Towards a Cost and Energy Efficient Leading Edges Hot Strip Mill

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Abstract: The industrial implementation of innovative research developments during the last years has let to a strong improvement of the aptitude, the performance and competitiveness of a traditional hot strip mill. The focus of technical innovation has been:

- to control product quality related to surface aspects, geometrical tolerances and the reproducibility and consistency of mechanical properties,
- to increase product mix and flexibility in scheduling including thinner hot rolled strips and an increased amount of high strength materials,
- to increase productivity by more powerful equipment's, increased work roll performance and by new technologies to adapt/control stock temperature at each position of the mill
- to reduce costs and energy consumption in hot rolling

A breakthrough in technology has been obtained with on-line work roll monitoring (Rollscope), high turbulence roll cooling (HTRC), pure oil lubrication and bar cooling.

Key words: Hot Rolling, Cooling, Lubrication, Inspection

1 Introduction

During the last decade, West European hot strip mills have been confronted with a new product mix and an increased competition.

Mills are challenged to roll new high strength grades (e.g. TRIP, DP, HSLA) in order to reduce the weight, especially in the automotive industry, and energy costs. Thinner hot strips are requested for direct application as a substitute to the cold rolled and annealed sheets. More and more electrical steels are being rolled and a continuous increase of customer requirements related to surface quality and dimensional tolerances is observed.

On the other hand the competitiveness from other countries strongly increased with the start-up of new mill concepts (e.g. mini-mill, endless rolling) leading to an increased import of low cost high quality products on the European market. Furthermore the cost of raw materials and energy increase stronger in Europe compared to other countries and the environmental constrains become more and more severe.

In order to stay competitive West European mills are focussing to optimise the rolling process to roll new grades, to improve the quality of the hot rolled material and to reduce the operating costs and environmental footprint. New investments have been introduced to increase productivity (e.g. reheating furnace capacity), but even more important process conditions have been optimised to assure product quality and process efficiency. The key targets have been:

- the control of the work roll surface state as it influences directly the product quality, the rolling schedule and the rolling cost,
- the control of the product quality related to the rolling of thin and new materials,
- the increase of the working ratio of the mill by new temperature control actuators,
- and the decrease of rolling cost and energy consumption.

Combined with an improved understanding of the rolling process, new means in IT and automation, significant progress has been made in the development of sensors and process actuators, maximising mill performances. Major technological innovations are:

- 'Rollscope': on-line inspection of the work roll surface state
- "Bar cooling": cooling of the transfer bar in front of the finishing mill
- "HTRC": High Turbulence Roll Cooling
- 'Pure oil lubrication': hot rolling lubrication by atomization of natural oils on the roll surface

Although the innovative potential is still high and progress is certainly not stopped, this paper aims to highlight some of the technical innovations implemented during the last decade towards a cost and energy efficient leading edges hot strip mill.

2 Increased work roll performance

The degradation of the work rolls in the early stands of the finishing mill is a major concern for the mill operators. It reduces the length of the rolling campaigns, increases the production costs and induces strip surface defects. The degradation of the work roll surface is a very complex phenomenon in which mechanical and thermal fatigue occur in combination with tribological factors, such as impact, abrasion, sticking, oxidation and corrosion [1-2]. Researchers, mill operators and roll manufactures have been studying the possibilities to increase the work roll life (ton/mm) and to maintain an optimum work roll surface aspect during the complete rolling campaign [3-4].

A constant evolution in roll grade for the early stands has been observed with the introduction of different composition and related heat treatments of CPC and Spin Casted HSS rolls. Shell bounding problems and friction increase related to the application of Spin Casted HSS rolls have been solved. Today HSS rolls from both processes can be applied with performances up to 20000 ton/mm with and without lubrication. The main improvement in roll performance is however related to grinding policies. The introduction of new grinding machines with improved accuracy, new sensors (e.g. eddy current, ultrasonic) and roll shop management systems has led also to HiCr roll performances of more than 10000 ton/mm in the early stands. By this the application of HSS or HiCr rolls is determined by the possibility to perform double or triple campaigns (HSS in favour) or the necessity to adapt the work roll crown related to different rolling campaigns (HiCr in favour). Work roll performance been increased by more than 50%.

