Advantages of induction reheating in integrated minimills

by **Klaus von Eynatten, Markus Langejürgen, Dirk M. Schibisch**

The basic idea of a minimill is the production and processing of steel for long products in an integrated factory. The hot billets from the caster are fed through an induction heating system directly into the rolling mill. The induction system detects the billet's incoming temperature and equalizes the surface and core temperatures on demand, in order to provide an optimum rolling temperature. Important to notice with regard to the sustainability is the fact that no fossil fuel combustion furnace is needed. This setup allows for significant energy and cost savings and causes less emission. The article describes the energetic and economic advantages of induction systems integrated in Minimills and, as an example, refers to a proven solution at Tung Ho Steel in Taiwan.

In conventional minimills the cast billets are fed either hot or cold from the continuous caster into a combustion furnace then brought to rolling temperature before being conveyed to the rolling mill. For many years this process was the global standard, however it did have several disadvantages. First, the thermal energy contained in the billet is eliminated when the billet cools down after the casting process and then needs to be restored in the combustion furnace, which costs both time and money. Secondly, scale formed on the billet surface during conventional heating processes results in a loss of output. Furthermore, the condition of the scale leads to low roll service lives in the mill, while considerable quantities of offgas are emitted into the environment from the combustion furnace.

Driven by the cut-throat competition among steel producers as well as new industry regulations and environmental laws with emission limits, three companies in the SMS group - SMS Concast, SMS Elotherm and SMS Meer, have jointly developed the innovative CMT™ technology, which compensates for the disadvantages described and offers steel producers a means of gaining a competitive edge.

A key feature of CMT™ technology (Continuous Mill Technology) is the replacement of the conventional gas- or oil-fired furnace with an induction plant positioned directly inline between the continuous caster and rolling line. Here the heat stored in the billet from the casting process is used for the direct rolling process, and the temperature is merely equalised over the length and cross-section and adapted to the optimum rolling temperature. Overall, therefore, far less energy is consumed here, compared to the traditional method, than would be the case if the entire billet had to be re-heated from room temperature or any other intermediate temperature to the optimum rolling temperature at the inlet section of the first roll stand (**Fig. 1**).

Depending on the planned annual production, CMT™ minimills are used at varying capacities in terms of casting, heating and rolling output (**Table 1**).

HIGH COST EFFICIENCY

The major benefits of this innovative minimill configuration with integrated induction technology above all include:

- Lower investment costs
  - Reduced overall plant size means smaller production bays are possible
  - Induction plant does not require foundations or pits
  - Less infrastructure for supply and discharge of fossil combustion fuels (e.g. gas, heavy oil)
  - No billet storage
  - Far less handling technology such as roller conveyors, cranes, etc.

- Lower operating costs
  - In most cases lower primary energy costs for operating the induction plant
  - Higher output with the low-scale induction heating method
  - Higher output with fewer crop cuts or short bars
  - Lower handling and logistics costs as the billets do not require intermediate storage and additional transportation

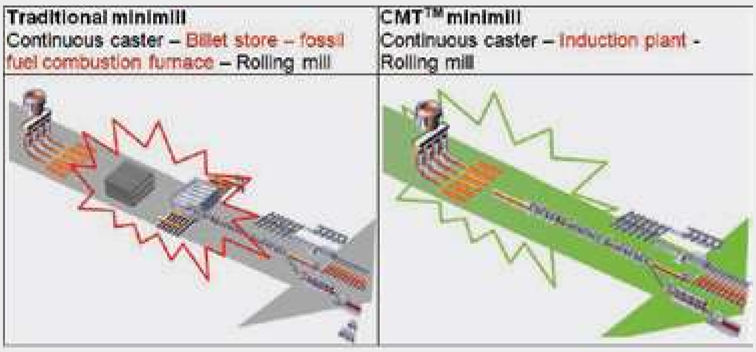

Fig. 1: Arrangement of a CMT™ minimill compared to the traditional layout (source: SMS Concast)

The lower investment costs are primarily achieved by dispensing with a conventional combustion furnace and reducing the logistics associated with billet production, e.g. storage facilities or crane tracks, as well as the reduced requirements with regard to space and accordingly to warehouse stock.

