HIGH-TURBULENCE ROLL COOLING IN TATA STEEL IJMUIDEN HOT STRIP MILL 2*

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Abstract

Tata Steel IJmuiden Hot Strip Mill 2 (HSM2, 5.5 Mtonnes/yr) is currently being upgraded, resulting in an increased rolling force and motor power capacity. With the current conventional work roll spray cooling, a deterioration in work roll & strip surface quality performance is expected as a result of the increased mill capacities.

In order to improve strip surface quality, HSM2 decided to do a full-scale production trial with High Turbulence Roll Cooling (HTRC) at stand FM2. HTRC is a novel way of roll cooling using a high turbulent flow regime. HTRC is positioned very close to the roll surface and gap exit, which is beneficial for the roll surface quality. It is operated at a high flow rate but at a low pressure. HTRC not only significantly improves the roll surface quality, in addition, it makes high pressure pumps, needed for the conventional spray cooling, redundant, leading to substantial savings on electricity costs and thus CO_2 emissions. HTRC is in trial operation since 7 August 2018. Results show no operational issues, an excellent roll surface quality and an increased cooling efficiency. In summer 2020 stands FM1-FM2-FM3-FM4 of HSM2 will be equipped with HTRC.

Keywords: Hot Rolling; Work Roll Cooling; Energy Savings

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* *Technical contribution to the 11th International Rolling Conference, part of the ABM Week 2019, October 1st-3rd, 2019, São Paulo, SP, Brazil.*

1 INTRODUCTION

Tata Steel IJmuiden Hot Strip Mill 2 (HSM2, 5.5 Mtonnes/yr) is currently being upgraded, resulting in an increased rolling force and motor power capacity. With the current conventional work roll spray cooling, a deterioration in work roll & strip surface quality performance is expected as a result of the increased mill capacities.

After consulting the most important mill builders in Europe (SMS, Primetals and Danieli), it turned out that the current conventional spray cooling of HSM2, although dating from 1985 [1], already has the highest water flow rate (1500 m^3/hr per stand) and the highest water pressure (16 bar) of all high-productivity mills in Europe. In addition, trials with the current conventional spray cooling (e.g. maximizing the wettability, minimizing the distance to the gap exit and different exit/entry water flow ratio) showed that the spray cooling is already operating at its maximum performance. That was the trigger to start searching for highly efficient, novel ways of cooling the work roll, preferably:

- **using less water**: less water usage provides opportunities to install, for example, a transfer bar cooling without having to expand the current water management system;
- **running at low pressure**: low cooling water pressure means that (part of) the 3 high pressure pumps can be bypassed (leading to substantial electricity costs savings);
- **enabling work roll lubrication**: the roll cooling should be compatible with an optional lubrication system (for possible future use).

High-Turbulence Roll Cooling (HTRC) is such an low-pressure roll cooling system with an advantageous water usage. HTRC is developed in a joint Research Fund for Coal and Steel (RFCS) project, funded by the European Union, together with, among others, Centre de Recherches Métallurgiques (CRM), Tata Steel Europe and ArcelorMittal (AM) [2-3-4]. Worldwide, HTRC is currently only applied at AM in Gent (Belgium) [5] and in Dofasco (Canada) [6]. Both ArcelorMittal HSM’s can be considered as benchmark with respect to strip surface quality and work roll usage, especially AM Dofasco.

A comprehensive study showed, that for the most critical, with respect to roll cooling, (upstream) stands, HTRC is also the most favourable option for HSM2. In order to improve the strip surface quality and save on energy consumption, HSM2, in close collaboration with CRM, decided to do a full-scale production trial with a prototype HTRC at the Finishing Mill Stand 2 (FM2) top work roll. Togehter with the Tata Steel R&D department, the HSM2 personnel, an external engineering office and the CRM process team, an unique HTRC design has been established, fitted to the HSM2.

The HTRC technology is described in chapter 2. Chapter 3 describes the trial results, followed by the discussion in chapter 4. Finally, the conclusions can be found in chapter 5.

2 TECHNOLOGY

HTRC is a cooling unit attached to the stand exit guide with a similar curvature as the work roll, which is positioned very close to the roll surface (5-15 mm), as can be seen in figure 1.

