Laminação Rolling
49º Seminário de Laminação - Processos e Produtos Laminados e Revestidos
49th Rolling Seminar - Processes, Rolled and Coated Products
ISSN 1983-4764

HOT ROLLING MILLS FOR SUSTAINABLE GROWTH OF THE DEVELOPING ALUMINIUM MARKET[1]

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Abstract

Aluminium is the second most used metal in the world with its production being greater than all other non-ferrous metals combined. The global Aluminium production capacity is expected to double by 2025, with developing countries leading the growth. The rising demand in Aluminium is attributable to the metal properties that can provide benefits for a wide range of applications and to its very high recyclability, which makes it an environmentally sustainable product. The main areas of growth are: automotive and transport industry applications, aerospace and construction. The increase in production capacity will proceed in parallel with the demand for more sophisticated Aluminium products by end users for new applications. Process knowledge and modern technology are essential to meet the rising demand for capacity, material properties and quality. Siemens Metals Technologies is a rolling mill equipment supplier at the forefront of Aluminium technology. This paper will focus on the hot rolling process of Aluminium products, presenting the most advanced technical solutions available in the growing market and the latest references of Aluminium hot rolling mills for the production of plate and coils.

Keywords: Aluminium; Hot rolling; Recyclability.

[1] *Technical contribution to the 49th Rolling Seminar – Processes, Rolled and Coated Products, October, 22nd-25th, 2012, Vila Velha, ES, Brazil.*

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ISSN 1983-4764

INTRODUCTION

Aluminium is one of the most abundant metals on Earth, but a fairly young material as it was not until 1886 that the *Hall-Heroult* process allowed the metal to be commercially exploited.
Aluminium is generally extracted from bauxite ore via a series of process steps, including refining and smelting, then cast into finished parts (e.g. automotive wheels) or semi-finished products (ingots, rods, slabs, billets) for further processing via rolling or extrusion to be converted into products which generally have long life spans due to the highly corrosion resistant nature of the Aluminium metal.
Resources of bauxite, the raw material for Aluminium, are not widespread throughout the world. There are only seven bauxite-rich areas [Fig. 1]: Western and Central Africa (mostly Guinea), South America (Brazil, Venezuela, Suriname), the Caribbean (Jamaica), Oceania and Southern Asia (Australia, India, Indonesia), China, the Mediterranean (Greece, Turkey) and the Urals (Russia).

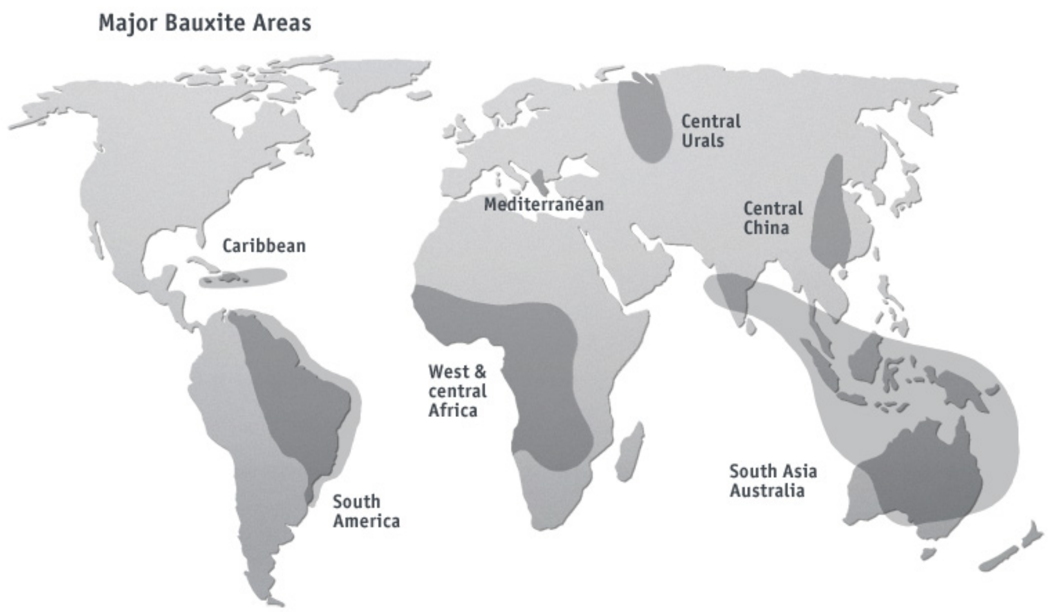

Figure 1. Bauxit Areas – Global.