The reduced operating costs can mainly be attributed to the energy savings from lower primary energy costs and higher output; this is covered in more detail later on. Furthermore, the capital stock is reduced by eliminating the billet store. Additional savings can be made as a result of a reduction in the maintenance work which would be required on a conventional reheating furnace, and by reducing manpower requirements for operating personnel.

USING RESIDUAL HEAT TO SAVE ENERGY

Traditional minimill operation is usually broken down as follows: 30 % of the billets are fed cold into a conventional combustion furnace from the billet store before the rolling process, 70 % are conveyed directly out of the continuous caster and through this furnace with residual heat. The specific energy consumption depends on the required rolling temperature and type of furnace (pusher, roller hearth, walking beam furnace), which in turn depends on the productivity of the rolling plant. With this type of production programme (30/70) and an entry temperature of 1,000 °C at roll stand 1, around 155–160 kWh/t of specific energy consumption can be taken as a general guideline value.

With CMT™ minimills the picture is different: here 100 % of the cast billets are fed directly – with no rerouting involved – through the induction furnace to the rolling line. The design of the induction plant substantially depends on the workshop layout, i.e. the distance from the continuous caster to the first roll stand, the required rolling temperature and the relevant rates of production of both the continuous caster and rolling line.

In CMT™ minimills that are optimally laid out and feature casting strand insulation to prevent heat losses and a compact continuous caster/rolling line set-up, the specific energy consumption for heating a billet to 1,000 °C is between 20 and 25 kWh/t. This equates to a reduction by a factor of 7 (**Table 2**).

Any decision in favour of the innovative CMT™ minimill technology with integrated induction heating system is essentially based on the primary energy costs for fossil fuels (gas, heavy oil) or electric power, as well as their regional availability in each case.

The benefits of modern CMT™ minimills with integrated induction reheating prevail significantly in cases where fossil fuel costs are far greater than electricity costs. The following applies as a rule of thumb: The benefits of the CMT™ minimill concept with induction furnace can be fully brought to bear if the electricity/natural gas cost ratio is lower than 0.75. And this only takes the energy costs into consideration. Looking at other advantages such as output, low investment and space requirements or fewer operating personnel, to name just a few, this ratio increases even further, with the result that the number of plant operators able to benefit from induction-assisted CMT™ technology over the long term also continues to rise.

Fig. 2 shows the industry prices for natural gas and electricity in Germany (in 2013) and the savings

Table 1: Overview of various minimill layouts depending on annual production

CMT™ core data	CMT™ 1	CMT™ 2	CMT™ 3+
Annual capacity [1,000 t/y]	100 - 350	350 - 700	500 - 1,000+
Line productivity [t/h]	15 - 50	50 - 100	85 - 140+
Steel grades	Structural steel and high-grade steel (carbon steel)		
Casting radius [m]	7.0 - 10.25		
Cast cross-section [mm]	100 - 150		
Billet length [m]	"endless"	12 - 16	
Temperature homogenisation	Induction heating with various output capacities		
	1 - 2 units	2 - 4 units	variable
Number of roll stands	variable		
Number of casting strands	1	2	variable

that plant owners can achieve if they use an induction-assisted CMT™ minimill and direct rolling instead of a conventional minimill with combustion technology. It is clear that even with existing minimills the break-even point for the integration of induction heating is very quickly reached through the primary energy savings alone. If other factors, such as those as described above, are included in the cost-efficiency analysis, then a decision in favour of an induction-assisted CMT™ minimill becomes all the more obvious.

