Parametric Study of the Hot Rolling Process Using FEM

Shailendra Dwivedi [1] Dr. Geeta Agnihotri [2] Dr. K.K.Pathak, [3]

1. (Ph.D Scholar, Mechanical Engineering Department, Maulana Azad National Institute of Technology, Bhopal)
2. (Professor, Mechanical Engineering Department, Maulana Azad National of Technology, Bhopal)
3. (Professor, Civil Engineering Department, National Institute of Technical Teacher's Training and Research, Bhopal)

ABSTRACT

Numerical Simulation has become a quite important tool in the Manufacturing Industries. Rolling process is one of the most popular processes in manufacturing in order to make different parts with a long range variety of dimensions. In this procedure the internal raw material transform into desirable shape by at least rolls. In comparison with other methods for analysing the rolling process, the finite element method is the most practical and accurate one, so a coupled thermo elastic plastic three dimensional finite element model is considered to analyse the hot rolling process. In present research the influence of Modelling and Simulation of various parameters such as geometry of the slab, temperature, friction between work-rolls and slab, percentage of thickness reduction, rotational speed of work-roll have been studied on process. Outputs like temperature distribution, stress, strain and strain rate fields, roll force have been obtained through different inputs. The outputs of finite element simulation are used to investigate the effects of parameters on product integrity and mechanical properties.

Keywords - FEM, Hot Rolling, Mathematical Model, Thermo mechanical Behaviour of Strip.

I. INTRODUCTION

The rolling process is one of the most popular processes in manufacturing industries in that almost 80% of metallic equipment has been exposed to rolling, at least one time in their production period. Among all kinds of the rolling processes, the flat rolling is the most practical one. In industrial countries, about 40-60% of rolling products are produced with this type of rolling. [3]

Rolling is a fabricating process in which the metal, plastic, paper, glass, etc. is passed through a pair (on pairs) of rolls. In flat rolling the final shape of the product is either classes as sheet (typically thickness less than 3 mm, also called "strip") or plate (typically more than 3mm). Flat rolling is classified according to the temperature of the metal rolled. If the temperature of the metal is above its recrystallization temperature, then the process is termed as hot rolling and if the temperature of the metal is below its recrystallization temperature, the process is termed as cold rolling.[6]

There are many studies concentrating on evaluating the temperature field during the hot rolling process. For example, Hollander (1970) has used a one dimensional FED model and the assumption of homogenous deformation to estimate the temperature distribution during the hot strip rolling. Samarasekara et.al. (1986) have predicted the temperature distribution in the hot strip rolled strip rolled metal as well as in the work roll. In their work the effects of process parameters on the temperature field have been evaluated. Chen et.al (1993) calculated the temperature and strain fields by coupled FEM and FDM code. The kinetic of iron oxidation during hot rolling has also been investigated in their paper. The temperature variations in work roll have been considered in a few papers. Sluzalec (1984) has utilised a two dimensional finite element method to predict the temperature distribution during hot rolling and Teseng et.al (1990) have estimated the temperature variations in the work roll in order to evaluate the thermal stress distribution in the rolls. Mori er.al (1982) has developed a finite element method, using the assumptions of rigid-plastic and slightly compressible material to predict the velocity field during isothermal steady and unsteady plane strain rolling conditions. Hwu and Lenard (1988) have used finite element formulation for flat rolling process to assess the effects of work roll deformation and various friction conditions on the strain field. Yarita et.al (1988) have analysed the plane strain rolling process utilisation an elastic plastic finite element model. They have attempted to predict the stress and strain distribution within the deformation zone using an updated Lagrangian code. Hwnag and Joun (1992) have assessed the hot strip rolling process. The temperature distribution in the rolled metal and in the work roll and strain field have been determined in their work. Serajzadeh et.al (2002) investigated strain in homogeneity in hot strip rolling using two dimensional unsteady sate finite element method .Duan and Sheppeard (2004) investigated the influence of the constitute equation on the FE modelling of the rolling of aluminium alloy.

