SLAB RESIDENCE TIME CONTROLLED BY VARIABLE SPACE BETWEEN THE SLABS FOR DIFFERENT FINAL STRIP THICKNESS IN A WALKING BEAM TYPE REHEATING FURNACE IN A STECKEL HOT STRIP MILL PRODUCTION LINE *

Altair Lucio de Souza[1]
Fabio de Oliveira Soares[2]
Jacson Morais Borges[3]
Joao Junio Pereira Lino[4]
Rogério Antão Cardoso[5]
Willy Schuwarten Junior[6]

Abstract

In a Steckel hot rolling mill production line, the productivity of the reheating furnace is closely related to the one of the rolling mill since the rolling time increases as the desired final strip thickness is reduced. The residence time ranges from 180 to 300 minutes depending on the final strip thickness. Higher residence time at the hot oxidizing atmosphere inside the furnace intensifies the oxide layer formation on the slab surface causing large steel losses as well increasing the gas consumption. In this context, a possible strategy to optimize the residence time and the furnace productivity is to increase the space between the slabs during the charging as them move faster and are heated for shorter times at each heating zone. The purpose of this work was to evaluate the space between the slabs in a walking beam type reheating furnace considering the rolling time for achieve different final strip thickness in a Steckel mill, searching for optimize the slabs residence time and its effect on metallic yield and in the specific energy consumption behavior.
Keywords: Walking beam furnace; Steckel Mill; Space between slabs; Productivity

1 *Engenheiro Metalurgista, Mestre em Metalurgia, Assessor Técnico, Laminação de Tiras a Quente, Gerdau Ouro Branco, UFOP e UFMG, Ouro Branco, Minas Gerais, Brasil;*
2 *Engenheiro Civil, Laminação de Tiras a Quente, Gerdau Ouro Branco, FASAR, Ouro Branco, Minas Gerais, Brasil;*
3 *Técnico de Processos, Assessor Técnico, Laminação de Tiras a Quente, Gerdau Ouro Branco, Minas Gerais, Brasil;*
4 *Engenheiro Mecânico, Mestre em Engenharia de Materiais, Assessor Técnico, Laminação de Tiras a Quente, Gerdau e UFOP, Ouro Branco, Minas Gerais, Brasil;*
5 *Engenheiro Metalurgista, Laminação de Tiras a Quente, Gerdau Ouro Branco, UFOP, Ouro Branco, Minas Gerais, Brasil;*
6 *Engenheiro Mecânico, Mestre em Metalurgia, Gerente da Linha de Laminação de Tiras a Quente, Gerdau Ouro Branco, UFMG, Ouro Branco, Minas Gerais, Brasil*

1 INTRODUCTION

The rolling load in hot strip mill strongly depends on the slab temperature and temperature gradient inside the slab after the residence time in the reheating furnace. Sufficiently high temperatures promote austenitization of steels and reduction in dislocation density during the recovery and recrystallization processes that take place in the intervals between rolling passes [1,2].

The slabs are heated inside the furnace chamber which is coated with refractory ceramic material with low thermal conductivity to reduce the heat loss through the furnace walls. In a walking beam type reheat furnace, all the load is supported by fixed beams and transported toward the discharge end of the furnace according to the movement cycle of moving beams. [3,4].

A system of chemical reactions occurring in series and parallel during the combustion of a gas mixture releases thermal energy that is transferred to the system composed of steel slabs, refractory material and surrounding gases. The slab reheating process is based on heat exchange mechanisms that depend fundamentally on temperature difference between the components of the system. The surrounding gases account for the highest temperature of the system and the heat transfer occurs by convection and radiation [4,5].

The gaseous products of combustion, i.e., CO_2, H_2O, O_2 e N_2, form an oxidizing atmosphere. Carbon dioxide and water vapor have significant effect on heat transfer because they absorb and emit, in specific wavelengths, the thermal energy [5-7]. Radiation is the predominant heat transfer mode in reheat furnaces operating at high temperatures and accounts for more than 95% of the incident heat flux on the slab surface [8]. Convection heat transfer depends on the temperature difference between the components whereas radiation heat flux depends on the difference between their absolute temperatures, each raised to the fourth power [5,8].

