MIDA endless and direct casting and rolling: the Danielli way to energy efficiency and CO₂ reduction

Danielli’s minimills based on MIDA endless and direct casting and rolling processes are now well established worldwide, providing greater productivity, lower capital and operating costs and lower greenhouse gas emissions than hitherto possible. The technology and plant examples are described.

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Prior to the 1960s, construction steel, including rebar, was made mainly from new raw materials, and large volumes of CO₂ emissions were produced, up to 2.5t of CO₂ per t of hot rolled product. Since the early 1970s, the mini-mill philosophy pioneered by Danielli has been marked by low investment costs, minimal manning, and low operating cost plants that serve specific geographic areas with a good balance of scrap supply and markets for finished products. With this EAF scrap recycling route, CO₂ emissions have been lowered to a more sustainable 0.4-0.6t per t of hot rolled product. However, in the late 1990s global CO₂ emissions exceeded 30Gt and the steel industry was responsible for around 6.5% of the total emissions[1].

Under these circumstances, the steel industry has recognised the need to take actions to limit the impact of its own activities on climate change: one of the most effective initiatives was to establish a method to calculate the CO₂ emission intensity of steel plants, irrespective of products manufactured and geographic characteristics[2]. Also clear is the relationship between CO₂ emission reduction and energy efficiency as roughly 60% of CO₂ emission reduction can be attributed to energy-saving activities.

Over the past 20 years sensitivity to environmental issues has increased and the technology has evolved to fulfil the vision of green steel production. Cooperating with customers, Danielli has developed a multi-part approach in the casting-rolling process to cope with more demanding requests for sustainability and profitability.

The MIDA ECR (Endless Casting and Rolling) process, introduced in 2000 to reduce energy in reheating before rolling, among other factors, is now a commercial reality, reducing the total amount of CO₂ emissions down to 0.3t per t of steel (-30%). Moreover, Danielli has remained determined to pursue improvements in energy savings and productivity by exploring new solutions to be combined with the already proven, high speed casting technology called Power Mould[3].

In this context Direct Casting and Rolling (DCR) technology has been also developed with a new approach in layout and operations. The relevant results of this new solution compared to the existing state-of-the-art for rebar steels and the latest experience in FENG HSIN, Taiwan, are described.

MIDA TECHNOLOGY CONCEPTS

A key factor for energy conservation is the integration of discontinuous process flows, for instance, the production and storage of billets in continuous casters, transport to rolling mills, reheat through gas furnaces, and finally rolling to finished size. The focus has been on operations in continuous casting machines and rolling mills to achieve higher billet temperatures, thereby achieving significant energy savings through not having to reheat the billets.

Hot rolling is performed at a temperature of about 1000°C to produce the final shape, so in order to feed billets at this temperature into the rolling mill, a gas-fired continuous heating furnace (pusher-type, stepping-type) is usually used. With older mills the billets are cold charged (~20°C), and in some more modern ones a proportion may be warm charged (600-800°C) direct from the caster (see ‘A’ and ‘B’ in Figure 1). The furnace usually includes three preheating zones, a heating zone and a soaking zone.

By contrast the Direct and Endless Casting and rolling processes pioneered by Danielli are shown in ‘C’ and ‘D’:

‘C’ DCR – single or multiple billets cast at high casting speed are directly rolled after passing through an induction heater, with or without use of a billet welder for endless rolling.

‘D’ Endless casting and Rolling (ECR) – extremely...
high speed endless casting and rolling is applied, with or without utilising an induction heater.

**A. CONTINUOUS CASTING WITH RF COLD CHARGING FROM STORAGE**

In this traditional configuration, cold billets are transferred to the reheating furnace (RF) from a cooling bed or from a storage area. Considering an ambient temperature of 20°C, an estimate of energy consumption for reheating is about 1.2GJ/t [4]. The scale produced during reheating could be up to 1%, in addition to what may be produced in continuous casting.

**B. CONTINUOUS CASTING WITH RF HOT (WARM) CHARGING**

If the billet is moved from the cooling bed to the reheating furnace at about 600°C, the possible saving in terms of reheating energy is estimated at 0.4GJ/t. The scale losses are lower compared to the cold charge option.