In the Tata Steel HTRC, a part of the water is injected through the first nozzle row. The water flow is going upwards, in the same direction as the circumferential roll speed, which is beneficial to prevent wiper water leakage and also to cool as efficiently and as closely as possible to the gap exit (minimal “wet angle”). Minimizing the wet angle is reducing the repetitive heat penetration, and thus the cumulative strain during one roll rotation, into the roll as much as possible, which is known to be beneficial for roll degradation and thus strip surface quality.

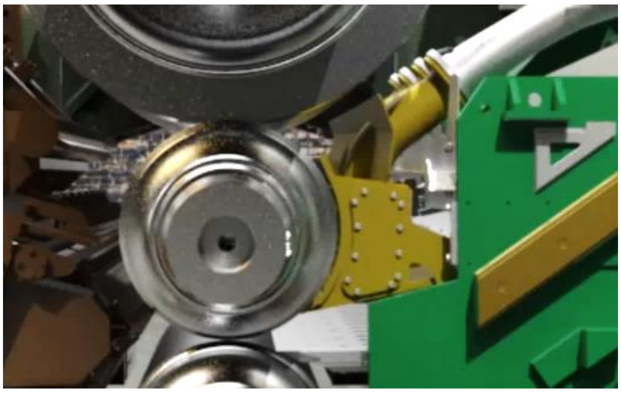

Figure 1. Technical drawing of the HTRC implemented in the FM2 stand exit guide of HSM2.

Fluid mechanics tells us that a high turbulent flow regime and thus a high Heat Transfer Coefficient (HTC), is achieved by high Reynolds number (Re) values. High Re values are achieved by high water flow rates (up to 700 m3/hr per HTRC unit) through a narrow and tightly controlled gap, but also by perturbation of the flow regime. Therefore, besides the first nozzle row injecting a part of the water flow, the HTRC unit also has a specifically designed pattern of extra nozzles, which are causing perturbation of the flow regime, as can be seen in figure 2. This is based on the same principle as the dimples in a golf ball or the "zigzag" strips on the suits of the very successful Dutch high speed skating squad at the Sochi Olympics in 2014.

Consequently, key aspect of HTRC operation is close positioning to the roll, creating a narrow 5-15 mm gap in-between the HTRC and the roll surface. If the gap is too wide, the water velocity will drop, as will the Re-value and consequently the HTC. To prevent scratching the roll, the wiper nose at the bottom side and the blocks at the top side of the HTRC unit are not only used to prevent water leakage, but also to maintain the gap distance. If one pushes the HTRC unit too hard to the roll, there will be no water leakage and the gap will be tightly controlled. However, it comes at the cost of a (undesired) high wear rate of the wiper nose and blocks. If the pressure is not high enough, the water will push the HTRC unit away from the roll, possibly leading to water leakage and a decreased cooling efficiency. If one is operating in the optimum window, high cooling efficiency, no water leakage and low wear rates of the blocks can be achieved all together. Then the wiper nose and blocks can last for even months. For this purpose, the position of the HTRC unit in HSM2 must be tightly controlled, as can be schematically seen in figure 1.

Figure 2. HTRC in (top) stand FM2 of IJmuiden HSM2.

Laboratory experiments at CRM in Gent showed that the HTC of a HTRC unit can reach more than 60000 W/(m2/K), almost doubling the HTC of a conventional, high pressure spray cooling. In addition, because HTRC is operated at a relatively low pressure (2-3 bar), HTRC makes high pressure pumps, needed for conventional spray cooling, redundant, resulting in substantial savings on electricity costs and reduction of CO_2 emissions. Finally, HTRC may be operated without roll entry cooling, providing opportunities to apply roll lubrication (which otherwise would be washed away by the entry cooling water).

3 TRIAL RESULTS

The trial results will be split in three parts, each of equal importance; the operational performance (paragraph 3.1), the process performance (paragraph 3.2) and the maintenance performance (paragraph 3.3).

3.1 OPERATIONAL PERFORMANCE

With respect to operations, running the HTRC goes very smoothly. After starting up production with HTRC, it was noticed that:

- Water splattering at the HTRC stand was significantly less than the water splattering at a conventional spray cooling stand. Figure 3 shows the water splattering at stand FM2 compared to stand FM3. The water is nicely guided downwards to the water management system.

Figure 3. HTRC water splattering.