The reduction of Aluminium from alumina by means of electrolysis is highly energy intensive, environmentally unclean and the profitability is dependant on securing a low cost energy source meaning most smelters are situated near to sources of inexpensive power (water energy or cheap gas). Most vertically integrated companies are generating their own power.
Currently the main producers and exporters of Aluminium are Russia, Canada, Australia and Norway primarily due to the relatively low energy costs in these regions. The main importers of Aluminium are USA, China, Japan and Germany due to the relatively high energy costs and associated environmental issues with the smelting process. The Aluminium industry is however targeting efforts to reduce per-fluorocarbon (PFC) emissions by 50% by 2020 (from 2006), according to the International Aluminium Institution.

ISSN 1983-4764

PRESENT ALUMINIUM PRODUCTION AND GROWTH TRENDS

The expected Compound Annual Growth Rate (CAGR) of primary Aluminium production is 5.5% between the years of 2010 – 2016 and is forecast to be 56.6 Mt by 2016. By 2025 the global capacity is expected to be 78.4 Mt (current base is 41.9 Mt) [*Source: Metals Market Service Aluminium Long-term Outlook – Brook Hunt March 2011*].
The current applications of Aluminium products are shown in Table 1.

Table 1. Aluminium Applications

Transport	
Cars	18%
Trucks	7%
Other (incl. aerospace)	2%
Industrial Equipment	
Electrical Cable	9%
Mechanical Equipment	7%
Electrical Equipment	4%
Metal Products	
Packaging (cans, foil)	13%
Appliances	7%
Other (incl. lithographic)	9%
Construction	
Buildings	24%

An average car contains 120kg of Aluminium. 35% is in the cast engine, requiring high strength and wear resistance. 15% is in the cast transmission casing, providing stiffness for gear teeth alignment and thermal conductivity for dissipation of frictional heat. 15% is in the cast wheels. The remaining Aluminium is mainly in the heat exchanger and forgings in the chassis and suspension. Aluminium is increasingly used in car engines and bodies to save weight.

The increase in demand is associated with the metals properties. It is light in weight and of high strength and has excellent corrosion resistance in comparison to steel. It has high electrical and thermal conductivity making it suitable for cables and objects requiring excellent heat transfer properties such as cook ware and heat exchangers. Aluminium has high ductility and good machining ability and is easily joinable making it highly formable into a wide range of products. During the rolling process it can be made to take on an almost mirror finish making it suitable for reflective products such as light diffusers and substitutes for automotive trim. Its impermeable nature and low odour and zero toxicity make it the perfect food packaging.

Automotive and Transport Industry

The transport industry consumes around a quarter of all Aluminium produced.
The demand in this sector is increasing, albeit at a slower rate. Vehicle manufacturers are devoting much greater research and development into the use and application of Aluminium in order to reduce the cost of Aluminium and to meet the legislative requirements for a reduced total lifecycle CO_2 footprint (including emissions during production).
Aluminium (and for the same reasons, magnesium) is used for parts such as engine blocks, wheels, brake and suspension components, and increasingly for chassis and body panels.

ISSN 1983-4764

Aerospace

This industry is expected to grow at approximately 5% per annum and is particularly interested in the reduction of yield loss rates, currently much greater than in the automotive sector. Moreover the demand for new cleaner aircrafts continues with countries like China looking to produce their own aircrafts in competition to Boeing and Airbus.

Construction

The global construction activity is still only modestly contributing to growth. However, the construction industry is expected to pick-up, influenced by infrastructure and development work at an increased level in the Asian countries. Typical applications include window frames and other glazed structures ranging from shop fronts to large roof superstructures for shopping centres and stadiums; for roofing, siding, and curtain walling, as well as for cast door handles, catches for windows, staircases, heating and air-conditioning systems.

