Adjusting Hot Strip Mill Level2 Setup Using Tribological Approach to Eliminate Biting Refusal

1. Abstract

Since the invention of hot strip rolling, the strip biting has been a subverting moment as it is considered the most critical rolling moment. This paper studies the probable biting cobbles during the hot strip rolling concluded with taxonomy for classification based on their possible causes based on an empirical experience.

An adjustment for hot strip mill Level2 setup is proposed in order to have a successful biting and reduce the biting cobbles. As a proof of concept, a success story is presented after adopting such adjustment in Level 2 Pass Schedule model of EZDK hot strip mill plant in Egypt.

2. Keywords


3. Introduction

Steel industry is facing continual challenges due to the market increasing competiveness which requires enhancing the production of thinner gauges with lower cost, energy consumption and better quality [7]. In order to achieve such requirements, stable rolling is needed with the least quantity of cobbles.

Roll bite during steel rolling has always been a topic of interest as it is the most critical moment for hot rolling. Higher reduction ratio causes some troubles such as the increase of the rolling force [8] and leads to critical biting conditions. The extreme environment of the steel hot mill roll bite with so many influencing process parameters makes it very difficult to find the root causes of such biting troubles.

Our work addresses the biting troubles and aims to avoid having cobbles during strip biting by proposing three new contributions. The first contribution is a criticized review of the previous related research work. The second is taxonomy for biting cobbles based on an empirical experience. The third is a proposal for avoiding Cat.A biting cobbles is presented through adjusting mill level2 setup by adopting Weihua deduced tribological equations. As a proof of concept, our approach is supported by an empirical evaluation after applying it in Level 2 Pass Schedule model of EZDK hot strip mill plant in Egypt.

3.1. Related Work

1 EZDK, Ezz El Dekheila for Iron and Steel Company, Alexandria, Egypt.
2 IGSR, Institute of Graduate Studies and Research, Alexandria University, Egypt.
In hot sheet steel rolling, a lubricant is applied in order to form a thin lubrication film between the work roll and the rolled stock [2, 8, 18, and 22]. Such thin film reduces the frictional forces accordingly the rolling force and the roll wear [2, 8, 18, 22, 24 and 25]. Such phenomenon is used the1970s [8, 18, 24 and 25]. Sato et al. examined the effect of the composition of rolling oils on the coefficient of friction [26]. Mase stated that using of lubricant leads to noticeable reduction in rolling force values by 10–30% lower than those without lubricant [25].

Lenard et al. studied the significant components of tribology in hot rolling and considered the friction, lubrication and heat transfer in his study [18].

Many aspects of the tribology of hot metal forming are poorly understood [23] however many authors presented formulae to calculate friction coefficient for hot rolling of flat steel [15]. Also many tests were performed on low carbon steel strips with the objective of determining the coefficient of friction as a function of the process variables especially when high reduction is applied. Lenard et al. presented an empirical study to determine the effective coefficient of friction by using one-dimensional model of the flat rolling process [20]. They used an empirical relation to connect the coefficient of friction to process variables by non-linear regression analysis [20].

In order to measure the coefficient of friction, Azushima et al. had a lot of contributions. They developed a new simulation testing machine in the laboratory instead of the small scale hot rolling mill [14]. Using such coefficients, they proposed a lubrication model at the interface between roll and work piece in hot sheet steel rolling [12, 13]. They also discussed about the effect of surface roughness on coefficient of friction in hot rolling using the proposed lubrication model [11] and investigated the effect of the rolling speed on the coefficient of friction is investigated using the tribo-simulator testing machine for hot rolling [8].

In order to better understand the tribological condition and its relationship with several process parameters, Augusto et al. presented their study to determine the values of the friction coefficient in the several stands and the quantitative relationships between this coefficient and relevant process parameters, like strain degree and peripheral work roll speed. Such study was applied on the finishing hot strip mill at Usiminas-Cubatão which is an integrated steelworks near São Paulo in Brazil [5]. They used the forward slip values to calculate the friction coefficients. Their study shows that such method could be applied on a finishing hot strip mill for all rolling stands, except the last one. As the looper angle is used to correct the forward slip values while the there is no looper for the last stand.

Tavasci et al. presented an experimental study to assess friction coefficient for the severe case of piercing of hot steel billets by means of plugs in seamless pipe production [30]. Through ring-on-ring tribological experiments, factors affecting friction such as surface oxide, temperature, billet material, sliding speed and contact pressure were investigated.

Roberts deduced that the friction coefficient increases with temperature by analyzing the data from a 2-high experimental rolling mill, an 84-inch hot strip mill and a 132-inch hot strip mill [24] while Rowe and Underwood [27] found the opposite influence of the temperature on friction coefficient.

