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An Optimal Design Approach for Adamite Hot Rolling Mill Roll

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Abstract- *In this paper, micro-structural, mechanical and tribological behaviors of roll materials i.e. high speed steel (HSS), high chromium iron (HiCr), indefinite chill irons (IC) and other have been reviewed. The technological process of the rolling consists of many factors that influencing the fatigue life of rolls like rolling temperature, roll groove design, rolling speed and turning due to wearing. These parameters are analyzed to advance maximum fatigue life of the rolls as well as to shrink overall energy consumption, increase production and decrease overall costs. Finite element analysis of adamite roll is carried out by applying process parameters and variables at high temperature those are responsible for roll wear. According to appropriate chemical properties, microstructure and mechanical property some new wear-resistant roll grades for conventional hot rolling process is suggested.*

Keywords— *Mechanical wear, Thermal fatigue, Fatigue life, Oxidation, Adamite roll.*

I. INTRODUCTION

Rolling is one of the most important steel production processes. Over 90% of all materials that are ever deformed are subjected to rolling. Rolls as the tool of rolling mill play an important role in the rolling mill production. Rolls generally contribute some 5-15 percent of overall production costs without including the cost of mill down time because of the roll changes. The percentage will be more for the hot rolling mill because failure of the roll is more severe at elevated temperature. The ever increasing demands for rolls with improved performance represent an important goal of the steel industry, where the hot rolling conditions are becoming more and more severe. Work rolls are exposed during service to thermal fatigue, mechanical fatigue, wear, impacts so that good thermal, mechanical and tribological properties are required for the materials employed for their fabrication. For economical reasons, high hot wear resistance represents the most important property for rolls in the finishing stands, since their yield is determined in terms of tons strip rolled per millimeters of roll consumption. Tribological properties of rolls determine their life and wear is the main cause of roll consumption. If roll wear can be reduced, roll cost is directly reduced. The indirect cost for roll turning, grinding and maintenance will be decreased as well. On the other hand, wear of the roll directly influences the dimensional and shape accuracy of products, which influences the strip production to a much higher degree. Therefore it is very important to study the roll performance, especially in the domain of wear. Since increasing roll life can bring significant cost reductions for rolling processes, some endeavour has been conducted to develop special roll materials and some new materials are still in development. Wear resistance is certainly one of the most essential properties to estimate new materials. Many experiments and studies have been done for sliding wear in the tribology community, but a relatively small amount of progress has been achieved on rolling friction and wear. Furthermore, study on rolling wear at high temperature has received very little attention. The rolling process is a kind of continuous production, in which the setting of process parameters and measurement of variables is very difficult and expensive, thus it is nearly impossible to study the tribological properties of rolls on a 'real' rolling mill.

A. Problem Definition

Mahalaxmi Dhatu Udyog Pvt. Ltd. Nagpur is in the business of hot re-rolling of steel. The hot steel re-rolling industry is continuously facing the problem of rolls failure. Mechanical wear of adamite type roll is due abrasion, adhesion, and erosion. Roll surface is subjected to crack formation and oxide scale formation. Fatigue life of roll is also found very less.

B. Objectives

This research aims

- To analysis of hot rolling process parameters and variables at high temperature that are responsible for roll wear and expected to develop and suggest some new wear-resistant roll grades for hot rolling processes.
- To obtain some regularities for wear condition monitoring and to find suitable process parameters of rolling mills concerning tribological properties.

- To improve the fracture toughness and wear resistance of hard-faced hot rolling mill rolls.
- To improve fracture toughness and wear resistance of hard-faced hot-rolling-mill roll and suggest different method of surface hardening.

II. LITERATURE SURVEY

Hot rolling mill rolls during process mainly subjected to mechanical wear, thermal fatigue, lower fatigue life etc. The above stated failure modes and their impact on rolls discussed below briefly.

