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DESIGN AND ANALYSIS OF A MECHANICAL SCALE BREAKER FOR THE HOT STEEL ROLLING PROCESS

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ABSTRACT

The presence of leftover scale after water jet descaling on the rolling stock affects the quality of the rolled products due to surface imperfections. This scale also has an impact on the roll wear and its working life. The mechanical scale breaker is meant to break the scale on the bloom surface that aids ease in entry of the water jet, explode and remove scale comparatively at lower pressure and flow rate. The mechanical scale breaker was designed, 3D model was developed using Autodesk Inventor and analysed for its application using ANSYS R 18.1. Constraints such as mill pass line, bloom dimensional tolerance, thermal stress of the impacting material, and ease in adaptation and implementation in a brown field project were considered. The mechanical scale breaker had eliminated the rolled product rejections due to scale inclusions and also paved the way for energy and water conservation.

KEYWORDS: Scale Breaker, Scale Remover, Hot Rolling, Water Jet Descaler.

1. INTRODUCTION

Hot rolling is a metal forming process in which the material is transformed to different shapes and sizes such as angles, bars, re-bars, channels, and beams. Initially when the material is heated above re-crystallization temperature for rolling, it is affected by the chemical action of the heating atmosphere. Between the heating environment elements and steel components, chemical reactions are initiated at the separation surface that affect a layer of metal of about a few microns to a few millimetres known as scale. The thickness of the affected layer is a function of the environment nature, heated material composition, chemical reaction type and kinetics, heating rate and temperature. Removal of the scale before rolling is essential to achieve quality rolled products free of inclusions and for better roll life.

Santosh [1] had studied the factors responsible for creating necessary stress for breaking/flushing the scale from the steel surface, steel–scale temperature difference, thermal gradient within scale, mechanical pressure by water jet, shear at interface and explosive creation of steam with cracks. Jin [2] had analysed that the method for continuously removing scale the method comprising cracking the scale on the hot-rolled steel strip, shot-blasting the cracked scale to remove the scale, and deforming the hot-rolled steel strip to weaken the bond between scales. M. Raudensky [3] had summarised that the forces that break the scale layer are the pressure forces inside the cracks lying perpendicular to the scale layer. The internal pressure developed due to water evaporation causes the shear stresses with their maximum at the crack tip. Fagundes [4] had found that the thinner the slab thickness, the smaller both its surface temperature and the difference in temperature between the nucleus and the surface. A smaller surface temperature reduces oxidation kinetics and, consequently, reduces fracture possibility in the oxidized layer during processing and also reduces the impression of this oxide on the metal base. Marcel and Rudolf [5] had analysed that the scale cracks start at the outside layer and grow along the thickness. The crack tendency increases along the rolling gap in the direction of exit. At the end of rolling gap or with greater whole deformation, more scale fragments which was pushed into the metal matrix. Mikako **[6]** studied that the thermal stress generated by the difference in the thermal expansion coefficient between the inner-most layer and steel causes a spalling and cracking of the scale during the hot-rolling process. Hikaru [7] had studied that the scale cracks when the rolling temperature is high, and the thickness is large. While the base metal was elongated by rolling, the scale was divided rather than elongated. Scale was considered to break not in the roll bite but by cracking and flaking off the base metal at the entry to it. Chenand Yuen [8] conducted high-temperature tensile tests of steel sheets with scale on the surfaces and exhibited that while scale was capable of elongating together with the base metal, maintaining adhesion, cracks formed at its grain boundaries. Kizu [9] had reported that steel oxidation for only several seconds was enough for blister formation. The scale cracks after rolling scale undergoes rolling while being flaked off the metal at many positions. Libor [10] had analysed the mechanism of water jet acting on scales, mechanical penetration in the material and the formation of steam bubbles inside the material, which creates tensile and shear stresses in the material of scales, leading to its breaking and separation.

