2020 Technology and Operation of a Hot Rolling Mill

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Abstract. The state-of-the-art of both technology and operational practice of a hot rolling mill are discussed. The focus is first on the control of entry temperature in the finish mill. Transfer bar cooling and induction heating are presented. Next, the safe keeping in the finishing mill of surface quality, crown and flatness are discussed. Important tools to achieve these properties are lubrication, friction measurement, roll cooling, inter stand and skin cooling, bending, shifting and prediction of roll forces. The third and final topic is the run-out table cooling. Ultra-fast cooling is compared with laminar cooling. The cooling strategies and their importance to realise the required micro-structure and properties are discussed for hot rolled Dual Phase steel, pipe line grades and rebar.

Keywords: hot rolling mill, reheating furnace, transfer bar cooling, bar induction heating, finishing mill tools, runout table, laminar cooling, ultra-fast cooling.

The first major operation in the hot rolling mill is the reheating of slab or billet. There is a lot to be said about reheating furnaces, both about their technology and their exploitation. The reheating operation is very important for the environment, cost and metal yield. About 30% of the variable cost to transfer a slab into a hot rolled coil is spent on natural gas for the reheating furnaces. That is why the attention that is paid to the reheating furnace is very much justified. The energy requirement is minimised by loading the slabs at high temperature (=hot charging) and keeping the necessary reheating temperature as low as possible. The latter is done by reducing the heat loss in the line. Radiation losses are reduced using heat panels. When applying water spraying, as in the case of descaling, attention should be paid to convection losses too.

Although reheating furnaces are the preferred way to bring the slabs to high temperature, they have a number of distinct drawbacks:

- Direct flame contact in the reheating furnace will oxidize the slab with typically 1% of material loss as a consequence.
- The inertia of a reheating furnace is high. Changing the temperature takes time. The discharge temperature can only be changed gradually. A reheating Furnace is not suitable for a precise, slab to slab adjustment of the discharging temperature in correspondence with the aimed entry and exit finishing mill temperature.

This lack of flexibility is a serious drawback. Because it is not possible to change the unloading temperature from slab to slab, consecutive slabs are heated to a temperature sufficiently high to accommodate the slab that needs the highest temperature discharge temperature. This is the slab that is going to be rolled to a small thickness (=high heat loss) and with a high finishing rolling temperature. As a consequence, the other slabs will be heated to a higher temperature than strictly necessary. Not only too much energy is put into them, the production pace is reduced because time must be given for the bar to cool down. Reheating energy is spent and rolling capacity is lost. That is a double loss. Fortunately, tools exit to compensate this poor flexibility of the reheating furnace :

- Transfer bar cooling, and
- Induction heating of the slab/billet or transfer bar.

Whereas transfer bar cooling is installed on HSM's [1,2], induction heating is more frequently used for mini mills, that is, combined casting hot rolling lines [3, 4].

Figure 1: Transfer bar cooling system installed at the hot strip mill of Tata Steel´s Port Talbot [2].

Transfer bar cooling is installed just after the roughening mill. To realise an average temperature drop of 50°C on a 32 mm roughing mill bar, the surface needs to be strongly cooled for several hundreds of degrees. Deforming a transfer bar with such inhomogeneous temperature profile will have a negative influence on the resulting microstructure. It is therefore necessary to allow time for temperature homogenisation before entering the finishing mill.

An alternative way to control the entry temperature of the finishing mill is by induction heating. The heat produced with induction can be produced through thickness in case of thick bars with longitudinal induction and at the surface on thin bars with transfer induction. Combined casting rolling lines are used to produce thin hot rolled grade, as thin as 0.6 mm [3]. Keeping the reduction capability in the finishing mill limited, this requires thin transfer bars. These thin transfer bars lose too much heat to finishing the rolling above AR3. To roll to such small thickness it is difficult to do without a transfer bar heating installing at the entry of the finishing mill.