The hot-oxidizing gases react with the iron in steel slabs to form a surface oxide layer known as scale. Abuluwefa *et al.* [7] showed that CO_2 and H_20 contribute little to scale formation and described that high temperatures and the concentration of free oxygen have the greatest effect on the formation of the oxides. The scale removes surface defects from the continuous casting process. However, high oxidation rates and thicker oxide layers have a negative effect on the metallic yield (or steel yield losses), namely steel losses due to scale formation. According to Jang *et al.* [6] the rate of scale growth is function of the exposure time at high temperatures. Therefore, longer residence time inside the furnace thickens the oxide layer and increases the production costs.

Wustita (FeO) is the phase in the highest proportion in the scale and its thermal conductivity is very low in comparison with the steel. Thus, the existence of scale restricts the heat transfer from the surface to inside the slab and more time is required to achieve low temperature gradient inside the slab [7,9].

Steel losses due to surface oxidation depend on some operational parameters such furnace temperature, residence time and air/fuel ratio [7]. Longer residence time at high temperatures, exceeding the one necessary for the slabs to attain the requirements of rolling temperature and thermal uniformity, generate thicker layers and increase the depth of the decarburized layer formed due to carbon extraction under the action of oxygen [10].

The energy balance showing the total energy input and heat losses provide information about the efficiency of the reheating furnaces. The furnace efficiency is evaluated as the percentage of the total energy transferred to the slabs. Generally, the efficiency of reheating furnaces is around 45-50%. The exhaust gas energy can be recovered by recuperators and heat exchangers in order to heat the combustion air, enhancing the thermal efficiency and optimizing the energy consumption [3,11,12].

The productivity of slab reheat furnaces is defined as the weight of reheated slabs per unit of time [4]. The discharge frequency follows the time needed to achieve the desired final thickness of the strip. Therefore, the productivity of the reheating furnaces is closely related to the productivity of rolling mill. Steckel mill is a single-stand reversing hot strip mill that employs multiple passes. This mill has the particularity of winding the strip on coiler drums inside the side furnaces after each finishing pass in order to reduce the heat loss. Thus, Steckel mill nominal capacity is inherently slower as compared to continuous multi-stand mills and requires larger time to roll the strip to the final thickness.

The management of discharging frequency associated with the rolling time maintains the productivity rates, preventing overheating time and optimizes fuel consumption. One possible strategy to enhance productivity and fuel consumption is to act on the quantity and distance between the slabs in function of final strip thickness.

Proper spacing between the slabs expands the passage of heated gases and optimizes the effective area of exposure of the load to heat flux, increasing the rate of heat transfer and reducing the time required to homogenize the temperature inside the slab. Jaklič *et al.* [4] demonstrated that the productivity has a strong dependence on the spacing between the billets and showed that there is an optimum spacing that maximizes productivity and, below this value, productivity decreases.

In this context, this work studied the influence of the distance between the slabs on productivity, metallic yield and energy consumption of the walking beam type reheating furnace in the hot strip trip mill of Gerdau Ouro Branco.

2 MATERIAL AND METHODS

Figure 1 shows the schematic representation and geometry of the walking beam reheating furnace currently in use in the hot strip mill of Gerdau Ouro Branco.

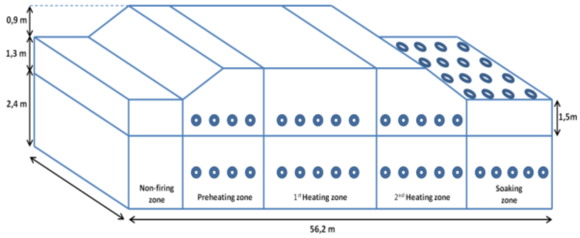

Fig. 1:Schematic of the reheating furnace.

The furnace was manufactured by LOI Italimpianti and has nominal production of 220 t/h (cold charge). It has side burners arranged into 8 temperature control zones according to Table 1.

Table 1: Temperature control zones and number of burners.

Control zone	Position and number of burners
Top preheating zone	4+4 side burners
Bottom preheating zone	4+4 side burners
Top 1st heating zone	5+5 side burners
Bottom 1st heating zone	5+5 side burners
Top 2nd heating zone	5+5 side burners
Bottom 2nd heating zone	5+5 side burners
Top soaking zone	16 roof burners
Bottom soaking zone	5+5 side burners

5 fixed beams and 4 walking beams support and transport the load toward the discharge end of the furnace. The walking beams move the slab to a distance of up to 685 mm at 100 mm/s.