Table 2: Specific energy consumption for different production layouts

Production capacity	CMT™ minimill with induction 100 % direct rolling	Conventional minimill with combustion furnance (30 % cold + 70 % warm)
	Specific energy consumption	
	20 – 25 kWh/t	~155 – 160 kWh/t
300,000 t/a	6,750 MW/ a	47,250 MW/a
500,000 t/a	11,250 MW/a	78,750 MW/a
800,000 t/a	18,000 MW/a	126,000 MW/a

HIGHER OUTPUT WITH NEGLIGIBLE SCALE

With the conventional reheating process the cast billet is fed either cold or with some residual heat into the fossil fuel-fired furnace. The formation of scale, which depends on the time factor as well as a few material-related variables, increases above a temperature of around 900 °C. In other words: the longer a billet is held in the reheating furnace above 900 °C, in order for it to be "heated through", and the higher the furnace outgoing temperature is, the more primary scale is formed. Today´s modern combustion furnaces with optimal temperature adjustment and combustion air regulation in the holding zone are capable of achieving values of around 0.6 % scale loss.

In CMT™ minimills the billets are brought directly to rolling temperature in induction heating systems at very high heating rates. At less than 60 seconds the holding time within the critical temperature range above 900 °C is very short, with the result that virtually no scale is able to form. Compared to an atmosphere furnace, the level of scale formation with induction heating is, at around 0.02 %, lower by a factor of 30 and therefore negligible. This results in a higher metal yield of approx. 0.6 % which, given the high production volumes, very quickly adds up in terms of cost efficiency (**Fig. 3**). By comparison with conventional minimills this increased output can be viewed as "cost-free“ production. In minimills with an annual production volume of 800,000 t, the economic effect from the higher material output alone amounts to almost € 2.2 million each year.

Moreover, further benefits can be gained from the low-scale billet surfaces in the subsequent rolling process. The brittle-hard scale has an abrasive effect and results in the rolls becoming worn. Low-scale surfaces following induction heating mean the service life of the rolls increases significantly.

LONG-TERM OVERALL SAVINGS

The overall cost reductions are thus the result of various individual cost reductions such as energy costs, increased output thanks to the higher metal yield as well as other factors. In the example of Germany given above, savings of around € 5 million per year or € 6.25 per ton of structural steel produced for a steel mill with 800,000 t/a output can be made from the point of view of energy costs and material yield alone. What’s clear, therefore, is that an investment in state-of-the-art CMT™ minimill technology very quickly pays for itself.

The following table shows the long-term savings offered by a CMT™ minimill with integrated induction technology compared to a conventional line with gas furnace based on an international comparison (**Table 3**). It should be noted here that the price and availability of gas are heavily dependent on the regional situation with regard to production. In cases where gas is not available, expensive heavy oil supplied by road tanker is usually used as fuel. This means additional costs which further promote the use of induction technology.

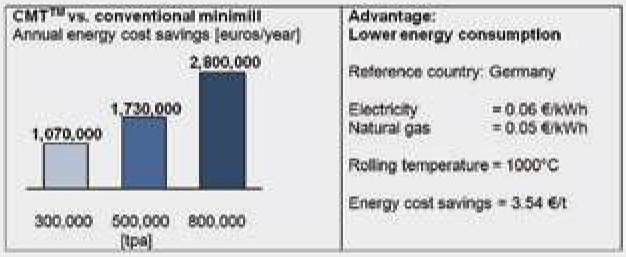

Fig. 2: Energy savings based on various production figures in Germany (source: SMS Concast)

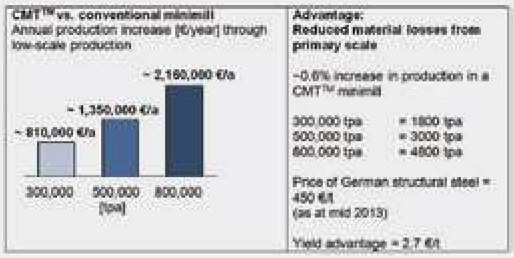

Fig. 3: Annual production increase using low-scale induction technology in a CMT™ minimill (source: SMS Concast)