- The roll change cycle times with HTRC or conventional spray cooling are equal, there is no delay in changing the work rolls when using HTRC.
- Although vast volumes of water (up to 700 m^3/hr) are used for the HTRC, there is no water leakage at the strip surface, which is clearly shown in figure 4.

Figure 4. Strip surface at FM2 exit.

- There has been a period during the trial where the measured HTRC water pressure was gradually increasing while the system struggled to achieve the target water flow rate. This turned out to be a maintenance issue and is discussed in paragraph 3.3.

3.2 PROCESS PERFORMANCE

With respect to the process performance, several aspects have been analysed:

- The cooling capacity (paragraph 3.2.1). For this purpose, many centre line temperature measurements have been done. The centre line temperatures provide information about the cooling capacity of HTRC compared to the conventional spray cooling.
- The work roll surface (paragraph 3.2.2). One of the key aspects of HTRC, is that the so-called wet angle, in the case of HTRC, is less than in the case of conventional spray cooling, see figure 5. It is known that minimizing the wet angle is minimizing the repetitive (harmful) heat penetration into the roll, which is resulting in less cumulative strain over the roll circumference. From fatigue regime models, both low-cycle (Coffin-Manson) and high-cycle (Basquin), it is clear that reducing the (cumulative) strain over the roll circumference is extremely beneficial for the number cycles to failure.

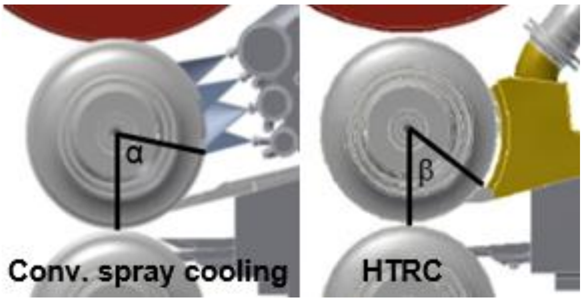

Figure 5. Difference in wet angle of conventional spray cooling (α) versus HTRC (β).

- <u>The work roll thermal expansion</u> (paragraph 3.2.3). The thermal profile of the roll is measured. It is investigated what the possible effect is of the HTRC thermal profile on the shape and profile control.

Figure 6. Measurement with CRM tablet.

The information of the work roll temperatures and the surface condition of the used work rolls was collected using a new work roll surface inspection system from CRM. This tool is based on tablet technology with dedicated software developed at CRM, which is used to collect all roll data including roll surface temperature measurements and work surface aspects. The photo in figure 6 gives an impression how the main process data was obtained.

3.2.1 WORK ROLL TEMPERATURE

The graph in figure 7 shows the measured roll temperatures of the FM2 work rolls, after producing a rolling campaign.

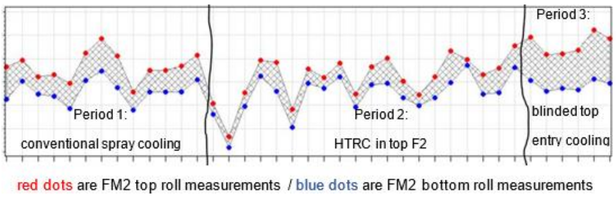

Figure 7. Measured FM2 centre line temperatures after a work roll change.

The measurements show, that the top rolls are higher in temperature when compared to the bottom rolls, however the amount differs:

- During period 1 (left of first black line in figure 7), there was conventional spray cooling on both FM2 top and FM2 bottom. The temperature difference top-bottom was in that period 10.2 ± 5.2 °C.
- During period 2 (in-between black lines in figure 7), the conventional cooling of the top work roll was replaced with the HTRC unit. In that period the difference was reduced to 7.9 ± 6.2 °C. Thus from this period, it was calculated that the effect of the base HTRC unit was a reduced temperature of about 2 °C, where about 6 °C was expected. The HTRC has a higher cooling capacity than the conventional *exit* spray cooling.
- During period 3 (right of second black line in figure 7), the entry cooling of FM2 top was blinded. This configuration is tested, because it is likely an enabler for hot rolling lubrication. In the future work roll lubrication may be necessary to produce wide, thin and hard steel products. The effect of blinding off the entry cooling is quite obvious. Temperatures well above 90 °C were measured. The temperature difference increased to 23.7 ± 7.0 °C, an increase in top work roll temperature of 15.8 °C. The HTRC *without* entry cooling has less cooling capacity than the

* Technical contribution to the 11th International Rolling Conference, part of the ABM Week 2019, October 1st-3rd, 2019, São Paulo, SP, Brazil.

conventional spray cooling (both entry and exit).

