to ensure a constant heat transfer coefficient (positively correlated to the applied force) and tight strip geometrical tolerances, especially regarding longitudinal gauge variations and strip cross profile. This is achieved with hydraulic screwdown cylinders located at the top of the top roll, on each side of the caster. Each screwdown cylinder is equipped with a position sensor, allowing a measurement of the position of each side of the top roll with an accuracy of +/- 1 µm, and a pressure sensor, allowing a measurement of the separating force applied on each side of the caster with an accuracy of +/- 0.5 ton.

This double set of sensors is at the heart of the highly reactive hydraulic roll gap control, allowing two working modes :

- The position mode, where the caster Programmable Logic Controller (PLC) regulates the position of each screwdown cylinder, is used for accurate gap setting during caster preparation before start-up, and during start-up to avoid any bleed-out when the first liquid metal comes into the roll bite (no gap opening)
- The pressure mode, where the PLC regulates the separating force applied through each screwdown cylinder, is used as the standard production mode as it allows an accurate regulation of the separating force, resulting in a constant flexion of the caster rolls, and thus in a strip cross profile kept within tight tolerances
- The switch from the position mode to the pressure mode after start-up is triggered automatically when the separating force reaches a preset level, which depends mainly on the casting width and on the alloy. This automatic switch allows a smooth transition between the start-up transitory phase and the stable casting regime.

As in twin-roll casting the rolls behave primarily as a heat exchanger, Novelis PAE roll design criterion is to have a uniform cooling efficiency across the width and over the circumference as well as a maximum heat extraction power in order to maximize the casting rate without impacting the strip quality negatively.

This approach led to design the cooling channels of the roll core with a checkered pattern of circumferential and transverse grooves at the core-shell interface (see Figure 4). This way, the surface temperature differences over the circumference and across the width of the shells have been reduced to a maximum of 2 to 3°C, providing a homogeneous heat extraction in the solidification and rolling zone, thus reducing longitudinal gauge variations of the cast strip to a minimum [12].

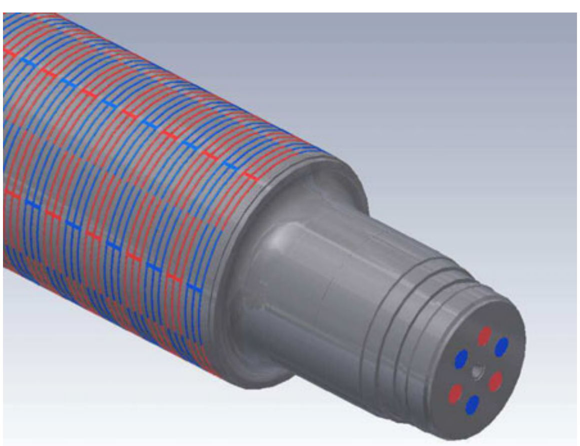

Figure 4. Schematic view of the water temperature in the cooling grooves at the core-shell interface. Patented 6-hole roll core design with checkered pattern of cooling channels.

Shell lubrication and coating control

At the roll/metal interface, the roll coating plays a key role in the quality and geometry of the as-cast strip. The main parameters that govern the roll coating are the composition and consistency of the oxide layer at the roll/strip interface, the amount of release agent that is deposited on the shells, and how the release agent is deposited on the shells.

Therefore, when developing the shell lubrication and coating control system for twin-roll casting of Aluminium, Novelis PAE focused on achieving :

- A good control of the quantity of release agent applied on the rolls, using an accurate lubricant flow rate control device based on peristaltic pump technology (one per caster roll)
- A uniform deposit of the lubricant on the shells. The spraying guns are mounted on a traveling support system and connected to a specific brushless drive to allow smooth and fast motion of the gun support arm across the roll width. The traveling speed can either be set manually but is preferably automatically controlled by the caster PLC, based on a setpoint which is calculated according to the cast width and roll rotation speed. In automatic mode it optimizes the deposit of lubricant on the rolls
- A high output of the guns, i.e. more release agent on the rolls and less in the atmosphere and especially less on the strip. The spray guns use low air pressure to break up the jet of release agent and to get a flat spray pattern. The low-pressure spray leads to less rebound of the release agent droplets on the rolls. These droplets are also much finer and cover the rolls more efficiently and more homogeneously
- A good stability over time of the spray quality, by feeding the spray guns from a mixing station where the mother suspension of release agent is diluted in water and continuously mixed. There is a second mixing vessel to insure continuity of supply of release agent.