**C. DANIELI MIDA DCR – DIRECT CASTING AND ROLLING**

Direct Casting and Rolling layouts have been designed to take the major energy saving benefits from high speed continuous casting and, at the same time, reduce CapEx and OpEx.

The core of the process is the high speed caster equipped with a Fast Cast Cube (FCC) oscillator and Power Mould (see Figure 2), so as to be able to cast at very high speed then quickly hot charge the rolling mill at a temperature in excess of ~850-950°C, having the possibility of additional heating when necessary through an inductive heater. To minimise radiation losses the roller tables to the mill are insulated. The majority of losses are due to the radiative thermal effect and they are heavily affected by the time needed to cut the billet and to take it from the cutting area to the induction heater. This process permits energy savings up to 1GJ/t.

The induction heater allows close control of billet temperature because the power is set according to the actual thermal load of the individual billets, hence contributing to additional energy saving. Moreover, it has limited emissions (electrical power supply) compared to the other furnace types. Additionally, its compact design contributes to lower investment cost, future maintenance and the length of the production line.

As an example, at the same total productivity, a three-strand caster operating at 5.0m/min saves up to 0.15GJ/t comparison to a five strand caster operating at 3.0m/min.

Danieli MIDA DCR technology is proposed for production exceeding 500,000t/y, with one or more casting strands, with or without the installation of a billet welder for endless rolling, and with the latest induction heater technology.

**Fig 1 Hot rolling mill layouts**

**DANIELI MIDA ECR ENDLESS CASTING AND ROLLING**

An example Danieli MIDA ECR plant is shown in Figure 3 [5]. The single-strand process eliminates the need for billet cutting, which, along with eliminating multiple head and tail crops on the final product, maximises product yield and guarantees stable conditions in the rolling process over several hours. This allows tight control of product physical and dimensional tolerances, and dramatically improved the run-light opportunities. Rebar production at 5% continuous run-light has been reported.

Over the years, fine-tuning of the operation and technological improvement has progressed, with casting speeds increasing up to 8m/min. The high casting speed helps keep the thermal charge in the billet and compensates for the thermal losses during the transfer to the rolling mill, such that today’s mills operate practically without induction heating.

As a result, billet reheating energy is reduced by 50% when compared to the best conventional reheat furnace hot charge, and drops to zero in ECR mode. Table 1 shows there are no reheat emissions in this option while Figure 4 compares energy requirements for the four options A, B, C and D, described earlier.
THE ECR SUCCESS STORY

The ECR process began in the late 1990s at the ABS Luna plant (Italy), following extensive research on high speed casting and endless rolling. The first industrial application at Sidenor Sovel (Greece) started in 2005 where one of six existing casting strands was upgraded to high speed casting by installing the Power Mould and the FCC oscillators.

Later, Danieli approached Commercial Metal Company with an endless design concept that eventually led to the construction of a mill in Arizona, CMC Steel Arizona. The plant started in 2009. Since then Danieli has commissioned nine more ECR plants in North America, North Africa, the Far East and MENA regions.

Plant No. 11 at Nucor Steel Sedalia (NSSED) started recently. With a rated capacity of 380,000 short t/y for #4 to #11 rebars (12.7 to 35.8 mm) in straight and spooled bars, and featuring the latest energy saving and environmentally friendly melting, casting and rolling processes. This plant also includes the Danieli ECS® scrap preheating system which continuously charges hot scrap into a 40 t side-charge AC EAF, which is followed by a ladle treatment furnace. The core of the endless casting-rolling section is a single-strand, high speed continuous casting machine connected to a 16-stand, ultra-compact rolling mill. Finishing facilities consist of Danieli-patented, Direct Rolling and Bundling (DRB) system and K-Spool technologies.

A second ECR for Nucor in Frostproof, Florida is under construction together with a twin ECR plant in China equipped with one co-rolling line to produce 700,000 t/y of ribbed wire rod and a second line to produce 700,000 t/y of rebars. A second twin ECR is planned to startup in China in 2021, so within the next few years, twenty Danieli MIDA ECRs will be in operation worldwide.

The advanced automation and innovative digital solutions fully integrated and optimised into the MIDA ecosystem, not only to supports the operators in decision-making with an impressive flow of information but also replaces them in the most unsafe operations and dusty places.