Roll performance determined as the mass of hot rolled steel produced per millimeter of ground roll diameter (T/mm) is however not completely representative for the work roll performance because it does not take into account the evolution of the work roll surface during the rolling campaign, but it gives only an indication of the wear resistance of the shell. The evolution of the work roll surface is however of prime importance since it determines the quality of the rolled product. An important tool in optimising the process conditions related to the evolution of the roll surface has been the installation of an on-line work roll surface inspection 'Rollscope' in the stands. It was observed that the increase of roll degradation is directly related to the work roll grade, the existence of protective oxide layer on the surface, the corrosion resistance and coolant water composition and process parameters as the rolling force, speed, slip, entry/exit thickness, length and rolling time of one strip.

The macroscopic degradation of the roll surface is strongly in favour of HSS rolls. But also in this field a strong progress has been obtained for HiCr rolls with the introduction of skin cooling and high turbulence roll cooling (HTRC), the adaptation of rolling schedules related to a protective oxide layer and the control of the chemical composition of roll coolant water.

2.1 'Rollscope': On-line work roll surface inspection system [5]

The on-line work roll surface inspection system, 'Rollscope' consists of viewing, containing a CCD camera, a stroboscopic flash light and a focus adjustment unit, mounted on a translation/rotation system attached to the entry table of finishing stand F2 (Fig.1).

Figure 1: On-line work roll inspection system in stand F2 at ArcelorMittal Gent

The principle of the inspection system is to illuminate the work roll surface by means of a stroboscopic light source and to acquire simultaneously a CCD image, representing a work roll surface size of 8 by 6 mm (Fig.2).

Figure 2: Work roll surface degradation observed by the 'Rollscope': oxidised surface with pitting, degraded surface with comet tails, banding (full degradation)

2.2 Adaptation of rolling schedules related to roll performance

Rolling parameters as forward slip, reduction, strip length strongly influence the growth and wear of an the protective oxide layer on the roll surface. At low reductions (<40%) it takes about 20 strips to form an oxide layer. This oxide layer is however completely removed by the consecutive rolling of about 5 strips with high reduction (>40%). In order to assure the existence of a protective oxide layer on the surface rolling schedules have been adapted to try to limit the number of consecutive high reduction in one stand [3]. It several cases it is however not possible to limit stand reduction or the order of rolled products.

2.3 Implementation of product surface chilling

The most important actuator related to reduce the breakdown of roll surface particles has been the implementation of product surface chilling [3]. Today product surface chilling is installed successfully in the early stands of several high productive hot strip mills. The principle of product surface chilling is to cool intensively the strip surface at the entry of the roll bite over a short distance, 100–300 mm, by means of flat jet nozzles with a flow of 30 to 150 m^3/h at each side. By this strip surface temperature in contact with the work roll is reduced by 100 to 200°C reducing strongly the work roll thermal fatigue. The average strip temperature decreases by 5°C/stand. This actuator is today indispensable to assure an optimum work roll performance.

2.4 'HTRC': High Turbulence Roll Cooling [6]

Another important actuator to decrease work roll degradation is the performance of the work roll cooling system.

Since mid-September 2006 the work rolls in stand F2 at the ArcelorMittal Gent HSM are being cooled by means of a new revolutionary cooling design, High Turbulence Roll Cooling (HTRC) (Fig.3).

Figure 3: HTRC work roll cooling in stand F2 at ArcelorMittal Gent

The work rolls are cooled without nozzles, without a scraper and with a low water pressure. This success has been the result of a close co-operation between ArcelorMittal Gent and CRM with the support of the European Commission in the frame of an ECSC pilot and demonstration program [6]. The principle of the new technology is based on the formation of a high turbulent water cushion between the header and the work roll surface (Fig.4).

