FATIGUE IN WORKS ROLLS AT TERNIUM'S PLTCM PLANT*

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Abstract
The Pickling Line Tandem Cold Mill (PLTCM) at Ternium's Pesqueria plant with a 5 stands, 6 high configuration started in 2013. At the time of the start up the work roll specification and grinding practices were stablished following a low risk policy to be able to sustain any start-up associated accident. Once a stable operation has been achieved both these policies are being modified to improve productivity and reduce costs. The specified hardness of the rolls has been increased and efforts are being made to optimize the grinding according to the rolling campaign length and materials. The fatigue damage in work rolls, after rolling and its removal by grinding was followed by hardness measurements made at the end of the rolling campaign and after grinding. Softening of the rolls after rolling was found mainly in final stands to be related to the averaged stress experienced during the campaign, the original roll hardness was recovered after grinding. Hardness evolution was also followed after each grinding step finding that the total amount of grinding could be reduced. The grinding practice was modified accordingly for the first stands and the yield of work rolls in them has improved.
Keywords: Work roll; Grinding; Lamination campaign

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1 INTRODUCTION

The implementation of the new grinding practice is presented. This research was made in Ternium Mexico plant in Pesqueria N.L. The new practice was implemented from the conclusions derived from this investigation.

With this was possible to reduce the average grinding of the work rolls.
A series of statistical, computational and scientific techniques were used to gather information about the rolling process, the grinding process and the properties (mainly hardness) in order to have a database that included a set of variables selected based on their contribution, to the wear of the work rolls.
The selection of the variables, the recompilation of the data, and the interpretation of some factors, allowed us to build a statistical analysis between these variables.
This relationship was relevant for the determination of an optimum grinding criterion, which increased the useful life of the rolls, reduced the operation and consumption costs of rolls in the cold tandem mill.

2 MATERIAL AND METHODS

2.1 Microstructural analysis

As part of the project, a chrome roll (5%) was characterized by optical and scanning microscopy and also hardness measurements.

In the microstructure characterization by optical microscopy, a Zeiss Axio was used (500x), and scanning electron microscope, JEOL IT-300 LV (3000x).
The sample was attacked with 2% Nital reagent.

2.2 Hardness measurement

The hardness of the work rolls was obtained using an Equotip durometer piccolo bambino 2, ASTM A 956-06.

Three areas of interest of the roller table were selected to measure hardness, motor, center and operator side. The motor side and operator side was determined to 300mm from the edge of the roller table as shown in Figure 1.

According to the standard ASTM A 956 - 06, to have a hardness data representative of any area of the roll, is necessary to make five measurements in an area of 25 mm square, having an space of at least 20 mm between each measurement and calculate the arithmetic average of the five measurements.

Before performing these tests, the measure area was cleaned with degreasing liquid to avoid any wrong data.

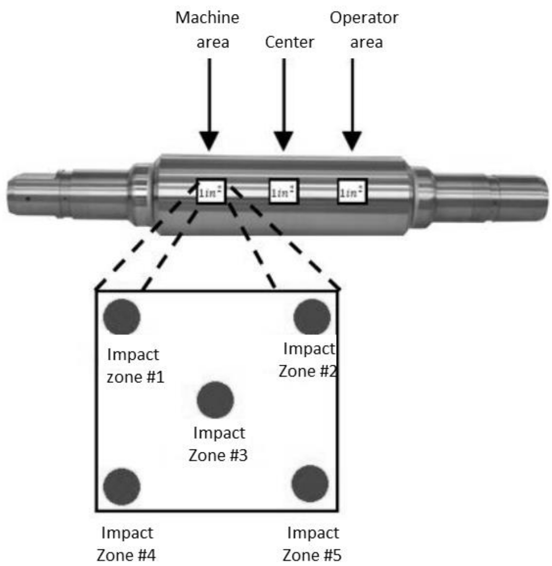

Figure 1. Location of areas of interest of the roll and impact zones for hardness measurement.

The hardness of the rolls were measured between campaigns before being grinded (Hq), that is when the rolls finish his campaigns, and after grinding (Hb).