A. Mechanical Wear

During hot rolling process, a superficial oxide scale forms on the work rolls due to thermal cyclic working conditions. This oxide scale plays a major role in hot rolling because it allows the starting and driving of metal sheet between the rolls [1]. Wear of rolls occurs either comparatively uniform on the contact surface or narrow in deeper wear bands. The uniform wear is mainly caused by abrasion in grouping with micro chipping caused by thermal induced surface fatigue [2]. The formation of a thin oxide scale on the roll surface seems to certainly affect the roll performances [3]. The temperature fluctuation at the roll surface was sufficient to induce thermal fatigue cracking on the surface of the sample [7].

The rolling processes of materials create very important thermal heating. The work piece and roller of the rolling mill may damage by reaching the temperature to very high levels [8]. Work roll in hot rolling mills is concurrently excited by cyclic thermal and mechanical stresses, respectively. A non-uniform temperature distribution over the work roll surface causes thermal stresses. It is induced by strip heating and water jet cooling, whereas rolling pressures and contact actions with back-up rolls produces mechanical stresses. In hot rolling thermal stresses are generally comparable or even higher than mechanical stresses [11]. Thermal crown of the roll is an important factor to be considered, because it affects the strip profile [12]. The increase of rolling force and the reduction of work roll radius increases work roll deflection with rigid displacement of the work roll changes little. The work roll end might appear negative displacement for narrow strip width and high rolling pressure, which should be avoided for reducing the wear of work roll end [13]. Three time dependent damage mechanisms seem to be possible in ceramic rolls when rolling high-strength metals and alloys: wear, subcritical crack growth and cyclic fatigue [15].

B. Fatigue life

W. S. Dai and other studied to investigate the influence of rolling speed and various ingredient phases on the thermal fatigue behavior of cast iron. The simulated alloy cast irons results indicated that the thermal fatigue life of cast iron was reduced with decreasing rolling-speed because of the higher inducing temperature. The observations stated, the rising fatigue-crack mainly initiated on the surface and penetrated into the interior of material; the nucleation and propagation of fatigue cracks were preferentially directed along the clustering zone of bulk carbides and graphite nodules. The dissolution of eutectic Fe_3C and extruded-deformation of graphite will cause this cast iron to occur severe fatigue crack, and thus was harmful to its thermal fatigue resistance.

The development orientation of surface crack gradually tended to the circumferential direction when it had faster solidification structure [9]. Main factors influencing the fatigue life of rolls result from the technological process of the rolling; rolling temperature, rolling speed, roll groove design and turning due to wearing. In order to improve maximum fatigue life of the rolls, as well as to reduce overall energy consumption, increase production and reduce overall costs, an analysis of the influence of these parameters on roll fatigue life has been carried out by Z. Domazet and other see figure[10].