In case of bloom or billet rolling, there are lines in which there is no more reheating furnace. It is replaced by an induction heater. The reported advantages are [4]:

1. a flexible solution for heating hot charged billets,
2. reduction of scale losses.

Figure 2 : Induction heating for billets [4].

Next, the finishing mill is discussed. The tools that are used in the finishing mill to control the surface quality, the crown and flatness, thickness and width are:

1. lubrication, roll cooling, inter stand and skin cooling,
2. bending, shifting, prediction of roll forces and looper tension.

The first set of tools are there for the surface quality. Actually, their goal is to avoid finishing mill rolled in scale. In case the scale is not able to deform to the same extent as the steel, it is broken. This gives an incrustation of oxide particles. This principle is schematically presented in figure 3.

Only in one, neutral point, the roll and the sheet have the same speed. In all other positions, there is relative, movement of roll compared to sheet. The lubrication reduces the friction between roll and sheet and, in this way, makes the deformation more homogeneous. This helps to avoid finishing mill rolled in scale. But, this is only one of the many influencing parameters. Other parameters are the size of the reduction, the temperature, the thickness and the nature of the scale and the condition of the work rolls. Traditionally, oil is sprayed on the work roll as a mixture of water and oil with the goal that the oil sticks to the roll and remains there until the roll comes in contact with the sheet. It should be clear that this is not evident, and is influenced by many parameters. Recently, there have been a development to apply pure oil on the roll without water [7].

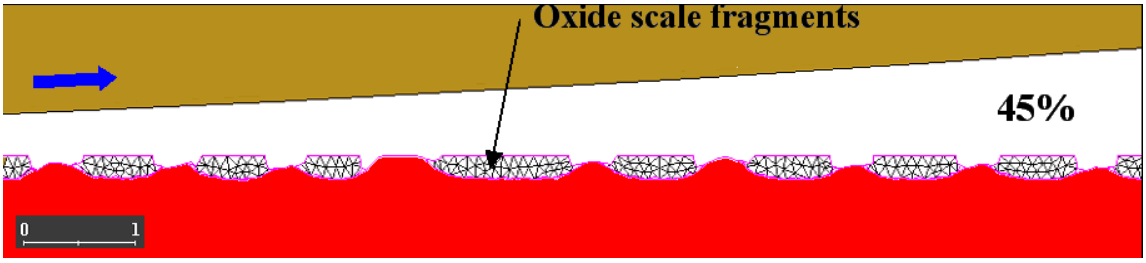

Figure 3 : Scale breaking in the roll bite, simulation of 45% reduction [5].

Several technologies are used to measure the result of the lubrication, that is the friction coëfficient between sheet and roll and how much it is reduced thanks to the lubrication. All of these measurements are indirect:

- slip forward
- torsion measurement
- comparison of predicted and measured rolling forces
- comparing rolling forces with and without lubrication

An example of the comparison of rolling force with and without lubrication is given in figure 4.