Table 3: Long-term economic benefit of a CMT™ minimill with integrated induction heating system compared to conventional facilities with a gas furnace. (source: Platts, SBB Steel Prices, Dec. 2013 [1 € = 1.3 $])

Country	Energy input (cost/ unit)			Δ Energy	Δ Output (Primary scale only)	Overall cost saving
	Electricity	Natural gas	Sales price of structural steel			
	[€/kWh]	[€/Nm³]	[€/t]	[€/t]	[€/t]	[€/t]
Brazil	0.11	0.40	845	-4.4	-5.1	-9.5
China	0.04	0.22	400	-2.9	-2.4	-5.3
Germany	0.06	0.28	515	-3.5	-3.1	-6.6
India	0.08	0.37	510	-4.4	-3.1	-7.5
Russia	0.04	0.05	400	+0.2	-2.3	-2.1
Middle East	0.03	0.05	510	-0.2	-3.1	-3.3
East Asia	0.07	0.30	430	-4.8	-2.6	-7.4
USA	0.05	0.10	545	-0.6	-3.3	-3.9

If one brings together the various individual benefits in terms of energy costs and material output, then the picture gained is quite clear: In all major industrialised countries with significant steel production and processing industries the superiority of the CMT™ minimill concept is plain to see. Even in countries with a high availability of natural gas resources and correspondingly low gas prices, a minimill equipped with induction technology pays off through increased material output (**Fig. 4**).

Up to now attention was paid only to the monetary aspects associated with the use of induction technology in minimills. In addition to this, however, aspects relating to ecological sustainability, which may well be of greater importance in future, should be taken into consideration.

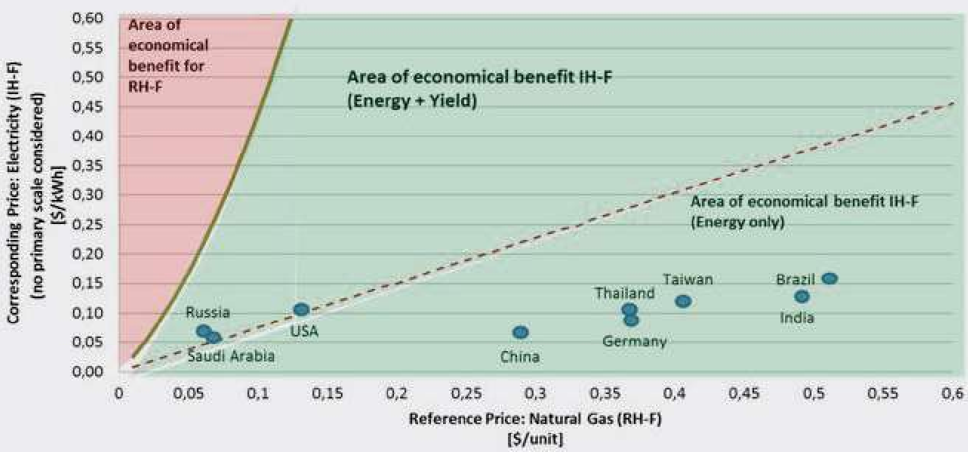

Fig. 4: Preferred concepts for reheating systems in minimills, depending on energy costs and primary output by international comparison (source: SMS Concast)

ECO-FRIENDLY PRODUCTION

Traditional minimills featuring conventional furnace technology for reheating billets use either natural gas or heavy oil as fuel. When looking at the general environmental impact, it is not just the combustion process alone that needs to be considered but the upstream manufacturing, transportation and storage processes, too.

The burning of fossil fuels produces greenhouse gases such as CO_2, NO_X and SO_X. These gaseous substances are emitted into the atmosphere during the burning process, thus contributing to the greenhouse effect by absorbing some of the infrared radiation given off from the ground which would otherwise escape into space. This interference with the natural equilibrium which makes life on Earth possible in the first place ultimately leads – through anthropogenic causes such as, for example, the combustion of gas and heavy oil for reheating billets – to global warming and all its known consequences.