In hot rolling process, hot steel bloom from the furnace is placed on the roller discharge conveyor (shown in Figure1) by the billet extractor. Before the bloom enters the roughing mill, it passes through the water jet descaler at the spraying axis to remove the primary scale on its surface. The water jet descaler circuit diagram is shown in Figure 2. A part of the pressurized water is fed back to the reciprocating pump by means of auto operated puppet valve. In case a bloom is sensed by the sensor and feedback is sent to the puppet valve to close the return circuit line directing the total pressurised water on the hot roll stock for descaling.

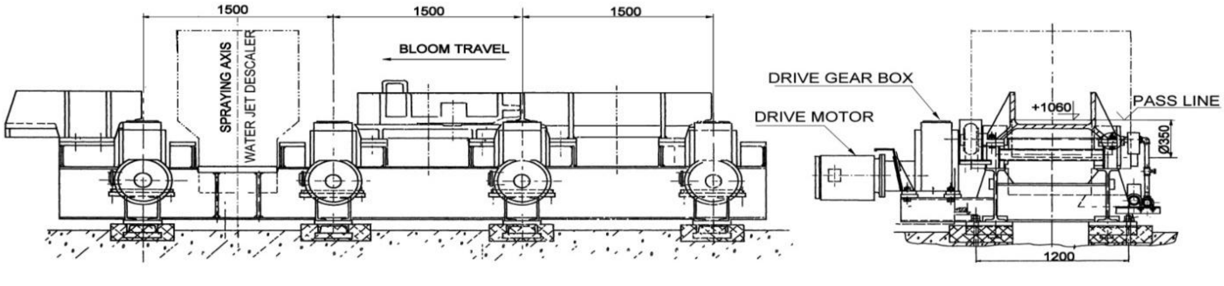


Figure 1: Roller Discharge Conveyor.

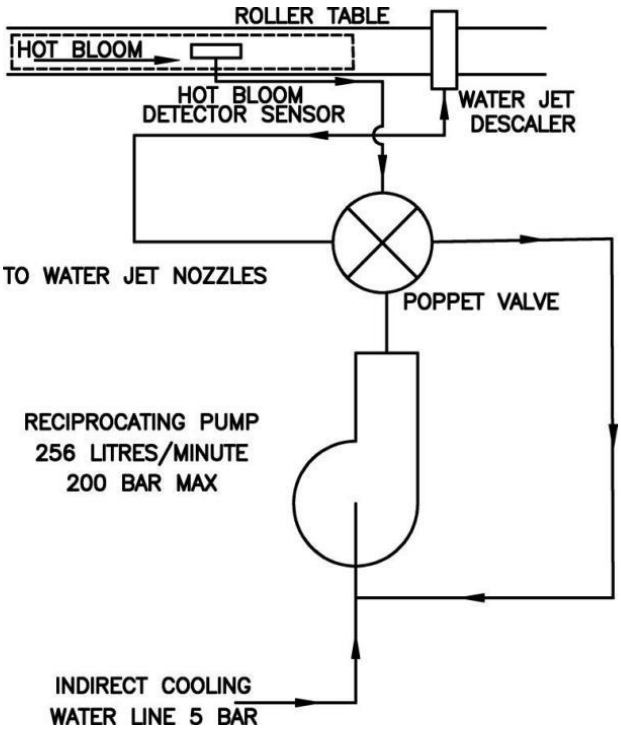


Figure 2: Water Jet Descaler Circuit Diagram.

2. DESIGN OF MECHANICAL SCALE BREAKER

The scale gets easily removed from the bottom side and vertical side of the bloom before roll bite, due to contact force of the roller and by gravity separation method. The scale being brittle in nature a force at regular interval is envisaged to break the scale on the top surface of the bloom that aids in easy entry of the water jet. Once the water jet touches the steel surface, it vaporises, expands in volume, leading to cracking and flushing out of scale from the bloom surface completely. The breaking of the scale at regular intervals is made possible by applying a load on the scale surface at regular intervals by design of a new mechanical scale breaker. (Refer Figure 3)