The contact problem has not much been considered in past literature. However, because of its non-linear nature and its complex conditions, it is very important to consider it particularly. Combining the finite element and boundary element methods, Shangwu et.al (1999) carried out the 3D modelling of hot roll for both rigid and flexible roll cases. Cavaliver et.al (2001) did research on the influence of parameters such as coefficient of friction and temperature on the distribution of contact stresses. Duan and Sheppard (2002) besides studying the effect of three friction models, considered the contact pressure distribution. They concluded that contact pressure distribution, as a convergence criterion, is greatly sensitive to the number of elements. Arif et.al. (2004) simulated roll and strip interaction for cold rolling process. The main object of this study is to predict roll stresses and deformation behaviour by considering both mechanical and thermal loads. Studying the influence of number of elements on the tangential and normal components of contact stresses, they showed that the contact stresses are much sensitive to the number of contact elements. Phaniraj et.al.(2005) compared the contact pressure of the roll surface for five rolling stands of a steel strip.

Although the finite element method is a very powerful tool for simulation of the engineering problems, the FEM simulation of non-linear problem is a time consuming procedure. Nowadays, steel and aluminium manufacturing industries go ahead towards online fault detection in the rolling process with the aim of elimination of these faults during the manufacturing process. For this to be achieved, faster prediction methods for predicting the behaviour of the slab under rolling are needed. In the present paper, the hot rolling process of strip is simulated with Abaqus 6.10 Software. The rolling is assumed to be rigid and for the deformable aluminium strip, the thermo elastoplastic analysis, through 2D sequential transient thermal and incremental lagrangian analysis, is carried out. This way the effect of different process parameters such as initial thickness of the strip, rolling speed and roll diameter, thickness reduction are studied.

Finite Element Modelling: A 2-D rolling model has been developed to simulate a single pass of the hot rolling process for aluminium alloy using the Abaqus 6.10 Software .the rolling parameters use in this work is shown in table 1 and the finite element model is shown as fig 1. Due to the symmetric nature of flat rolling only a quarter of the slab is modelled.

Table 1. Rolling Parameters.

Parameter	Value
Width	1800mm
Length	500mm
Inlet Thickness	580mm
Outlet Thickness	522mm
Reduction	10%
Temperature	300°C
Roll Speed	40rpm
Roll Diameter	495mm
Roll Width	2000mm

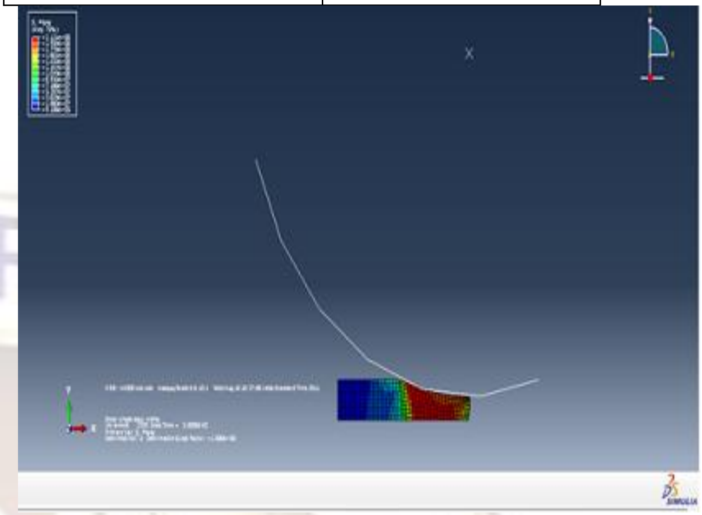

Fig.1. FEM Model

The deformation material Al 2024 .its flow stress is expresses as Norton- Hoff Equation:

$$\bar{\sigma} = K_0\left(\sqrt{3}\right)^{m+1} \exp(\beta T)\,\bar{\dot{\epsilon}}(\bar{\epsilon} + \bar{\epsilon}_0)^n$$

(1)

Where k_o, β, are the material constant , m the strain rate sensitively index, n the strain-hardening index, $\bar{\epsilon}$ the equivalent strain, $\bar{\dot{\epsilon}}$ the equivalent strain rate and $\bar{\dot{\epsilon}}_o$ is the samll constant 0.001 for Al 2024.

k_o = 216.29 MPa, β = -0.00524, m = 0.11, n = 0.0198, $\bar{\dot{\epsilon}}_o$ = 0.001 (for material Al 2024)

Mechanical and thermal property parameters used in this simulation are given in table 2 &3.