- At last, during period 4, the flow rate was increased from 600 to 700 m^3/hr. The measurements show that the increased flow rate significantly lowers the FM2 top roll temperature with > 6 °C. Note, period 4 is not shown in figure 7.

Statistical analysis shows that the differences in the four periods are significant to level of 0.05 (based on twice the standard deviation).

3.2.2 WORK ROLL SURFACE

The status of the work roll surface was scored using the pictures collected with the before mentioned work roll surface inspection system. Each individual roll photo is scored on the appearance of banding. An example of respectively banding and no banding is given below in figure 8.

Figure 8. Examples of banding (left) and no banding (right) of the roll surface.

Figure 8 shows the different FM2 roll cooling configurations, which have been evaluated with respect to roll surface quality performance, the results show that:

- Compared to the situation with conventional spray cooling at the top and bottom roll (configuration 1), the percentage of FM2 top rolls with a poor roll surface drops with a factor of 14 when using HTRC at the top exit side (configuration 2).
- Blinding the top roll entry cooling (configuration 3) effects the roll temperature (see paragraph 3.2.1), but rolling with or without entry cooling has <u>no effect</u> on the top roll surface quality.
- If the entry cooling of the FM2 bottom roll, using conventional spray cooling, is also switched off (configuration 4), then the percentage of bottom rolls with a poor surface quality increases significantly.

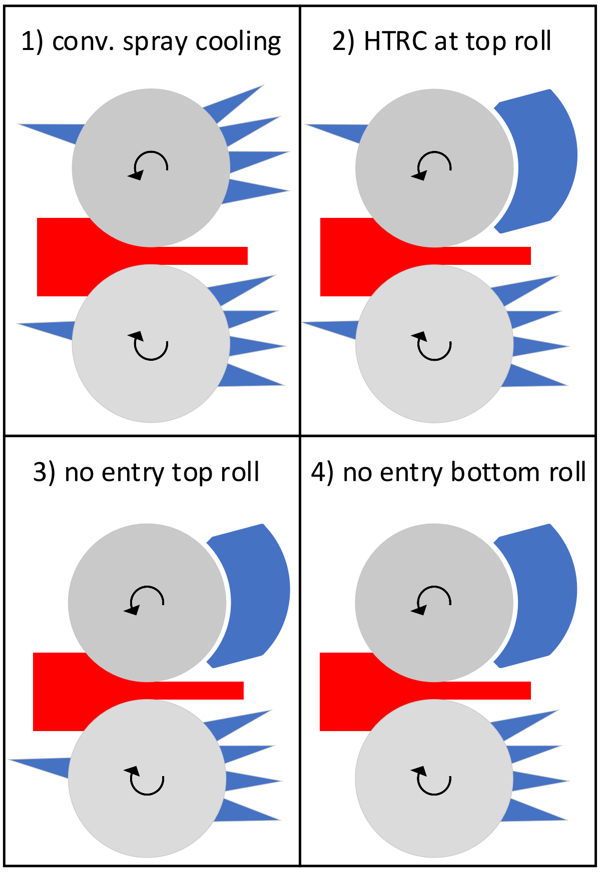

Figure 8. Schematic overview of different trial roll cooling configurations at stand FM2.

Although started as a trial, it has been decided to continue production with HTRC and a blinded top entry cooling (configuration 3) until the upgrade of the mill in the summer of 2020 (see chapter 4).

3.2.3 WORK ROLL EXPANSION

By applying a specific pattern of open and closed nozzles in the HTRC unit, a similar water flow distribution as for the conventional spray cooling should be obtained. This is important for the shape of the thermal expansion and the ability of the work roll bending force actuators to compensate for thermal crown.

To check the performance of the HTRC with respect to the thermal profile, temperature measurements have been done over the barrel width, in time and simultaneously for top and bottom work roll. Figure 9 shows an example of such a temperature measurement. The 16 thermocouples are alternately placed at respectively the top and bottom work roll. A data logger is saving the measured temperatures each 5 sec. Figure 10 shows a typical example of a measured temperature profile at FM2.