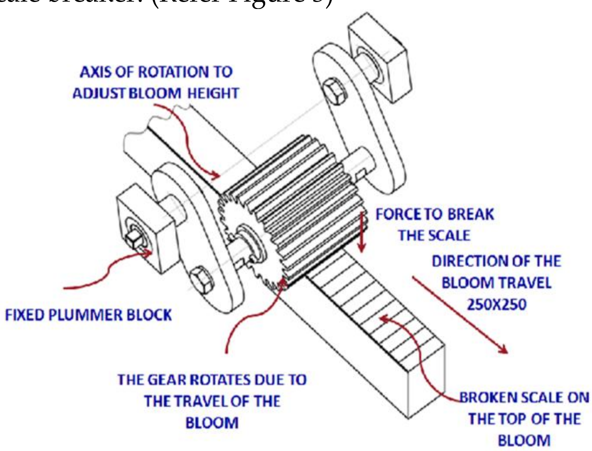


Figure 3: Mechanical Scale Breaker.

The spur gear is made to rotate over the hot bloom surface which cracks the scales existing on the top surface of the bloom due to the self load of the mechanical breaker assembly. The gear rotates freely on the bloom powered by the friction with the bloom movement on the roller discharge conveyor. The bearing bushes of the mechanical breaker assembly are carbon impregnated to provide solid lubrication for the free rolling of the gear in a hot environment. The mechanical scale breaker is designed to adapt to the little change in the bloom height without causing any hindrance to the normal bloom movement on the roller table.

Considering the drive power of the discharge roller conveyor,

Motor torque, $T = P \times 60 / 2\pi N$ (1)

Where P is the power of motor in KW

N is the speed of the motor shaft in rpm

Gearbox Output shaft speed = N / i rpm (2)

Where i is the reduction ratio of the gearbox

Linear velocity of the bloom, $V = \pi D N / 60$ (3)

Where D is the diameter of the roller in m

By using the formula $V^2 = U^2 + 2aS$, (4)

$a = (V^2 - U^2) / 2S$ (5)

Where a = acceleration of the bloom travel in distance S in m

Initial velocity of the bloom after placing on conveyor discharge roller, U= 0

Considering the spur gear to cut the scale at an interval is equal to the circular pitch of the spur gear, P_c

The module of the spur gear, $m = P_c / \pi$ mm (6)

The width of the gear = width of the scale to be cut in a given time

The frictional force exerted by the spur gear on the bloom surface $F_f = \mu M_g$ (7)

Where μ is the static coefficient of friction between the spur gear and the hot bloom,

The mass of the spur gear, M_g

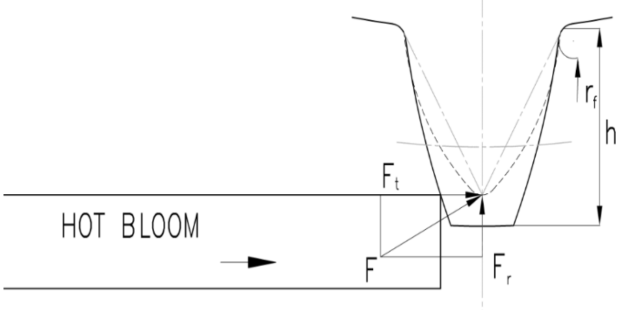


Figure 4: Gear Tooth as Cantilever Beam.

Force at which the bloom hits the spur gear roller, $F = M_b a$ (8)

Where M_b = Mass of the bloom

As the initial tangential force F_t exerted by the bloom on the spur gear is greater than the frictional force F_f exerted by the spur gear on the bloom surface, the spur gear starts rotating on the bloom surface as the spur gear gets over the bloom surface. The weight of the mechanical scale breaker is arrived such that it breaks the scale due to its shear load while rolling.