Recycling

Defective or no longer required components (life expired) can be readily recycled by melting in specially designed furnaces. A significant obstacle in the process is that alloying elements cannot be removed from the liquid metal and therefore it is necessary to effectively and precisely sort scrap material before the melting stage.
By careful segregation, it is possible to recycle the metal as many times as necessary making recycled Aluminium one of the most cost effective green metals. Recycling consumes only 5%-10% of the energy necessary to extract Aluminium from the bauxite ore and as such has a much lower CO_2 footprint over its entire lifecycle. This has become one of the key "drivers" for the use of Aluminium in consumer products.
The recycling rate for Aluminium is high, but in certain areas recyclability is restricted to packaging, building and construction materials, which are easily identified and segregated in the scrap processing industry.
China currently imports 80% of the scrap it needs, but in the future there will be a drive to develop recycling collection programs within China and elsewhere. Major Aluminium producers have stated that they will invest in recycling plants, which by their nature will be close to major urban centres thereby changing the geographical spread of the production of Aluminium.

Future Applications for Aluminium Products

The drivers in the Aluminium industry are essentially: reduction of yield loss rates, improved recyclability and enhanced efficiency of the production process, thus reducing both energy consumption and CO_2 emissions.

Packaging Industry

This industry will continue to benefit from the advantages offered by Aluminium for the production of cans, foil and pharmaceutical packaging. Recycling will be of paramount importance, since packaging waste can be more easily sorted. The cycle of a can from primary production to recycle and back to secondary production can be as short as 60 days. The recycling process can occur again and again.

ISSN 1983-4764

Appliances

The drivers in this industry are re-manufacture and re-use (without melting), along with reduction of yield losses in the production process and lighter design.

Automotive and Transport Industry

The utilisation of Aluminium for automotive parts is predicted to rise by an average of 3.5% per year [*Source: Aluminium in Transportation, The Aluminium Association, Inc.*] with a target of 250kg per car used in 2025 (twice as much as today). Aluminium is already well established throughout high class car manufacture, but is now gaining a significant share in smaller high volume compact car designs. Light weight is the key advantage. The main challenges to Aluminium usage in the automotive industry are joining and surface treatment issues, for which many solutions have and are continually being developed. Aluminium also has heavy competition from other light weight materials such as light weight steel grades, magnesium which is already being utilised in specialist engine parts along with carbon fibre reinforced polymers (CFRP). Aluminium is however maintaining a preferred position due to its availability, recyclability, and economic mass production capabilities.

For transport and naval applications the light weight vessels have greatly increased speeds and range with reduced power requirements.

Train applications are increasingly utilising Aluminium as a viable source for increased performance. Early generation trains have historically utilised Aluminium in some form but the potential of the material is increasingly being utilised with the developments of high speed trains. The Japanese bullet trains are a notable example of extensive Aluminium utilisation. The double skin Aluminium bodies allow significant weight reductions coupled with extensive rigidity and insulation improvements.

Aerospace

Aeroplanes require a relatively small fraction of the total Aluminium use, albeit a high profile one. The key driver here is the efficiency of the production process with reduction of the yield losses, for instance rolling plates with a wedge profile, using better forging processes to achieve nearer to net shape stock products and diverting swarf back into use via solid bonding. Aluminium plate is predominantly machined for structural parts of the aircraft as well as the fuselage skin.

Although newly developed aircraft such as the Boeing 777 (Dreamliner) and the Airbus A350 XWB are heavily integrated with Carbon Fibre Reinforced Polymer (CFRP), Aluminium still represents a significant portion of the materials used. The material distribution of the Airbus A380 also remains predominantly Aluminium based with approximately 61% of the structure being made from Aluminium alloys [Fig. 2].

ISSN 1983-4764

Figure 2. Aluminium in Air crafts.

Construction

Construction industry accounts for a quarter of the Aluminium consumption.
Presently Aluminium is utilised as a finishing material for components such as roofing, windows and doors, guttering, facades, cladding and curtain walls [Fig. 3]. The durability of Aluminium presents sustainable low maintenance applications with particular aesthetic appeals.
Aluminium provides clear strength to weight advantages allowing architects to reduce costs attributed to building foundations as well as the transport costs involved with moving materials to site. The insulation potential Aluminium provides also decreases the overall carbon foot print of buildings which is another reason why Aluminium is increasingly utilised within sustainable construction.
Both structural and non-structural applications are expected to increase and re-use of Aluminium building components is expected to develop.