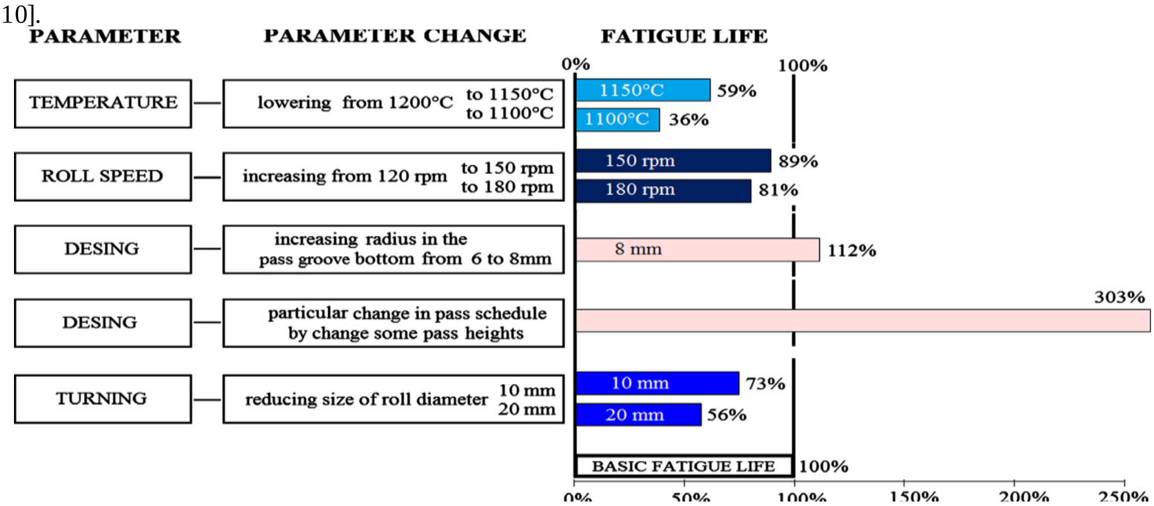

Figure 1. Fatigue life parameter change overview

III. INVESTIGATION OF PROCESS

This paper presents a process for forming variable web depth angle sections by hot-rolling. Firstly, the literature on variable geometry rolling processes is reviewed. The process concept for rolling variable web depth angle section is then introduced. A detailed review of the process is then conducted numerically and experimentally to determine the operating window of the process. The potential of the process for producing optimized angle section and optimal design approach for improving fatigue life of adamite roll are discussed. Work would extend the capabilities of the process are discussed.

The current industry has six numbers of stages to produced final product i.e. six number of passes required to complete the rolling process. Very first and second stages consist of EN8 type roll material has hardness in the range of 22-25 HR and temperature in range of 1000^oc - 1200^oc. Third and fourth stand roll having adamite steel material with temperature range 700^oc - 1000^oc. The hardness for stand number three and four is 42 - 50 HR. Five and six roll also having adamite type material with hardness range 42 - 50 HR. The temperature range for passes five and six is about in the range of 650^oc- 750^oc.

Angle section product length is 10000 mm and thickness is 5mm.

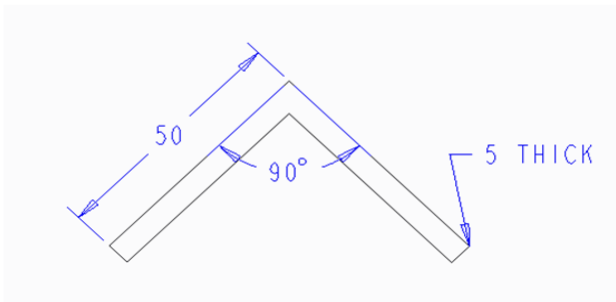

Figure 1. Product details

A. Process overview

The process for rolling angle section is based on a conventional type process in which hot raw billet inserted manually. Angle section products are finished by six numbers of passes. This process causes huge temperature drop, ultimately increases the deformation forces in last passes. The stress produced due to this deformation forces are responsible for failure of roll. There is different roll profile in every stage of entire process to accomplish the final product.

For passes 5 and 6

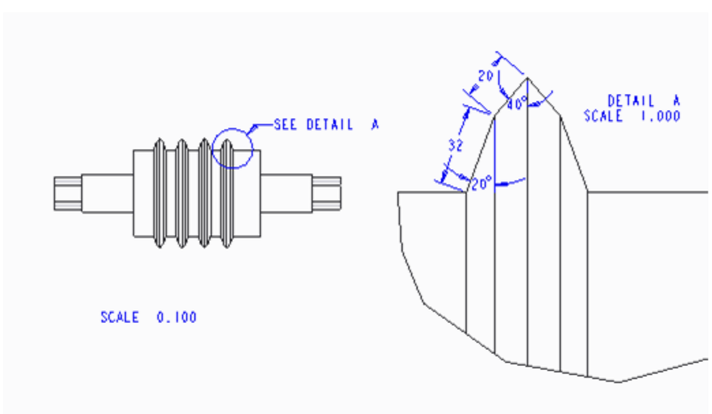

Figure 2. Pass 6 roll detail

Material: Adamite steel
Hardness: 42 - 50 HR
Temperature: 650 - 750^0c
Pressure: 1200 -1300 Mpa
Rolling Speed: 250RPM

Chemical composition:

C (>1.68%)	Si (0.517%)	Mn (0.851%)	P (0.0147%)
S (0.0279%)	Cr (1.27%)	Mo (0.307%)	Ni (1.25%)
Al (0.0065%)	Cu (0.12%)	V (0.0546%)	N (0.011%)
Fe (93.7%)	CE (2.24%).		