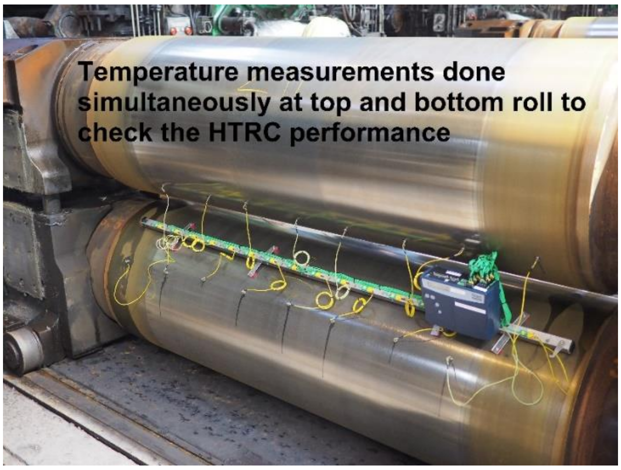

Figure 9. Work roll temperature profile measurements at FM2 in HSM2.

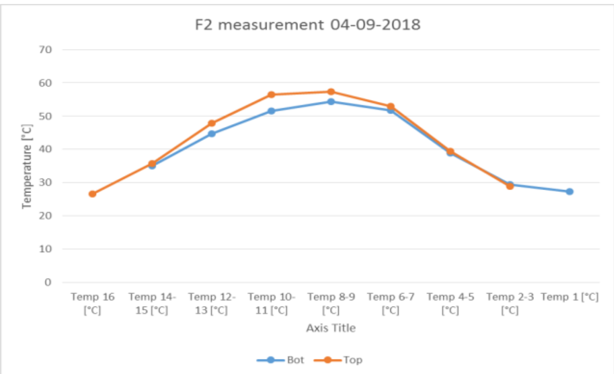

Figure 10. Typical example of a measured temperature profile at FM2 in HSM2.

The temperature profile measurements show that:

- There is no difference in the shape of the thermal profile top versus bottom work roll. It can be concluded that the cooling water flow distribution of HTRC is indeed similar to the distribution of the conventional spray cooling.
- The absolute level of the thermal profile may vary. Especially in the case of the blinded entry cooling, the top work roll temperatures are significantly higher than the bottom work roll temperatures, see also paragraph 3.2.1.

3.3 MAINTENANCE PERFORMANCE

If operating is done correctly, HTRC is a low-maintenance device compared to conventional spray cooling. Worthwhile mentioning with respect to maintenance:

- As described in chapter 2, incorrect positioning of the HTRC unit leads to either wiper water leakage or excessive wear of the cold and hot (wiper) spacer.

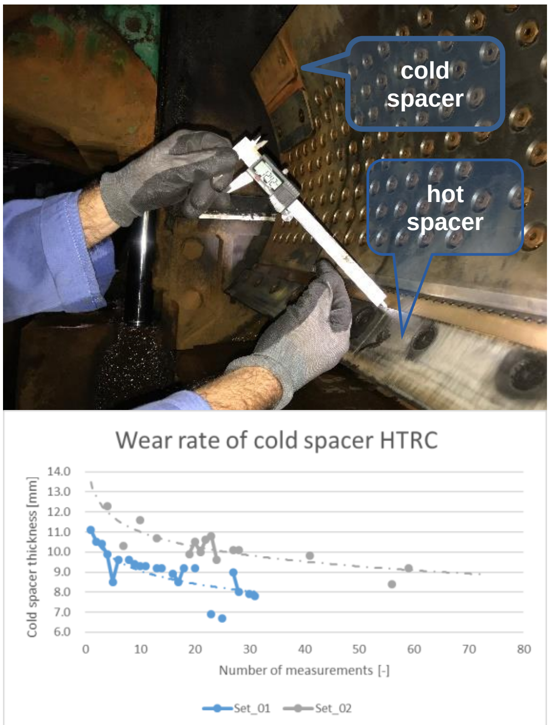

Figure 11. Hot (wiper) and cold spacer wear rate.

At first instance, to prevent wiper water leakage, the pressure of the HTRC positioning cylinders was relatively high, resulting in relatively poor spacer stands times (see figure 11). Afterwards, the cylinder pressure was gradually lowered to find the optimum pressure resulting in satisfying long spacer stand times and no wiper water leakage.