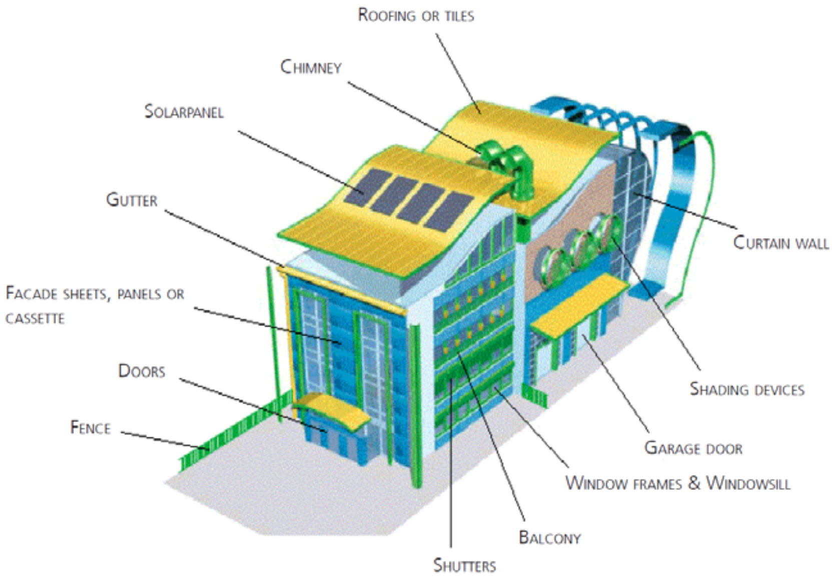

Figure 3. Aluminium in Construction Area.

Aluminium Hot Rolling Technology

Currently half of all Aluminium is made from ore (by electrolysis) and half from scrap (recycled via remelting or refining). Aluminium made from ore or remelted scrap is

ISSN 1983-4764

used in wrought products made via deformation processes. Aluminium from refining is used for casting products by pouring liquid metal into a mould. Two thirds of wrought Aluminium is rolled into sheet or plate, so that hot rolling constitutes the predominant deformation process in the production of Aluminium.
Siemens Metals Technologies is a rolling mill equipment supplier at the forefront of Aluminium technology and is constantly developing the most advanced technical solutions for rolling mills. A brief description of some of them – for Hot Aluminium Mills in particular – is presented in this paper.

SmartCrown
This is a powerful profile and flatness control actuator based on the utilisation of lateral shifting of the work rolls to adjust the roll gap contour.
Work rolls are ground non-symmetrically and show a characteristic bottle-shape. The grind is exactly the same for the top and bottom roll, but they are installed in a diametrically opposite arrangement [Fig. 4].

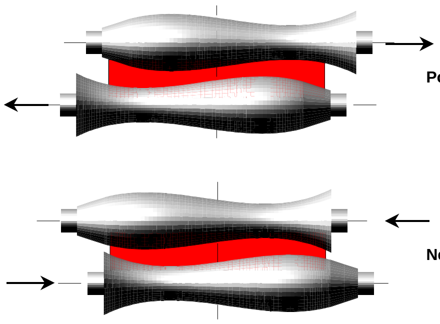

Figure 4. Smart Crown Technology

Unlike similar actuators with a roll contour that can be expressed mathematically by a third-order polynomial function (like CVC rolls), the SmartCrown roll contour can be described as a sum of a sinusoidal and a linear function (SMART = Sine Contour, Mathematically Adjusted and Reshaped by Tilting). The coefficients of this function are chosen in such a way that, at an arbitrary roll shifting position, the resultant unloaded roll gap profile is always cosine-shaped for SmartCrown rolls, whereas it is parabolic for third-order polynomial contour rolls [Fig. 5].

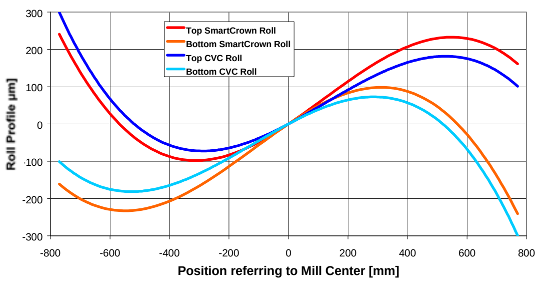

Figure 5. Unloaded Gap Profile.