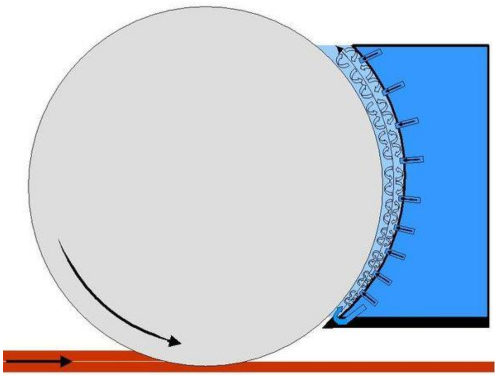


Figure 4: Principle of HTRC cooling

A curved water pillow cooling (WPC) header is placed at a close distance to the work roll surface: 10 to 140 mm. The coolant flow out of the stand is controlled by side masks in order to assure the formation of a water cushion between the roll surface and the cooling header. The critical factor is the injection of coolant water through a multiple number of holes in the front plate of the header. The form, distribution and impact pressure of the straight water jets have been designed to create a homogeneous high turbulent water cushion, to avoid direct impingement of water on the roll surface and to control the work roll crown. In addition a water curtain functionality has been added to the header design to replace the mechanical wiper, to intensify the cooling near to exit of the roll bite and to stimulate the circulation of the coolant water.

The macroscopic degradation of the roll surface has been studied by means of the on-line work roll surface inspection system, 'Rollscope'. An improvement of 25% in wear rate could be observed related to the rolled kilometres compared to the classical cooling system with flat jet nozzles.

3 Product quality control

Based on the better understanding of product defect, the implementation of new sensors, improved control systems and process actuators has led to a better and constant product quality related to geometric values like thickness, width and flatness as well as mechanical properties and surface quality.

Today robust on-line product sensors have been implemented for flatness, thickness, width, head/tail shape, temperature, speed and surface defects [7-10]. Trials are being performed with sensors to measure scale thickness, scale cracking, mechanical properties, composition and grain size [11-13].

Advance control units are installed based on hybrid model for thickness and width control [14-15].

Strip flatness on the run-out table has strongly been improved by the implementation of new measurement systems and temperature control actuators such as edge masking on the ROT inducing differential cooling over the width [16]. Customer flatness is however not under control as it has not yet been possible to link it with ROT flatness, coiling tension and coil temperature evolution. Different models have been developed indicating especially the importance of temperature homogeneity and internal stresses [17-18]. By this, the focus today is to avoid temperature differences over the width by the use of walking beam furnaces and better furnace control. The application of control actuators to increase temperature homogeneity over the width by edge heating, interstand edge cooling and edge masking on the run out table, linked to a coil temperature and stress evolution model and to improve the flatness before coiling by better control of mill stand actuators [19].

The control of homogeneity of mechanical properties remains a major concern for traditional HSM related to the temperature difference over the length and the width and the development of on-line measurement systems is still on-going and being optimised [11-12]. The focus is to increase the temperature homogeneity of the hot rolled strip linked to the flatness control. During the last years also new cooling techniques have been developed [20-21]. An example of increased cooling homogeneity is Ultra Fast Cooling (UFC). UFC consists in a controllable compact cooling unit with a cooling power density as large as 5 MW/m2 for the highest specific water flow rate of 65 l/m2.s. The cooling power can be easily controlled, simply by acting on the cooling water flow rate. Even on a high-speed rolling mill, the cooling rate and the cooling stop temperature on the run-out table can be kept under control on strips. A very good temperature homogeneity (along length and width), ensuring constant mechanical properties, is obtained.

The most important results obtained during the last years are related to the control of the surface quality of the strip by:

- The implementation and use of automatic strip surface inspection systems (ASIS) [7]
- The decrease of roll gap friction related to improved roll performance and the application of hot rolling lubrication.
- The application of selective cooling systems such as bar cooling, edge cooling and interstand cooling [22,16]

3.1 Implementation of automatic strip surface inspection systems (ASIS)

Different generations of automatic strip surface inspection systems have been implemented during the last decades based on area or line inspection resulting in a full image of strip surface on the top and bottom side. Image algorithms have been developed identifying strip defects and alerting operators. The ASIS systems are today a main tool to control and optimise the rolling process [4,8]:

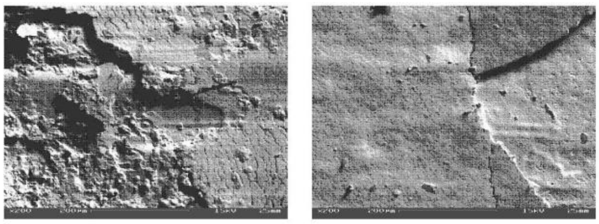
- Strip surface quality is an indicator of mill performance
- Defect crisis are alerted immediately reducing the response time and material yield loss.
- An objective overview is given of the impact of process changes on strip surface quality.

Customer complaints have strongly been reduced as products are inspected before sending. The amount of material loss are downgraded material is reduced by pro-active majors, direct response and an improved understanding of process conditions on surface quality defects.

3.2 Decrease of roll gap friction

The processing conditions with an increased risk for defects are well known (e.g. increased roll gap friction, high forward slip, increased scale thickness) and scheduling rules have been defined. It remains however impossible to assure a defect-free strip combined with increased mill productivity and the tendency to roll thinner materials. One of the major defects observed in hot strip rolling is the occurrence of line type rolled-in-scale. With the ASIS system this defect has been linked to the friction coefficient in the early finishing mill. By the introduction of hot rolling lubrication and high turbulence roll cooling the rejecting rate of hot rolled strip for line type scale has been reduced from 0.05% to less than 0.01%. In addition it has been possible to relax the programming rules: the number of thin strips in a campaign was increased by 20% and the length of hard campaigns was increased from 130 Nkm to 150 Nkm.

Based on this positive result a detailed study has been performed to get a better understanding of each individual process actuator on scale deformation in the roll bite. Dedicated continuous hot rolling trials have been performed at the CRM pilot line with work rolls equipped with inserts of different roll materials with low and high wear. The impact of roll roughness on scale deformation can be observed in figure 5. High roll roughness leads to a strong cracking of the scale layer and an extrusion of the metal through the cracks.



BSE TOPO 200X - Insert 1 - Ra=4. 8µm BSE TOPO 200X - Insert 5 - Ra=2.17µm

Figure 5: Impact of roll roughness on scale deformation and extrusion of material in the roll bite

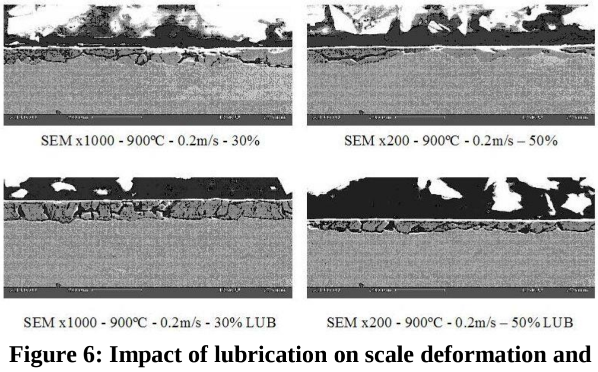


Figure 6: Impact of lubrication on scale deformation and extrusion of material in the roll bite

Secondly, the impact of lubrication on scale deformation has been studied (Fig.6). Lubrication leads to a great number of small cracks. At high reductions a shearing effect of the cracks can be observed. The deformation of the material matrix is however much smoother with the application of lubrication.

3.3 Application of selective cooling systems

Some rolled-in-scale defects frequently observed are high temperature related. With the ASIS system is was linked to the higher temperature of the head of the strip and to the hot shoulders originating in the reheating furnace and by width reductions. This defect has been suppressed (<50%) by cooling always the head of the strips with the bar cooling unit (see next paragraph) and by the installation of additionally nozzles to perform edge cooling between the early finishing stands [22].