Furthermore, carbon dioxide as well as sulphur and nitrogen oxides are considered some of the main causes of what we call acid rain, and the effects thereof on our ecosystem are well known.

The use of heating technology that minimises the negative impact on the environment can help improve the situation. By using induction technology instead of conventional combustion furnaces, direct emissions of CO_2, NO_X and SO_X when heating the billets before the rolling process are completely eliminated in a CMT™ minimill. Fig. 5 shows that with a conventional minimill featuring combustion technology and an annual production of 800,000 t, for example, 53,000 t of CO_2 and 73 t of NO_X would be produced; using an induction system eliminates this (**Fig. 5**).

In summary the CMT™ minimill can be classed as a typical "ecoplant" thanks to the integrated induction technology. "Ecoplants" is the term given to sustainable solutions from SMS Meer which also offer plant owners economic benefits at the same time. This takes account of the fact that sustainability has become a significant business growth factor – for both economic and ecological reasons. Economic because saving energy and raw material reduces costs, and ecological because protecting resources is becoming increasingly important. Ecoplants solutions do both.

REHEATING USING THE INDUCTION PROCESS

Before we look at the design and implementation of an induction system which is integrated in a CMT™ minimill, a brief explanation should be given of the technology involved.

As already explained in the preceding sections, a key feature of the induction technology used in a CMT™ minimill is the very rapid and therefore low-scale heating it offers, as well as the fact that fossil fuels and the resulting emissions are completely eliminated.

Induction heating is a non-contact type of heating whereby the heat is generated directly in the workpiece. The billet to be heated is encompassed by a coil, through which current flows, thereby creating a magnetic flux in the workpiece.

This magnetic flux, in turn, produces an eddy current in the billet surface, which generates heat due to the specific resistance of the material. This enables the temperature in the billet to rise using a current flow in a non-contact manner. Depending on the capacity and frequency of the current, it is possible to influence the temperature in the workpiece very precisely (**Fig. 6**).

Due to the geometry of the billet longitudinal-field heating is used in CMT™ minimills. Here the workpiece is fully encompassed by the coil. The resulting eddy currents run along the billet's surface at the current penetration depth. The simple design of the longitudinal-field inductors makes them very robust and capable of being integrated into the rolling mill process.

The high power density values that can be achieved can be used to full advantage in minimills, thereby enabling compact heating systems with high thermal efficiency levels to be integrated into the processing lines. As the following example of Tung Ho Steel in Taiwan shows, a total output capacity of 8,700 kW has been installed over a length of approx. 8 m. This output capacity is sufficient, for example, for a temperature rise of more than 200 K at a production rate of 100 metric tons/h. This effectively compensates for temperature level fluctuations in the upstream processes and ensures constant conditions at the inlet section of the rolling mill. This means no equalising through the rolling mill is required, plus any spares or reserves in terms of the layout and design as well as increased wear and tear are avoided.

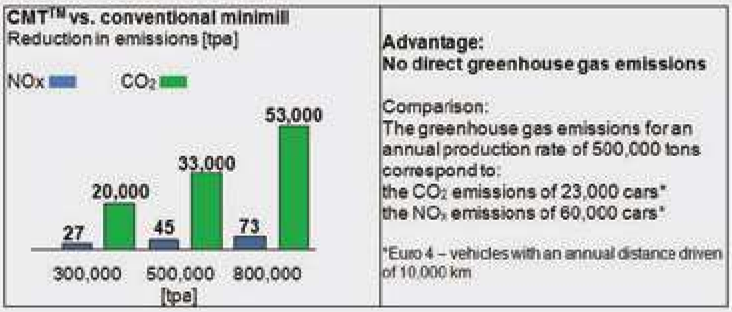

Fig. 5: CMT™ technology with integrated induction heating reduces greenhouse gas emissions (source: SMS Concast)