Table 2. Physical properties for Al 2024

Temperature (^{o}c)	Heat capacity (J/kg. n)	Thermal conductivity (W/m. K)
14	930	143.4
280	990	167.1
306	1010	170.2
410	1050	174.1

Table 3. Thermal Properties

Heat transfer between slab and air	$30\,\frac{K\omega}{m^2K}$
Hear transfer between slab and roll	$25\,\frac{K\omega}{m^2K}$

The slab model is elastoplastic and young's modulus 70 Gpa and passion ratio is 0.33.

The friction model is coulomb friction model: $\tau = \mu P$
(2)
Where μ is the coefficient of friction and P is the normal pressure [4].

Cook and Maccrum proposed the following formulas for roll separating force P and torque M.

$$P = R'\omega c_p I_p$$
(3)
$$M = 2RR'\omega c_g I_g$$
(4)
Where ,
C_p, I_p: geometrical coefficient used for the force calculation.
C_g , I_g : geometrical coefficient used for the torque calculation.

The value for these geometrical factors Cp,Ip,Cg and Ig can be determine from reference[5].

During the rolling process, the temperature distribution in the strip and the work roll can be calculated using the governing partial differential equation shown in the following equation:

$$K\nabla^2 T + \dot{q} = \rho C \frac{\partial T}{\partial t}$$
(5)
Where
ρ (kgm^{-3}) is the density, C ($jkg^{-1}c^{-1}$) is the specific heat, k (Wm^{-1C-1}) is the thermal conductivity and $\dot{q}$ (Wm^{-3}) is a heat generation term representing the heat released due to plastic work.

The thermal boundary conditions in the model are defined as:

At the centreline of the strip, symmetry condition is assumed

$$-K_{strip}\frac{\partial T}{\partial Y} = 0\ at\ t > 0; y = 0$$
(6)

And at the contact interface between the strip and the work roll, an interfacial heat transfer coefficient is assumed:

$$q_{srtrip} = -q_{roll} = h\left(T_{strip} - T_{roll}\right) at\ t > 0; y = \frac{y(t}{2}$$
(7)
In this paper a FEM with 16000 elements and 18954 nodes is used with Lagrange incremental solver Verification of the results:

The model developed in this investigation is validated by comparing the model predictions of rolling force, temperature and strain with theoretical results of Duan and Sheppard[2] (fig 2-4) .table 4 & 5 shows the rolling parameters using for validation.

Table4: Rolling parameters

Parameters	Value
Inlet Thickness	50mm
Outlet Thickness	47.3mm
Width	1050mm
Roll Radius	465mm
Temperature	283℃
Roll Speed	10rpm
Reduction	9.43%

Table 5: Thermal properties:

Heat transfer between slab and air	$0.01\frac{K\omega}{m^2K}$
Heat transfer between slab and roll	$25\frac{K\omega}{m^2K}$

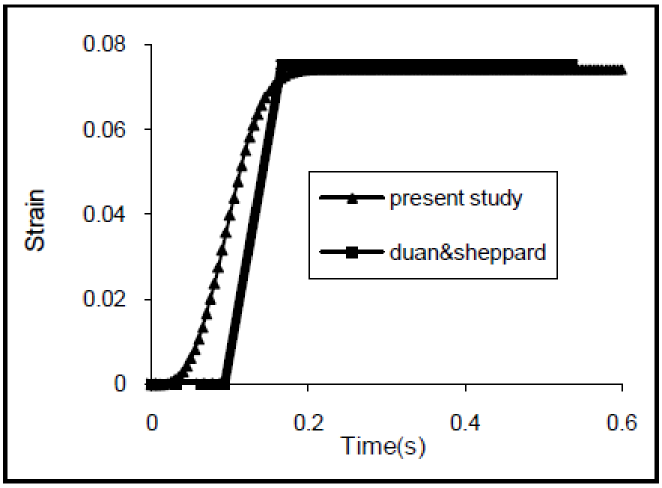

Fig 2: Strain Histories of rolling Single pass at the center point for rolling force per unit width.