- As already mentioned in paragraph 3.1, during the trial there was a period where the cooling water pressure increased gradually and the system sometimes struggled to reach the target water flow rate, see figure 12.
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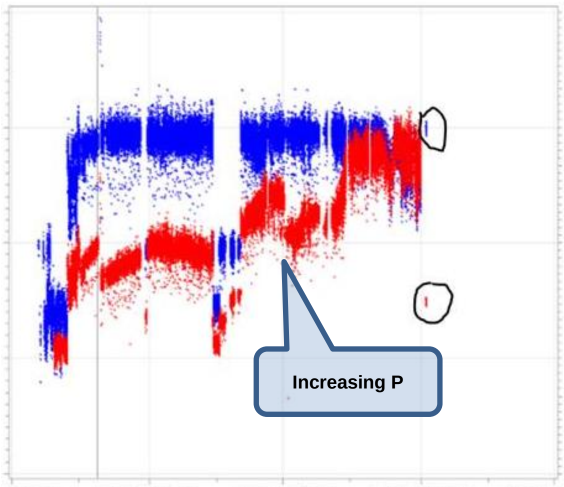

Figure 12. Graph showing the gradually increasing pressure (red) and the realized water flow rate (blue).

Because the nozzle diameters used in the HTRC are larger than the conventional spray cooling nozzle, blocked nozzles were not considered at first instance. When finally opening the HTRC unit, it turned out surprisingly that pieces of plastic and oxide had blocked a considerable part of the nozzles, see figure 13. The pieces of plastic were leftovers from installing the HTRC unit, which were not properly removed. The origin of the pieces of oxide is not yet known. By the way, inspecting and cleaning the HTRC inside takes approximately 1.5 hours compared to 8 hours in case of the conventional spray cooling. After cleaning the HTRC unit, operation was as usual, which can be seen in the circled parts of figure 12.

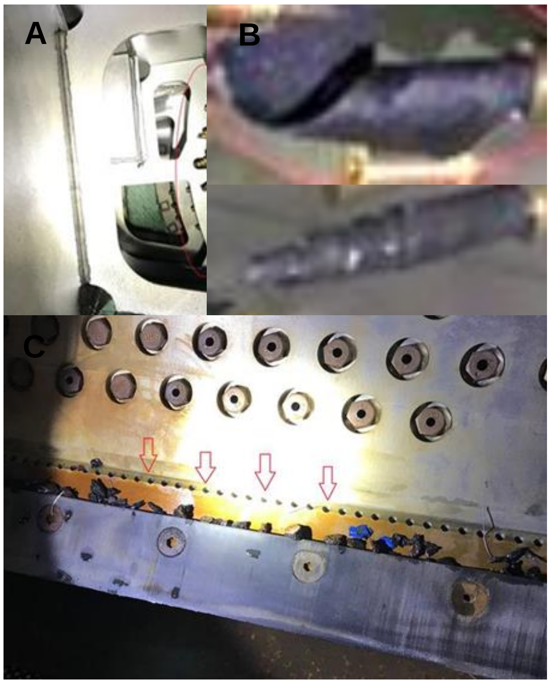

Figure 13. Photos showing the inside of the HTRC (A), the blocked HTRC nozzles (B), caused by pieces of plastic and oxide particles (C).

- The nozzles of the HTRC all have a uniform diameter. The stepwise water flow distribution in the HTRC unit is accomplished by the applied pattern of open and closed nozzles, instead of using different nozzles over the width of each conventional spray cooling header. This makes changing the nozzles of the HTRC less time consuming and less prone for mistakes than changing the nozzles of the conventional spray cooling.

4 DISCUSSION

After the upgrade, there is (obviously) more capacity with respect to rolling torque / power and rolling force. Key question is, what will happen if the extra mill capacity will be used after the revamp, while still using conventional spray cooling?

If the extra mill capacity will only be used **to increase the width** of the existing products, then the specific load per meter work roll length will be equal. Currently, the heavy grades are rolled at relatively small widths and are therefore scheduled at the end of a campaign. However, if the width of those grades is increased, then the coils are scheduled more towards the beginning of the campaign. Rolls are likely to degrade after rolling such tough grades. Consequently, to maintain good surface quality, there is a reasonable chance also the number of early roll changes will increase during the remainder of the campaign.

It is likely that the extra mill capacity is also used **to decrease the thickness** of the existing products. As a result of thinner gauges, roll degradation will increase, most probably leading to extra early FM1-FM4 roll changes. Figure 14 shows an example of roll banding after rolling a relatively thin gauge, 1.8 mm, heavy HSLA grade.