DANIELI MIDA DIRECT CASTING AND ROLLING

The Danieli MIDA DCR design capitalises on the best available technologies, where melting, casting and rolling are carried out in one continuous and uninterrupted production process, from scrap to finished product, and...
which can guarantee CapEx savings and outstanding OpEx results by conserving energy and improving yield and final product quality.

Direct charging layouts also take great advantage of high speed casting, introducing the possibility of reducing reheating energy consumption by up to 0.15 GJ/t, compared with a conventional speed casters.

In 2010, Sidenor Sovel in Greece was the first plant to take full advantage of direct casting and rolling, increasing the plant’s production capacity by 300,000 t/y to a total of 1,200,000 t/y. Strand 0 had been previously upgraded to high speed casting by installing the Fast Cast Cube and Power Mould technologies for ECR configuration to produce special quality 140mm rebar in bars and coils, from 8 to 20mm diameter.

After optimising production, the new target was to conserve energy in the production chain, particularly for reheating furnaces. In 2014, a bypass roller table was added in the route to the old mill and a new set of induction heaters was installed at the entrance of the old mill, disconnecting it from the gas reheating furnace (see Figure 5). The new configuration and a different setup in the caster have contributed to an energy saving up to 0.1 GJ/t. Since 2014, the plant has operated in 100% direct-charge mode, with zero reheating furnace gas emissions.

In addition to high speed casting, the Danieli Q-Heat induction heating technology has proven to be a key factor in the efficient operation of direct casting and rolling.

**Q-HEAT – INDUCTION HEATING**

Based on the extensive experience in endless and hot charging, and the know-how in converter units, Danieli Automation has developed an advanced induction heating system, Q-HEAT (see Figure 6).

The system perfectly fits the Danieli Automation 3Q concept – Quality, Quantity, Quickness – and is designed according the MIDA philosophy of reducing OpEx costs. Electrical efficiency is one of the most important drivers in the system design. The induction heater includes a converter cabinet with a Voltage Source Inverter based on the most modern Insulated Gate Bipolar Transistors technology (IGBT). Thanks to the AC/DC converter characteristics, the power factor is greater than 0.95 in any working condition.

This high power factor makes it possible to reduce losses on the upstream distribution equipment and cables due to a lower reactive current. The power coils are specifically designed by Danieli Automation, with particular care in the selection of the materials (eg, premium grade copper and high quality refractory), allowing for a high electrical efficiency, best quality and long life. Particular attention is paid to design low power-loss electrical connections between the equipment (converters, resonating capacitor

![Table 1: Emissions from reheating](image)

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<th>Conventional production route through reheating furnace</th>
<th>DANIELI MIDA casting and rolling process</th>
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<tr>
<td>Nox [g/t]</td>
<td>7-12</td>
<td>none</td>
</tr>
<tr>
<td>Sox [g/t]</td>
<td>7-12</td>
<td>none</td>
</tr>
<tr>
<td>CO [g/t]</td>
<td>5-10</td>
<td>none</td>
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![Figure 4: Energy use and savings with various process routes](image)

![Figure 5: Sovel Almyros layout of caster and rolling mill](image)
banks and heating coils); special coaxial cables and water-cooled bus duct are used.

This focus on electrical efficiency immediately translates into a low OpEx cost.

Other drivers in the design process are the flexibility, modularity and high availability of the system. It is important to highlight that each individual coil is controlled independently by an individual power generator. The independent power control of each inverter and related coil allows for precise control of the temperature rise during reheating. Also, it allows for optimum setting of the discharge temperature, and for adjusting the head-to-tail temperature variations, thereby optimising material temperature equalisation. Figure 7 compares measured billet entry and exit temperatures.

The system was designed to have the possibility of excluding individual coils without stopping the process. In this case the automation control system will automatically rearrange the power distribution on the other active power inductors. The power equipment incorporates a simple and quick maintenance concept. The modules are designed for quick-change operations and the system is ready to be connected in remote teleservice, if required.

The control structure is based on a powerful, state-of-the-art Danieli Automation Process Automation Controller (DA-PAC) that communicates with a power part controller (modulator board), with Ethercat, and with any field bus with Level 1 and Level 2 plant automation. The system receives the temperature samples from the pyrometers installed on field (Level 1), temperature set from Level 2 and automatically calculates and sets the right amount of power on each coil to achieve the target temperature.