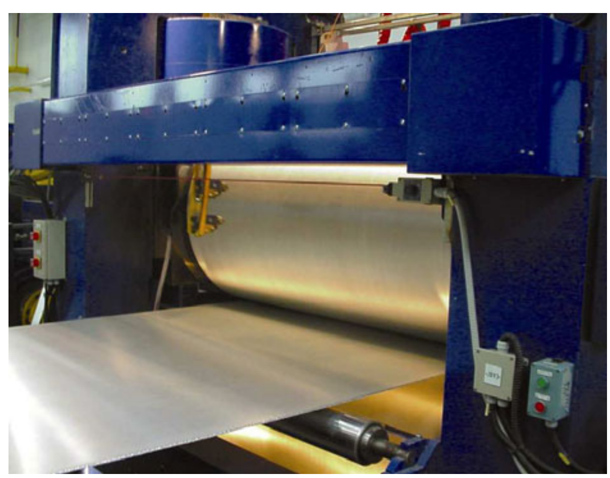

Figure 5. Roll lubricant spraying system.

The above technology features can be applied directly for twin-roll casting of Magnesium. However, the addition of the following specific devices is beneficial :

- Roll scrapers, made of adjustable bronze blades positioned very close to the roll surface on the caster exit side, in order to remove any piece of metal that may be stuck on the shell surface at start-up. This device reduces the risk of tip damage during the start-up transitory phase and increases operator safety by limiting the needs to access the caster stand exit side
- Roll brushing device to further improve coating homogeneity, each roll being equipped with a rotating brush positioned on the caster exit side after the spray guns. Roll brushes have a smoothening effect on the shell coating, thus improving the heat exchange homogeneity and reducing the likeliness of strip surface segregations.

<u>In-line monitoring of the strip cross and longitudinal profile</u>

The technological features described here above certainly help in reducing the chance of uncontrolled parameter drift or change, thus keeping the strip quality and geometry within the required specifications and tolerances. Yet, if there has been a change in the casting parameters such as shell lubrication or metal level, then it may be detected only at the first rolling pass. In order to avoid that, a continuous monitoring of the strip gauge is highly recommended. Consequently, most new twin-roll continuous casters are now equipped with a traveling X-ray gauge installed on the exit side of the caster stand.

Figure 6 shows a typical supervision computer display of an X-ray gauge color map of the strip gauge for a complete coil. It is then very easy for the operator to judge if the strip being cast meets the requirements or not on cross profile and longitudinal gauge variations. Any drift is also immediately detected to permit a quick corrective action.

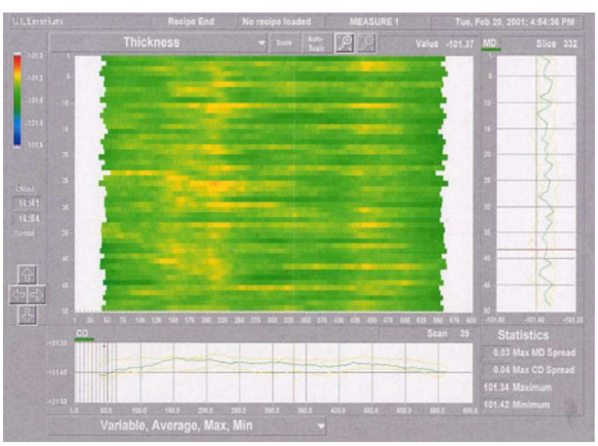

Figure 6. Supervision computer display of an X-ray gauge color map of the strip gauge.