Weihua et al. studied the effect of hot rolling parameters on the friction coefficient by inverse calculation on the experimental roll loads [15]. Hot rolling parameters, including reduction, roll speed, work piece entry temperature and lubrication conditions, were investigated. They deduced some important findings which are as follows:

1. Friction coefficient increases with reduction increases and as temperature decreases for rolling without lubrication.
2. With oil as lubricant, the influence of temperature on the friction coefficient is insignificant.
3. Friction coefficient decreases as rolling speed increases.
4. Effect of entry temperature on friction at each rolling speed is insignificant.
5. Examination on the effect of emulsion lubricant on friction coefficient indicates the effectiveness of oil-lubrication at reduction less than 35%.
6. At a higher reduction, the 1:100 oil/water mixed emulsion proves to be more effective.
7. The original sample surface roughness also displays a significant effect on friction coefficient.

They deduced two equations using linear regression of the friction coefficient as a function of relative rolling parameters with and without using lubricant as follows:

Without Lubricant: \( \mu = 0.405 + 0.0047 \varepsilon - 0.057 \nu - 33 \times 10^{-5} T \)

With Oil Lubricant: \( \mu = 0.138 + 0.0028 \varepsilon - 0.017 \nu - 8.17 \times 10^{-7} T \)

Where \( \mu \): Friction coefficient, \( \varepsilon \): reduction in %, \( \nu \): work-roll circumferential velocity in m/s, \( T \): the entry temperature in ºC.

However, the scale thickness is not included as they found that the oxide scale layer thickness does not have a significant influence on friction coefficient and could be neglected.

3.2. Motivation

Hot strip mills around the world are always searching for any new methods for enhancing the productivity, reducing the overall costs and improving the final quality [2]. Today’s challenges which face flat steel industry require an integrated holistic taxonomy which considers the different types of the biting troubles in order to understand their phenomenon and avoid them.

As the previous section shows that there are many researches presented empirical and theoretical studies in order to understand the tribological conditions for hot strip flat steel rolling. However no previous research were presented to define the biting troubles, categorize them or to use any of the previous deduced equations to avoid such biting cobbles for the real situations in today’s industrial production.

This work is motivated by avoidance of biting cobbles for hot strip steel rolling and improving the mill stability as a result of minimizing the rolling cobbles rate.

4. Bite Cobbles Taxonomy

Based on our practical experience, cobbles during head biting could be concluded into two main categories as shown in fig.1. Each with several subcategories due to the different conditions and causes of each type of them as follows:
4.1 Friction Related Cobbles

Despite having different circumstances for each category among those sub categories, all can be considered under the umbrella of the friction at biting instance.

4.1.1 Category A Cobbles:

This cobble category is happened while using roll gap lubrication (RGL) since head end and the strip is not able to pass the roll stand. This cobble forms a big loop due to material accumulation between rolling stands (fig. 2) as the preceding rolling stand continues rolling while the strip hasn’t been bitten by the current rolling stand.

Figure 2 - Loop during F2 Biting

For an example, fig.3 shows rolling forces for rolling campaign of the second rolling stand in hot strip mill plant. The blue line represents the rolling force value while the red represents when the stand becomes loaded. The figure shows two successful rolled strips followed by other two cobbled strips. For both cobble cases, there is no value for the stand rolling force signal which means that the strip head hasn’t been bitten by the roll.
4.1.2. Category B Cobbles

This category of cobbles is happened also while using roll gap lubrication since strip head end however it is totally different than category A. For this category, the head has been bitten successfully as shown in fig.4 but slippage occurred inside the rolling stand gap which led to material accumulation.

For an example, fig.5 shows rolling forces for rolling campaign of also for the second rolling stand in hot strip mill plant. The blue line represents the rolling force value while the red represents when the stand becomes loaded. The figure declares the difference between category A and B by expressing two different cobbled strips. For the first cobble, there is an instantaneous value for stand rolling force which is sufficient for head biting. Such value means that the strip head has been bitten by the roll which classifies this cobble into category B. On the other hand, there is no value for the rolling force signal for the second cobbled strip case which classifies it into category A.

4.1.3. Category C Cobbles
For this cobbles category, however no lubricant is used during the strip head end; the strip fails to be bitten. Cobbles of this category are always preceded by cobbled lubricated strip. Those cobbles may be caused due to remaining or leaking lubrication on the roll surface from the previous cobbled strip or low head temperature due to the time delay of the previous cobble removal treatment process.

4.2. Friction Unrelated Cobbles

Those categories have completely different phenomenon of having biting cobble without using lubrication. Those cobbles are unrelated to the surface friction at biting.

4.2.1. Category D Cobbles

This cobble type is normally happened in later stands. The strip head end has not been bitten because of skied up head shape. Such strip head skiing leads to strip folding before entering the next stand which represents increasing in its entry thickness more than the pre-set gap.

This category may be happened mainly due to presence of different conditions between top and bottom work rolls. For example, difference in rolling speed, rolls diameters, roll cooling, roll lubrication amount. This difference affects the strip head towards one of the work rolls far of the other one causing the skiing up phenomenon.

4.2.2. Category E Cobbles

This cobble category concerns with difference between the preceding rolling stand pass line height and the entry side guide height

5. Avoiding Cat. A Biting Cobbles

This section presents our new proposed approach to avoid cobbles of the first category of biting cobbles.