The actual contour of SmartCrown work rolls can be adjusted by means of the so-called contour angle. The unloaded roll gap contour corresponds to a certain portion of a cosine curve around its vertex and the position of the barrel edge is at the

ISSN 1983-4764

contour angle. By fine-tuning this contour angle, the transverse profile of the resultant roll gap can be adjusted such that quarter buckles can be avoided [Figure 6-7-8].

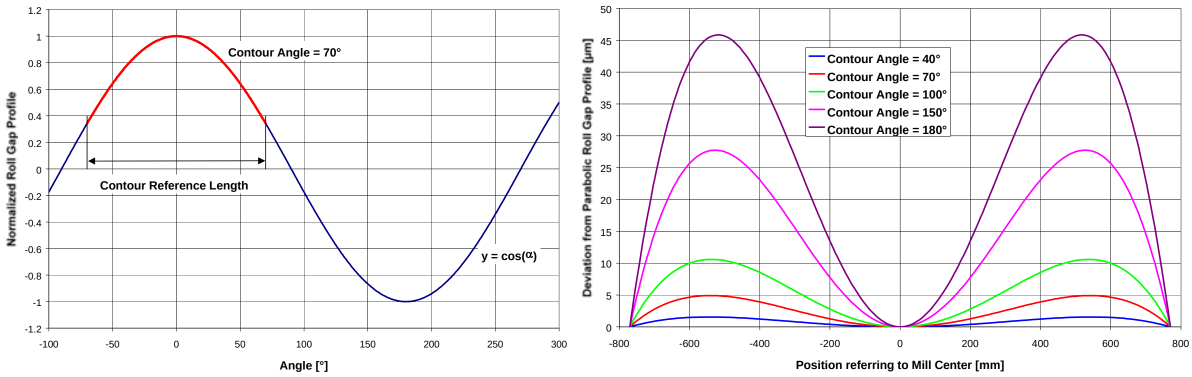

Figure 6. Gap Adjustments.

The avoidance of quarter buckles is based on the fact that the local thickness reduction in the quarter-buckle sensitive area is decreased, since the unloaded roll gap height is somewhat larger in this region.
The relationship between work roll shift and equivalent work roll crown is linear therefore [Fig. 8]; setting target profile can be performed both conveniently and accurately.

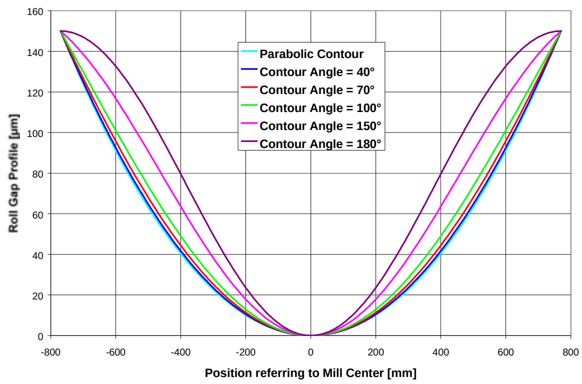

Figure 7. Gap Adjustments.

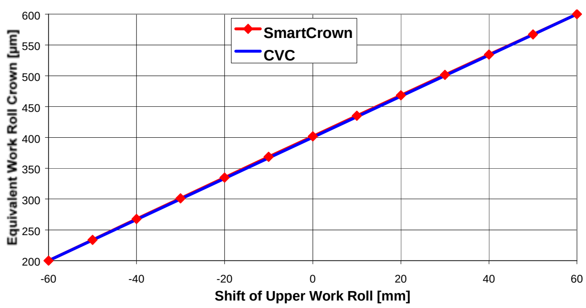

Figure 8. Gap Adjustments.