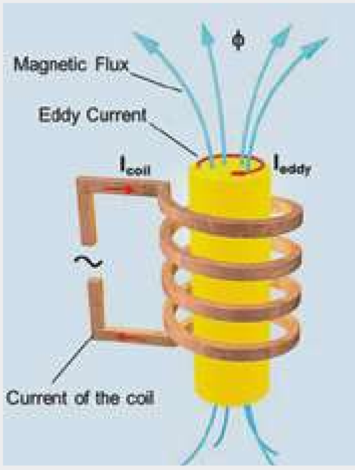

Fig. 6: The principle of induction heating (source: SMS Elotherm)

Fig. 7 shows the options available using two randomly selected, typical examples. With both dimensions, 100 mm and 195 mm square section, the temperature at the mill entry can be maintained at a constant level. An alteration of the production speed of between 3 m/min and 9 m/min has been taken into account here.

As the thermal conditions at the rolling mill entry are being stabilised, the temperature over the cross-sectional

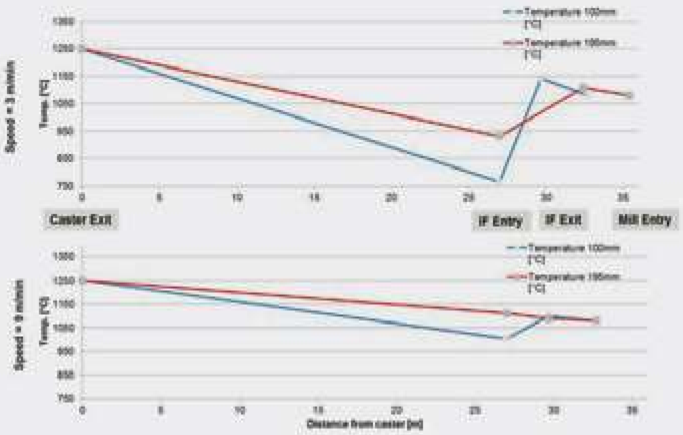

Fig. 7: Typical temperature curves with the induction heating of square material with dimensions of 100 mm and 195 mm at a conveying speed of 3 m/min and 9 m/min (source: SMS Elotherm)

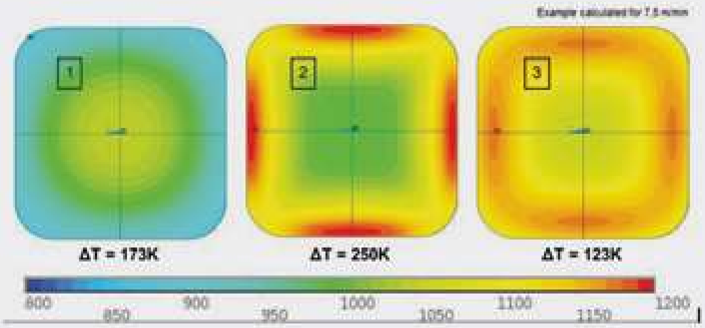

Fig. 8: Example of a typical temperature profile for a 160 mm square section on entering the induction unit from the continuous caster [1], following induction heating [2] and at the rolling mill entry [3] (source: SMS Elotherm)

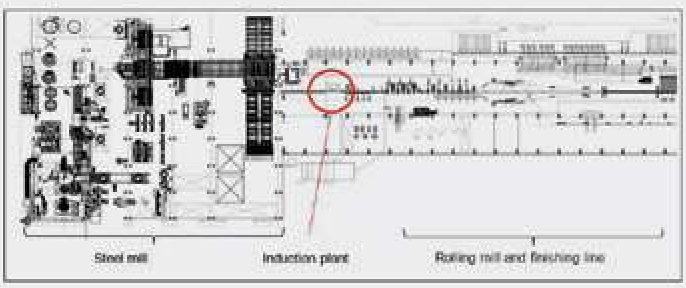

Fig. 9: Integration of an SMS Elotherm EloHeat™ induction heating plant between an SMS Concast continuous caster and an SMS Meer rolling mill (source: SMS Concast)

