UTILIZATION AND MAINTENANCE PRACTICES OF HOT STRIP MILL BACK UP ROLLS FOR IMPROVING MILL PRODUCTIVITY[1]

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Abstract
The predominant mechanisms of spalling (main failure mechanism of Hot Strip Mill back-up rolls), namely rolling contact fatigue, work hardening and roll wear, have been examined and the utilization and maintenance practices (campaign length and dressing amount) of the Hot Strip Mill back-up rolls have been evolved according to the mill-service requirements (contact stresses present on the surface and sub-surface regions of back-up rolls and number of co-rotation between back-up and work rolls for the strip geometries and steel grades rolled at Hot Strip Mill, Bokaro Steels Limited) and roll material and quality. The rolls used at Hot Strip Mill of Bokaro Steels Limited are based on 5% Cr forged alloy steel heat treated to a hardness of 60-65 Shore C. The rolls are used with a campaign length of 4000-4500 km of rolling stock with a dressing amount of 2.5-3.0 mm. The optimum utilization and maintenance practices have resulted in substantial reduction in consumption of back-up rolls and production delays. The use of portable Ultrasonic and Eddy Current flaw detectors has also been employed for inspection of back-up rolls.
Keywords: Rolls; Back up rolls; Hot strip mill rolls.

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INTRODUCTION

The technological advancements in the area of hot rolling of steel have enabled modern hot strip mills to roll more and more critical steel grades and strip geometries. The rolls, being one of the most critical tools in hot rolling mills, are to sustain the burden of ever increasing higher rolling loads and mill speeds. In order to meet the ever growing demands in the steel industry and the upcoming technological changes, the roll materials and qualities have been brought up to date by the roll making communities with the aid of continuing research in the field of roll technologies. Similarly, the roll users have also become more and more aware to effectively utilize the costly roll materials with the aid of modern diagnostic tools and maintenance techniques. Because of its critical role in producing quality strips, the work rolls of hot strip mills have attracted considerable attention from the researchers and manufacturers whereas back-up rolls have received due attention in the recent past. As a part of continuing research, Research & Development Centre for Iron & Steel (RDCIS) and Bokaro Steels Limited (BSL), Steel Authority of India Limited (SAIL) have jointly studied the mill-service requirements of the Hot Strip Mill (HSM), BSL and have evolved several utilization and maintenance strategies for the back-up rolls. The study includes understanding of predominant failure mechanism of HSM back-up rolls, analyzing the mill-service requirements and evolving the appropriate utilization and maintenance practices of the back-up rolls according to the roll materials and quality in use at HSM, BSL. The back-up rolls used at BSL are of 0.9% C & 1.5% Cr and 0.5% C & 3-5% Cr grades of forged steel. The results of the present study might not be directly translated elsewhere since the back-up rolls used might be of some different materials and qualities and the varying mill-service requirements due to variation in strip geometries and steel grades being produced. However, the present study would provide a framework for and evolving the most appropriate roll utilization and maintenance practices for the specific mills.

METHODOLOGY OF ANALYSIS

The back-up rolls in a 4-high hot strip mill are subjected to rolling contact fatigue due to cyclic loading. The rolling loads applied to the journal ends are transferred to strip through the interface of work and back-up rolls and as a result the back-up rolls are subjected to repeated application of stresses in surface and sub-surface regions of the rolls. These stresses cause initiation of cracks in the surface and sub-surface regions of the back-up rolls which propagate and join each other leading to removal of materials from the surface, termed as spalling. Spalling accounts for almost 80-90% of the failures of back-up rolls. The spalling of back-up rolls occurs mostly in the regions, some 200-300 mm inside from the barrel edge, with some incidences of spalling at the barrel edge. The other failure modes of back-up rolls include fracture resulting from mill accidents and residual stresses.