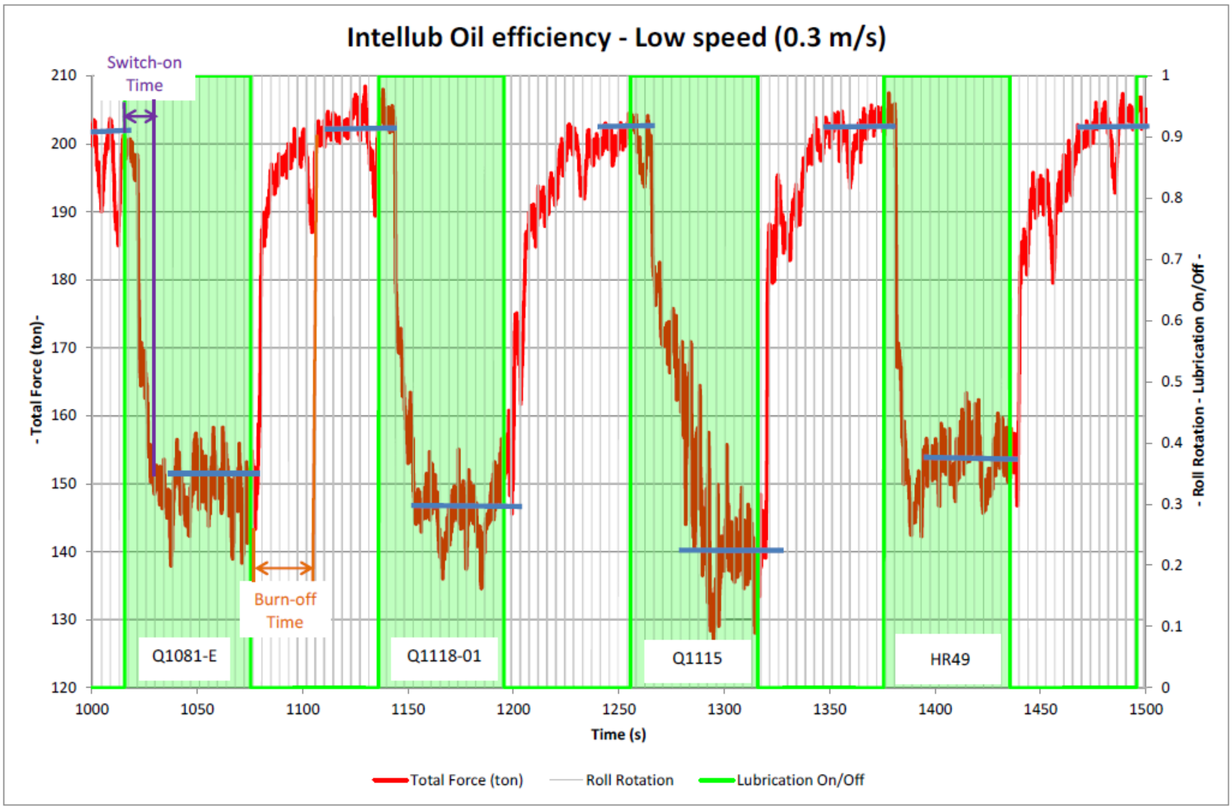

Figure 4: Rolling Forces with and without Lubrication [6].

Roll cooling is traditionally performed with sprays at high pressure. Performance improvement and reduction of cost are reported for a new type of low pressure cooling called High Turbulence Roll Cooling (HTRC) [8].This type of cooling module is presented in figure 5.

Figure 5: High Turbulence Roll cooling module [8].

The profile and flatness are determined by the shape of the roll gap. The differences in roll gaps from stand to stand must be sufficiently small so that the deformation can be realised without creating unflatness. The maximum allowable differences are determined experimentally and translated to a 'deformation trumpet'. An example is given in figure 6.