4 Increase of productivity

Today high productive hot strip mills are able to roll 5 to 6 million ton/year. Key actions required to increase productivity are:

- the handling of the material before and after rolling
- the capacity of reheating furnaces taking into account hot charging
- the capacity of rolling stands: cooling drive systems
- the capacity of the cooling towers
- the work roll cooling performance
- the working ratio of the mill: waiting time entry finishing temperature, roll changes, maintenance stops,

The first four topics can be obtained with an upgrade or new process equipment. Work roll cooling performance has successfully been increased with the development of high turbulence roll cooling. Improved automation and maintenance management results today in roll changes less than 10 minutes and maintenance stops limited to 1.5 day every 2 weeks. A main parameter however limiting the working ratio is the waiting time before the finishing mill. From a metallurgical point of view, each product has its optimum finish rolling temperature domain. To fulfil the very diversified thermal constraints as required for the different grades, the mill manager is faced to a problem. The difference of slab reheating temperature on consecutive slabs is small (due to the low thermal inertia of the furnace) for all the grades within a defined campaign (with generally very different grades and formats). However, the thermal requirements can change from one strip to another due to the metallurgical prescriptions. Consequently, it appears not feasible to combine a high productivity and the strict respect of the imposed thermal schedule for about 50% of the total amount of strips. An ideal solution to keep working on the highest capacity of the mill while respecting the thermal requirements, is to have a flexible cooling system between the roughing mill and the finishing mill. A "bar cooling" unit has been successfully implemented at ArcelorMittal Gent in 2001 to lower the bar temperature with a maximum of 70°C in order to avoid a waiting time before the finisher. The cooling pattern is homogeneous related to the high turbulence cooling principle and the mechanical properties are not affected.

4.1 'Bar cooling': Cooling of the transfer bar at the entry of the finishing mill [22]

Bar cooling, is a compact cooling equipment placed between the roughing and the finishing mill, in order to cool in a very fast and controllable way the bar coming out of the roughing mill so that the desired finishing rolling temperature is obtained at the maximum rolling speed.

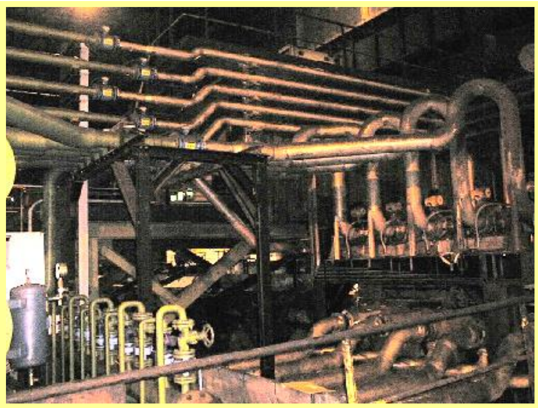


Figure 7: Bar Cooling at ArcelorMittal Gent

Moreover, the equipment control system is designed in such a way that the entry temperature in the finishing mill can be modulated along the length of the bar. The top and bottom cooling (temperature drop) can be controlled separately, in order to ensure more through thickness temperature homogeneity. The cooling unit is situated at 2370 mm behind the roughing mill R3 (speed of the bar = 3.9 m/s). The characteristics of the equipment have been fixed taking into account main factors like optimum working conditions, feasibility, maintenance and safety for the equipment in case of ski. The maximal flow rate is 2200 m3/h for the narrow mode (up to a width of 1400 mm) and 2700 m3/h for the wide mode (up to a width of 1950 mm). If necessary, the flow rate could be increased up to 3000 m3/h. The control system of the cooling equipment has been integrated in the existing control systems for the rolling mill.

5 Cost and energy efficiency

In order to reduce the production costs, a high productive hot strip mill (HSM) has three major objectives:

- to decrease energy consumption
- to enhance the mill availability
- to reduce the yield losses by ensuring a prime quality for the whole mix-product
- to reduce the cost of raw materials (e.g. work rolls, lubricants)

All activities mentioned in the article lead to a reduction of cost and energy savings.