STRESS

The stresses present on the surface and sub-surface regions of the back-up rolls are defined in terms of the maximum occurring contact stress, P_{max} suggested by Hertz. The Hertzian contact pressure is expressed by the following equation:

$$P_{max} = 0.591\sqrt{\frac{P}{l}\left(\frac{E_1 * E_2}{E_1 + E_2}\right)\left(\frac{R_1 + R_2}{R_1 * R_2}\right)}$$

P = Rolling load
l = Length of contact between work and back-up rolls
E_1 & E_2 = Young's Modulus for work and back-up rolls
R_1 & R_2 = Radii of work and backup rolls

The nature of stresses present in the surface and sub-surface regions of back-up rolls are presented in Figure 1. The stresses generated on the surface in radial (σ_x), tangential (σ_y) and longitudinal (σ_z) directions become maximum on surface with a magnitude of $\sigma_x = \sigma_y = 1.0P_{max}$ and $\sigma_z = 0.6P_{max}$.

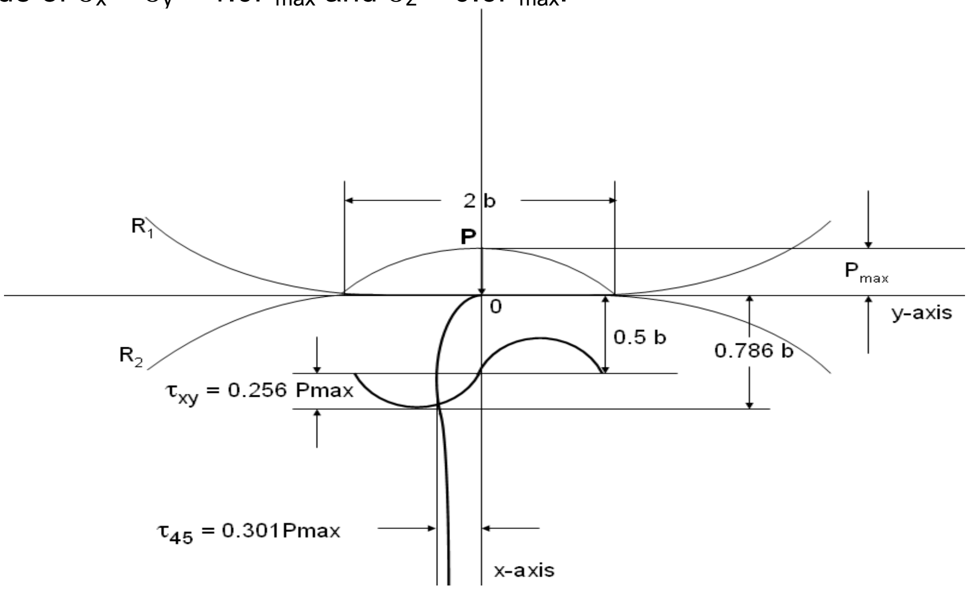


Figure 1 Distribution of surface and sub-surface stresses on the hot strip mill back-up rolls

According to the Hertz theory, the pressure on the contacting surfaces is in elliptical distribution. If 2b is the width of elliptical contact resulting from elastic deformation, then b can be expressed as follows:

$$b = 1.08\sqrt{\frac{P}{l}\left(\frac{E_1 + E_2}{E_1 * E_2}\right)\left(\frac{R_1 * R_2}{R_1 + R_2}\right)}$$

The stresses generated in the sub-surface regions are also defined in terms of P_{max}. The shearing stresses on a plane inclined to 45^o to the x-y plane (ι_{45}) and on a plane parallel to x-y plane (ι_{xy}) are of special significance since these stresses correspond to the highest mean stress and stress amplitude respectively. Since the fatigue intensity of a material is a function of both the stress magnitude and stress amplitude, these stresses need to be examined while studying the rolling contact fatigue behaviour of a material. These shearing stresses are expressed by the following equations:

$$\tau_{45} = 0.301 P_{\max} \text{ at a depth of } 0.786b$$
$$\tau_{xy} = 0.256 P_{\max} \text{ at a depth of } 0.5b$$

WEAR

The amount of wear on back-up roll surface depends on the rolling load and number of co-rotation between back-up and work roll. The number of co-rotation in turn depends on the rolling stock being produced. The wear on the roll surface is not uniform along the roll barrel due to the variation in the geometries of the strip being rolled. The non-uniform wear profiles generated on the surface of back-up rolls gives rise to localized high contact pressure zones. The contact pressures in these regions sometimes may be high enough to cause fracture of the roll surface.