Figure 14. Poor roll surface quality (banding) after rolling a 1.8 mm heavy HSLA grade.

Last, but not least, **the percentage of differentiated products** in the product mix, will only increase in the (near) future. Obviously, this will not be beneficial for roll surface degradation.

To predict the increase in early FM1-FM4 roll changes, as result of the above described shift in product mix, is fairly difficult. It will strongly depend on the market conditions and the demand for the so-called differentiated products. Conservatively, it is assumed, that the number of early work roll changes, in case of conventional spray cooling, will increase with at least 20 %. The trial results show the following findings.

- Implementing HTRC roll cooling in the first 4 stands FM1-FM4, which will be done in summer 2020, will fully counteract the expected increase in early roll changes by improved roll surface quality.
- In addition and equally important with respect to the annual benefits, HTRC in 4 stands enables us to switch off 2 (out of 3) high pressure pumps, which are needed for conventional spray cooling. This leads to substantial savings on electricity costs and thus reductions in CO_2 emissions. In fact, the energy savings account for one third of the (annually) energy saving target agreed on with the Dutch government.
- Finally, possibly also roll lubrication must be applied in the future to be able to fully utilize the updated mill capacity. HTRC can be applied without using entry work roll cooling and is therefore an important enabler for applying roll lubrication.

5 CONCLUSIONS

Tata Steel IJmuiden Hot Strip Mill 2 (HSM2) will be upgraded the coming year, leading to an increased mill capacity. Without any measures in the work roll cooling, it is very likely that the number of intermediate work roll changes of stands FM1, FM2, FM3 and FM4 will increase, as results of poor surface quality, in such a way that the annual scheduled throughput of HSM2 will not be achieved.

Discussions with contractors revealed that they had no better solution for the work roll cooling than is already installed in HSM2. A comprehensive study has led to High-Turbulence Roll Cooling (HTRC) as a possible solution for HSM2. Therefore, a trial with HTRC, which seems to be the best new technology for work roll cooling available, on stand FM2 top work roll was executed.

In this report the results of this test are described. The final conclusion is that HTRC seems to be an excellent alternative for the conventional spray cooling, showing a striking improvement in surface quality. Equally important, HTRC results in substantial savings on electricity costs and thus reductions in CO_2 emissions. Finally, HTRC is an enabler for applying work roll lubrication in the future (if needed).

Acknowledgments

The authors would like to thank colleagues at CRM Gent and Tata Steel IJmuiden HSM2 maintenance and operation teams. Without their support and help, this trial would not have been as successful as it is now.

REFERENCES

1 G. van Steden and J.G.M Tellman, “A new method of designing a work roll cooling system for improved productivity and strip quality,” in Proc. of the fourth International Steel Rolling Conf.: The Science and Technology of Flat Rolling, vol. 1, Deauville, France, June 1-3, 1987, pp. A29.1-A29.12.

2 H. Uijtdebroeks, J.F. Noville, D. Vanderschueren, P. Van Poecke, “High turbulence roll cooling”, Final Project Report Technical Steel Research, 1 July 2002 to 31 December 2005, ISBN 92-79-06658-0, ISSN 1018-5593.

3 H. Uijtdebroeks, P. Van Poecke, D. Vanderschueren and J.F. Noville, “Device and Method for Cooling Rollers Used for Rolling in a Highly Turbulent Environment,” U.S. Patent, US 8,281,632 B2, 9 October 2012.

4 D. Vanderschueren and P. Van Poecke, “Rolling Mill With Cooling Device and Rolling Process,” World Intellectual Property Organization, WO 2008/149195 A1, 11 December 2008.

5 H. Uijtdebroeks, J. Noville, D. Vanderschueren and P. Van Poecke, “Implementation of a High-Turbulence Roll Cooling in the HSM of ArcelorMittal Gent,” European Steel Industry Conference Proceedings, ATS, 2007.

6 Z. Koont, A. Ianos, G. Gebara, P. Van Poecke, H. Uijtdebroeks and J.J. Fitzpatrick, “Implementation of High-Turbulence Roll Cooling at ArcelorMittal Dofasco’s Hot Strip Mill”, AISTech 2014 Conference Proceedings, Indianapolis (USA).