The rotation speed of the spur gear, $N_{SG} = V \times 60 / \pi D_{SG}$ (9)

Where D_{SG} = Tip circle dia of the spur gear

In reference to Figure 4, by Lewis equation, the bending stress $\sigma = F_t / b\,Y\,m$, (10)

Where F_t is the tangential force exerted by the bloom on the spur gear,

b = width of the spur gear

Y = Lewis form factor

Heat lost by the hot body = Heat gained by the cold body

$(\Delta T_b)\ (M_b)\ (S_b) = (T_{gf} - T_{gi})\ (M_g)\ (S_g)$ (11)

Where ΔT_b= Temperature lost by the bloom in the given time

M_b = Mass of the bloom

S_b = Specific heat capacity of hot bloom

T_{gi}= Initial temperature of the Spur gear

T_{gf} = Final temperature of the Spur gear

M_g = Mass of the Spur gear

S_g = Specific heat capacity of Spur gear

Thermal Stress induced in the Spur gear, $\sigma_T = E\,\alpha\,\Delta T_g$ (12)

Where E = Young's Modulus of alloy Steel

α = Coefficient of thermal Expansion

ΔT_g = Temperature gained by the Spur gear

Based on the total stress acting the gear, case-hardening steel was selected for gear material.

3. GEOMETRIC MODELLING OF MECHANICAL SCALE BREAKER

The part model of the mechanical scale breaker was made and assembled in the Autodesk Inventor assembly environment. The top axis of the lever plate hole is free to rotate about its axis enabling the spur gear roller arrangement to lift according to the height of the bloom. The bottom axis of the lever plate rigidly holds the shaft. The spur gear rolls over the hot blooms due to the friction between the gear and the bloom. The assembly has two degrees of freedom with rotation of both the lever about top axis and the rotation of the gear with graphite impregnated brass bush about its own axis. The assembly model of the mechanical scale breaker is shown in Figure 5. The assembly was welded to the roller discharge conveyor side supports taking the mill pass line constraint into consideration.

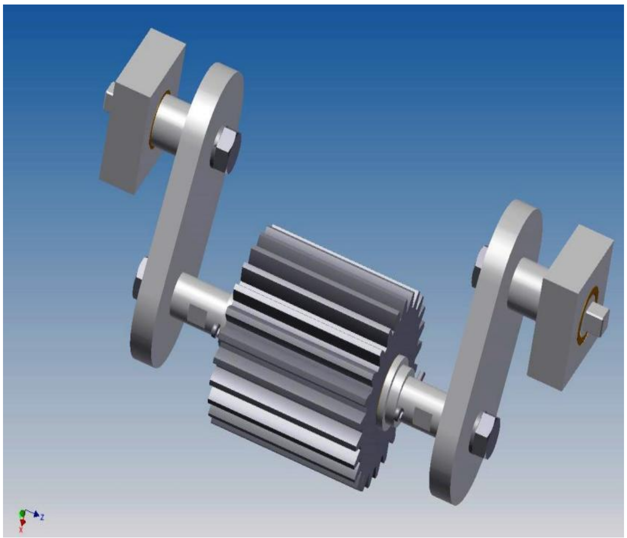


Figure 5: Mechanical Scale Breaker Assembly Model.

4. ANALYSIS OF THE MECHANICAL SCALE BREAKER IN ANSYS

The virtual model of the mechanical scale breaker was evaluated using ANSYS software. The meshed model is shown in Figure6. The bloom body temperature was set to 1200 °C. Natural convection of the atmospheric air over the mechanical scale breaker model was set to 8e-005 $Wmm^{-2}\ {}^{o}C$. The maximum shear stress is XY plane was found to be 59.692 MPa. (refer to figure 7) The equivalent Von Mises stress maximum stress value of 112.66 MPa (refer to figure 8), was found to exist at the corners of the bearing block. The minimum safety factor was found to be 2.2191(refer to Figure 9). The directional deformation in the Y axis was found to be 0.036 mm (refer to Figure 10), and in the X direction was found to be 0.043 mm (refer to Figure 11). The results obtained from static structural analysis from ANSYS are as follows.