WORK HARDENING

The surface of the back-up rolls are plastically deformed under the influence of high contact stresses in the localized regions resulting from constantly shifting zones of high contact stresses due to non-uniform wear on the roll surface. These plastically deformed zones are prone to initiation and propagation of cracks that may lead to in-service failures of back-up rolls. The plastically deformed regions are marked by increase in hardness after the service campaigns and it becomes necessary to restore the hardness of the rolls while dressing to the levels before the service campaigns in order to avoid in-service roll failures.

RESULTS & DISCUSSIONS

STRESS ANALYSIS

The stress analysis has been carried out and based on the nominal rolling loads applied for various thickness and width of steel strips rolled in a particular campaign, the contact stresses present on the surfaces of back up rolls in each mill stands have been computed. Besides contact stresses present on the roll surface, based on the mill speed applied for various steel grades and strip geometries, the number of back up roll rotations in each mill stands have also been calculated.
The stresses present on the Hot Strip Mill back-up rolls and the number of co-rotation between work and back-up rolls are presented graphically in Figure 2.

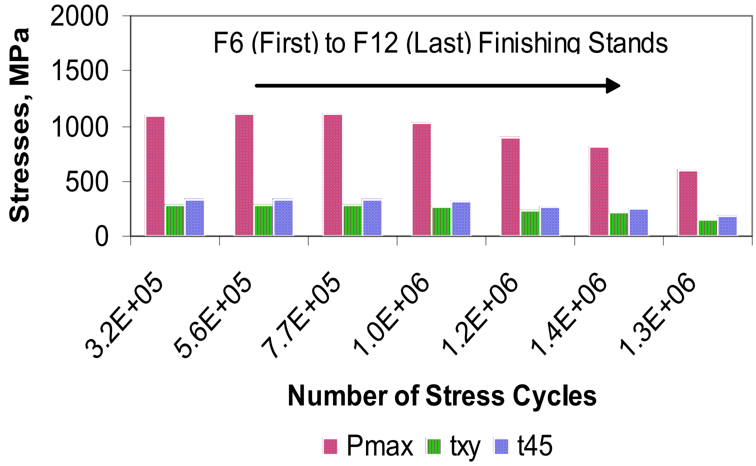


Figure 2 Surface and sub-surface stresses present on back-up rolls and number of co-rotation between back-up and work rolls

The level of contact stresses present on the surface and sub-surface regions of back-up roll dictates the maximum number of stress cycles (Campaign Length) that the back-up rolls can be subjected to according to the S-N curve and fatigue limit of the roll material. Besides, after being subjected to a certain number of stress cycles, a certain degree of fatigue damage occurs during service and this governs the amount of dressing in order to completely remove the fatigued layer and to prevent spalling in subsequent campaigns. The nominal mechanical properties of different back-up rolls, as summarized from the information available in published literatures, are presented graphically in Figure 3.

The campaign length of about 1.0 lakh tons of strip rolling for 0.9% C & 1.5% Cr back-up rolls can be maintained with a corresponding dressing amount of 4.0 mm (~1.0 mm dressing for 30,000 tons of strip rolling) for the current rolling schedule and rolling parameters. For 0.5% C & 3-5% Cr back-up rolls, it is suggested to maintained the campaign length of about 1.5 lakh tons of strip rolling with a subsequent dressing of 2.5-3.0 mm (~1.0 mm for 50,000 tons of strip rolling). However, any major change in the strip geometries and steel grades would influence the rolling parameters. It is, therefore, recommended that the campaign length and dressing amount be adjusted according to the changes made in rolling schedule.