B. Therotical Calculations

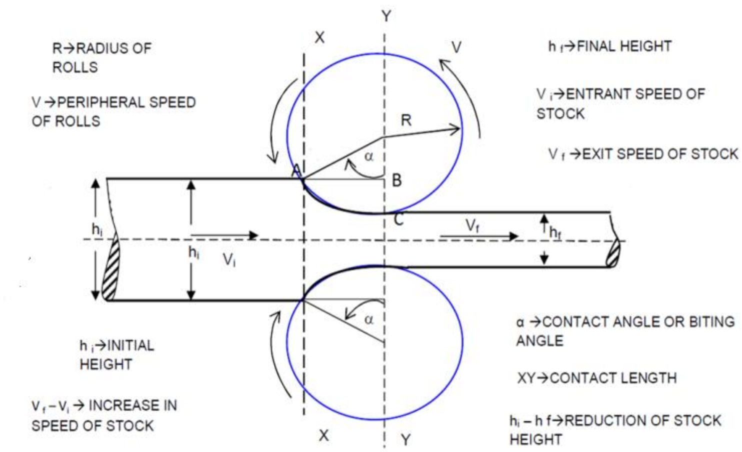

Figure 3. Rolling process

The above figure shows rolling process in which hot billet is inserted in between two rolls at one end and get compressed with required shape to other end. Here V is the peripheral speed of roll, h_i be the initial height, and h_f be the final height of billet. v_i, v_f be the initial and final velocity of billet respectively and 'R' is the radius of roll.

Bite angle (α) or Deformation angle

$$\cos\alpha = \frac{OB}{OA} \qquad \cos\alpha = \frac{R - \Delta H/2}{R} \tag{1.1}$$

From ΔOAB

$\alpha = 6.21^{o}$ as R= 171mm, ΔH= 2mm

Length of Deformation Zone

L=18.5mm

Coefficient of friction (μ)

$$\mu = tan\,\beta \tag{1.2}$$

Where β = Friction Angle

$\mu = 0.11$

Average Pressure on contact surface of roll:-

As, σy = 400 N/mm^2

$$P = \frac{2\sigma_y\left[1 + \frac{\mu L}{4Havg}\right]}{\sqrt{3}} \tag{1.3}$$

H_{avg} = 6mm

P = 500 N/mm^2

Average Force on roll:-

$$F_{avg} = P * b * L \tag{1.4}$$

= 500*100*6

F_{avg} = 300 KN

Stresses in Roll:-

$$\sigma_{stress} = \frac{F_{avg}}{A}$$

(1.5)

As, A= 100*18.5 mm^2
σ_{stress} = 162.16 N/mm^2
Fatigue Life
Fatigue strength-
Sf = (0.8 to 0.9) Sut (1.6)
As, Sut = 700 N/mm^2
Sf = 630 N/mm^2
Endurance Strength-
Se= 0.5 Sut (1.7)
Se = 350 N/mm^2
Besquine Equation-
$A = S_f L^B$ (1.8)

Where A & B are Constants and Calculated from S-N curve
L= Life of roll in cycle
A= 1134 & B= 0.085
From Besquin Equation
Life L= 40,743.79 Cycle
Life in Hours:
L= 60*n*L_H
Where L_H is Life in hours
n= RPM = 250
L_H = 10.86 Hr
L_H = 11 Hr

Even though the stresses induced in the adamite roll is less than the maximum permissible stresses, cyclic loading condition is responsible for wear of a roll. The fatigue life of adamite roll is very less about 11 Hr which increases the overall production cost.

C. Finite Element Analysis of adamite roll

Finite element analysis of adamite roll has been done according to process parameter.