The main energy input in hot rolling is the latent heat of hot charged slabs and the gasses applied in the reheating furnaces (1.26 GJ/ton). The second energy input is electricity. Today several companies are developing technologies and control units to optimise the use of energy in the reheating furnaces as the energy efficiency is less than 40% [23-24]. Another aspect is the increase of hot charging. It remains however difficult to balance casting operation and hot mill scheduling. The energy loss in the hot rolling mill after the reheating furnace can however not be neglected as it represents 50% of the total energy loss in hot rolling operations. The energy loss consists mainly of electricity loss in the rolling stands and the coilers (70 KWh/ton) and the loss of thermal energy of the hot products by descaling systems, cooling systems and radiation. Two technologies are presented in this article that had a strong impact on the consumption of electrical energy: 'high turbulence roll cooling' and 'hot rolling lubrication'. High turbulence roll cooling operates at low pressure (2-4bar). With the implementation of this technology in the early stands of the finishing mill it was possible at AM Gent to reduce the operating pressure for roll cooling in all stands from 8 bar to 2.4 bar. This results in an energy saving of 600 k€/year. On the other hand the impact of pure oil lubrication, reducing the rolling force and by this the electrical consumption of the main drives is estimated at a saving of 65 k€/stand/year.

Mill availability has strongly been increased with the implementation of 'bar cooling' reducing the waiting time in front of the finisher. A mill productivity can be obtained of 830 ton/hour with average interstrip times less than 20 seconds. Combined with optimised roll changes and maintenance scheduling a maximum of 5.4 million ton/year production has been obtained at ArcelorMittal Gent with a complex product mix.

The yield losses have been reduced by more than 50% due to a better understanding and control of process conditions related to strip surface defects.

Roll wear is strongly reduced by new grinding policies combined with optimised roll cooling and lubrication systems.

Finally, the consumption of lubricants for hot rolling operation has been reduced by more than 40% by the application of pure oil lubrication.

5.1 Pure oil lubrication

'Pure oil lubrication' is a new lubrication technology proposed by CRM based on the atomising of pure (natural) oils. The technology has been successfully tested in stand F2 at ArcelorMittal Dunkerque (Fig.8) and is implemented today in stand F4 at ArcelorMittal Gent [25].

Figure 8: Pure oil lubrication implemented at ArcelorMittal Dunkerque

With this new technology it is possible to spray very low pure oil amounts on the work rolls, reducing the rolling forces up to 20% and with an increased efficiency of 50% compared to emulsions. Flow rates down to 5 ml/min/nozzle can be reached on a width of 120mm. A big advantage is also that oil and airflow can be separately controlled. By changing the air pressure the airflow is adapted, which is then used to control the size of the oil droplets. Changing the pump rating will affect the oil flow rate and help to regulate the amount of oil and the plate-out. Lubrication is applied with a pure 'green' natural oil without any additives combined with the application of skin cooling. Thanks to the use of pure oil, no soap formation occurs in the lubrication tubes, avoiding nozzle blockage.

6 Conclusions

With a more complex product mix, containing harder grades (e.g. TRIP, DP, HSLA) and more electrical steels, research activities lead to new standards in the field of productivity, product quality, cost management and energy consumption.

A mill productivity has been obtained of more than 800 ton/h with a yearly productivity between 5 and 6 million tons by investments in more powerful pushing furnaces, hot charging, increased cooling and work roll performance and the implementation of a bar cooling unit.

Line type and temperature related rolled-in-scale have been strongly suppressed by improved roll performance, lubrication and selective cooling.

The increased productivity, combined with reduced energy costs for reheating, increased roll performances (<50%), reduction of work roll coolant pressure (600 k€/year) and the application of hot rolling lubrication (65 k€/y/stand) lead to a strong decrease of the total hot rolling cost, less than 30€/ton for reheating and rolling.

7 Future trends

Also in the future, the hot strip mill will have to adapt to a constant change in product mix related to new grades and market request. This will request a constant adaptation of process actuators.

Strip quality remains the most important research topic focussed especially on surface aspects but also control of mechanical properties and internal stresses.

A key activity will be recovery of energy and the reduction of electricity in auxiliary systems (30% of the total electricity) by the use of new advanced technologies.

But the main challenge for the coming years is the transfer of the new technologies.

Aknowledments

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