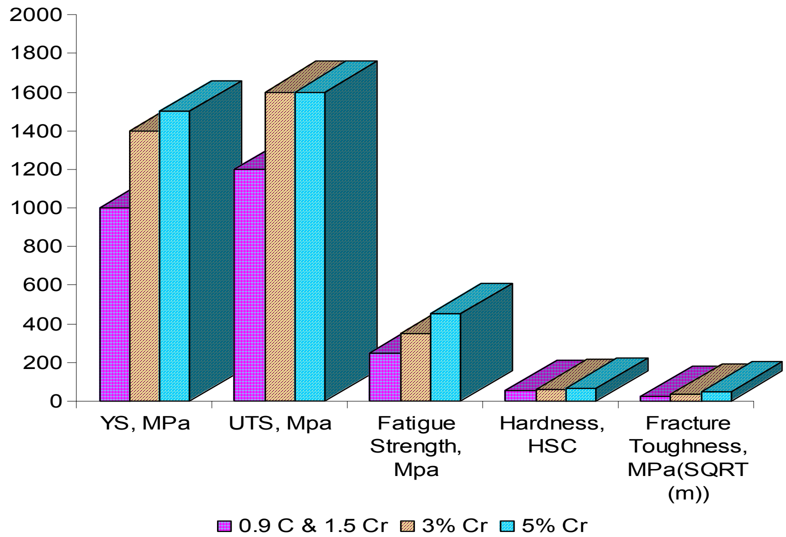
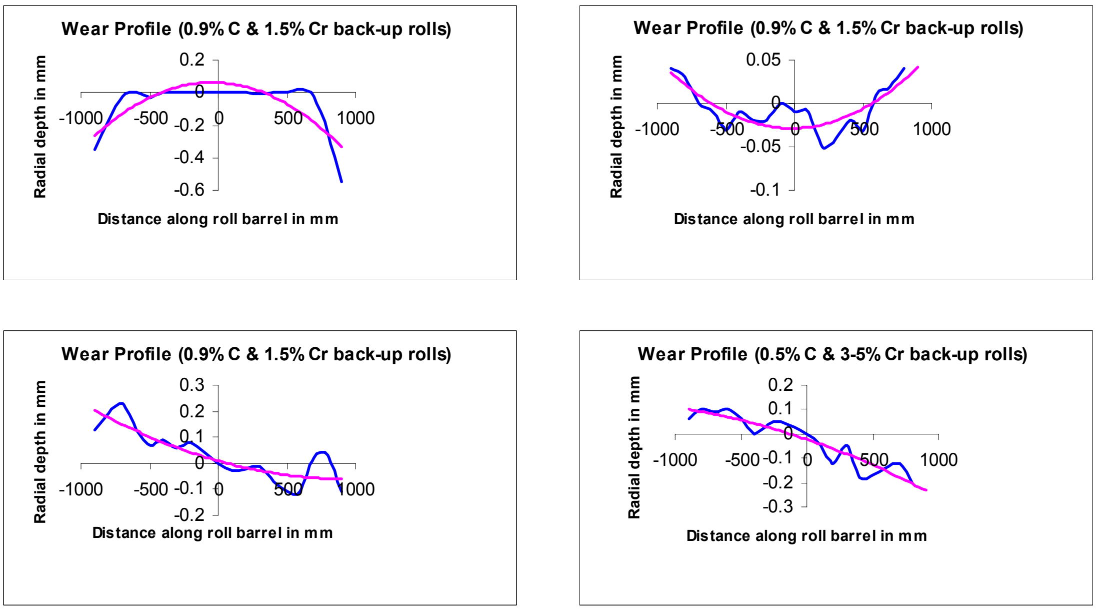
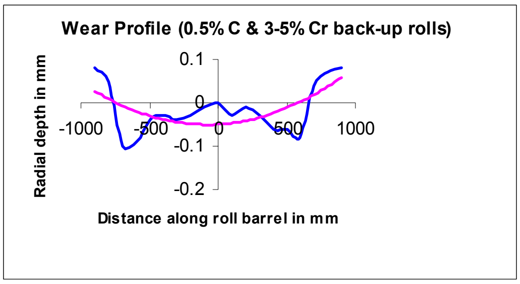