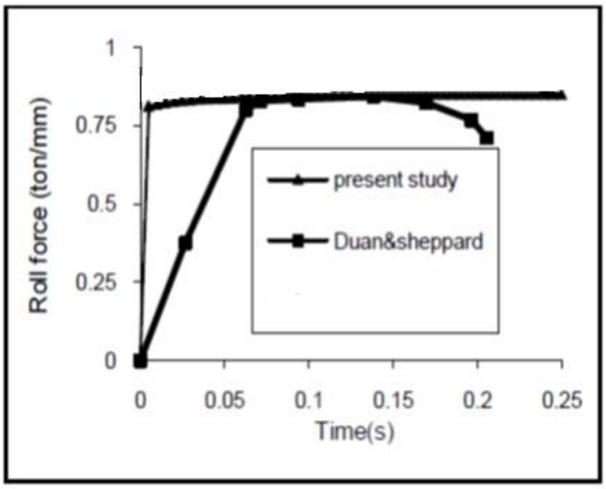

Fig 3: Comparison of the histories.

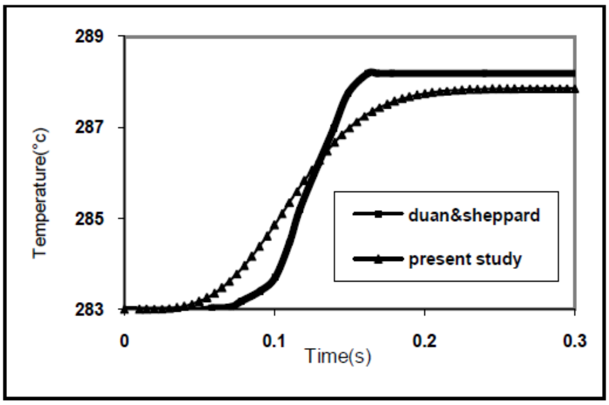

Fig4: Comparison of the histories for rolling temperature.

Discussion of Results: The rolling process is analysed in terms of the rolling speed, the rolling diameter, reduction and temperature of the slab.

Rolling Speed: Fig 5. Shows the effect of rolling speed on strain rate. it is seen that increasing the rolling speed increases the strain rate .

Fig 6&7. Shows the effect of rolling speed on roll force. It is seen that increasing the rolling speed increases the roll force. This is because of increasing the strain rate results in hardening which causes material to be more resistant to the deformation.

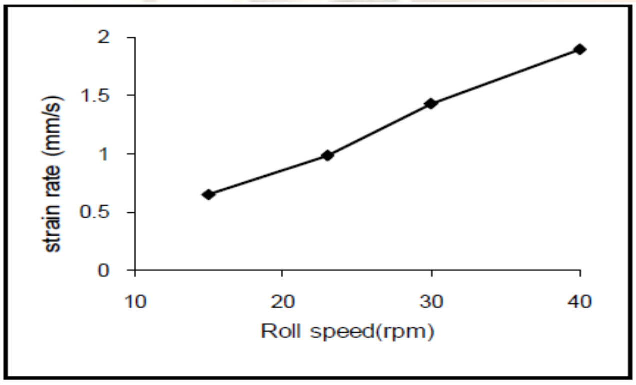

Fig5.Strain rate versus roll speed

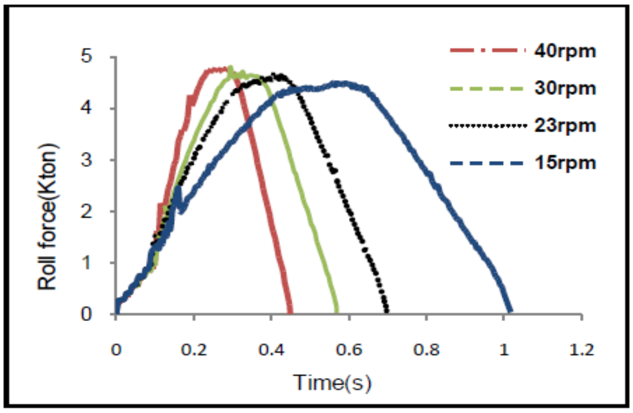

Fig6.Roll force versus time with variation of roll speed.