To have a more representative hardness of the rolls at the end of the campaign ($H_{q_{ave}}$) the measurements were averaged (Equation 1):

$$\frac{H_{q_{motor}} + H_{q_{center}} + H_{q_{operator}}}{3} = H_{q_{ave}} \qquad (1)$$

To have a more representative hardness of the rolls grinded (H_{bave}) the measurements were averaged (Equation 2):

$$\frac{H_{b_{motor}} + H_{b_{center}} + H_{b_{operator}}}{3} = H_{b_{ave}} \qquad (2)$$

Table 1 are observed the steps who explain, where the hardness was measurement.

Step 1	Step 2	Step 3	Step 4	Step 5
	Grinding Machine			
Hardness measurement	Roll being grinded	Hardness measurement	Cold Rolling PLTCM	Hardness measurement
H_{qave1}		H_{bave1}		H_{qave2}

Table 1. Hardness measurement steps.

Then the differential was calculated with Equation 3:

$$H_{b_{ave1}} - H_{q_{ave1}} = \Delta H_{grinding} \qquad (3)$$

The rolls hardness differential was calculated with Equation 4:

$$H_{q_{ave2}} - H_{b_{ave1}} = \Delta H_{PLTCM} \qquad (4)$$

The contact stress between roll and strip was calculated Equation 5.

$$\sigma = \frac{F_g}{(\alpha R)b} \qquad (5)$$

where

F_g=Roll Force

α= Contact arc
R= Work roll radius
B=Strip width

More than 1000 measurements were made, and were recorded in a database. The hardness differentials between the mill and the grinding machine was correlated with the average stress applied to the roll during the campaign ($\overline{\sigma}$), the rolled kilometers (KmL) among others variables.

The information was processed by means of statistical software using linear regression and multiple correlation to compare the aforementioned variables.

3 RESULTS AND DISCUSSION

3.1 Microstructural analysis of work roll.

A microstructure with 99% of the martensite phase and 1% of chromium carbide was observed (Figure 2, 3), further corroborated by an image analyzer, the percentages of phases present in the sample. The grain size obtained was 10.5, based on ASTM E112

Figure 2 Microstructural analysis of work roll by optical microscopy (500x)

This microstructure is achieved in the roll manufacturing, where a thermal treatment is applied in the surface of the roll. The martensitic phase is a non-stable phase that has high hardness properties and if also have precipitates of chromium carbides (Cr_3C_2), a roll with the necessary

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hardness is obtained, this hardness is then adjusted by a thermal tempering.

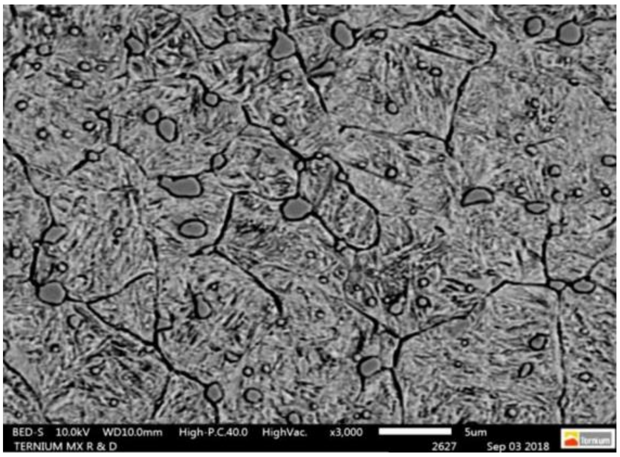

Figure 3 Microstructural analysis of work roll by scanning electron microscopy 3000x 10kV

3.2 Analysis of variables

The first important interpretation of these variables analyzed by a multiple correlation matrix is the low correlation between the rolls kilometers (Kms) and differential hardness variation in a campaign ΔH_{PLTCM}. Figure 4 shows the relation between these variables, with very little correlation between them, with the trending line near to 0 HLD.

It is also observed a lot of campaigns around 200 kms. In general terms, there are no correlation between these variables of the process, which allows us to confirm that the rolled kilometers are not the most important factor related with the hardness change of the work roll during its campaign. So there are other variables with much more weight and relevance to determine the hardness differential ΔH $PLTCM$ obtained in the mill campaigns.