5.1. Roll Bite Condition

Roll bite is influenced by the coefficient of friction. For successful biting, the component of the frictional force must be equal to or greater than the horizontal component of the normal force.

\[ F \cos \alpha \geq Pr \sin \alpha \]

\[ \frac{F}{Pr} \geq \frac{\sin \alpha}{\cos \alpha} \]

But; \( F = \mu Pr \)

Therefore: \( \mu \geq \tan \alpha \)

Where: \( F \) is the tangential friction force, \( Pr \) is the radial Force, \( \mu \) is the friction coefficient, \( \alpha \) is the biting angle

![Strip Biting](image)
where: \[ \text{Biting Angle (}\alpha\text{)} = \frac{180}{\pi} \times \cos^{-1}\left(1 - \left(\frac{\text{Entry Gauge} - \text{Exit Gauge}}{\text{WR Diameter}}\right)\right) \]

If \( \mu < \tan \alpha \), the biting will not be succeeded as the work piece will not be drawn; but when \( \mu=0 \), the rolling will not be applicable [10, 31].

5.2. Proposed approach

As explained by section 5.1 that higher biting angle means higher possibility for having biting cobbles. From the biting angle definition, it is clear that it depends on the entry and exit gauge and the work roll diameter with considering the flattening effect. The possible reasons for getting high biting angle is either when using of small work roll diameter or having high reduction by either increasing the entry gauge or decreasing the exit gauge. So the reduction value could be used as the controlling item for maintaining the biting condition.

In order to avoid category (A) biting cobbled, the biting condition has to be maintained. The idea is to maintain this condition while calculating the mill setup by calculating the friction coefficient value based on weighted factors of process parameters (stand relative reduction, work roll velocity, strip temperature … etc.). The main obstacle for such proposal is that all existing formulas representing the relation between the friction coefficient awith only one or two of the process parameters. Also measuring the coefficient of friction isn’t a piece of cake process the matter which forces the current approaches to use theoretical constant value for representing the friction coefficient.

As explained within section 3.2, that only Weihua’s a tribological equation considers several tribological factors. The proposed tribological equation of Weihua et al. will be adopted because it calculates the friction coefficient as a function of relative rolling parameters including reduction, roll speed, work piece entry temperature and lubrication conditions while the scale thickness effect will be neglected as Weihua et al. found that its influence is insignificant.

\[
\begin{align*}
\mu \text{ (no lub)} &= 0.405 + 0.0047 \varepsilon - 0.057 \upsilon - 33 \times 10^{-5} T \\
\mu \text{ (oil lub)} &= 0.138 + 0.0028 \varepsilon - 0.017 \upsilon - 8.17 \times 10^{-7} T
\end{align*}
\]

Where \( \mu \): the friction coefficient, \( \varepsilon \): the relative reduction in %, \( \upsilon \): the work-roll circumferential velocity in m/s, \( T \): the entry temperature in °C.

Such approach will limit the relative reduction of mill stands by the value of the friction coefficient in order to maintain the biting condition and consequently, achieve successful biting.

5.3. Adoption of the proposed approach by EZDK mill

EZDK (Al Ezz El Dekheila) company is located in Alexandria, Egypt. It belongs to Ezz Group Corporation which is a great leading steel producer in the Middle East, with a growing presence in markets around the world. Company’s overall capacity is 5.8 million tons per year, including 3.5 million tons of long products and one million tons of hot rolled coils (HRC), plus 1.3 million tons of flexible capacity (long products or HRC).

EZDK has a hot strip mill which produces micro alloyed steel coils. This production line consists of six stands hot strip finishing mill. This mill suffered from such type of biting cobbles (cat. A) with the second mill stand.
EZDK management decided to adopt such proposed approach for avoiding such kind of cobbles. In order to monitor the mill line response, EZDK management decided to apply the approach by two implementation phases. Firstly, to apply it on the Human Machine interface (HMI) of the Level2 automation system such that, an alarm will be displayed in case of any violation to the biting condition which means there is a possibility of having Cat.A cobbles. Secondly, after monitoring the results and train the mill operators for such approach, Level2 automation system will be modified to adopt such approach while calculating the setup values.

![Figure 7 - Biting Angle Alarm on EZDK L2 HMI](image)

After implementing the first phase, the mill operator can interfere when seeing the warning by changing setup (reducing the relative reduction). The modification shows significant improvement for the cobbles rate and has a good feedback from the mill operators.

6. Conclusion

This study focused on the biting troubles during hot strip steel rolling. Three contributions have been presented in order to well understand and avoid the biting troubles during flat steel hot rolling. Firstly, a review of the previous related research work is presented with criticized point of view. Secondly, taxonomy for biting cobbles based on an empirical experience is presented in order to differentiate between the different biting cobbles categories. Thirdly, a proposal for avoiding Cat.A biting cobbles is presented through adjusting mill level2 setup by adopting Weihua deduced tribological equations. As a proof of concept, our approach is supported by an empirical evaluation after applying it in Level 2 Pass Schedule model of EZDK hot strip mill plant in Egypt.
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