area of the material is homogenised. As shown in **Fig. 8**, the result is a temperature profile during transportation from the casting machine to the rolling mill whereby the surface is 173 K colder than the centre. This situation is often referred to as a natural temperature profile. This temperature profile changes due to the rapid heating process in the induction heating system, such that the highest temperatures occur on the surface. This is caused by the typical power density distribution of induction heating. However a crucial factor here is the fact that, on entering the rolling mill, the temperature differences over the cross-section can be reduced by around 30 % compared to natural cooling. Billets with a homogeneous temperature distribution can be more easily formed and therefore ensure a stable rolling process. Since less rolling force is required for forming billets with higher absolute and relative heat, there is also less roll wear and the rolls last longer.

EXAMPLE OF APPLICATION: TUNG HO STEEL, TAIWAN

As an emerging economic power, Taiwan is faced with huge challenges. Oil and gas have to be imported. So energy costs are correspondingly high. Therefore, Tung Ho Steel decided to install a CMT™ minimill – with a high production capacity and low energy consumption and reduced emission values thanks to the integrated induction technology – in its works near Taipei.

What's more, this minimill is a shining example of how a heavy oil-fired combustion furnace can be replaced by a compact yet powerful induction heating system, thus resulting in sustainable and measurable ecological and economic success. As there was no natural gas available at the site, heavy oil would have had to be used. Using induction heating technology meant that Tung Ho Steel was able not only to save almost 20 €/t of rolled steel but reduce its emissions in particular. This workshop at Tung Ho is therefore now capable of reducing its emissions by around 72,000 tpa CO_2, 410 tpa SO_2 and 225 tpa NO_X – year in, year out.

The steel mill is equipped with a 120 t electric arc furnace (EAF), a ladle furnace and a caster with 5 strands. At a production rate of 40-45 t/h per casting strand, this results in an annual capacity of around 1.2 million t of cast billets. The attached rolling mill produces around 800,000 t of rolled structural steel every year.

The induction heating system was integrated inline between the casting machine and rolling mill (**Fig. 9 and Fig. 10**).

The induction plant comprises 3 individually controllable modules with two induction coils each (**Fig. 11**). With an overall length of around 8 metres the plant has an installed capacity of 8.7 MW. This ensures both a tem-

Fig. 10: SMS Elotherm EloHeat™ – induction heating plant with 6 induction coils at Tung Ho Steel in Taiwan (source: SMS Elotherm)

Fig. 11: Billet before reheating at the inlet of the Elotherm EloHeat™ system at Tung Ho Steel in Taiwan (source: SMS Elotherm)

perature rise of up to 150 K and a consistent temperature distribution of the billets between the continuous caster and rolling mill. So on the one hand high process speeds of 140 t/h can be attained in the rolling mill, while on the other hand optimal rolling processes can be conducted with only minimal wear.

For this the induction heating plant is equipped with state-of-the-art IGBT converters, which themselves feature transistors and can therefore be flexibly adapted to the respective heating process and help to achieve a high level of overall plant availability.

Fig. 12 shows the calculated temperature profile between the casting machine and the entry section of the rolling mill at Tung Ho Steel. The green curve shows the temperature of the surface, the first third of which is influenced by the secondary cooling and contact with the support rolls. Following complete solidification upstream of the cutting torch position, the material goes through an even cooling-down phase, whereby any losses are minimised by radiation protection measures.

The induction heating section is identified by a red circle in Fig. 12 and shown in detail in **Fig. 13**. This is where adjustments and stabilisation of the thermal conditions for optimum rolling process preparation take place. The penetration depth at a frequency of 300 Hz is ~ 30 mm, ensuring near-surface heating can be achieved. The colder temperature at the core is equalised by means of heat conduction around 5 m after the billet exits the last induction coil, in order that a homogeneous temperature can be achieved over the billet cross-section for the purpose of the rolling process.

CONCLUSION

The demands being made by plant owners for flexible steel production in terms of the production volumes, the discussions currently being held with regard to low-emission production methods as well as the regional and limited availability of fossil fuels have been translated into innovative production concepts by manufacturers of plant and equipment for steel and rolling mill technology.