ISV Spraybars

On Hot Aluminium Finishing Mills work roll cooling spray patterns are used in the mill set-up and dynamically to influence the work roll thermal camber for profile control. Work roll cooling sprays are also used on the final stand / pass to control strip

ISSN 1983-4764

manifest shape (1/4 buckles). This is achieved by pulse width modulation of the coolant by integral solenoid valves in narrow zones across the strip width.
The **ISV** spray bar is manufactured from fabricated stainless steel section. The front chamber carries the coolant medium, while the rear chamber carries the electrical connections and compressed air [Fig. 9].
The **ISV** spray valve is manufactured from stainless steel and all elastomeric parts are manufactured from Viton hence the valve is suitable for all Aluminium rolling mill coolants up to a maximum temperature of 75^{o}C.

Figure 9. Spray Valve.

Each **ISV** supplies coolant via a nozzle plate to the mill rolls. Compressed air applied via the electrical solenoid deflects the diaphragm blocking the coolant flow through the valve. When this air pressure is vented the diaphragm relaxes and again allows coolant to flow through the **ISV**. Each **ISV** valve has its own 24V DC driven solenoid mounted within each valve body.
The **ISV** spray valve is ideally suited to Aluminium hot strip mills because unlike other solenoid valves it is fail safe in operation, i.e. coolant on.

Hot Planicim Roll

As strip gauges go below 2 mm and widths increase above 2.2 m the requirement for shape measurement and control on Aluminium hot tandem mills will be beneficial.
Siemens Hot Planicim Roll [Fig. 10] has a thin steel shell and uses position transducers to measure the deflection of the shell and hence calculate the strip tension distribution across the strip width.
Cooling sprays within an enclosure are used to maintain acceptable working temperature of the roll and bearing assembly.

ISSN 1983-4764

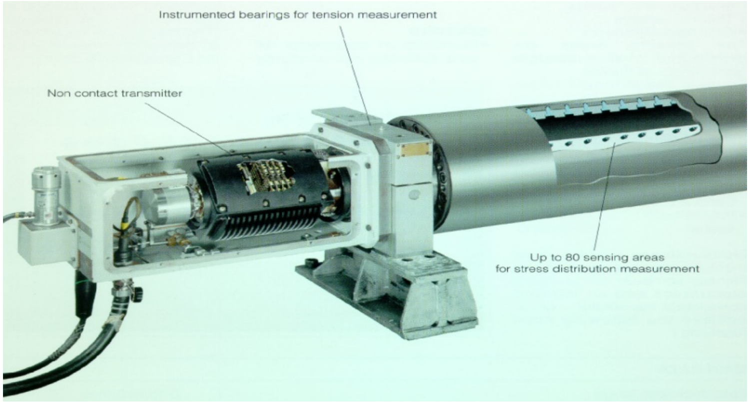

Figure 10. Hot PLANICIM Roll.

Edge Trimmer

The hot mill edge trim quality for strip products is important to minimise strip breaks on the cold mill. Hence Siemens Aluminium hot mill edge trimmers use separate trimming knives and drum type scrap chopper to avoid strip edge marks. The trimmer knives have automatic horizontal blade gap adjustment normally proportional to strip gauge and automatic vertical overlap adjustment normally dependant on material hardness to achieve optimum edge trim quality [Fig. 12].

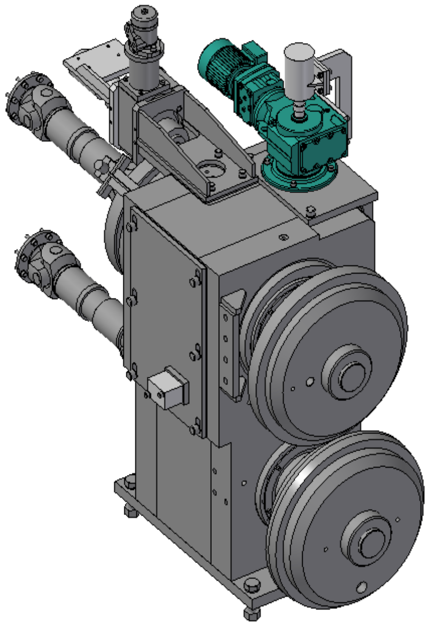

Figure 11. Edge Trimmer.

The trimmer and chopper can either be driven independently or with a single drive motor with fixed gearing / speed ratio between trimmer and chopper (105%).
The mechanical design of the edge trimmer / chopper is also important to ensure trouble free high speed threading on Aluminium tandem mills, generous allowance for off centre strip and large diameter trimmer blades.