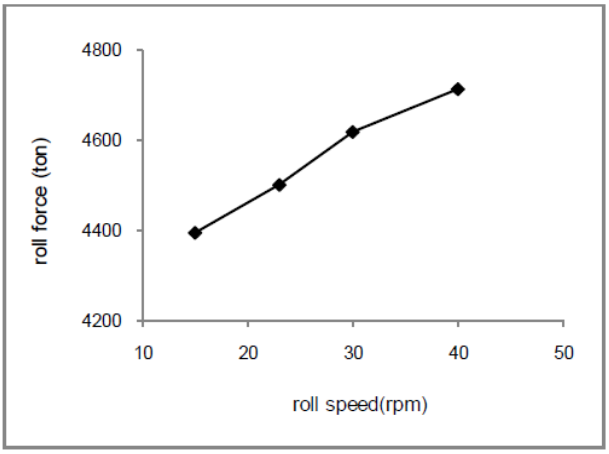

Fig7.Roll force versus roll speed.

The temperature history of the slab surface for different rolling speed is shown in fig8.the temperature distribution of the slab center versus the time is also shown in fig9.

It is evident from Fig 8, that increasing rolling speed results in shorter contact time which decreases heat flow from the strip to the roll and environment. On the other hand, increasing rolling speed can results in more strain rate in the deformation region together with more internal heat generation due to rate of plastic-work.

Therefore it is observed that the minimum temperature of the slab surface is decrease with decreasing of rolling speed with this behaviour. From Fig 9, it can be seen that the temperature of the centre of the slab increases with time until it reaches its maximum. This is because of heat generation due to the rate of plastic deformation. Thus it can be that the maximum temperature of the slab surface is not very much influenced by rolling speed.

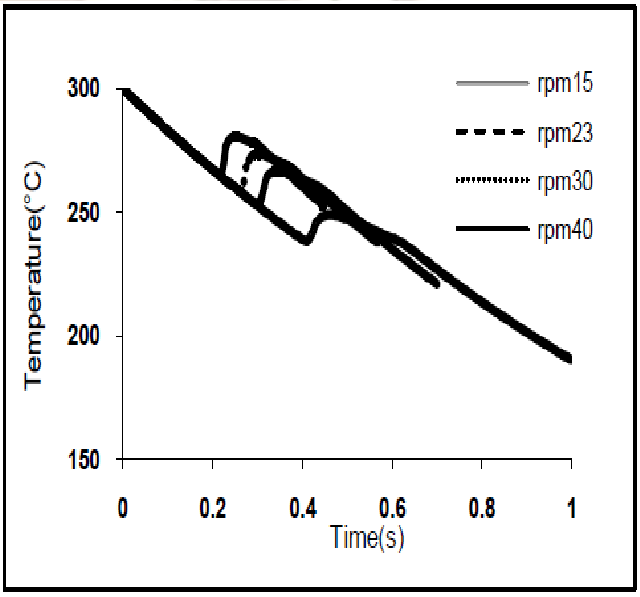

Fig 8.Temperature on surface versus time with variation of rolling speed.

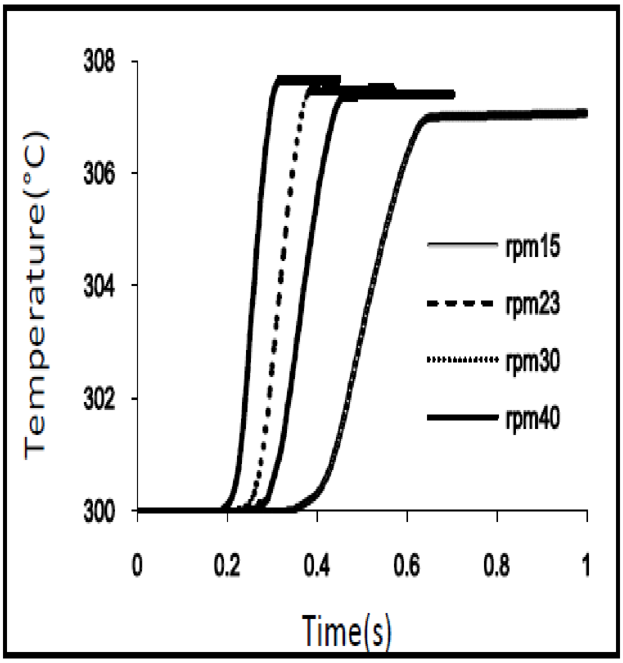

Fig 9. Temperature on center versus time with variation of rolling speed.