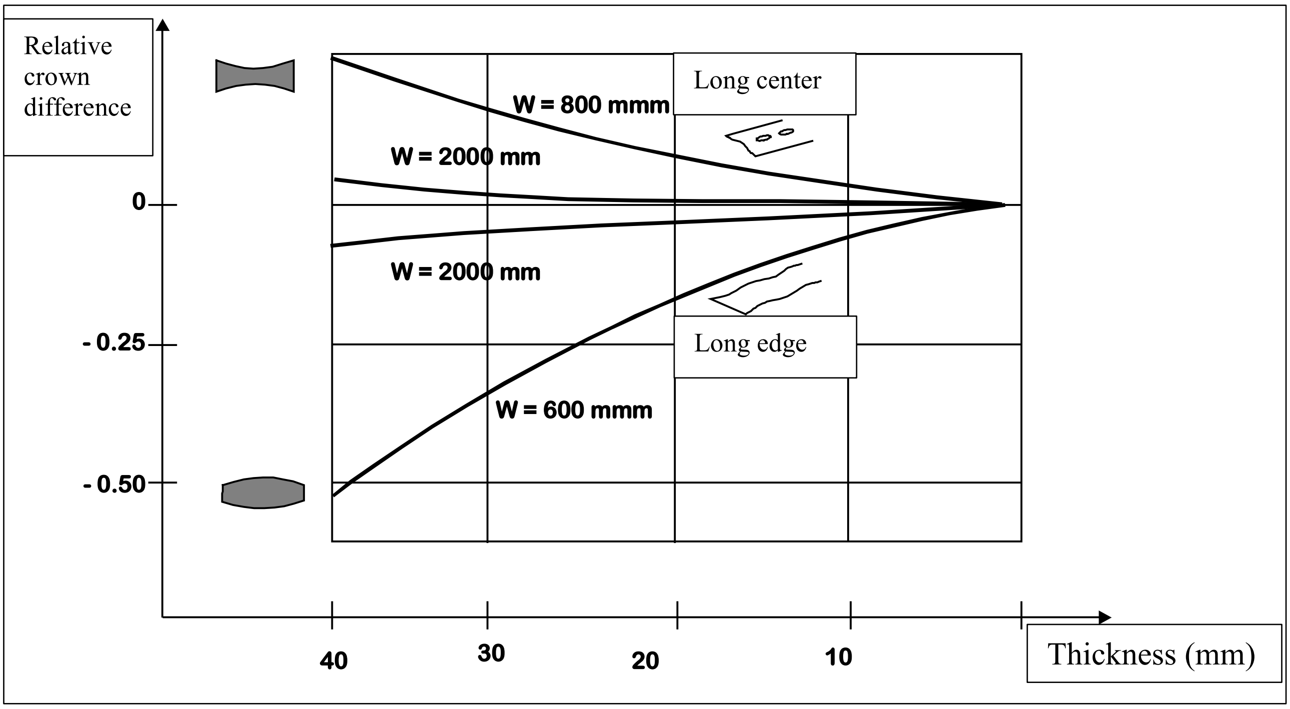

Figure 6 : Allowable roll gap difference for two widths as function of thickness to avoid unflatness.

The roll gap is adjusted using bending and shifting. However, everything start with the prediction of the roll forces. The roll gap set-up is chosen so that the expected opening and bending-out of the roll because of the rolling forces is compensated. The more precise the prediction of the rolling forces is, the better is the set-up and thus the thickness, crown and flatness at the head. The importance of the prediction of the rolling forces cannot be underestimated. It is important for the properties of the product and for the stability of the process (= avoidance of rolling incidents). A large part of the planning rules are intended for this reason, to improve this prediction. This is done by limiting 'the changes' from one coil to the next. These differences are hardness, rolling temperature and dimensions. Out of lack of pure predictability, the help of adaption is required. The prediction of the rolling forces is all to more precise if the change is small.

After the last deformation, the steel is cooled in 2 very different modes to room temperature. First there is a fast cooling on the run-out table. There is a typical temperature drop of 250°C in about 10s. Once the sheet is coiled, the cooling is slow. It takes 24h+ to realise the remaining 500°C to RT. The reason for the first fast cooling is the increase of the driving force for transformation and (cementite) precipitation. This is the route for the production of fine grained, non-ageing C-steel. It is argued that ultra-fast cooling has the advantage of creating more driving force and thus is able to reduce the amount of alloying elements. Please note that it is equally important to pay attention to the whole thermal history after the finishing mill. The distance, and thus the time between the last deformation and the start of accelerated cooling, is equally important.

The cooling on the run-out table is controlled precisely to influence the final microstructure. An example of this is the production of rebar with tempcore cooling [11,12] which is a strong, short cooling. As shown in figure 7, this creates a heterogeneous cooling over the thickness. On the surface, there is a fast cooling, giving martensite. At the core, the cooling is slower, resulting in a ferrite-perlite structure. Moreover, the martensite is subsequently relieved by the heat of the core. As a result, a high strength steel with a YS > 500MPa and an uniform elongation of 10% can be obtained using a simple 0.2% C chemistry.