One result is CMT™ minimill technology with integrated induction technology for energy-efficient reheating. As well as a variety of innovative solutions in the steel and

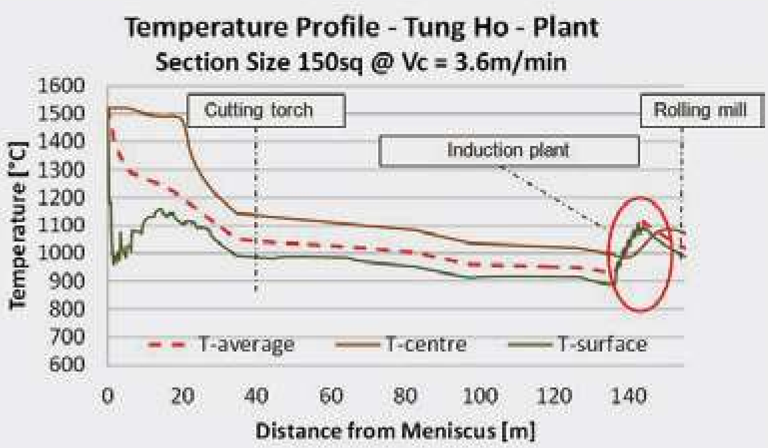

Fig. 12: Temperature profile of the billet with a cross-section of 150 mm at Tung Ho Steel in Taiwan (source: SMS Concast)

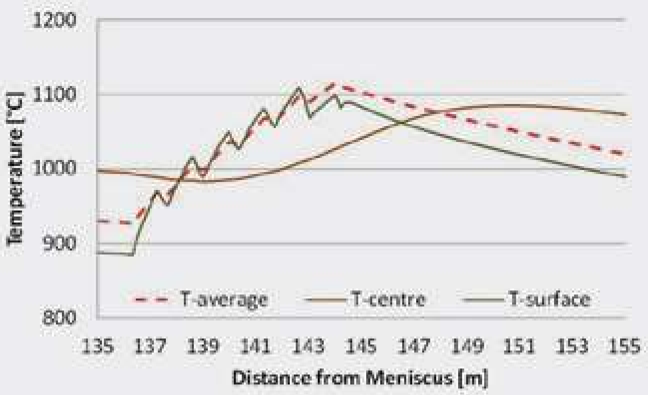

Fig. 13: Illustration of a temperature increase through the six induction coils and core temperature homogenisation by means of heat conduction (source: SMS Concast)

rolling mill sections of these minimills, special mention should be made at this point of the benefits of integrated induction technology: individual, rapid attainment of the optimum rolling temperature despite variable incoming temperatures, no energy consumption during downtimes and stoppages, increased metal yield with low-scale heating and above all no direct emissions – these are the means with which plant owners can secure their competitive edge on the international stage.

In future higher costs for CO_2 certificates will further increase the pressure on production costs for steel products. Plant owners would be well advised to bear in mind the economic advantages that can be attained with energy-efficient induction technology, both on an individual level and in terms of the total costs of a minimill over its lifetime. The CMT™ minimill concept offers manufacturers of rolled products a variety of solutions here, especially as any investment in most cases quickly pays for itself, even with revamps of existing lines.

AUTHORS


Dr. **Klaus von Eynatten**
SMS Concast Italia S.p.A.
Udine, Italy
Tel.: +39 (0) 432 / 654600
klaus.eynatten@sms-concast.ch


Dr. **Markus Langejürgen**
SMS Elotherm GmbH
Remscheid, Germany
Tel.: +49 (0) 2191 / 891-218
m.langejuergen@sms-elotherm.com


Dipl.-Wirtsch.-Ing. **Dirk M. Schibisch**
SMS Elotherm GmbH
Remscheid, Germany
Tel.: +49 (0) 2191 / 891-300
d.schibisch@sms-elotherm.com