THE FENG HSIN EXPERIENCE

Established in 1969, Feng Hsin, based in Taiwan, today produces over 1.8Mt/y of commercial steel grades in sections, bars, wire rod, and large rounds in coils. Having expanded its market position over the years, Feng Hsin now competes successfully with the major steel suppliers in the region.

Danieli’s cooperation with Feng Hsin started in 1983 with the first caster installation, followed by several other plants in subsequent years. The most important of these was the 425,000t/y ‘Super Flexible Rolling Mill’ for bars and sections installed in 1993. Other projects there have included new roughing stands, a rolling mill for small profiles and LF, VD and caster for meltshop No. 1.

In addition, in 2015 Feng Hsin contracted Danieli to supply a new, high speed bar mill, confirming the continuing decades of successful partnership with the Taiwanese long-products producer.

This latest high speed bar mill shown in Figure 8 produces
FINISHING PROCESSES

745,000 tpy of deformed bars from D10 up to D36, applying two-strand slitting for D10-D19 at a maximum finishing speed of 40m/s for constructional grades CNS 560, A2006, and grades SD280(W) up to SD420(W).

The existing, walking beam type gas holding furnace has a capacity of 40t/h. It is used only for the fine tuning of the mill before starting the long sequence of direct rolling. The principal route is to feed the mill using the roller table connected with the four-strand caster. Then, the billets (165mm sq.) pass through an 8MW induction heater with a rated output of 140t/h, to equalise/increase billet temperature before rolling (temperature range from 800 to 1050°C). Fine control of temperature is possible since the power is set according to the actual thermal load of each single billet.

The mill comprises 18 housingless stands, with four, two-pass modular Fast Finishing blocks fitted with an M2 Multiple Drive system, a 102m long cooling bed and associated entry/exit facilities, a cold shear for final cutting to length and a 28m wide counting/sub-bundling/master bundling station. Danieli Automation provided the Q-LONG Level 2 automation and all the electric systems for the whole plant.

Today the operating practice is to process more than 99% of rolling operations by direct charging, and with a 98% yield, this rebar mill is a competitive, energy saving and high quality operation.

Another important factor contributing to energy and cost savings is the possibility of rolling low alloy rebar thanks to the inline Ultra-Fine-Grain (UFG) process, which allows a significant reduction in the expense of alloying elements, such as niobium and vanadium.

With a dedicated and optimised chemistry, it is possible to minimise and even avoid the use of some alloying elements in low carbon-manganese steels through low surface temperature rolling. In this way the low mechanical properties that result from poor chemistry are balanced by the microstructure obtained via the UFG process, which promotes a very fine microstructure (1-5 µm; see Figure 9) and enhanced final mechanical properties. A typical mill temperature profile is shown in Figure 10.

Grain size-controlled grades can ensure high stress ratios.
and ductility, thanks to a dedicated, controlled temperature rolling strategy (hardness difference between surface and core should be less than HV 40). Higher ductility than with a conventional QTB quenching process are possible.

The UFG process is the most advantageous way to produce structural steel grades in bars and coils due to the reduction in microalloy additions, avoiding the martensitic microstructure phase during rolling.

The average transformation cost savings resulting from the absence of vanadium micro-alloy addition have been evaluated at ~17US$/t.

Considering the overall CapEx and OpEx index, the Feng Hsin MIDA DCR mill has become a very competitive, world benchmark operation.

CONCLUSIONS
Since the end of the last century, Danieli has understood and accepted the challenge posed by new trends in the energy-saving economy and arrived at a new vision, which eventually led to the innovative MIDA concept, an extremely compact mini-mill producing rebar in bundles and coils, with a high-speed caster directly connected to the rolling mill.

With zero emissions for billet reheating the Danieli Energy Saving Compact Minimill MIDA, featuring Direct or Endless Casting and Rolling technologies, are now a consolidated technology – the best available in the market – to fulfill the demands of high efficiency and energy saving in the production of rebar bundles, spooled coils and wire rod. **MIS**

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REFERENCES
4. A De Luca, A Sgrò, M Fornasier, Energy Saving: the high speed solutions in Danieli CCM, AISTech Proceedings 2018