ISSN 1983-4764

Recent Siemens Aluminium Hot Mill References

Novelis Ulsan

In 1991 Hyundai in Ulsan, South Korea, placed an order with Siemens (formerly Davy Mckee (Poole) Ltd) for a new 150,000 tonne per year Aluminium rolling plant. This plant consisted of a 2.8 m wide single stand twin coiler hot mill [Fig. 12] and two 2.2 m wide 4 high VC cold mills.
This plant was started up in 1993 and then purchased by Novelis (formerly Alcan) in 2000 and today the hot mill rolls 198,000 tonnes per year of coil and plate products.

Tandem Mill Technical Data	
Work Rolls	Ø 750 mm x 2500 mm
Backup Rolls	Ø 1500 mm x 2400 mm
Maximum Load	40,000 kN
F3 Speed	0 / 180 / 450 m/min
Mill Drive Power	3 x 5000 kW (AC)
Roll Bend	+/- 2000 kN

Figure 12. Novelis Mill, Ulsan, South Korea.

In 2011 Novelis decided to expand automotive sheet production in Asia and placed an order with Siemens for a new tandem hot finishing mill to be installed at the end of the existing hot mill exit tables. The existing hot mill will operate with the new tandem mill and be used for roughing passes on coil products and for plate rolling.
The new tandem mill installation has been designed to minimise disruption to the existing hot mill production and is planned to start-up in 2013.
This is the fourth Aluminium hot tandem mill supplied by Siemens since 2005 and further strengthens Siemens position as a leading supplier of Aluminium hot strip mills.

Tandem Mill Features

- Top mounted double acting roll load cylinders and bottom mounted continuous wedge pass-line height adjustment to maintain a constant strip pass-line.

ISSN 1983-4764

- “E” block positive and negative work roll bend on all stands with automatic change to roll balance force prior to strip tail-out of each stand to prevent roll skidding.
- The back-up rolls are mounted on cylindrical roller bearings for low eccentricity values. Note the back-up bearings are also interchangeable with the existing mill.
- Side shifting automatic work roll change with automatic connection of all drive side services.
- Work roll chock mounted scratch brushes (nylon bristle), with hydraulic load control or chock mounted mechanical penetration stops, internal brush lubrication, variable speed A.C. drives and zero dwell oscillation.
- ISV pulse modulated work roll sprays on both entry and exit side of all stands, for effective thermal crown control and hence improved strip profile and shape. Strip wipes and blow offs on both side of all stands to prevent coolant carry-over and hence raise strip temperature. Inter-stand strip cooling sprays to lower strip temperature and to maximise pass speeds.
- Driven strip tension measuring rolls with oscillating cleaning brushes are installed between the stands.
- Multi-channel X-ray gauge for feedback of strip gauge and profile for in-coil control by the process control system. Entry and exit side calibrated pyrometers for in-coil strip temperature control with mill speed zooming.

Edge Trimmer

Edge Trimmer Technical Data	
Blade Diameter	Ø 610 mm
Maximum Thickness	6 mm all alloys
Maximum Speed	550 m/min

- Trimming blades are automatically positioned for strip width and blade clearance by the mill set-up computer.
- Offset adjustment for optimum yield on high magnesium alloys and toe-out adjustment for edge quality are also provided.
- Separate drum type scrap chopper with helical blades located below strip pass-line with independent drive.

Coiling Equipment

The down coiling equipment is designed for a threading speed of 3 m/s. It comprises a driven deflector roll with oscillating brush, tailing roll, down coiler and high speed twin fabric belt wrapper. The coiler mandrel is fitted with liners requiring no lubrication, hence preventing contamination of the coil bore.

Coils are automatically removed from the coiler mandrel, transferred for sidewall temperature measurement and then to floor level by a coil car with high lift. The coil is transferred automatically across the mill bay by a floor mounted coil buggy, to the weighing station and walking beam located in the coil storage bay.