Also in sheet rolling, the cooling on the run-out-table is adapted according the requirements. An example is the production of hot rolled Dual Phase steel. A two-step cooling is used, that is :

- first water cooling is applied,

- second, an air cooling in which 85% ferrite is formed, is used and finally,
- again water cooling is used to promote the formation of martensite for the remaining 15%.

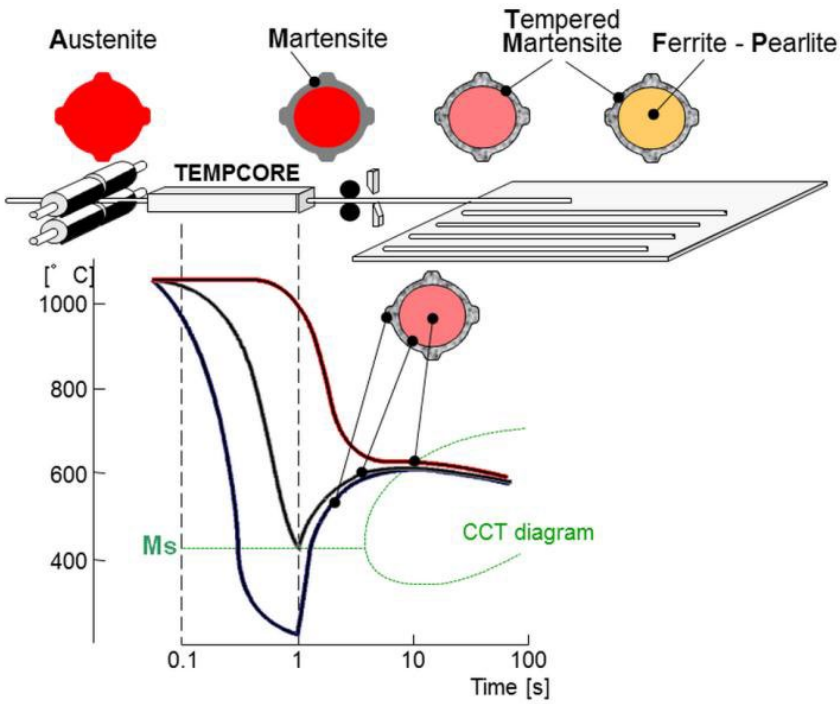

Figure 7: The principle of Tempcore (11).

The goal of the first water cooling is to increase the driving force for ferrite transformation. The highest kinetics are at 650°C. In order to be able to stay as long as possible in this temperature region, the speed to go to it is as high as possible. However, the 'nose' of the transformation speed is flat. Nor the exact temperature, neither the high speed to go to it, are crucial.

The situation is different for the production of pipeline grades for both plate and sheet. The desired microstructure is bainite and the sheet/plate is thick. In this case, an accelerated cooling of the ultra-fast type has advantages [13].

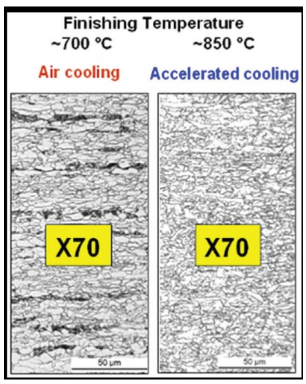

Figure 8: Grain structure under different cooling strategies [13].

Conclusion

Since the control of the entry temperature is important and the design of the line is not favourable for the thermomechanical needs of the products, tools have been developed to accommodate. There is bar cooling and induction heating.

Although pure oil application exists, Lubrication is generally applied as a mixture of water and oil. The efficiency of this oil is a concern and is influenced by many parameters. The prime goal of the lubrication is to reduce the rolled in finishing mill scale.

There are many tools to but a crucial point is the prediction of the rolling forces. The limited ability to do so has impact on set-up and is a hindrance for schedule free rolling.

Ultra-fast cooling and laminar cooling on the run-out table each have their strength and weaknesses and applications. The nature of the run-out table cooling for Dual Phase steel, Pipeline grades and rebar have been discussed.

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