Roll diameter: Fig10.shows the effect of roll diameter on roll force. It is seen that increasing the roll diameter increases the roll force. This is because of increase in the strain rate results in hardening which causes material to be more resistant to the deformation.

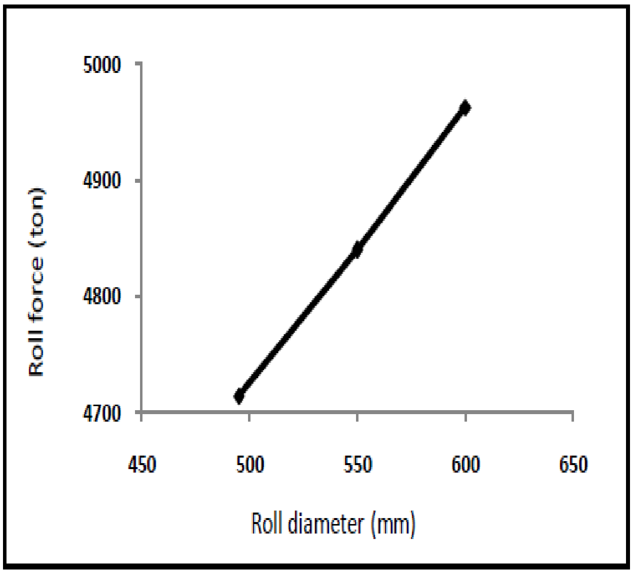

Fig10. Roll force versus roll diameter.

Reduction: The temperature history of the slab surface for different thickness reductions is shown in Fig. 11. The temperature distribution of the slab center versus the time is also shown in Fig .12.

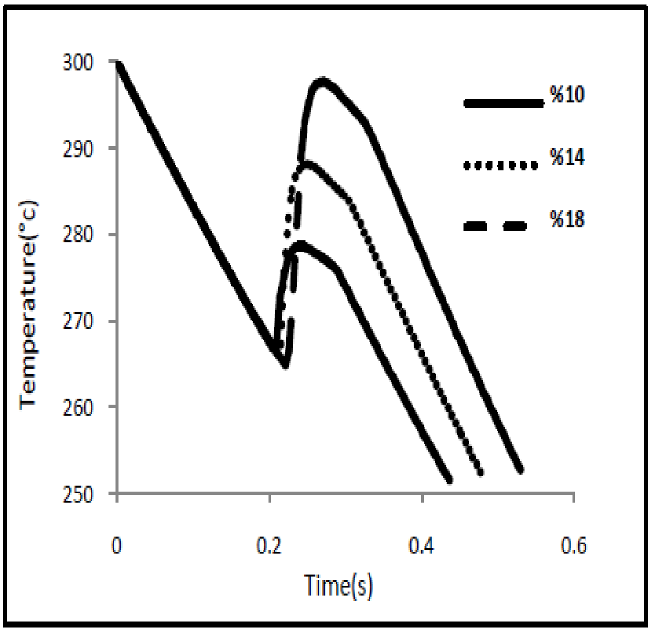

Fig 11.Temperature on surface versus time with variation of reduction.

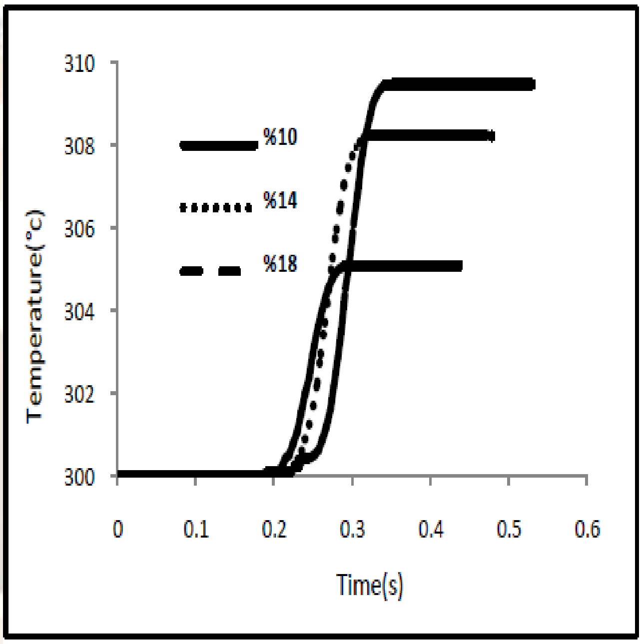

Fig 12. Temperature on center versus time with variation of reduction.