The benefits of an X-ray gauge in-line monitoring could be summarized as follows:

- Constant monitoring of the strip gauge and cross profile, allowing early detection of parameter drift
- Better control on the as-cast quality, resulting in an increase of the casthouse recovery (less scrap generated)
- Improvement of the understanding of the process by the operators. New operators therefore need less training time and follow a faster learning curve.

Conclusion

It has been shown (as well as operationally demonstrated) that twin-roll casting of Magnesium can largely benefit from the technology developed for Aluminium during the last 60 years. Liquid metal feeding and tip are key elements and required specific developments, especially regarding heat losses compensation, compatibility with liquid Magnesium, and positioning. Shell lubrication and roll coating control equipment have been adapted from Aluminium twin-roll casting standards. Finally, heat extraction needs being similar for Aluminium and Magnesium, the same technology can be applied for roll gap control and roll cooling system.

References

1. H. Pircher, M. Weber, R. Kawalla, "Magnesium sheet materials for auto body construction", *Proceedings of the International Conference on New Developments in Sheet Metal Forming Technology*, June 4-5, 2002, Stuttgart.

2. Lothar Löchte, Håkon Westengen, John RØdseth, "An Efficient Route to Magnesium Alloy Sheet: Twin-Roll Casting and Hot Rolling", *Magnesium Technology 2005*, TMS (The Minerals, Metals & Materials Society), 2005.

3. P-Y. Menet and L. Calaque, "Process and device for controlling the thickness profile of a thin metal strip obtained by continuous casting between mobile molds", French patent FR 2 775 916, international patent WO 99/00527.

4. R. Cayol, "Latest Technical Development in Thin Gauge Continuous casting of Aluminium Alloys", *Alumitech '97: 2nd International Aluminum Conference and Trade Exposition* (The Aluminium Association, 1997), 471-476.

5. R. Cayol, F. Basson, K. Maiwald, and P-Y. Menet, "JUMBO 3CM® Thin Strip Casting: An alternative for a wide range of products", *Light Metals 1999* (Canadian Institute of Mining, Metallurgy and Petroleum, Aug. 1999), 265-275.

6. F. Basson, M. Jamet, K. Maiwald, P-Y. Menet, and J-C. Terrier, "JUMBO 3CM® Thin Strip Caster - Recent Developments", *6th Australian Asian Pacific Conference*, July 26-29. 1999, Sydney, Australia.

7. F. Basson, P-Y. Menet, K. Maiwald, and M. Bosch, "Strip Casting Technology… A Key to Product Quality", *Aluminum 2002, Proceedings of the TMS 2002 Annual Meeting : Automotive Alloys and Aluminum Sheet and Plate Rolling and Finishing Technology Symposia,* ed. by S.K. Das and M.H. Skillingberg, TMS (The Minerals, Metals & Materials Society, 2002), 143-150.

8. M. Bosch, P-Y. Menet, F. Basson, and P. Charlier, "Continuous Casting Technology – A Driver of Evolution in the Aluminium Transformation", *Proceedings of the International Conference on*

Aluminium, INCAL '03, April 23-25. 2003, New Delhi, India, Eds. S. Subramanian and D.H. Sastry (2003), 2, 445-454.

9. B. Engl, "Potential uses and new production technology for Magnesium sheet", *Steel Grips 1*, 2003, No. 6, 413-418.

10. B. Engl, "Future aspects of Magnesium sheet materials using a new production technology", *Proceedings of the 62nd Annual World Magnesium Conference*, May 22-24, 2005, Berlin.

11. B. Engl, "A New Technology for Magnesium Sheet Production", *Light Metal Age*, October 2005, 14-19.

12. "Process and device for correcting the out-of-round of rolls for the continuous casting of metal strip", US patent 5 642 772.