Type of Deterioration in Active Rollers for Hot Rolling Mill

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Abstract. The high prices of rolling mill cylinders, the energetic consumption and the lack of the alloying elements, determine the research development and studies regarding the improvement of the cylinder life service. The research presented within this paper aimed, at first, to describe the main rolling mill rollers failure types emphasizing the main destruction form – exfoliation of the external hard layer. The goal was to link the origin of this failure type to the Jacq thermal anomaly in heat transfer. This is a new approach on thermomechanical contact fatigue, taking into account the same location of the critical stresses for both mechanical load and thermal tide on the same contact surface. After the research was conducted on a lot of rolling mill rollers made by the same producer by cast iron with a hardened layer, one observed that the exfoliation, as a form of roll-specific damage, is due to the temperature difference between the layers. In poor or insufficient cooling conditions, which causes an adhesion phenomena in areas where the cohesion structure is affected in the superficial layer, a cleavage between the layers appears at a depth of installation of both the decisive mechanical stress and the Jacq thermal anomaly.

1. Introduction

The rolling mill rollers belong to the high energy and raw material consumption category of products, having a high price. The quality and quantity of the rolling mill products depend on the rolling mill roller’s performances.

Industrial users define the life time of rolling mill rollers as total rolling quantities of rolling billet produced until final failure. This measurement unit is a global one, but well accepted by the industrial users. The results are obtained after monitoring the functionality of several batches of rolling mill rollers. It is noticed that rolling mill roller’s lifetime has random values in a great dispersion for a lot of rollers functioning under the same conditions. Therefore, the problem of rolling mill rollers reliability will be solved not for any individual roller, but for a lot of identical rollers. Hence, an additional statistical analysis can be performed using the Weibull method (or other statistical models) for these experimental results [2].

The causes for rolling mill rollers failure are: fabrication faults (due to precarious technology used in alloying, casting and forging), the wear of the superficial layer (due to tribological, thermal or mechanical stresses) and scuffing in bearings (a random phenomenon unconnected to the mechanical characteristics of the active layer, which leads to total roller failure) [2].
2. Material and methods
The research was performed on a lot of 64 rolling mill rollers made by the same producer and having the following sizes: \( \Phi = 750 \text{ mm} \), 1740 mm active length and 4200 mm total length, with a mass of 8500 kg (Figure 1). The rolling mills are made of cast iron with a hardened layer (medium HB 500) and are used for milling steel billets.

![Figure 1. Cast iron with a hardened layer rolling mill roller](image)

The rolling mill rollers were used in industrial conditions for a period of one year; during this time, the following failure forms were observed:
- spindle or rosette destruction (breaking of the roller’s training elements) – 14 cases;
- scuffing in bearings – 11 cases;
- exfoliation of the active layer, leading to a total wear of the hardened surface – 39 cases.

All of the above mentioned cases were analyzed using the Weibull statistical model.

3. Results and discussion
The results for the Weibull statistical analysis in the case of these failures are presented in the following figures (Figure 2, Figure 3, Figure 4 and Figure 5):

![Figure 2. Weibull statistical diagram for all rolling mill failures](image)
Figure 3. Weibull statistical diagram for spindle or rosette destruction

Figure 4. Weibull statistical diagram for scuffing in bearings
One can observe in Figure 2 that the succession of points defining the statistical straight line presents a natural changing slope because there are at least three kinds of failures, each one with different causes. This diagram is not entirely relevant for the overall analysis and this alone cannot produce an objective conclusion.

Figure 3 and Figure 4 present non-random destruction forms for rolling mill rollers because the slope of the straight line is close to 45°; these cases are not in connection with the failure of the hardened layer, thus not quite relevant to the research at hand.

The statistical analysis for destruction through exfoliation cases (Figure 5) presents an additional changing slope for the rolling mill rollers that produced greater quantities of rolling mill plate (a lengthier lifetime).

When describing the statistical data, one must take into account the following aspects:

- with the decrease for the angle of the statistical Weibull straight line (in comparison to the Y axis), the described phenomenon presents more random characteristics;
- contact fatigue is a random occurring phenomenon, which appears when the solicitation exceeds a high number of cycles.