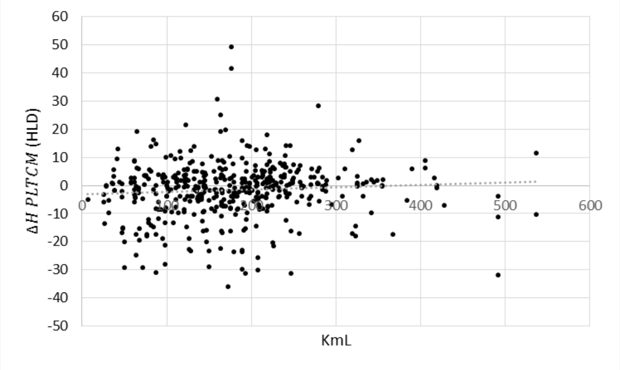

Figure 4 Comparative km vs ΔH $PLTCM$

One of the most important correlations obtained in this investigation was the differential ΔH_{PLTCM} with the average stress during a campaign (in the roll-strip contact zone), the correlation coefficient between both variables was inversely (-0.473). A more force is used to reduce the thickness of the strip, the work roll tends to soften or lose hardness. The graph presented in Figure 5 confirms this relationship. For this configurations 5 stands mill. The final stands (4 and 5) usually work a higher stress and is precisely where is observed more softening of the work rolls. To explain this behavior there are a couple of theories about it.

One relates a softening due to tempering, as mentioned by K.S. Kim [1], is produced by the local accumulation of heat in the roll surface during the campaign. When this heat generates temperature close to or greater than 300 ° C, it is believed that there is a significant thermal treatment that modifies the mechanical properties of the roll surface. This heat treatment can be relieves the residual tensions in the atomic structure of the roll generated by quenching (in its manufacture) which results in a loss of surface hardness of the roll.

The second mechanism of softening is by fatigue, explained by Mirko Klesnil and Petr Lukas [2], usually appears in configurations where two pieces are in contact and at least one has curved geometry. In the case of the PLTCM, the work rolls are constantly subjected to loads and unload during the campaign. This could cause a shear of precipitates on preferential sliding planes. When these precipitates are sheared, the displacement occur of the dislocations and allowing the free movement, the material "softens" or lose hardness.

Both mechanisms affect the properties of the roll surface, they cause over the roll, a soft surface with poor hardness, this is unwanted in the process of cold rolling because having soft rolls can cause a premature loss of roughness, which would cause a skid, "forward slip" between the rolls and the strip during the campaign. Therefore, it is extremely important to remove the fatigued material in the grinding process, before entering to a new campaign.

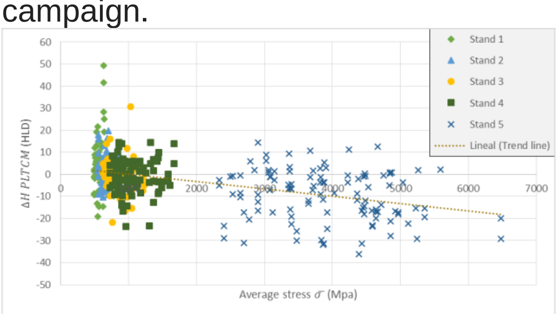

Figure 5 Hardening in PLTCM versus the average applied stress WR-strip and its trend line

In Figure 5, it is observed that the work rolls, stands 1, 2 and 3 have lower stress, (between 0-1000Mpa), mainly due to the roll-strip contact that is greater than the last stands 4 and 5. There is a wider range (1000-7000 MPa), which is precisely where the rolls tend to lose their hardness.

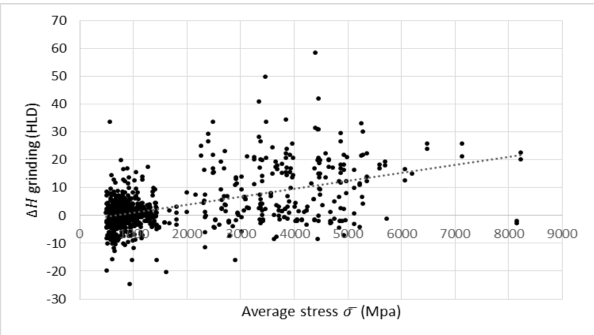

Figure 6 Hardening measured in grinding machine versus the average applied stress wr-strip during the campaign and the trending line.