Figure 3 Nominal mechanical properties of back-up rolls used in hot strip mills

WEAR PROFILES

The typical wear profiles generated on the roll surfaces may be concave, convex or asymmetrical (Figure 4) depending upon factors such as work roll crown, thermal expansion of the work roll, body crown of the back-up roll and some kind of mechanical misalignment. The maximum wear on diameter for 0.9% C & 1.5% Cr rolls has been found to be of the order of 0.4-0.6 mm for about 1.0 lakh tons of strip rolling whereas the maximum wear on diameter has also been observed to be of the order of 0.6-0.8 mm for about 1.5 lakh tons of strip rolling. With the use of 0.5% C & 3-5% Cr rolls, the maximum wear on diameter of rolls remains below 0.3 mm with a campaign length of up to 1.5 lakh tons of strip rolling. The maximum wear on diameter reaches a level of 0.5-0.6 mm and even higher sometimes when the rolls are subjected to a campaign length of more than 1.5 lakh tons (1.8-2.0 lakh tons) of strip rolling.





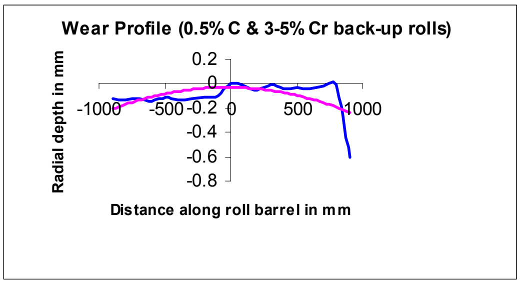
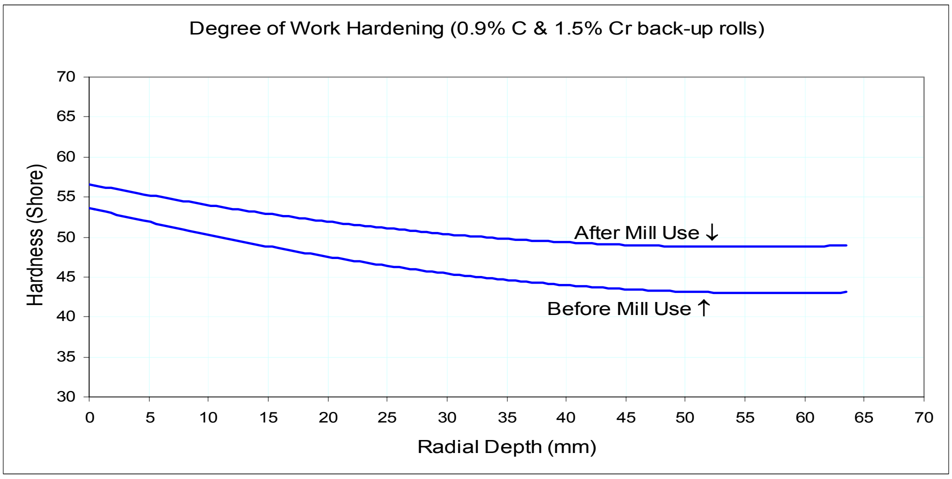


Figure 4 Typical wear profiles generated on the surface of back-up rolls

DEGREE OF WORK HARDENING

The hardness profiles with reducing roll diameter have been studied. The hardness of the fresh back-up rolls (0.9% C & 1.5% Cr) has been found to be in the range of 50-55 HSC. The hardness drop with reducing roll diameter has also been studied. It has been observed that a hardness drop of approximately 10 Shore points has occurred for a diameter loss of 100 mm (radial depth of 50 mm). The degree of work hardening has been studied. It has been observed that an increase in hardness by 4-6 Shore points occurs for a campaign of 1.0-1.2 lakh tons of strip rolling and the work hardened layer gets removed upon a dressing of about 4.0-5.0 mm on diameter. The increase in hardness upon a strip rolling of 1.5 lakh tons (approximately) in a campaign is of the order of 4 Shore points (from an initial hardness level of 58-62 Shore approximately). The dressing of 2.5-3.0 mm is sufficient to remove the work-hardened layer. These rolls, when subjected to a campaign length of more than 1.5 lakh tons (1.8-2.0 lakh tons) of strip rolling, sometimes results in a hardness increase of more than 4 Shore points (approximately 5-6 Shore points and even higher at some of the instances) which even upon dressing remains higher by 1-2 Shore points compared to the initial hardness levels (before mill use).