1. Static structural analysis

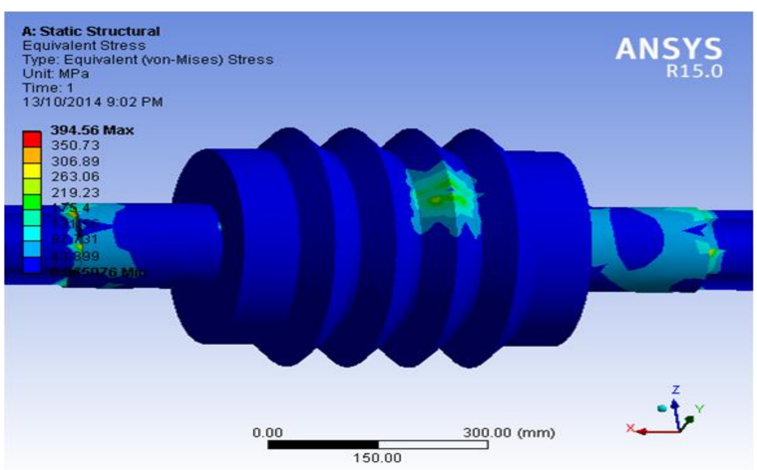

Figure 4 Stress analysis of roll

Figure 5 indicates the stresses induced in the roll groove. It is found that the stress induced in rolls at the point of contact is 175 N/mm^2 which is matching with theoretical stress result.

2. Fatigue Analysis

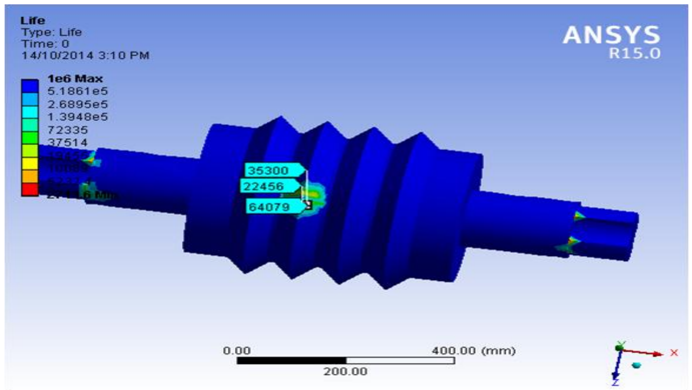

Figure 5 Fatigue life analysis of roll

Figure 6 indicates the fatigue analysis of roll. It is found that fatigue life of a roll is 37514 Cycles.

Table 1 Comparison of results

Parameter	Theoretical result	Ansys result
Stress (N/mm^2)	162.16	175
Fatigue life (Cycle)	40,743	37,514

In the above table theoretical and results from Ansys are compared and it is found that the result matches nearly.

IV. THE CLASSIFICATION AND PROPERTIES OF ROLL MATERIALS

A. Roll material classification

Recently, ferrous materials with highly alloyed, mainly high chromium irons and steels, as well as high speed steels, have been promoted as roll materials with extremely good wear resistance. Figure 7 shows a classification of roll materials based on the tensile strength and hardness of roll materials. High speed steel (HSS) and high chromium cast iron (H-Cr) shows good tensile strength and high hardness than adamite roll.