Looking the Figure 5 arise a question, if the work rolls lose hardness when work at higher stresses, the rolls gain hardness when being grinded? This question can be easily answered comparing. The variables ΔH grinding and the average stress $\bar{\sigma}$. Figure 6 shows this comparison, shows a strong positive correlation between both variables, which means that the work roll gains hardness when it is grinded after was subjected to higher stress during the rolling campaign. This increase of hardness is due to the removal (grinding process) of the soft layers of the roll during the rolling campaign.

3.3 Modification of work roll grinding practice, PLTCM Pesqueria Plant.

After a detailed analysis of the overall results, and with the information collected and analyzed, the decision was made to modify the roll grinding of work rolls for the stands 1, 2 and 3. This modification was made reducing the average grinding by 20% of the rolls from the stand 1, 12% the stands 2 and 3 (with respect to the conventional average grinding). This modification was implemented on July 2018 and was followed 5 months, after its implementation. Suspending it in September for work rolls incident in the mill.

Conventional practice		New practice	
Stand	*%Grinding	Stand	*%Grinding
1	100%	1	80%
2	100%	2	88%
3	100%	3	88%
4	100%	4	100%
5	100%	5	100%

Table 2. Comparative conventional practice vs new practice.

The results of the modification of the grinding process is described in Table 2, and Figure 7. Its shows the relationship "microns per ton" (Mt) per month corresponding to the months of April to November 2018. There is a stable tendency from April to June and a decline relation on July, which coincides with the start of the trials. On September the practice is suspended and there are an increase of Mt, which falls again in the months of October and November.

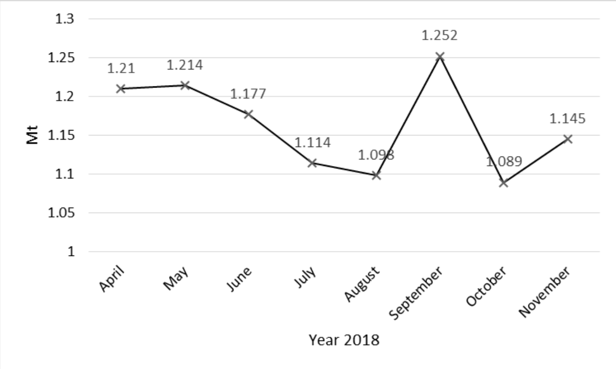

Figure 7 Microns per month per ton April-November 2018.

It is important to say that to calculate the microns per ton per month, only 91% of the total data was taken, the remaining data were discarded because they were identified in histograms as outliers.

4 CONCLUSION

After analyzing in detail the data we can conclude the following:

1. Laminated kilometers were not a determining factor in the wear of the work rolls. Although a possible relationship was supposed in the initial hypothesis, the analyzed data show a very low correlation coefficient between these variables and the hardness characteristics of the roll after its campaign. What is proposed to give a lower weight as independent variables in any grinding model for cold rolling work rolls.

2. The work rolls have an important relationship between hardness differential during the rolling campaign and the average of the stress in the roll-strip contact. This relationship, although it was expected, draws the attention to the fact that it is an inverse correlation that is, the roll have a "softening" during the campaign. This softening is due to a higher stress during the campaign. Softening mechanisms that are present during cold rolling, are cyclical fatigue by temper softening.

3. In this tandem cold mill, stands 4 and 5 have high stresses compared to the first stand (1, 2 and 3), these high stresses cause a softening from the surface of the work rolls during the campaign. In accordance with the above, with these, the grinding practice for the work rolls was modified, stands 1, 2 and 3 after the campaign, reducing the average of rectified grinding. This modification was found to be successful according to the results obtained. To modify the amount of grinding on stands 4 and 5, it is recommended to perform an independent analysis of the correlation of process variables exclusively for this type of rolls

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