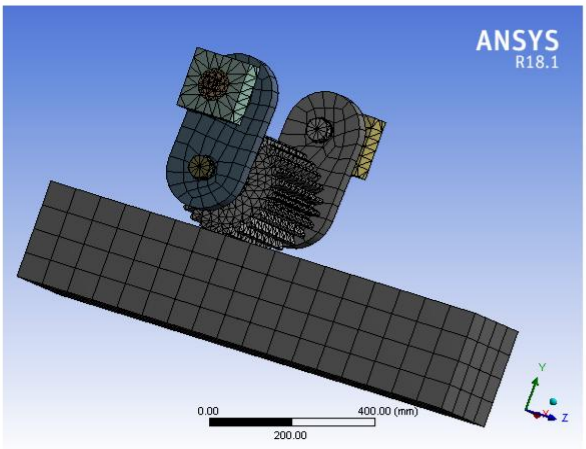


Figure 6: Discretisation of the model.

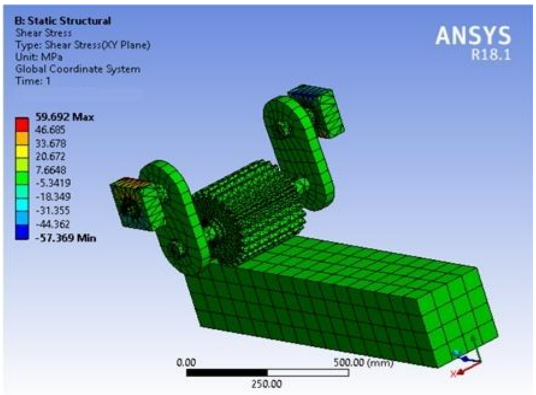


Figure 7: Shear stress in XY Plane.

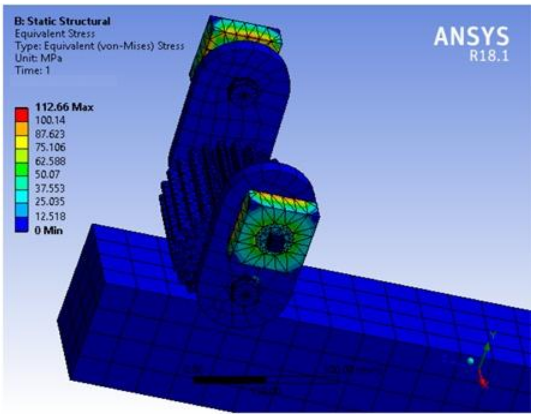


Figure 8: Equivalent (Von Mises) stress.

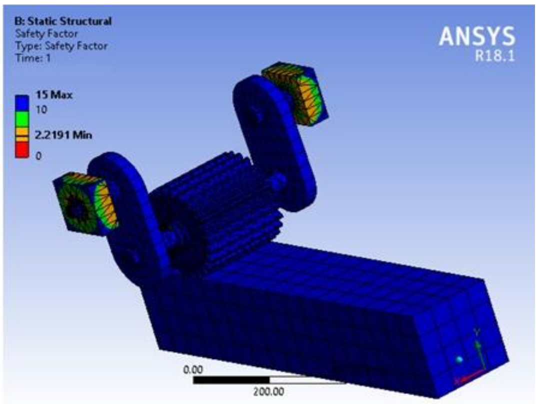


Figure 9: Factor of safety.

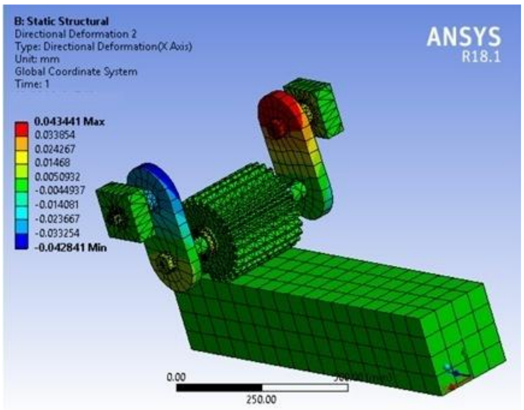


Figure 10: Directional deformation (X Axis).