This observation can lead to the following deductions:

- there are three separate destruction causes with the same exfoliation failure form: 1. a premature exfoliation due to functionality errors (uncontrolled thermal usage conditions for rolling mill – manufacturing faults for the rolling mill rollers); 2. functional exfoliation due to global wear and 3. thermo-mechanical contact fatigue, corresponding to the cases of rollers located to the second slope zone of the statistical points succession.

**Figure 5.** Weibull statistical diagram for the exfoliation of the active layer
• the lifetime of rolling mill rollers is decisively limited by the thermo-mechanical contact fatigue because it is the main origin of failure with a high frequency of manifestations and a random character.

At The Heat Transfer Congress in Paris in 1961, the French researcher J. Jacq presented some experimental tests regarding an anomaly in heat thermal conduction [1]. The experimental results show that in a metal wall the thermal field is different than the theoretical thermal field given by the Fourier law for a certain X conductivity equal in the entire structure of the metal wall (Fig. 6 and Fig. 7). The temperature distribution within the structure of the metal wall is different in these two approaches; one of the consequences of this anomaly in heat thermal conduction is linked to the position of thermal fatigue origin point.

In figures 6 and 7 [4] the notifications have the follow meanings:
• \( t_{pcl} \) is the classic temperature for the wall after Fourier law;
• \( \Delta t_{\text{cond}} \) is the thermic fall in conduction transfer (classic);
• \( t_{pri} \) is the real temperature distribution for the wall taking into account the Jacq thermal effect (entrance);
• \( t_{pre} \) is the real temperature distribution for the wall taking into account the Jacq thermal effect (exit);
• \( \Delta t_{pi} \) is the thermic fall in the entrance wall, according to the Jacq effect;
• \( \Delta t_{pe} \) is the thermic fall in the exit wall, according to the Jacq effect;
• \( \Delta t = t_{pi}+t_{pe} \) is the thermic fall after the Jacq effect;
• \( Q \) is the transferred heat;
• \( \delta \) is the wall thickness.

The considerable decrease of temperature in a very thin layer induces a significant stress value at that level. It’s important to notice that the increase in the thermal stress value is located very near the surface at a certain depth.

\( \Delta t_{pi} \) is located near the contact surface and produces a very high thermal tension, which is the origin of smaller cracks in the first exploitation stages. In [5], Trozzi and Barbadillo present the initial deterioration and its progress in time of rolling mill rollers (Fig. 8).

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Figure 6. Theoretical thermal field aspect through a metallic wall (classical theory)  
Figure 7. Real thermal field aspect through a metallic wall in the case of Jacq thermal anomaly
Stage I – The region below the contact surface has a biaxial compressive residual stress (C);
Stage II – The formation of cracks (fissures) totally changes the tension characteristics during the running cycle stages.

Tensions induced by pressure roller become more important as the surface is no longer constrained by the roller mass. The smaller cracks are the effect of the Jacq anomaly in thermal conduction, due to the increase of thermal stress values at that depth. During this stage, both thermal and mechanical deteriorations occur. In this supplementary loaded position, located very near under the contact surface, conditions are created for the emergence of small dislocations in the overall structure, presented as small fractures or cracks that will eventually evolve to cover the entire surface.

4. Conclusions
The significant temperature gradient determines a difference between the values of the thermal stresses on different levels, but in a small depth-deep interval (Δt° significant in a very low Δh).

This variation of the thermal stresses between layers in the immediate vicinity determines the additional tension of the layer in certain levels and initiates thermal cracking. This deterioration with substrate initialization is more pronounced (visible) when mechanical contact variables are applied to structures under a significant external heat flux.

The paper highlights the importance of the Jacq thermal anomaly in the positioning of the decisive tension, which causes damage in the case of the variable thermo-mechanical contact.
In time, the installation of the Jacq thermal anomaly, which causes the significant temperature jump between adjacent layers, is faster than the mechanical influence of the layer by mechanical stresses; thus one can conclude that the initiation of the damage to the substrate has mainly a thermal character.

References
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