ISSN 1983-4764

Coiling Equipment Technical Data	
Mandrel Diameter	Ø 610 mm
Maximum Tension	236 kN
Maximum Speed	500 m/min
Drive Power	1 x 1500 kW (AC)

Fluid systems are installed to provide the tandem mill with operating media:

- Roll coolant systems for mill stands and inter stand strip cooling.
- High pressure hydraulic systems for light duty shear, mill load and roll bending.
- Medium pressure hydraulic systems for all other equipment.
- Centralised oil lubrication systems for tandem mill drive, edge trimmer and coiler gearboxes.
- Oil - Air lubrication systems for mill rolls and strip pass-line rolls.

Roll coolant condition has a significant impact on the finished strip quality and the smooth operation of the mill. Installation of vacuum filters, tramp oil skimmers, heaters, coolers, make-up systems as well as modern pressure control using variable speed pump drives and comprehensive monitoring maintains the coolant in its optimum condition. The roll coolant is used extensively for work and back-up roll cooling, strip cooling, bite lubrication, scratch brush cleaning, lubrication of the edge trimmer blades, roller table rolls, side guide rolls and pass line rolls to prevent the build-up of Aluminium on the surfaces.

Aleris Dingsheng

Aleris-Dingsheng JV, a company partially owned by the US Aluminium producer Aleris International Inc. has contracted Siemens in 2011 to supply a new Aluminium Plate Mill to be installed in the town of Zhenjiang in the Jiangsu Province in China.
This order forms part of a major investment by Aleris-Dingsheng JV and is scheduled to come into operation at the end of 2012.
The single stand plate mill is designed for future potential to produce 250,000 tonnes per annum of heat-treated and non-heat-treated sheets and plates up to 3.8 meters wide.
The mill will be able to process Aluminium ingots weighing up to 22 tons and produce rolled product with final thickness of between 6 to 250 millimetres.
The finished product will be used by the aerospace industry, mechanical engineering, tool and mould making, as well as in the petrochemical and transport industries.
Siemens are supplying the complete mechanical and electrical equipment for the four-high rolling stand as well as a hydraulic shear, roller tables for the new rolling mill and plate piling equipment.
The equipment has a number of special design features specifically focused on meeting the demanding requirements for high quality Aluminium plate production.
The order also includes the supply of a state of the art electrical and technological process control system based on Siemens SIROLL architecture. The SIROLL ALU addresses the complex technological correlations of hot rolling Aluminium, for example optimising thickness, profile and flatness using process models, from the rolling temperature model to the material flow model.

Technical Parameters

Plate Mill

ISSN 1983-4764

Work Roll:	1,175/1,100 mm x 4,100 mm
Back-up Roll:	1,750/1,600 mm x 4,100 mm
Load:	60,000 kN
Bending:	+3,500 kN / chock
Speed:	0/108/270 m/min
Power:	2 x 7,000 kW

Down Cut Hydraulic Shear

Blade Load:	12,000 kN
Blade Rake:	1 in 22
Maximum Width:	3,900 mm

Product Data

Material:	AA Series 1xxx, 2xxx, 3xxx, 4xxx, 5xxx, 6xxx, 7xxx, 8xxx
Plate Thickness:	6 to 250 mm
Plate Width:	1,070 to 3,800 mm
Plate Length:	2,000 to 24,000 mm

CONCLUSION

The global Aluminium production capacity is expected to double by 2025.
The primary production of Aluminium is highly energy intensive and environmentally unclean, but Aluminium products generally have long life spans and are highly recyclable, which makes them environmentally sustainable.
Currently half of all Aluminium is made from recycled scrap and recycling is expected to grow significantly, changing the geographical spread of the production of Aluminium, which will not be predominantly concentrated in regions with low energy costs as it is today.
Reduction of yield loss rates and enhanced efficiency of the production process – along with improved recyclability – are the main drivers for the growth of the Aluminium industry.
Main areas of growth will be in the transport industry, including automotive and aerospace, and in construction (already accounting for half of the Aluminium consumption).
Two thirds of wrought Aluminium (produced from ore or remelted scrap) is rolled into sheet or plate, so that hot rolling constitutes the predominant deformation process in the production of Aluminium.
Siemens Metals Technologies is at the forefront of the development of the most advanced and sustainable technical solutions for Aluminium rolling mills. Some of their applications to Aluminium Hot Mills are described in this paper.
Two recent references of Siemens Aluminium Hot Mills implementing these technical solutions (Novelis Ulsan and Aleris Dingsheng) are presented in this paper.