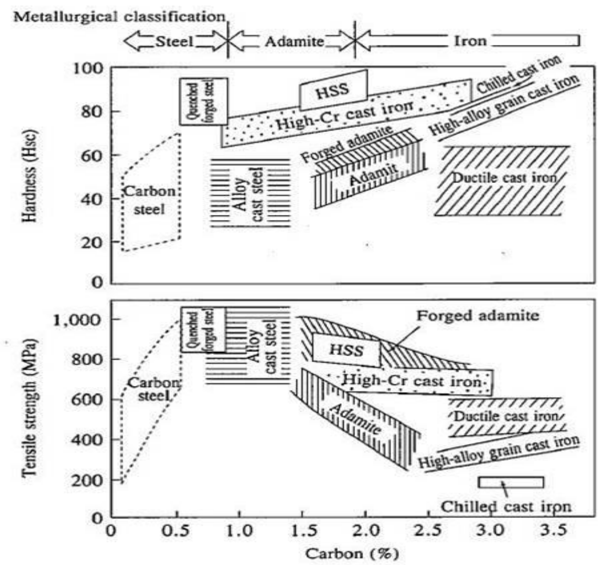

Figure 6. Tensile strength and hardness of roll materials

B. Chemical composition, microstructure and hardness of roll materials

Table 2. Properties of roll material

Material	Chemical composition (wt %)	Microstructure	Hardness HR
Indefinite Chill Iron	C 3.0-3.4 Ni 4-5 Cr< 2 Mo< 1	Fe_3C Bainite Intercellular Graphite	70/85
Adamite Steel	C 0.7- 1.4 Ni 1.2-1.5 Cr < 2 Mo <1	Tempered Martensite Pearlite	45/60
High Chromium Iron	C 1- 3 Ni 1-2 Cr 10- 25 Mo 1- 3	M7C3 Tempered Martensite	70/90
High Speed Steel	C 1.5 – 2.4 Cr 2 – 4 Mo 2 – 10 V 2- 10 W 2- 10 Co < 10	MC + M6C Tempered Martensite	80/90

From table 2 it can be conclude that high speed steel, high chromium iron, indefinite chill iron have high hardness than adamite steel. Chemically more ingredients are added to those three materials than adamite material.

C. Mechanical properties of roll materials

Table 3. Mechanical properties of roll materials

Mechanical Properties	Materials		
	HSS	HCr	Adamite

Tensile Strength (MPa)	700-1100	600-900	400-700
Compressive Strength (MPa)	2500-3200	1700-2200	1300-1900
Rupture Strength (MPa)	1200	1100	950
Toughness (MPa)	25-28	21-34	15-21

Mechanical properties like tensile strength, compressive strength, rupture strength and toughness for High Speed Steel, High chromium and Adamite materials are compared in table 3. HSS and HCr gives extraordinary result over adamite material.

V. DISCUSSIONS

In order to increase the maximum fatigue life of the rolls, increase production, reduce overall energy consumption, and reduce overall process costs a review has been done. In this review influence of rolling process parameters like temperature, rolling speed, roll groove design and turning due to wearing on roll fatigue life is studied. All parameters were changed according to technological limits. The retention of high hardness at elevated temperature is very important to reduce abrasive wear and also to support the protective oxide layer which develops on the surface of the roll material. To achieve this alternative materials like high speed tool steel (HSS), high carbon high chromium (HCHCr), forged alloyed metals which are responding to rolling process conditions for longer time than adamite roll are suggested. The above stated materials have good mechanical properties, high hardness, longer fatigue life etc. These materials produced by centrifugal casting, present a microstructure constituted by a martensite matrix and an interdendritic network of primary carbides. These two phases contributing their properties, as hardness, strength, toughness, thermal fatigue and wear resistance.

VI. CONCLUSIONS

The theoretical calculation for adamite roll shows lower fatigue life. Even though the stresses induced in the roll is less, roll failure occur at lower thermal cycle because of cyclic loading in the process.

It can be conclude from the review

- The change of groove bottom radii size from 6 mm to 8 mm may increase the fatigue life up to 12%.
- The reduction of rolling speed 250 rpm to 200 rpm, may improve the fatigue life up to 30%.
- The increment in temperature from 1100 ^{0}c to 1200 ^{0}c may increase fatigue life up to 30%.
- Welding followed by hammering improve fatigue life [10].
- HSS, HCHCr, HGr material have high toughness, moderate hardness and good mechanical properties over adamite roll.
- Wear rate of HSS, HCr is less than adamite.
- HSS rolls are more costly than HCr roll and adamite rolls.
- Tungsten Carbide is one of the best roll materials for groove profiled roll because it has infinite roll life.

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