Heating occurs due to the combustion of a gas mixture composed of two or three of the following gases: natural gas, blast furnace gas (BFG) and coke oven gas (COG). The gas mixture in adjustable proportions has a nominal lower calorific power of 2300 Kcal/Nm^3.

Table 2 shows the charged slab characteristics.

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Table 2: Slab's characteristics.

Thickness	220 - 250 mm
Length	3600 - 7500 mm
Width	900 - 2100 mm
Maximum weigth	31 t
Max. number of slabs	60

Discharging temperatures are between 1220 to 1250°C depending on the kind of steel.
This study was carried out by means of reheating furnace and hot strip mill rolling logs contained several data such slab's residence time, metallic yield, energy consumption and strip rolling time.
The values range of final strip thickness is classified in classes as follows in table 3.

Table 3: Strip thickness classes.

Thickness (mm)	Class
1.8 - 2.5	Extra thin
2,51 - 3.5	Thin
3.51 - 5.99	Middle
6 - 12.7	Thick
> 12.71	Extra thick

The distance between the slabs was adjusted according to the equation 1, which is a reference based on LOI Italimpianti reheating furnace instructions.:

$$Gap = \frac{(Rol.time \times 56200 \times n) - (Rt \times Sw)}{Rt} \quad (1)$$

$Rol.time$: rolling time
Rt: residence time
Sw: slab width
gap: distance between slabs
n: number of rows. In this study, n=1.

In the preceding equation, 56200 is the effective furnace length (mm).
Five days over the analysis period were selected for evaluation and comparison with another five days, in usual production period. These days were chosen because they showed similar production (ton). Thus, the comparisons were made in terms of slab residence time, metallic yield, energy consumption, and cover ratio.

3 RESULTS AND DISCUSSION

3.1 Analysis Period

As expected, the rolling time was longer for thinner final strip thickness. For instance, the difference between the rolling time for extra thin and thick thickness class, in terms of average values, was about 190s, during the analysis period. These values are explained due to the longer interpass intervals in a reversing stand of the Steckel rolling mill and the increasing number of passes to achieve thinner strip thickness.
The metallic yield is defined as the percentage of the slab that ends up as usable final product. From the reheating furnace and rolling mill logs it was possible to obtain the metallic yield of each slab.
During the analysis period, slabs that were rolled into strips within the range of Extra Thin thickness class were the ones that needed longer residence time and presented the higher discharging temperature. In addition, this thickness class attained the least metallic yield in comparison to thin, middle and thick thickness class (there was no participation of extra thick thickness class during the evaluated period).
Table 4 shows the difference in residence time, discharging temperature and metallic yield, in terms of average values, of the thickness classes relative to the Extra Thin thickness class.

Table 4: Difference in parameters of the thickness classes relative to Extra Thin thickness class.

Thickness classes compared to Extra Thin class	Difference in residence time (min.)	Difference in discharging temperature (°C)	Difference in metallic yield (%)
Thin	-28.15	-23.16	+0.24
Thick	-29.84	-30.34	+0.93
Middle	-37.45	-34.67	+0.63

The results presented in table 4 show that the steel losses were sensitive to the slab residence time and discharging temperature, despite the small difference in these parameters. However, it is worth

mention that this behavior may be also related to other two factors.
First, a crop shear of the entry side of the Steckel mill is used to cut off a small percentage of the material at the tail and head ends of the strip before the finishing passes due to an uneven widening and formation of a so called dog-bone shape at the ends of the strip during the roughing passes. The cutting quantity is controlled so as not to impair the metallic yield. The amount of material discarded due to this defect increases with the reduction in final strip thickness.
Moreover, the metallic yield values may also be related to secondary and tertiary scale growth after the first descaling and the longer time available for scale growth during the rolling of slabs to thinner final thickness.
According to the studies of Lee *et al*. [15] and Jang *et al*. (2010), longer residence time, as well as higher furnace temperature and steel composition intensifies the scale growth during the reheating process, which explains the results in table 4. However, the influence of the cutting quantity of head and tail ends of the strip and secondary and tertiary scaling cannot be ruled out.