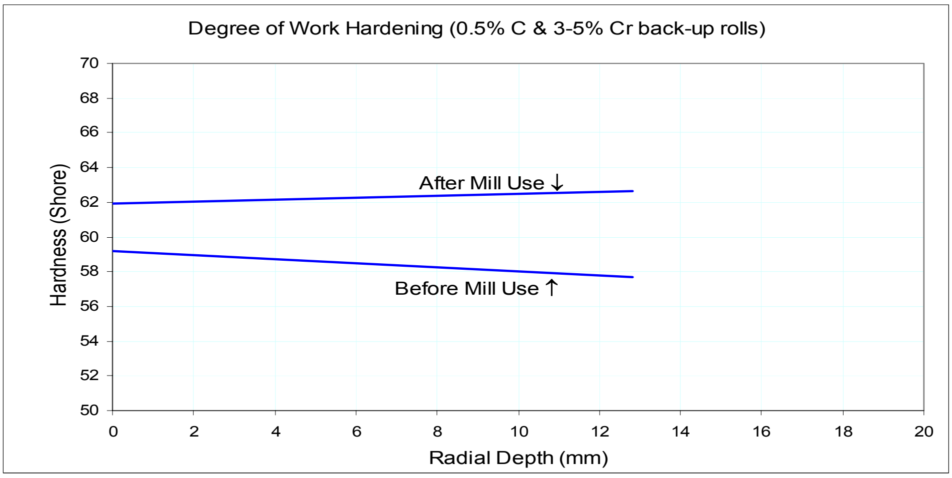


Figure 5 Increase in hardness (work hardening) during service campaigns of back-up rolls

RECOMMENDATIONS

(1) The stresses present on the surface & sub-surface regions of the back-up rolls should be estimated according to the applied rolling loads in the specific mill.
(2) The number of co-rotation between work & back-up rolls should be estimated according to the applied mill speed in the specific mill.
(3) The campaign length for back-up rolls should be determined according to the stresses present, number of co-rotation between work & back-up rolls and the fatigue strength of the roll material.
(4) As a preliminary guideline, a campaign length of ~4000 km of rolling stock can be maintained. However, the campaign length must be altered according to the changes in the strip geometries and the hardness levels with reducing roll diameter.
(5) The degree of work hardening must be assessed by continuous hardness measurement before and after the mill use and the dressing amount should be determined in a manner so as to restore the hardness to the before mill use levels.
(6) As a preliminary guideline, a dressing amount of 2.5-3.0 mm can be maintained for a rolling stock of ~4000 km.
(7) The use of NDT (UT & EC) systems should be made to accurately determine the degree of damages and the roll dressing performed accordingly.
(8) A stress relief chamfer of 0.5 degree or 500 mm arc should be ideally maintained to eliminate the possibility of edge spalling.
(9) The structural integrity of the mill should be periodically monitored in order to eliminate the possible roll misalignments.

TECHNOLOGICAL OUTPUTS

The application of recommended practices has resulted in reduction of consumption of back-up rolls and production delays in Hot Strip Mill at Bokaro Steel Plant by ~50%.

CONCLUSIONS

The predominant mechanisms of back-up roll failures, namely Rolling Contact Fatigue, Wear and work Hardening, need to be examined in context of the service requirements of the specific mill and the optimum utilization and maintenance practices need to be evolved in order to meet the ever increasing demand of rolling special steel grades and strip geometries employing higher rolling loads and mill speeds. The influences of several other operational and maintenance practices and state-of-the-art technologies, such as Roll Bite Lubrication, NDT assisted roll dressing need to be examined in order to reduce roll consumption and production delays.

Acknowledgements

The authors wish to express their deep sense of gratitude to the management of RDCIS & BSL (SAIL) for the support and encouragement provided without which it would not have been possible to complete the work. The authors would also like to thank all the members of the HSM and Roll Grinding and Bearing shop (RGBS) of BSL for the cooperation extended to the project team.

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