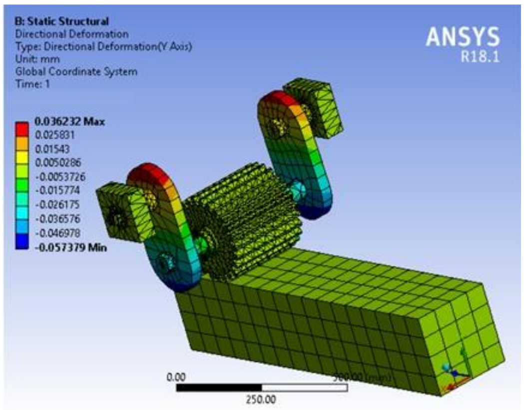


Figure 11: Directional deformation (Y Axis).

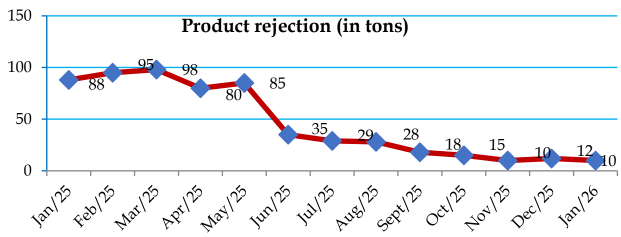
5. COST-BENEFIT ANALYSIS

By the experiment, it was found that once the scale is broken by a mechanical scale breaker, the pressure of the water was reduced to the range of 120 -140 bar from 200-220 bar. The required flow rate of water is reduced from 256 litres per minute to 154 litres per minute. The mechanical scale breaker had reduced the tonnage of wastage of rolled products from an average of 90 tons per month to less than 15 tons per month. The temperature drop of the bloom has been reduced due to a reduction in water pressure and flow rate of the water jet descaler. The de-scaling quality of the bloom has been improved. The quality of the rolled product has been increased. A huge saving of energy is achieved by reducing the water flow rate and its pressure.

As an intangible benefit it eases the maintenance required for the water jet de-scaler and last but not the least a step towards a better environment by saving the natural resource - water.

6. RESULT

The implementation of the mechanical scale breaker was taken up in the medium merchant structural mill with a capacity of 75,000 tons per month of structural channels, angles and rounds. The implementation was carried out in the month of May 2025 as part of the capital repair of the mill, as it requires the total shutdown of the mill. The product rejection of the mill has come down from an average of 90 tons per month to an average of 12 tons per month as the rejection due to scale inclusions has been eliminated from the produced product due to better descaling.



7. CONCLUSIONS

The mill scales on the top surface of the blooms are found to exist even after the bloom passes the water jet de-scaler, leading to scale inclusions in the final rolled products. Maintaining the pressure of the water jet had become difficult due to the ageing of the mill on one hand and the demand for water conservation on the other. A mechanical scale breaker was designed to assist the existing water jet de-scaler in the operation of scale removal by breaking the scale from the top surface of the bloom. By installing the mechanical scale breaker before the existing water jet de-scaler, the pressure and the flow rate of the water required were reduced by 38% and 39 %, respectively, with energy saving and water conservation. Thus, the implementation of the mechanical scale remover has drastically reduced the rejection of the final rolled product of the mill due to scale inclusions and also reduced the temperature fall of the bloom due to descaling.

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Sudesh Kumar M R S, M.tech (CAD/CAM) 26 years experience in steel industry in Reverse engineering by 3D modelling of spare parts and part assemblies of steel processing equipment's to facilitate proprietary substitution and facilitate in-house manufacturing. Modification of process equipment and facilities for better efficiency / better life cycle / safe working environment for the employees. An efficient inventory management by standardisation of spare parts and part assembles in a steel plant. My work has been awarded three patents by the Intellectual property of India. I am currently pursuing a part-time PhD at Andhra University, Visakhapatnam to enhance my academic knowledge while balancing my work experience.
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