3.2 Comparisons with Usual Production Periods

Five days over the analysis period were selected for evaluation and comparison with another five days, in usual production period, that showed similar production (ton). Table 5 shows the difference in production and the increase/reduction, in terms of average values, in slab residence time and metallic yield among these five days.

Table 5: Difference in the parameters during the analysis and usual production period.

Parameter difference	Day 1	Day 2	Day 3	Day 4	Day 5
Production (ton)	5.3	11.1	32.71	40.21	36.93
Residence time reduction (min.)	63.31	148.95	232.38	120.65	143.36
Metallic yield (%)	-0,16	-0,03	+0,06	-0,10	+0,11

As can be seen in table 5, the residence time during the analysis period was shorter than the ones achieved in the 5 days of usual production.
It is possible to note a considerable increase in the metallic yield, as can be seen in table 5. Table 6 highlights the gain and reduction in metallic yield for each thickness class.

Table 6: Gain and reduction (%) in metallic yield for each thickness class.

	Day 1	Day 2	Day 3	Day 4	Day 5
Extra Thin	0,013	0,105	-0,029	0,463	0,163
Thin	-0,162	-0,042	0,064	-0,089	0,102
Middle	-0,138	0,129	0,012	-0,049	0,106
Thick	-0,074	0,299	0,352	-0,011	-0,061

The increase was more pronounced in thin-thickness products. On the basis of the above data and despite the notable reductions, one can conclude that there were gains in terms of metallic yield.

3.3 Specific Energy Consumption and Cover Ratio

During the analysis period, there was an increase in the specific energy consumption that relates, in this context, the total of energy consumption to total quantity (ton) of slabs reheated. Table 7 presents the percentage increase in specific energy consumption relative to usual production period. The analysis was performed in terms of mega calories (Mcal) per ton processed. As can be seen, an increase in this parameter occurred in the 5 days selected during the analysis period.

Table 7: Percentage increase in specific energy consumption.

Day 1	Day 2	Day 3	Day 4	Day 5
+1.89	+13.49	+11.28	+4.24	+7.99

According to Abuluwefa *et al*. [7], the control of the input air/fuel ratio to reheating furnace decreases the scaling rates by lowering the concentration of free oxygen. The furnace pressure control is a parameter that accounts for great energy consumption improvements. The negative pressure inside the reheating furnace causes the entrance of ambient air into the furnace chamber and more energy is needed to heat this excess air to flue gas temperature [17]. The excess air increases the free oxygen concentration and, thus, the air/fuel ratio. Therefore, the management of furnace pressure can decrease the scale growth during the reheating process.

The increase in energy consumption presented in table 7 may be related to the slab cover ratio (CR). This parameter is closely related to energy consumption and corresponds to the use of the useful area of the furnace during the charge residence time. According to Chen *et al*. (2005) [16], the cover ratio is expressed as:

$$CR = \frac{\sum_{i=1}^{n}(l_i w_i)}{w_{ref}\sum_{i=1}^{n}(w_i)} \quad (2)$$

In the preceding equation:

n: number of slabs reheated in a given production period;
l: slab length;
w: slab width;
w_{ref}: width of reheating furnace. The furnace width in this study is 8500mm.

Table 8 shows the percentage reduction in cover ratio relative to usual production period. As can be seen, the reduction in cover ratio was small but may be caused the increase in the energy consumption.

Table 1: Percentage reduction in cover ratio.

Day 1	Day 2	Day 3	Day 4	Day 5
-1.89	-0.29	-3.89	-2.67	-4

4 CONCLUSIONS

Based on reheating furnaces and rolling mill information logs, it can be stated that it is possible to reduce the steel losses due to scale formation by management of the distance between the slabs. As expected, the behavior of the metallic yield presented an inverse relationship with the residence time and discharge temperature. However, it is necessary to take into account the influence of secondary and tertiary scale growth as well as the cutting quantity of head and tail ends of the strip. During the analysis period, the specific energy increased in comparison to a usual production period. However, this problem may be related to the air/fuel ratio increase due to negative pressure values inside the furnace chamber which can increase the energy consumption and intensify the scale growth.

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