From these figures, it can be seen that the minimum temperature of the top surface does not vary largely as the difference in reductions of dimensions. It can be explained that more reduction results in longer contact length, which increases heat flow from the strip to the roll. On the other hand, high reduction in constant rolling speed can result in more strain and strain rate in the deformation region together with more internal heat generation due to rate of plastic work. So we can observe the maximum temperature on the slab surface is increase with increasing of reduction.

Temperature: Fig .13. Shows the effect of rolling speed on roll force. It is seen that increasing the rolling temperature decrease the roll force. This is because of increasing the flow stress of material.

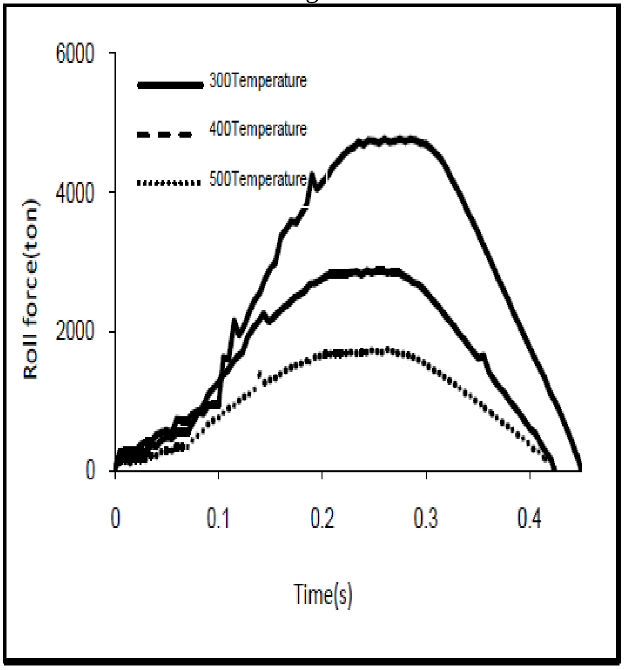

Fig 13. Roll force versus time with variation of temperature.

Conclusion:

Through the simulation of the hot flat rolling of aluminum alloy 2024, the following conclusions may be presented:

 Temperature of the strip, during rolling process, depends on several parameters such as interface heat transfer coefficient, rolling speed, and the amount of thickness reduction.

 Roll force of rolling process depends on several parameters such as temperature, roll diameter and rolling speed.

 All of the parameters on the Hot Rolling Process have been optimized.

References

[1] Duan, Sheppard, 2002. Three dimensional thermal Mechanical Coupled Simulations during hot strip rolling of AA3003. J.Mech. Sci. 44, (2155-2172).

[2] Duan, X. , Sheppard , T. , 2004. The influence of the constitutive equation on the simulation during hot rolling process. J. Mater. Process. Technil. 150, (100-106)

[3] Shaheni, A.R. , Setayeshi, S. , Nadamaie, S. A., Asadi, M.A., Rezaie, S. 2009 prediction of influence parameters on the hot rolling process using finite element method and neural network. J. Mater process. Technol. 209, (1920-1935)

[4] Xincai Tan, Xiu-Tian Yan, Neal P. Juster, Srinivasan Raghunathan, Jian Wang.2008 Dynamic friction model and its application in flat rolling. Journal of materials processing technology. 2 0 7 (222–234)

[5] Ginzburg, Vladimir, Ballas, Robert. “Fundamentals of flat rolling manufacturing engineering and materials processing”. 2000

[6] Zhous. S.X. 2003”An integrated Model for hot rolling of steel strips”, Journal of Material Processing Technology 134 (338-351).